NUREG-0782
Vol. 4

Draft Environmental Impact Statement

on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Appendices G-Q

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

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Appendix G

IMPACT ANALYSIS METHOLOLOGY

This appendix presents the methodologies utilized to calculate potential impacts resulting from the management of low-level radioactive waste (LLW). The appendix is summarized from information contained in Reference 1. The appendix considers three phases of waste management that may result in various types of impacts: (1) processing of the waste at the generation source or at a centralized location prior to disposal, (2) transportation of the waste from the generation source to a disposal facility, and (3) disposal of the waste.

The methodologies considered in this appendix include calculational procedures to determine:

- the occupational exposures and the exposure of the members of the public (individuals and population) resulting from the disposal of LLW;
- the occupational and the population exposures resulting from processing of the waste by either the waste generators or by operators of a centralized regional processing facility (assumed to be located nearby the disposal facility site);
- the occupational and the population exposures resulting from transporting the waste from the waste generators to the disposal facility site;
- the costs and the energy use associated with processing, transportation, and disposal of LLW; and
- the land area committed to disposal of LLW.

Thus, the calculational methodologies are used to determine five basic "impact measures" for consideration in the EIS--i.e., dose to members of the public, occupational exposures, costs, energy use, and land use.

These methodologies may be applied to a number of alternatives for waste form and packaging, facility design and operation, and institutional controls to determine performance objectives and technical requirements for acceptable disposal of the wastes and to determine the environmental impacts of the selected alternatives.

Section 1 provides an overview of the purpose and application of the impact analysis methodologies, presents a background rationale for the fundamental assumptions utilized in the development of the methodology, and presents the approaches adopted to define the interfaces of the three waste management phases.

Section 2 discusses the pathways involved in the calculation of exposures to members of the public. It includes a discussion of the basic rationale and background of the pathway analysis methodology, presents and analyzes the generic pathways considered in this report, and develops the equations applied in subsequent sections.

Sections 3, 4, and 5 address the three phases associated with the management and disposal of LLW, and discuss the disposal impact measures, transportation impact measures, and waste processing impact measures, respectively. Additional backup data and discussion regarding the pathway analyses may be found in Reference 1.

1. INTRODUCTION

The primary purpose of the impact analysis methodology is to provide a tool to enable determination of specific values of parameters that can be controlled and/or specified through technological or administrative action so as to assure the long-term and short-term protection of the human environment.

The secondary purpose of the impact analysis methodology is to enable calculation of the selected impact measures associated with a given disposal facility design containing several waste streams each having different characteristics.

1.1 General Approach

The most important rationale governing the selection of the methodologies and the calculational procedures used in this appendix is the generic nature of the analysis. The methodologies are focused toward helping to establish generic criteria for LLW management and disposal rather than calculating impacts at a particular disposal facility.

This is especially significant in view of the level of information available for a generic analysis as opposed to the level of data which will be available for a specific disposal facility site. Increased complexity and sophistication of a calculational procedure cannot compensate for a lack of data. Moreover, increased complexity and sophistication cannot compensate for the fact that all calculational procedures are based on an idealized picture of the system; this is an integral aspect of all predictive tools which are an essential part of many decisionmaking processes. Therefore, the sophistication and level of complexity of the calculational procedures should be consistent with the level of data that can be inferred and/or generalized for a generic system.

There are many possible methods or combination of methods which may be used to calculate the potential impacts of LLW disposal; these range from very simple to very complex techniques (Refs. 1-6). Complex calculations may be called for when analyzing a specific site where a significant quantity of site-specific information is available and where specific facility designs for waste disposal may be considered. However, for generic types of analyses to support an environmental impact statement and a rulemaking effort, where one is interested in the relative costs and impacts of alternative actions, simpler calculational schemes appear to be more appropriate. This concept of increasing the complexity

of calculational schemes with the increasing amount and specificity of the available data is consistent with the concept of tiering as set out by regulations promulgated by the Council on Environmental Quality (CEQ) (Ref. 7).

A second governing rationale for the selection of the methodologies and the calculational procedures in this appendix is the necessity to consider viable alternatives during three different waste management phases (waste processing, transportation, disposal) and the requirement that the interfaces of these three phases be properly coordinated. For example, waste processing techniques which reduce waste volumes would also likely result in an overall increase in the radioactive contents of the waste packages. This may result in additional transportation and disposal requirements that should be represented. Another example factor complicating an accurate definition of the interfaces is the possibility that the waste processing may occur at the waste generator's site or at a centralized regional location. This aspect has to be included in the calculation of the impact measures.

A third rationale for the selection of the methodologies is the need to have a flexible tool that can be updated as additional information is obtained. Any methodology that cannot accommodate timely changes is bound to become obsolete in a short time. The methodologies selected provide for continuous updating of the calculational techniques and the data base used for the analyses.

To develop the calculational procedures, a reference near-surface disposal facility design is assumed and a description of this disposal facility design is provided in Appendix E. In addition, the continental United States is assumed to be divided into four regions corresponding to the five NRC regions (see Figure D.1 of Appendix D). The four regions considered include the northeast (NRC Region I), the southeast (NRC Region II), the midwest (NRC Region III), and the west (NRC Regions IV and V). In each region, a hypothetical regional disposal facility site is characterized (see Appendices E and J). These sites, while not representing any particular location within a region, reflect typical environmental conditions within the regions. This allows consideration in the calculational methodology of a range of environmental conditions such as the amount of rainfall or the average distance from the waste generator to the disposal facility. (One of these sites, the southeast site, is frequently referred to in this appendix as the reference disposal facility site.)

The calculational methodology also allows consideration of a wide range in waste forms and processing options. In many previous studies on LLW disposal, the disposed waste was usually assumed to be a mostly uncharacterized mass with little attempt to distinguish in a quantitative manner the different waste forms. In this EIS, however, LLW has been separated into 36 waste streams, including nuclear fuel cycle wastes such as filter cartridges and ion exchange resins, as well as nonnuclear fuel cycle streams such as sealed sources and biological wastes. As described in Appendix D, each waste stream is characterized in terms of its radionuclide concentration (up to 23 different radionuclides are considered), its relative ability to burn, its stability over the long term, and other properties. The volumes of each waste stream are considered on a regional basis. That is, the volume of each waste stream

is projected for each of the four regions over the next 20 years, which again allows consideration of the regional impacts of management and disposal of LLW.

In this EIS, four generic alternative waste form and processing options are considered. These generic processing options, called "waste spectra," represent four relative levels of waste processing activities applied to the 36 characterized waste streams. The spectra were developed to limit the number of waste form and packaging alternatives that would have to be analyzed, since an indefinitely large number of possible combinations of various waste streams and processing options are available. The four spectra, which are described in detail in Appendix D, are as follows. Waste spectrum 1 characterizes existing and, in some cases, past waste management practices. Waste spectrum 2 characterizes improvements in the form of the waste through processing and reduction in waste volume with relatively modest expenditures of time and money. These two spectra bound existing waste management practices, which are currently in a marked state of change due to state initiatives, a lack of disposal capacity, and economic considerations. Waste spectrum 3 characterizes further waste form improvements and volume reduction at further increased costs, while waste spectrum 4 characterizes the maximum volume reduction and improved waste forms that can currently be practically achieved. The 36 waste streams corresponding to a given waste spectrum may be transported to and disposed into disposal facilities located at the regional sites and the resulting potential impacts calculated. A number of alternative disposal facility design and operation alternatives (e.g., thicker disposal cell covers, use of cement grout) may be then considered to estimate the effect of these alternatives upon the impact measures.

From the above, it can be seen that when considering the effect of alternative regional, waste form, and facility design characteristics on the magnitude of the impact measures calculated, an extremely large number (thousands) of possible permutations can be considered. To enable development of performance objectives and technical requirements for LLW disposal, the number of these permutations should be controlled and analyzed on a systematic basis. To do this, two features have been adopted: (1) use of a reference disposal facility and a reference waste volume distribution and (2) extensive use of computer technology, including use of waste form and disposal technology indices.

For the first feature, a reference disposal facility is described in Appendix E, which is assumed to be located in the humid eastern United States. For this EIS, the reference disposal facility is assumed to have environmental characteristics corresponding to the southeast regional site, although either the northeast regional site or the midwest regional site could have been used for this purpose. As discussed in Appendix D, this reference waste volume distribution is generated through averaging of all the waste volumes assumed to be generated in each of the 36 streams for each of the four regions, and normalizing these volumes to one million m^3 of waste for waste spectrum one. This allows the effects of alternative waste spectra and alternative disposal facility design and operational options to be compared on a common basis.

For the second feature, five computer codes have been written to manipulate the alternatives and to determine impact measures. These include the codes INTRUDE, GRWATER, OPTIONS, INVERSI and INVERSW, and a description of each of these codes is provided in Appendix H. In these codes, extensive use of integer "indices" have been used to characterize waste stream properties or disposal facility environment and design options. For example, a specific index (the "leachability index," I6) in the codes represents the relative degree that a particular waste stream resists leaching by water percolating through a disposal trench cover. The integer value given to this index for a particular waste stream can change from one spectra to the next. Depending upon the index value, the leaching fraction assumed for the waste stream is altered in the calculations. As another example, the index IC (the "cover index") represents alternative disposal cell cover designs. Setting the index to a specific integer value results in the codes in a variation in the calculated impact measures which would be influenced by the cover thickness (e.g., groundwater impacts, costs).

Use of the integer indices enables rapid and convenient consideration of alternatives for rulemaking. In addition, use of the indices enables any updates of the data base and calculational procedures to be readily accomplished without changing the value of the indices or the structure of the calculational methodology. In the remainder of this appendix, and in particular, Sections G.3-G.5, the calculational procedures are developed and discussed in the context of these indices.

1.2 Impact Measures

The impact measures quantitied in this EIS to determine a preferred alternative or option associated with the management and disposal of LLW are summarized in Table G.1. These impact measures can be summarized into five groups: dose to members of the public, occupational exposures, costs, energy use, and land use. Two of these measures--individual and population exposures associated with the handling and disposal of the waste--are representative of the level of short- and long-term protection of the human environment from radiological impacts.

The other measures--e.g., costs, energy use, and committed land area associated with the disposal of waste--are representative of the level of long-term protection of the human environment from socioeconomic impacts. Other potential impact measures, such as man-hours and material requirements (e.g., clay, gravel, concrete), are implicitly included in the above five impact measures. In view of past disposal history and practices, impact measures related to long-term protection of the human environment are stressed.

The methodologies selected for determination of individual and population exposures resulting from the disposal of waste, which are discussed in Section 3, are primarily geared towards the generic nature of the analysis. Accordingly, determination of the relative effects of various barriers between the waste and the human environment--waste form and packaging, site selection, site design and operation, and institutional controls--occupy a prominent place in the formulation of the calculational procedure for the disposal

Table G.1 Quantifiable Impact Measures Considered in the EIS

Waste Management Phase	Impact Measure
Waste Processing	Costs Energy Use Occupational exposures due to waste processing Population exposures due to waste incineration
Waste transportation	Costs Energy use Occupational exposures Population exposures
Waste disposal	Costs Energy use Land use Occupational exposures Exposures to individuals and populations due to: o operational accidents o ground-water migration o inadvertent human intrusion

impacts. Potential occupational exposures from waste disposal are calculated based upon assumptions regarding the interface between waste transportation and waste disposal. In comparison, calculation of other impact measures--cost, energy use, and land use--is relatively straightforward based on the information and assumptions presented in the other appendices of this environmental impact statement and other references (Refs. 1-6).

The impact measures associated with waste processing and transportation--i.e., occupational and population exposures, costs, and energy use--are all representative of the level of short-term protection of the human environment afforded by the alternatives considered; it is assumed that no land is permanently committed during waste processing and transportation activities. Again, impact measures other than these four are implicitly included in the selected set of measures.

The transportation impact measures are straightforward functions of the packaging and shipping mode assumptions detailed in Section 4, and the population exposure calculational procedures given in documents such as References 8 and 9. Impact measures associated with waste processing, presented in Section 5, are

calculated based on the assumptions presented in Reference 6 and the transfer factors developed in Reference 1.

2. PATHWAY ANALYSES

After the waste has been disposed of through an acceptable method, control mechanisms such as waste form (processing), site selection, site design and operation, site closure, and institutional controls begin to function. It is these control mechanisms that constitute "barriers" which confine and control to acceptable levels the interaction of the waste with the environment. This section discusses the mechanisms through which the waste may interact with the environment after disposal, and provides an overview of the interaction mechanisms in terms of applicable control mechanisms and the characteristics of the disposal system. The characteristics of the disposal system include those associated with waste form and packaging (see Appendix D), facility design and operation (see Appendices E and F), and administrative requirements.

2.1 Introduction

There are many diverse mechanisms through which radionuclides contained in LLW may be potentially released (i.e., mobilized from the waste and become accessible to a transport agent such as wind or water), transported through the environment (i.e., moved from one location to another through the atmosphere or soil by a transport agent), and thereby become accessible to humans through various pathways. Human access to the radioactivity may result either through direct human contact with contaminated material (e.g., inhalation of air, ingestion of water, or direct exposure to radiation) or indirectly through contaminated biota (through a multitude of pathways involving vegetation and animals) which have come into contact with contaminated material.

Each of these radionuclide release/transport/pathway combinations (scenarios) represents a complex series of interactions which are affected by a wide range of parameters such as waste properties, disposal site properties, and operational procedures. These diverse release/transport/pathway scenarios should be unified so as to achieve a simple, accurate, and readily usable methodology for pathway analysis. The development of the methodology employed in this EIS for pathway analysis is based on the following procedure:

- Define and analyze the potential release/transport/pathway scenarios that may lead to radiation exposures to either individuals or populations, and select the significant scenarios for future analysis.
- Simplify the structure of the selected release/transport/pathway scenarios by separating the radiation release and transport mechanisms from the pathway mechanism. In other words, separate the calculational procedures used to model release of radionuclides and movement through the environment from those calculational procedures used to model the resulting dose to humans.
- Determine applicable radionuclide-specific dose conversion factors for various human organs for human exposure to contaminated material

for all release/transport/pathway scenarios. The dose conversion factors, henceforth called the pathway dose conversion factors (PDCFs) to distinguish them from the conventional use of the term "dose conversion factor," are determined for an entire pathway to permit rapid determination of dose equivalent rates to human organs.

- o Model the radioactivity release and transport mechanisms between the disposed wastes and the locations where the radionuclides may be contacted by humans (the "biota access locations"). Then, identify the control mechanisms and barriers that may be technologically or administratively implemented that affect these release and transport mechanisms.

- o Utilizing the information presented in Appendices D, E, and F, determine the various options available for these control mechanisms in terms of waste form, site selection, site design, site operation, and institutional requirements.

- o Finally, determine the potential radiological impacts from the disposed LLW for various alternative options.

The methodology considers only one radionuclide at a time. Total impacts resulting from the movement of radionuclides from the waste and through the environment are obtained by summing over all of the radionuclides assumed to be present in the LLW. Several radionuclides considered, however, result in decay chains (Ref. 6). These decay chains are implicitly included by incorporating the effects of the daughters through the dose conversion factors for the parent radionuclide or by decaying the appropriate fraction of the parent radionuclide and adding it to the daughter radionuclide inventory (as in the example case of the decay of Pu-241 to Am-241).

2.2 Release/Transport/Pathway Scenarios

In accordance with the first two steps outlined above, the definition and simplification of the potential release/transport/pathway scenarios that are quantifiable and can lead to significant radiation exposures to humans are discussed in this section.

2.2.1 Approach

The conventional approach to quantifying the routes and pathways between radioactive materials and humans, and thereby determining the resulting radiological impacts, is widely known and can be found in the literature (Refs. 10, 11). A representative diagram is given in simplified form in Figure G.1.

As shown in this figure and beginning with the disposed waste, the transfer of radionuclides (and/or direct gamma radiation) is traced along numerous transport paths as the contamination is transferred between adjoining compartments and is eventually taken up by humans. The boxes represent the contaminated media and the arrows indicate that containment transfer can occur between adjacent compartments via the stated radionuclide-mobilizing mechanism.

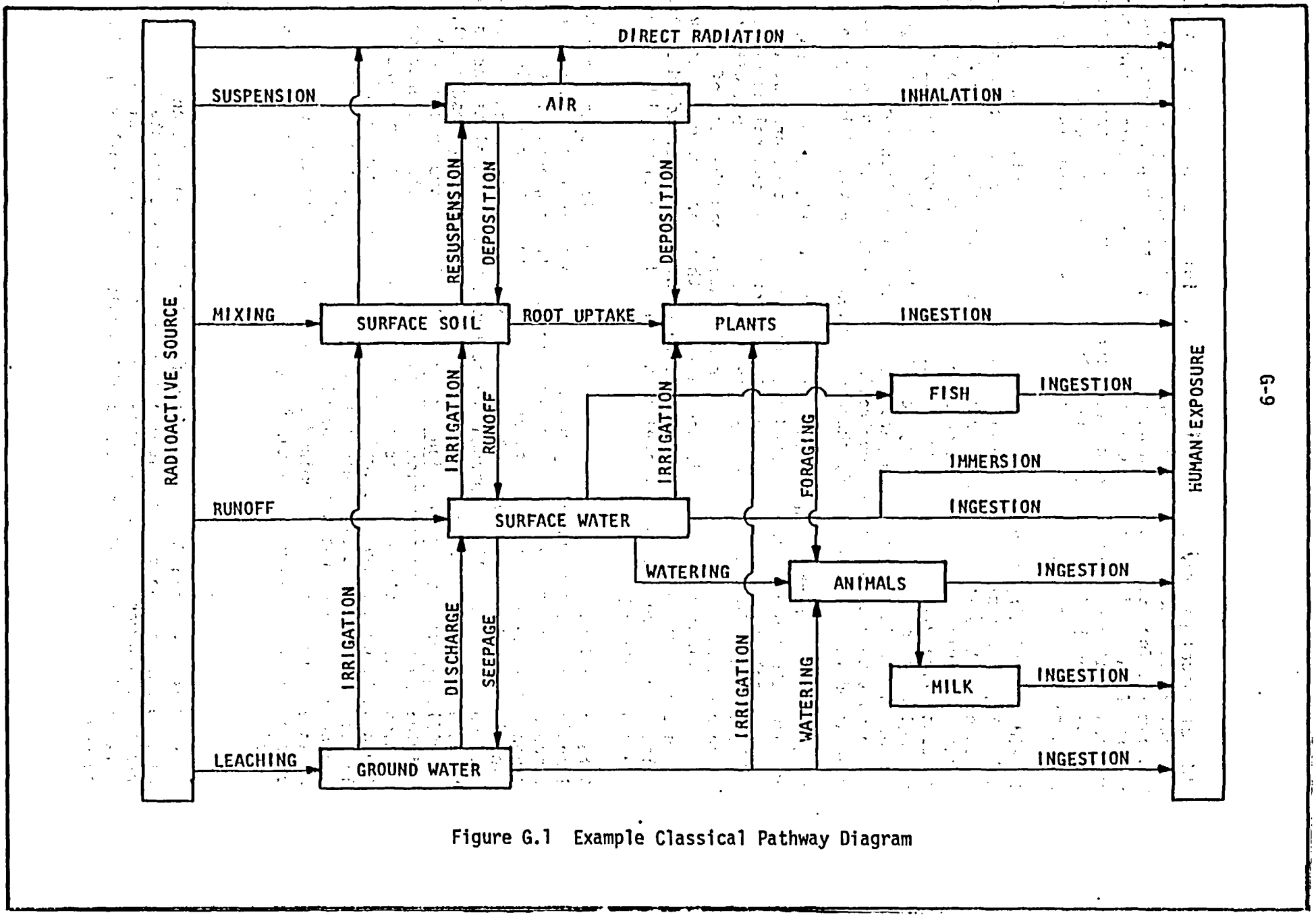


Figure G.1 Example Classical Pathway Diagram

This classical pathway methodology is very useful in determining specific impacts associated with a particular disposal facility, but is unfortunately a bit awkward for use in determining generic regulatory requirements. This results from the fact that most of the arrows between the boxes represent environmental parameters that are site-specific. Moreover, the diagram does not permit rapid identification and analysis of alternative control mechanisms, which may be used to reduce or eliminate the potential radiological impacts.

To aid in analyzing alternative overall performance objectives and technical criteria, a more practical calculational procedure is needed which separates those parameters that can be controlled (through technological and/or administrative requirements) with a high degree of confidence from those that cannot be controlled with the same degree of confidence. For example, waste form and packaging are parameters that may be potentially controlled with a higher degree of confidence than such parameters as the irrigation rate of crops, which must be assumed to be uncontrollable. A pathway diagram that has been rearranged in order to satisfy these conditions is presented in Figure G.2.

As can be seen in this figure, most of the site-secific pathway compartments and parameters have been separated from the rest of the diagram at the biota access locations. Most of the parameters which can be controlled (which are the solid waste/soil mixture box and the connections of this box with the other biota access locations) have been separated from the rest of the diagram. The significance of this separation is that performance objectives, technical requirements, and administrative regulations which would be formulated to reduce the radiological impact of LLW disposal would be aimed at the controllable parameters.

After contamination reaches a biota access location, it becomes available for immediate or eventual uptake by humans. Comparatively little control (mostly through site selection) can be implemented over the segments of the pathways beyond these biota access locations (e.g., selection of a desert location may minimize ingestion pathways). Because of this comparative lack of control, movement of radionuclides through the pathways beyond the biota access locations and resulting human exposures may be expressed through radionuclide specific pathway dose conversion factors (PDCFs) that are independent of the original means of contamination. Based on an appropriate reference concentration at the biota access location (e.g., 1 curie/m^3 of contaminated media), the dose to humans may be calculated for each pathway from the biota access location to the point of eventual human exposure. In other words, once the radionuclide concentrations at the biota access locations are known, potential human exposures may be determined by multiplying the actual access location concentration C_a (in units of Ci/m^3) by the PDCF (in units of millirem per Ci/m^3):

$$H = PDCF \times C_a \qquad (G\text{-}1)$$

where H is the human dose in millirem (see Section 2.4). As an example of the development and use of a particular PDCF, consider the impacts that could result to a human from the presence of a concentration of radioactivity in offsite air. Potential exposures could result from the following uptake pathways:

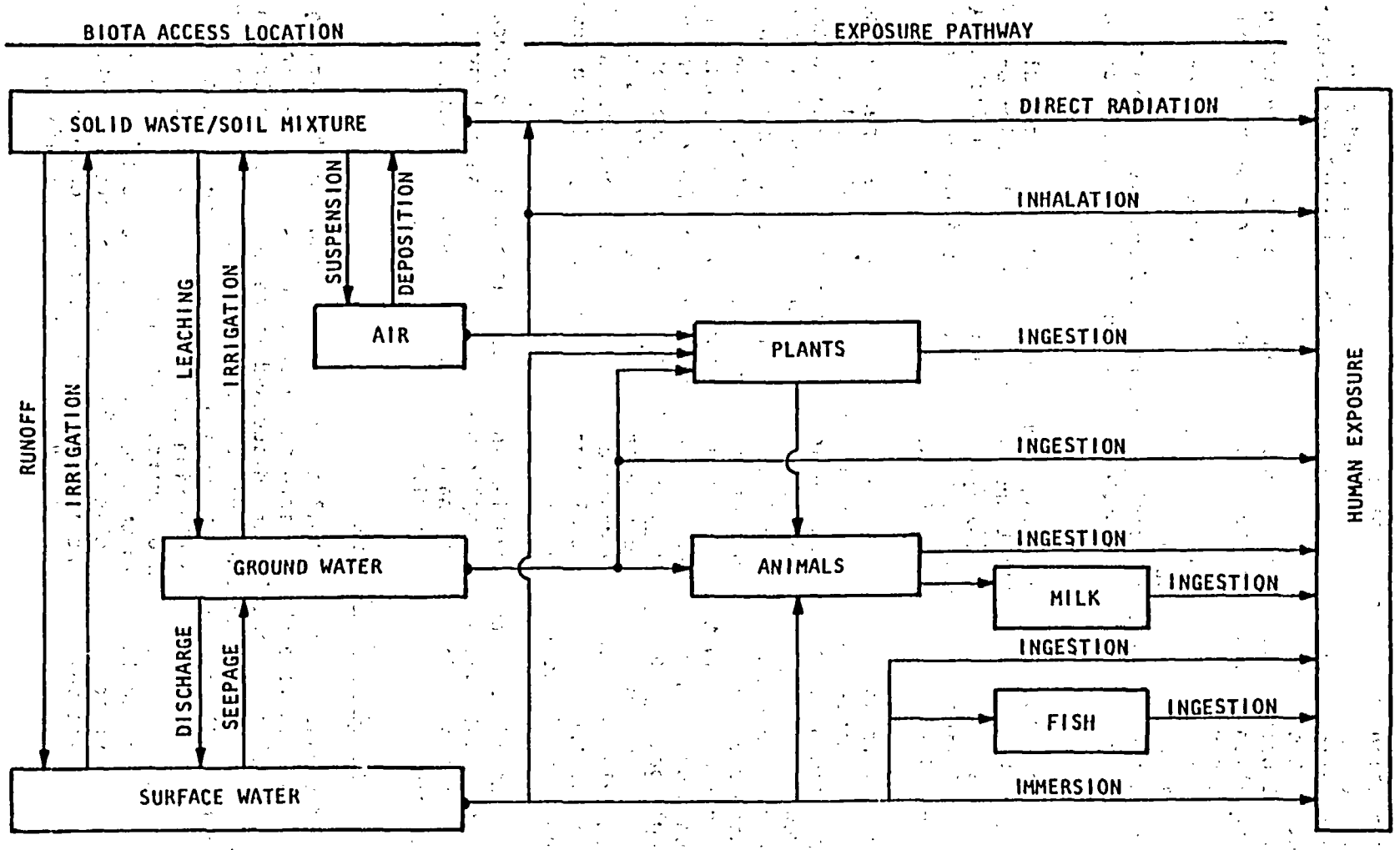


Figure G.2 Modified Pathway Diagram Illustrating Biota Access Locations

- o Inhalation of the contaminated air;
- o Direct gamma exposure from standing in the contaminated air;
- o Consumption of leafy vegetables dusted with radionuclides settled out of the air;
- o Direct gamma exposure from contaminated dust deposited on the ground;
- o Inhalation of contaminated dust which has been resuspended from the ground surface;
- o Consumption of vegetables containing radionuclides transferred into the plant through root pathways; and
- o Consumption of food containing radionuclides transferred to the food through various pathways such as plant-animal-meat or plant-animal-milk.

At a specific site, the dose resulting from these uptake pathways would be determined through the use of (1) transfer factors such as the air-to-leaf and soil-to-air transfer factors and (2) fundamental dose conversion factors (DCF) such as the inhalation DCF (50-year committed dose per pCi inhaled) and ingestion DCF (50-year committed dose per pCi ingested).

The transfer factors and the actual potential impacts would be specific to particular environmental conditions (e.g., humidity, types of food grown, etc.) and specific human actions at the location where the airborne contamination occurred. However, for generic analyses, reasonable yet conservative assumptions may be made regarding such environmental characteristics and human actions. Based upon these assumptions, the potential individual organ dose that could occur as a result of each uptake pathway can be calculated. The doses from each uptake pathway may be then summed to form, for each individual organ, a single pathway dose conversion factor that represents the total potential dose received from all uptake pathways. The end result is the ability to quickly determine on a generic basis (e.g., by consulting a table and multiplying), the total potential organ doses received by a human from any concentration of radionuclides in air.

This approach introduces a conservatism in the calculation of doses since not all of the uptake pathways may be applicable for every release pathway and environmental setting. The generic nature of the analysis, however, precludes a detailed consideration of site-specific pathway factors.

2.2.2 Release/Transport Mechanisms

This section discusses in more detail the release/transport mechanisms considered in this appendix. It is broken up into three subsections. In the first subsection, the release scenarios are discussed in relation to the transport agents potentially mobilizing the radioactivity in addition to the time periods during which the radioactivity may be mobilized and/or reach a biota access location. The second subsection (Section 2.2.2.2) describes the separation of the calculational methodology into control mechanisms. The specific release/transport scenarios considered in this section are then described against the background of the first two subsections. These scenarios are separated into those which are principally a function of the radionuclide concentrations in the waste (the "concentration scenarios," Section 2.2.2.3), those which are

principally a function of the total inventory of radionuclides in the waste (the "total activity scenarios," Section 2.2.2.4), and other short-term scenarios associated with processing, handling, and transporting the waste (Section 2.2.2.5).

2.2.2.1 Timing of Release/Transport/Pathway Scenario

There are three fundamental transport agents which can mobilize radioactivity from disposed waste:

- o Direct Contact--The waste may be directly accessed by humans through gama-ray exposure or through human activities which contact the waste/soil mixture.
- o Air--Air can mobilize radioactivity from the waste when the waste is directly exposed to or released into the atmosphere.
- o Water--Ground water and surface water can act as transport agents to mobilize radioactivity from the waste.

Moreover, there are two comparatively distinct time periods of the site lifespan during which releases from LLW can reach a biota access location: the operational period and the postoperational period. The postoperational period may be further divided into the closure and observation period, the active institutional control period, and the passive institutional control period.

Operational Period--The operational period includes the time during which waste disposal operations take place. During this period, the principal mechanism at a disposal facility that can result in significant transport of radioactivity to a biota access location is an operational accident. In this case, wind is the primary transport agent, the biota access location becomes offsite air, and the exposure period is acute--i.e., a discrete event occurring over a short time span.

During this period, the site operator is responsible for the control and maintenance of the site. Potential impacts from operational accidents are important but not directly related to the long-term performance of a near-surface disposal facility. Operational accidents are important insofar as potential operational releases may be precluded or minimized by improvements in waste form and packaging or site operational procedures. Potential offsite exposures due to surface run-off from contaminated onsite soil may occur; however, they are not quantitatively analyzed in the EIS. Such potential short-term exposure would be addressed as part of licensing specific disposal facilities. Routine occupational exposures during the operational period are considered in Section G.3. Ground-water migration is not calculated during this period for calculational convenience, and because of the short time span and operational measures that would be taken to minimize the potential for migration.

During the operational period, other short-term exposures would also result at locations other than the disposal facility site. Exposures to populations could result from airborne releases of radioactivity during waste processing

activities--especially if such processing activities involve incineration of combustible waste streams. Such processing activities would be performed by the waste generator or at centralized processing centers. Population exposures would also occur during waste transportation to the disposal facility. Occupational exposures would result to waste handlers while generating and processing waste streams, as well as to personnel transporting the waste to the disposal facility.

Closure and Observation Period--This period lasts from the end of disposal operations at the facility to the time that the title for the facility is transferred to the site owner. The period begins during the time that the disposal facility is closed and lasts through any period of observation carried out by the site operator to assure that the disposal facility is in a stable condition prior to transfer to the site owner. During this period, the facility operator is responsible for the control and maintenance of the site. The ground-water scenario is initiated during this period.

Active Institutional Control Period--The active institutional control period lasts from the transfer of the title of the site by the site operator to the site owner until a point in time at which a breakdown in institutional controls is assumed to occur. During this period, the waste is not exposed to the atmosphere. The waste may, however, interact with humans through direct radiation attenuated through the disposal cell cover. Thus, the waste itself is an access location. The other principal agent that can transport radioactivity from the waste during this period is ground water, which may transport the radioactivity to locations where the radioactivity may be accessed by humans. Possible access locations could include either a well drilled into the contaminated aquifer or open water (e.g., a stream) into which the contaminated aquifer has discharged. For both of these cases the exposure periods are chronic (i.e., continuous events).

Prior to the transfer of the title to the site owner, the site will be closed by the site operator. A desirable goal during the closure activities is that the site will have been stabilized so that there is essentially no need for active ongoing maintenance by the site owner. During the active institutional control period, the site owner is responsible for the care, surveillance, and maintenance of the site. Access to the site is restricted (e.g., fenced) and/or controlled by means of some manner of licensed surface use. The direct radiation exposure scenario, in comparison with other scenarios, is likely not to be significant since the radiation must pass through the intact trench cover. However, the ground-water scenario is assumed to continue during this period.

Passive Institutional Control Period--During the passive institutional control period (after active institutional controls are assumed to have ceased), the waste may be exposed to the atmosphere through erosion or human activities. During this period, the waste/soil mixture may be potentially directly accessed by humans. For example, a house could be inadvertently constructed on the waste disposal facility and, after the house is constructed, a person or small group of persons could live in the house and possibly consume garden vegetables grown in the soil/waste mixture. In addition, wind and water may act as

transport agents that may lead to dispersion of radionuclides and offsite contamination. The ground-water scenario continues during the passive institutional control period.

During the active institutional control period, it may be assumed that active controls exercised by the site owner on the closed disposal site will gradually lessen. The period of time between the site inspection and routine monitoring of the site will lengthen.

Eventually, a passive institutional control period may be assumed during which the control of the site is principally expressed through site ownership and control of land use. During this period, there may be occasions in which inappropriate use of the facility by humans occurs. As extreme examples of inappropriate use, a house may be constructed on the disposal facility and persons may live in the house. It is likely, however, that the passive institutional controls would preclude continuation of inappropriate site use for long time periods.

2.2.2.2 Control Mechanisms

The release and transport of radioactivity from the disposed of LLW are significantly affected by the properties and characteristics of the waste form and packaging, site design and location, disposal practices, etc. Most, if not all, of these items are controllable to some degree. Specific controls of these items can be made mandatory through administrative regulation; hence, these may be termed regulatable items or control mechanisms.

In order to permit the specification of controls and the quantitative assessment of their effects, these control mechanisms should be identified unambiguously. To accomplish this, each release/transport mechanism may be broken down into its component parts.

For example, consider the action of rainwater on a near-surface disposal facility. Rainwater (the initial form of the transport agent) may seep down into the waste, contact and leach radioactivity from the waste (thereby becoming leachate), become contaminated and continue seeping downward. The contaminated water may then move through the transport medium to a well or to a river (biota access location) where it is withdrawn for use in human consumption, crop irrigation, animal watering, etc. The following barriers and control mechanisms can be identified:

- Rainwater infiltration into the waste cell can be reduced by a low-permeability clay cover over a waste disposal trench. This barrier can be controlled through site design and stabilization operations during site closure.

- Water that does enter the trench can be partially inhibited from picking up contamination from the waste by either assuring that the waste container does not permit contact between the waste and water (this may be accomplished through the use of a high integrity container) or by permitting only the disposal of waste that releases

radioactivity very slowly upon contact with water. This barrier can be controlled through waste form and packaging.

- Release of contaminated water from the trench may then be reduced by another low-permeability clay layer at the bottom of the trench. However, this barrier may be undesirable and should be utilized with caution. Accumulation of leachate could occur which could fill up the trench and eventually possibly lead to overflow of the trench. This barrier can be controlled through site design.

- After the water enters the transfer medium (i.e., the soil), natural geologic barriers can impede and/or reduce the magnitude of the radionuclide transfer. These barriers can be controlled through site selection and include adsorbtion onto soil particles as the water moves through an underlying strata, dispersion of the radionuclides migration, and radioactive decay during travel through the geologic medium.

- Once the transport agent reaches the biota access location, another mechanism that would reduce the magnitude of the contaminant concentration is dilution with uncontaminated water at the discharge location. For example, the flow rate of a river or the pumping rate of a well affects the degree of dilution achieved. This barrier can also be potentially controlled through site selection.

- Finally, the point in time at which the ground-water scenario is initiated depends on waste form and packaging, site operational procedures, and administrative requirements. For example, the waste may be packaged in a high integrity container. This results in a time-delay factor, due to radioactive decay, that can reduce the magnitude of the source term significantly.

The barrier concepts that have been discussed above can be generalized and applied quantitatively to each release/transport scenario. This may be accomplished by using an interaction factor (denoted by the symbol I) that relates the radionuclide concentration in the biota access location to the radionuclide concentration in the waste:

$$C_a = I \times C_w \qquad \text{(G-2)}$$

where (C_a) and (C_w) are the concentrations of the radionuclide of concern, in units of[a] (Ci/m^3), at the biota access location and in the waste, respectively. The interaction factor (I) can further be compartmentalized in terms of the barriers discussed above:

$$I = f_o \times f_d \times f_w \times f_s \qquad \text{(G-3)}$$

where

f_o = time-delay barrier factor. This factor accounts for all the control mechanisms that increase the time period between termination of

waste disposal at the site and the initiation of contact between the transport agent and the waste.

f_d = site design barrier factor. This factor includes the effects of any engineered barriers designed into the waste disposal facility, plus any site operational practices that may reduce transport.

f_w = waste form and package barrier factor. This factor accounts for the physical and chemical characteristics of the waste at the time of the initiation of the release/transport scenario that may inhibit contaminant transfer to the transport agent.

f_s = site selection barrier factor. This factor includes the effects of the natural site environment that contribute to reducing the containment concentrations at the biota access location.

These four factors may be used to represent the control mechanisms. These four factors are not the barrier criteria themselves, but may be used to help determine the barrier criteria. Regulation through these factors may be accomplished by either specifying the value required for a given barrier factor, or by defining the characteristics of the barrier needed to achieve the desired effect.

For the remainder of this appendix, the release and transport of radionuclide from waste at a disposal facility is described in terms of these four barrier factors.

2.2.2.3 Concentration Scenarios

Three scenarios whose impacts are a function of the concentrations of radionuclides in the waste streams are considered in this section. The first scenario considered concerns accidents that may happen during the operational period of the disposal facility lifespan, and which may result in offsite atmospheric transport of radionuclides. The other two scenarios are concerned with exposures to a potential inadvertent intruder. An intruder may unintentionally come across a closed waste disposal site due to a temporary breakdown in institutional controls, and subsequently modify it for a specific purpose such as housing construction or agriculture. As a result, short- and long-term radiation exposures to the individual can ensue.

Two of the concentration scenarios (accident and inadvertent intruder-construction) are acute exposure events. Thus, the release and subsequent exposure occurs for a limited period of time (less than a year). The other scenario (inadvertent intruder-agriculture) is assumed to be chronic, since it is possible (but very unlikely) that the intruder would live for several years at the site before it is discovered that there is a hazard.

Few individuals are expected to be involved in the concentration scenarios, and they may also be distinguished from the total activity scenarios by the dose limitation criteria which may be applied. Different limits on allowable human doses may be used, depending upon whether a few individuals or populations

are exposed. The equation generally applicable to the concentration scenarios is:

$$C_a = I \times C_w \qquad \text{(G-2)}$$

where (C_a) denotes the radionuclide concentration at the biota access location and (C_w) denotes the radionuclide concentration of the waste, both in units of (Ci/m^3), and (I) is the dimensionless interaction factor, which depends on the specific scenario considered.

For these scenarios, the undecayed radioactive concentrations are utilized which neglect any decay during the operating life of the site (Ref. 1, 6). This is a conservative assumption for the construction and agriculture scenarios since the inadvertent intruder may initiate the scenario at a location containing waste from the first year of facility operation.

The interaction factor (I) can generally be expressed through the following equation:

$$I = f_o \times f_d \times f_w \times f_s \qquad \text{(G-3)}$$

where all the parameters are dimensionless, and where

f_o = time-delay factor;
f_d = site design and operation factor;
f_w = waste form and package factor; and
f_s = site selection factor.

The time-delay factor (f_o) is expressed as a radionuclide decay factor and incorporates the effects of the closure period and the active institutional control period. The activities are decayed to the time that the specific scenario is initiated. This factor is a property of the scenario and the disposal technology being considered. For the accident scenario, no credit for radioactive decay can be assumed and (f_o) will be taken to equal one. However, for the construction and agriculture scenarios, it is given by the formula:

$$f_o = \exp[-\lambda T] \qquad \text{(G-4)}$$

where λ is the radionuclide decay constant in units of 1/year, and T is the period of time between the cessation of disposal operations and the end of the active institutional control period.

The site design and operation factor (f_d) expresses the waste fraction that is available to the transfer agent. It usually depends on the efficiency of the disposal design. Furthermore, its definition and value depends on whether the scenario is an inadvertent intruder scenario or an accident scenario (see Sections 3.4 and 3.6).

The waste form and package factor (f_w) expresses the resistance of the waste to mobilization by the specific transfer agent initiating the scenario. For

example, this factor would be considerably less than unity for waste streams solidified in a matrix and/or packaged in containers that are likely to retain their integrity at the time of inadvertent intrusion. This factor is a property of the waste stream as it is being disposed.

The site selection factor (f_c) depends on many parameters. In some cases, it is proportional to the fraction of a year that the human exposure episode takes place. In other cases, however, (f_c) is also proportional to the release/transport/transfer factor between the biota access locations. For example, for the inadvertent intruder-construction scenario, it is proportional to the transfer factor between contaminated soil and contaminated air.

A brief description of the concentration scenarios is presented below. Specific values of the transfer factors used to calculate impacts are discussed in Section 3 and Reference 1.

Accident Scenario

Nonoccupational acute radiation exposures may result from planned and unplanned releases of material to offsite environs during the operational life of a disposal facility. Planned releases would be addressed on a site-specific basis during the licensing phase of site startup. Two accidental release scenarios can be postulated. One of them involves a postulated breaking open of a waste container and subsequent release of airborne radioactivity, and the second scenario coniders the consequences of a fire igniting in an open disposal trench, with subsequent burning of a portion of the waste and airborne release of combustion products. The comparative severity of these two scenarios depends on various parameters including those associated with the waste form and with site operation.

Construction Scenario

An inadvertent intruder may excavate or construct a building on a disposal site following a breakdown in institutional controls. Under these circumstances, dust will be generated from the application of mechanical forces to the surface materials (soil, rock) through tools and implements (wheels, blades) that pulverize and abrade these materials. The dust particles generated may be then entrained by localized turbulent air currents and can thus become available for inhalation by the intruder. The intruder may also be exposed to direct gamma radiation resulting from airborne particulates and by working directly in the waste-soil mixture. For convenience, this scenario is called the intruder-construction scenario, and appropriate values applicable to typical construction activities are used.

The length of time that the intruder is exposed to radioactivity will be a function of the stability of the waste encountered. If the waste is assumed to be degraded into an unrecognizable form, then it is possible that such construction activities could proceed. However, if the waste is stabilized to the point that the waste mass is clearly distinguishable as something different than ordinary dirt, then it is likely that the inadvertent intruder would stop and investigate. In this case, which can be considered a subset of the

intruder-construction scenario and is termed the intruder-discovery scenario, the inadvertent intruder is only exposed during initial discovery of the disposed waste. That is, the same exposure pathways would be involved as for the intruder-construction scenario, but the length of time that the scenario is assumed to occur is reduced.

Agriculture Scenario

In this scenario, an inadvertent intruder is assumed to occupy a dwelling located on the disposal facility and ingest food grown in contaminated soil. (This scenario is assumed to be possible only if the waste has been degraded to an unrecognizable form.) Garden crops may be subject to radionuclide contamination as a result of direct foliar deposition of fallout particulates. Garden crops may also uptake radionuclides via soil-root transfer from contaminated soil. The inadvertent intruder may also be exposed to direct gamma radiation from the naturally suspended radioactivity and from the waste-soil mixture. He may also inhale contaminated air particulates. For convenience, this scenario is called the intruder-agriculture scenario.

2.2.2.4 Total Activity Scenarios

This section considers those release/transport scenarios that are dependent upon the entire activity disposed of at the site. Therefore, all the waste streams disposed at the site contribute to the radionuclide concentrations at the biota access locations. The degree of contribution from a given waste stream is a function of its volume and characteristics (e.g., its form and packaging) and facility design and operating practices (e.g., waste segregation).

All of the total activity scenarios are chronic exposure scenarios (i.e., continuous release and exposure). The equation applicable to the total activity scenarios for each radionuclide is:

$$C_a = \sum_i I_i \times C_{wi} \qquad \text{(G-5)}$$

where (C_a) and (C_{wi}) denote the radionuclide concentrations at the biota access location and in the $(i)^{th}$ waste stream, respectively, and (I_i) is the interaction factor between the $(i)^{th}$ waste stream and the biota access location. The capital sigma indicates that the total radionuclide concentration at the biota access location is a summation of the radioactivity contributed by each waste stream. This summation may also include any potential integration that must be performed due to the areal extent of the disposal site and the areal distribution of the waste streams.

For these scenarios, radioactive concentrations averaged over the time of waste generation and disposal are utilized as a source term (see Appendix D and Reference 6). In other words, the radionuclides in waste streams that are disposed of at the beginning of the disposal site operational period are decayed to the end of the operational period.

The interaction factor (I_i) can generally be expressed through the following equation:

$$I_i = f_o \times f_{di} \times f_{wi} \times f_{si} \qquad \text{(G-6)}$$

where subscript i denotes the waste stream, and where:

f_o = time-delay factor (dimensionless);

f_{di} = site design and operation factor (dimensionless);

f_{wi} = waste form and package factor (m^3/yr); and

f_{wi} = site selection factor (yr/m^3);

and where the values of f_{di}, f_{wi} and f_{si} may be functions of the properties of the individual waste streams.

Ground-Water Scenarios

There are several ground-water scenarios depending on the assumed biota access location. One of the access locations is an onsite well which may be drilled and used by a potential inadvertent intruder (intruder-well scenario); another is a well at the boundary of the site which may be utilized by individuals (boundary-well scenario); a third location is a well pumped for common use by a small population some distance away from the disposal facility (population-well scenario); and the fourth location is a stream that receives the discharge from the unconfined ground-water table and which may be used by a larger population (population-surface water scenario). In this appendix, it is assumed that the water table gradient underneath the site is unidirectional, and that a well located at the boundary of the disposal area (rather than the boundary of the site) contributes to the intruder scenarios. This location is more conservative than a well located in the middle of the site since only about half of the potential effluent from the site would contribute to the contamination at a well located in the middle of the site (Ref. 1).

The barrier factors f_{di} and f_{wi} are assumed to be independent of the areal extent of the disposal facility; however, the factor f_{si} represents these areal relationships. The factors f_{di} and f_{wi} and their computations are straightforward, and representative values for these factors are given in Section 3. However, a brief discussion of f_{si} is presented below.

The following general equation is applicable to determine the site selection factor f_{si} (Refs. 2, 3):

$$f_{si} = r_{ti}\, r_g/Q \qquad \text{(G-7)}$$

where

Q = dilution factor in units of volume/time;

r_g = dimensionless time-independent reduction factor due to the transverse (perpendicular to the ground-water velocity direction) spatial relationship of the disposal facility with the discharge location; and

r_{ti} = dimensionless reduction factor due to migration and radioactive decay; this factor is dependent on both space and time including the longitudinal (in the direction of the ground-water velocity) spatial relationship of the disposal facility with the discharge location.

The factor Q is independent of the characteristics of the disposal wastes and is also independent of the geometrical relationship of the disposal facility with the discharge location. The factor Q may be the pumping rate of a well or the flow rate of a river. The factors r_g and r_{ti} are discussed in Section 3.5.

Exposed Waste Scenarios

In these scenarios, part or all of the surface area of the disposed waste is assumed to be exposed through some means. The mechanism that initiates uncovering of the waste may be erosion of the waste cover by surface water or wind action, or it may be anthropogenic activities such as farming. Initiating mechanisms related to human activities are examined in the intruder-agriculture and intruder-construction scenarios, and initiating mechanisms related to erosion of the waste cover are examined in Reference 1.

There are two basic exposed waste scenarios depending on whether the transfer agent is wind or surface water. Only population exposures are considered in these scenarios; individual exposures are bounded by the above intruder-construction and intruder-agriculture scenarios. The entire exposed waste area is assumed to be a point source for the impact calculations since the population is assumed to be comparatively distant. The equations and values for the various barrier factors used in the calculations are examined in Section 3.

2.2.2.5 Other Radiological Release/Transport Pathways Considered

A number of other radiological impact release/transport pathways are also considered in this EIS and appendix. These are all short-term pathways related to the management of LLW occurring at locations other than the disposal facility site. Unlike pathways involving releases of radioactive material from a disposal facility, component parts of these release/transport pathways are generally not broken out into the four barrier factors discussed in Section 2.2.2.2. These impact pathways include the following:

- airborne releases from incinerating combustible waste streams at waste generator locations;
- airborne releases from incinerating combustible waste streams at a centralized waste processing facility;

- o population exposures due to transportation of waste to the disposal facility;
- o occupational exposures received during waste processing;
- o occupational exposures received during waste transportation; and
- o occupational exposures received during waste disposal.

Specific values of parameters used to determine the magnitude of impacts from these pathways are presented in Sections 3.8, 4, and 5.

2.3 Other Potential Exposure Pathways

The above release/transport mechanisms are believed to be comparatively the most significant potential pathways to human exposure, and calculational procedures are developed in this appendix to determine potential human exposure levels resulting from these pathways. There are other potential pathways to humans which may be considered during development of performance objectives and technical requirements, but calculational procedures to estimate specific exposure levels were not developed. These potential exposure pathways include the following (Ref. 12):

- o Ground-water migration during the operational period of the facility lifespan;
- o The bathtub effect--filling up of the disposal cells with accumulated leachate and subsequent overflowing;
- o Diffusion of radioisotope tagged decomposition gases through disposal cell covers; and
- o Dispersion of radioactive material by means of surface runoff or wind dispersion from accidentally contaminated site surfaces and equipment.

All of these potential pathways have been observed at DOE-operated and/or commercial disposal facilities (Ref. 12). The first three pathways are fundamentally caused by site instability problems--that is, by degradation of compressive material within a disposal cell and subsequent subsidence of the disposal cell contents, leading to cracking and slumping of disposal cell covers and increased infiltration of rainwater into the disposal cell. At sites with moderate to high permeability soils, an infiltration problem (resulting from a subsidence problem) can lead to migration of some radionuclides being observed during the operational period of the facility life. This would principally involve very mobile radionuclides such as tritium. However, during site operations the potential for ground-water migration would be monitored and if it occurs, the licensee would take steps to correct the situation. Of more concern is the potential long-term migration of all the radionuclides in the waste after site operations have terminated. At sites with very low permeability soils, an infiltration problem can also lead to

collection of trench leacnate in disposal cells. This leachate would have to be removed and treated during disposal operations.

It has been demonstrated that potential problems of increased infiltration (migration during the operational period or the bathtub effect) can be minimized or avoided during the operational period through siting or operational procedures. For example, increased attention paid to compaction of disposal trench covers can greatly reduce the maintenance required during site operations. Of more interest from a regulatory point of view is the long-term stability of a disposal facility and methods which may be used to ensure this stability. Impacts from the bathtub effect could ultimately include overland flow of a few to some hundreds of gallons of leachate. The principal impact, however, is likely to be the very high costs of remedial action, which could include pumping, treating, and solidifying leachate, and restabilization of trench covers. This remedial action could result in an expense to a site owner of better than a million dollars per year for a number of years (Ref. 12). Treatment of leachate would involve airborne or waterborne release of radionuclides.

Past disposal experience indicates that potential diffusion of radioisotope-tagged decomposition products is small and can be significantly retarded by facility design and operating practices such as thicker trench covers (Refs. 13, 14). In any case, generation of decomposition gases would be reduced through efforts to minimize the degradation of trench contents. That is, actions undertaken to promote site stability and to minimize or eliminate trench subsidence will also serve to significantly reduce generation of decomposition gases.

Potential operational impacts due to run-off or wind dispersion of contaminated site surfaces are site-specific and would be addressed as part of the licensing of individual disposal facilities, and calculational procedures to estimate the levels of these potential impacts are not developed in this appendix. In any case, these impacts can be reduced to negligible levels through strict onsite contamination control at a disposal facility, and through better attention paid to packaging of wastes for transportation. In the past, one of the most significant contributors to onsite contamination has been accidental spillage of low-level waste liquids which were at one time delivered to some disposal facilities for solidification and disposal, and spillage of trench leachate during pumping for treatment. More recently, however, this practice has been discontinued and all disposal facilities accept only solid wastes for disposal. Probably another cause for onsite contamination is through excessive free-standing liquids in (and leaking out of) disposal containers.

Intrusion by deep-rooted plants or burrowing animals through disposal cell covers is another potential pathway. This intrusion could potentially result in increased human exposures by three general mechanisms: (1) surfacing of radioactive material which could then be dispersed by wind or water, (2) human consumption of contaminated plants or animals, or (3) increasing rainwater percolation into the disposed waste, thereby increasing radionuclide migration through ground water. These potential exposures, particularly the first two mechanisms, are difficult to quantify. Past occurrences of plant and animal

intrusion at existing disposal facilities, potential exposure pathways to humans, and methods to reduce or preclude such intrusion are site-specific and would be speculative to quantify in the generic analysis developed in this EIS. In any case, the major impact of deep-rooted plant and burrowing animal intrusion at a disposal facility is likely to be to increase the potential for ground-water migration. This effect is quantitatively considered in this appendix (see Section G.3.5).

2.4 Pathway Dose Conversion Factors

The use of the pathway dose conversion factors (PDCFs) in the calculational methodology is straightforward. It is multiplied by the radionuclide concentration at the biota access location(s) (C_a) to obtain the human exposures:

$$H = PDCF \times C_a \qquad (G\text{-}1)$$

where PDCF stands for the pathway dose conversion factor in millirem (mrem) per Ci/m^3 for the acute exposure scenarios and in mrem/year per Ci/m^3 for the chronic exposure scenarios. The radionuclide concentration at the biota access location (C_a) is in units of Ci/m^3.

In this work, for acute exposure, H will be taken as the dose in mrem, received during 50 years following a one-year exposure to the radioactive material; and for chronic exposures, H will be taken as the dose rate in mrem/year, received during the 50th year of an exposure period lasting 50 years.

Hereinafter, the qualifier equivalent is assumed to be implicit in the term dose; similarly, the dose equivalent rate will be referred to as the dose rate.

Some of the acute exposure scenarios last for much shorter periods than one year. However, for calculational convenience all acute exposures will be assumed to last one year. A correction factor, used to normalize acute periods to the one-year reference value, will be incorporated into the release/transport portion of the scenario, usually into the site selection factor f_s, as appropriate to the scenario.

2.4.1 Uptake Pathways

The PDCFs for the scenarios discussed in Sections 2.2.2.4 and 2.2.2.5 are the total pathway dose conversion factors for the individual pathways of importance which contribute to human exposures from concentrations of nuclides at biota access locations. The individual pathways that comprise the scenarios are shown in Figure G.3.

As presented in Figure G.3, all of the scenarios involve a secondary biota access location resulting from the primary biota access location. Two of the scenarios have four uptake pathways, four have five, and one has six, yielding a total of 34 uptake pathways. However, of these 34 uptake pathways only 9 are unique types of pathways, if only the uptake mode and transport agents are considered. These nine distinct types of pathways are described in Table G.2.

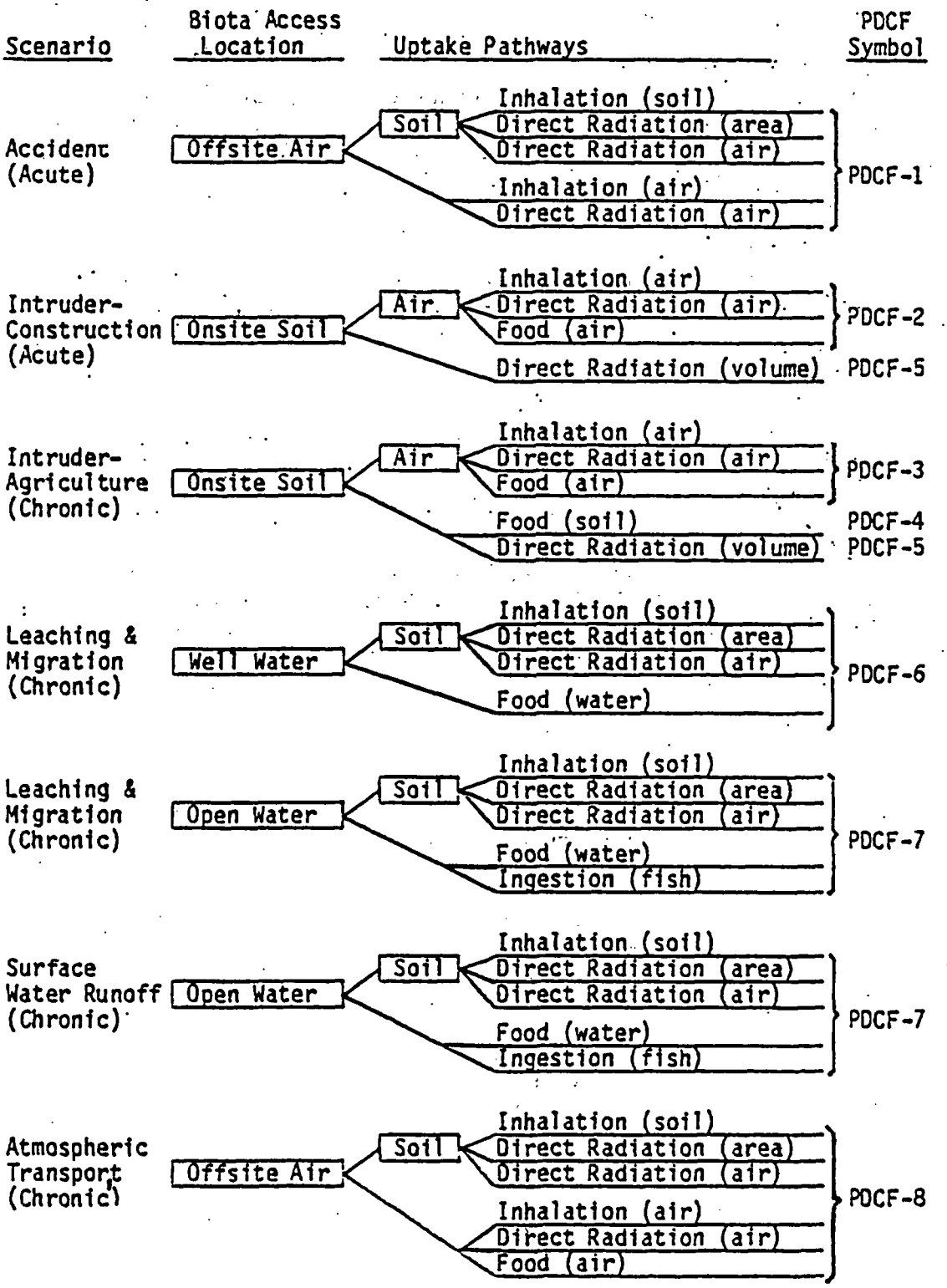


Figure G.3 Details of Uptake Pathways

Table G.2 Access Location-to-Human Pathway Description

Pathway Designation	Description
Food (soil)	This uptake pathway includes a total of three subpathways and denotes uptake of radionuclides originating in plants via soil-to-root transfer from contaminated soil: plant-to-human plant-to-animal-to-human plant-to-animal-to-product-to-human
Food (air)	This uptake pathway includes a total of six subpathways and includes the above three food (soil) subpathways resulting from uptake of radionuclides originating on plant surfaces via deposition from contaminated air and the same three food (soil) subpathways resulting from fallout contamination of the ground.
Food (water)	This uptake pathway includes a total of nine subpathways and includes all the food (soil) pathways resulting from radionuclides originating on plant surfaces via irrigation deposition from contaminated water and from irrigation contamination of the ground. The following three subpathways in addition to plant pathways are added: water-to-human water-to-animal-to-human water-to-animal-to-product-to-human
Ingestion (fish)	Uptake of radionuclides from eating fish caught in contaminated open water.
Inhalation (air)	Uptake of radionuclides from breathing air contaminated due to suspension of contaminated soil particles by human activities.
Inhalation (soil)	Uptake of radionuclides from breathing air contaminated due to natural suspension and volatilization of surface soil.
Direct Gamma (volume)	Direct exposure to gamma rays from standing on ground homogeneously contaminated.
Direct Gamma (area)	Direct exposure to gamma rays from standing on ground whose surface is contaminated.
Direct Gamma (air)	Direct exposure to gamma rays from standing in air homogeneously contaminated.

Only primary and secondary access locations are considered in the determination of these uptake pathways. The effects of possible tertiary access locations, such as air contaminated due to natural suspension radioactivity from soil which is originally contaminated from deposition of radioactivity from air, are not considered. These effects are considered, however, in the selection of transfer factors between the uptake pathways.

The accident scenario includes offsite air as the primary access location leading to two uptake pathways: inhalation (air) and direct gamma (air). It also includes soil contaminated by radionuclide deposition as the secondary access location leading to three more uptake pathways: inhalation (soil), direct gamma (area), and direct gamma (air). Since the exposure period is acute, the food (air) uptake pathway has been excluded from this scenario. However, the direct gamma (air) pathway is included in the secondary access location in addition to the primary access location.

The intruder-construction scenario includes onsite soil as the primary access location and leading to the direct gamma (volume) pathway. The scenario also includes onsite air as the secondary access location leading to three uptake pathways: inhalation (air), direct gamma (air), food (air). Although the exposure period is acute, the food (air) uptake pathway is included with a modification to account for nonequilibrium deposition and root-uptake conditions.

The intruder-agriculture scenario also includes onsite soil as the primary access location; however, the food (soil) uptake pathway is included in this case in addition to the direct gamma (volume) pathway. The scenario also includes onsite air as the secondary access location leading to the same three uptake pathways as the construction scenario secondary access location: inhalation (air), direct gamma (air), and food (air). However, in this case, chronic conditions are assumed to prevail, and equilibrium conditions are assumed for the food (air) uptake pathway.

The next three scenarios involving water are very similar. (The two open water scenarios are identical.) The only additional uptake pathway in the open water scenario as opposed to the well water scenario is the ingestion (fish) pathway. This pathway is included since the bioaccumulation factors for several fish species are significantly greater than unity. However, direct gamma exposure due to immersion in contaminated water was omitted; it turned out to result in negligible additional exposures (less than 0.1%) when compared with the other pathways.

The last scenario, the atmospheric transport scenario, is identical with the accident scenario with the addition of the food (air) uptake pathway to the primary access location. In this case, however, the exposure is assumed to be chronic as opposed to acute for the accident scenario.

A simplified version of Figure G.3 is presented in Figure G.4. The direct gamma (volume) uptake pathway is designated as PDCF-5, and the food (soil) pathway is designated as PDCF-4. Five of the scenarios are represented by a single PDCF. However, the two other scenarios are more complex since different

Figure G.4 Pathway Dose Conversion Factors

Scenario	Biota Access Location		Pathway DCFs
Accident (A)	Offsite Air		PDCF-1
		Air	PDCF-2
Construction (A)	Onsite Soil		PDCF-5
		Air	PDCF-3
Agriculture (C)	Onsite Soil		PDCF-4 PDCF-5
Leaching and Migration (C)	Well Water		PDCF-6
Leaching and Migration (C)	Open Water		PDCF-7
Surface Water Runoff (C)	Open Water		PDCF-7
Atmospheric Transport (C)	Offsite Air		PDCF-8

transfer factors are applicable to the individual components of the intruder-construction and intruder-agriculture scenarios. The differences in the transfer factors result from either differences in the mechanism mobilizing the radioactivity or differences in the access locations.

2.4.2 Pathway Dose Conversion Factor Tables

Seven human organs are considered in this EIS for each radionuclide and each pathway: total body, bone, kidney, thyroid, liver, lung, and gastrointestinal (GI) tact. These pathway dose conversion factors (PDCFs) have been derived from the 9 independent pathways presented in Table G.2. The information utilized to calculate the PDCFs includes human physiological parameters (e.g., breathing rates, nuclide metabolism), dietary intakes, and nuclide-specific food chain transfer rates (Ref. 1).

All the PCDFs are calculated based on five sets of fundamental dose conversion factors. Two of the sets include DCFs for determining the inhalation 50-year committed dose in units of mrem per pCi inhaled and the ingestion 50-year committed dose in units of mrem per pCi ingested. Three different gamma radiation exposure DCFs are used depending on the biota access location which can be either in-depth soil contamination (mrem/year per $pCim^3$), surface soil contamination (mrem/year per pCi/m^2), or air contamination (mrem/year per pCi/m^3). These fundamental DCFs depend on the radionuclides of concern and

the organ receiving the dose. A brief description of the fundamental DCFs is provided below.

The complete lung model, as proposed by the ICRP Task Group on Lung Dynamics (Refs. 15, 16) has been utilized in this appendix for the calculation of the fundamental inhalation dose conversion factors. This model permits a more realistic calculation of radiation dose to the human respiratory tract from inhaled radioactivity than does the initial ICRP lung model (Ref. 17). For the fundamental ingestion DCFs, DCFs given in Regulatory Guide 1.109 (Ref. 18) and NUREG-0172 (Ref. 19) have been utilized in this EIS.

The need to use three different fundamental direct gamma exposure DCFs arises from the geometry of exposure, and the attenuation and buildup afforded by the different contaminated media. In this EIS, fundamental direct gamma (volume) DCFs have been calculated based on the equations presented in Reference 20 and the emitted gamma energy characteristics of the radionuclides considered (Ref. 21). For the fundamental direct gamma (area) and the direct gamma (air) DCFs (which include exposure to electron radiation as well), the tables given in Reference 23 are utilized. The PDCFs calculated based on these fundamental dose conversion factors and pathway uptake factors (Ref. 1) are presented in Tables G.3 through G.10.

The I-129 PDCF for thyroid requires further discussion. The calculated I-129 PDCFs do not take into account the dilution of I-129 with natural iodine. Experimental environmental data and theoretical calculations (Ref. 1) have led some investigators in the past to utilize the total body dose to humans as a better indicator of the limiting exposure due to I-129 than the thyroid dose (Ref. 23). This selection results in a significant difference in limiting exposures since the fundamental dose conversion factors for thyroid are about 1000 times those for the total body (see Tables G.3 through G.10). However, a correction to the calculated thyroid PDCFs to account for dilution of I-129 with natural iodine has not been made in this appendix.

3. DISPOSAL IMPACTS

This section presents the calculational procedures utilized to determine the impact measures associated with the disposal of LLW. These impact measures include individual and population exposures, occupational exposures, costs, energy use, and land use.

The impact measures are strongly dependent on the waste form and package properties (Appendix D), and disposal facility environment, design, and operating practices (Appendices E and F). Accordingly, Section 3.1 presents the background assumptions regarding the disposal technology alternatives considered, and discusses how these assumptions are incorporated into the impact calculations. Similarly, Section 3.2 presents procedures through which the effects of waste form and packaging are incorporated into the calculations.

Following these two background sections, Sections 3.3 through 3.7 present the equations and specific parameter values used to calculate individual and population exposures for the applicable scenarios considered in Section 2.2.

Table G.3 Pathway Dose Conversion Factor - 1

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	1.25E+09	5.19E+07	1.25E+09	1.25E+09	1.25E+09	1.25E+09	5.19E+07
C-14	3.17E+09	1.40E+10	3.17E+09	3.17E+09	3.17E+09	3.17E+09	2.53E+09
FE-55	1.81E+10	1.89E+10	2.41E+10	1.61E+10	1.61E+10	2.08E+11	1.93E+10
CO-60	2.36E+12	2.34E+12	2.35E+12	2.34E+12	2.34E+12	2.63E+13	2.50E+12
NI-59	3.70E+10	9.38E+10	5.06E+10	2.58E+10	2.58E+10	5.78E+10	2.85E+10
NI-63	3.06E+10	9.60E+11	6.58E+10	1.56E+08	1.56E+08	8.82E+10	7.44E+09
SR-90	2.42E+13	9.62E+13	1.67E+11	1.67E+11	1.67E+11	1.98E+11	1.89E+11
NB-94	6.10E+11	6.11E+11	6.11E+11	6.10E+11	6.11E+11	1.33E+12	6.28E+11
TC-99	1.18E+09	9.68E+08	2.28E+09	7.60E+08	2.00E+10	7.40E+09	7.88E+09
I-129	9.14E+11	8.52E+11	8.52E+11	5.13E+13	8.52E+11	8.57E+11	8.52E+11
CS-135	2.37E+10	9.65E+10	8.85E+10	5.08E+08	3.33E+10	1.49E+10	1.00E+09
CS-137	4.50E+11	6.34E+11	7.78E+11	2.42E+11	4.26E+11	3.30E+11	2.44E+11
U-235	2.06E+12	3.06E+13	2.21E+11	2.21E+11	7.26E+12	3.36E+15	5.17E+11
U-238+D	1.69E+12	2.88E+13	1.45E+10	1.45E+10	6.57E+12	3.12E+15	2.55E+11
NP-237+D	5.20E+14	1.20E+16	1.12E+15	1.34E+11	3.84E+15	3.60E+14	3.74E+11
PU-238	2.00E+14	4.08E+15	2.80E+15	1.92E+10	8.80E+14	4.08E+15	3.31E+11
PU-239	2.24E+14	4.80E+15	3.12E+15	7.40E+09	9.60E+14	3.84E+15	3.03E+11
PU-241	3.04E+12	7.44E+13	4.56E+13	4.78E+07	1.44E+13	6.80E+12	5.57E+09
PU-242	2.16E+14	4.48E+15	3.04E+15	1.44E+10	9.60E+14	3.68E+15	2.94E+11
AM-241	5.04E+14	7.12E+15	6.64E+15	7.87E+10	3.84E+15	4.24E+14	3.59E+11
AM-243	4.96E+14	7.04E+15	6.48E+15	9.10E+10	3.76E+15	4.00E+14	3.63E+11
CM-243	3.84E+14	6.16E+15	5.60E+15	2.44E+11	1.76E+15	4.40E+14	5.48E+11
CM-244	2.80E+14	4.40E+15	4.16E+15	1.71E+10	1.28E+15	4.40E+14	3.05E+11

Table G.4 Pathway Dose Conversion Factor - 2

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	1.17E+10	5.19E+07	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.05E+10
C-14	6.68E+10	3.32E+11	6.68E+10	6.68E+10	6.68E+10	6.68E+10	6.61E+10
FE-55	9.28E+09	4.28E+10	3.94E+10	5.08E+07	5.08E+07	2.10E+11	2.12E+10
CO-60	1.24E+11	2.28E+10	7.60E+10	2.28E+10	2.28E+10	2.40E+13	8.59E+11
NI-59	3.87E+10	2.33E+11	8.13E+10	5.98E+07	5.98E+07	3.21E+10	1.44E+10
NI-63	1.04E+11	3.15E+12	2.18E+11	1.56E+08	1.56E+08	8.82E+08	3.91E+10
SR-90	5.52E+13	2.23E+14	1.76E+09	1.76E+09	1.76E+09	3.30E+10	3.69E+12
NB-94	1.39E+10	1.51E+10	1.45E+10	1.32E+10	1.45E+10	7.33E+11	4.43E+11
TC-99	2.25E+09	3.64E+09	6.26E+09	7.60E+08	7.00E+10	7.74E+09	1.38E+11
I-129	2.00E+12	6.88E+11	5.91E+11	1.57E+15	1.27E+12	6.37E+09	9.45E+10
CS-135	1.57E+11	4.21E+11	3.88E+11	5.08E+08	1.47E+11	4.89E+10	8.01E+09
CS-137	1.40E+12	1.72E+12	2.35E+12	1.53E+09	8.01E+11	2.94E+11	3.92E+10
U-235	2.64E+12	4.36E+13	1.59E+09	1.59E+09	1.01E+13	3.36E+15	1.59E+12
U-238+D	2.43E+12	4.15E+13	8.57E+07	8.57E+07	9.45E+12	3.12E+15	1.15E+12
NP-237+D	5.21E+14	1.20E+16	1.12E+15	8.40E+08	3.85E+15	3.60E+14	1.55E+12
PU-238	2.00E+14	4.09E+15	2.80E+15	8.87E+07	8.81E+14	4.08E+15	1.51E+12
PU-239	2.24E+14	4.81E+15	3.12E+15	5.17E+07	9.61E+14	3.84E+15	1.39E+12
PU-241	3.05E+12	7.47E+13	4.56E+13	4.78E+07	1.44E+13	6.80E+12	2.86E+10
PU-242	2.16E+14	4.49E+15	3.04E+15	6.93E+07	9.61E+14	3.68E+15	1.35E+12
AM-241	5.05E+14	7.13E+15	6.64E+15	3.80E+08	3.85E+15	4.24E+14	1.51E+12
AM-243	4.97E+14	7.05E+15	6.48E+15	6.09E+08	3.77E+15	4.00E+14	1.71E+12
CM-243	3.85E+14	6.17E+15	5.60E+15	2.26E+09	1.76E+15	4.40E+14	1.59E+12
CM-244	2.80E+14	4.41E+15	4.16E+15	7.23E+07	1.28E+15	4.40E+14	1.53E+12

Table G.5 Pathway Dose Conversion Factor - 3

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	4.45E+10	5.19E+07	4.45E+10	4.45E+10	4.45E+10	4.45E+10	4.35E+10
C-14	2.66E+11	1.33E+12	2.66E+11	2.66E+11	2.66E+11	2.66E+11	2.65E+11
FE-55	3.22E+10	1.90E+11	1.38E+11	5.08E+07	5.08E+07	2.64E+11	7.75E+10
CO-60	3.70E+11	2.28E+10	1.87E+11	2.28E+10	2.28E+10	2.40E+13	2.95E+12
NI-59	1.25E+11	7.48E+11	2.58E+11	5.98E+07	5.98E+07	3.21E+10	5.08E+10
NI-63	3.34E+11	1.00E+13	6.93E+11	1.56E+08	1.56E+08	8.82E+10	1.38E+11
SR-90	1.53E+14	6.21E+14	1.76E+09	1.76E+09	1.76E+09	3.30E+10	1.52E+13
NB-94	1.40E+10	1.55E+10	1.47E+10	1.32E+10	1.46E+10	7.33E+11	1.56E+12
TC-99	5.61E+09	1.20E+10	1.87E+10	7.60E+08	2.27E+11	8.80E+09	5.45E+11
I-129	8.06E+12	2.84E+12	2.44E+12	6.33E+15	5.24E+12	6.37E+09	3.87E+11
CS-135	5.73E+11	1.44E+12	1.33E+12	5.08E+08	5.02E+11	1.55E+11	3.00E+10
CS-137	5.12E+12	5.87E+12	8.03E+12	1.53E+09	2.73E+12	9.35E+11	1.49E+11
U-235	5.15E+12	8.50E+13	1.59E+09	1.59E+09	1.98E+13	3.36E+15	5.62E+12
U-238+D	4.77E+12	8.11E+13	8.57E+07	8.57E+07	1.85E+13	3.12E+15	3.99E+12
NP-237+D	5.24E+14	1.21E+16	1.13E+15	8.40E+08	3.87E+15	3.60E+14	5.65E+12
PU-238	2.01E+14	4.13E+15	2.81E+15	8.87E+07	8.85E+14	4.08E+15	5.28E+12
PU-239	2.25E+14	4.85E+15	3.13E+15	5.17E+07	9.66E+14	3.84E+15	4.83E+12
PU-241	3.06E+12	7.55E+13	4.57E+13	4.78E+07	1.45E+13	6.80E+12	1.01E+11
PU-242	2.17E+14	4.53E+15	3.05E+15	6.93E+07	9.65E+14	3.68E+15	4.72E+12
AM-241	5.08E+14	7.18E+15	6.66E+15	3.80E+08	3.87E+15	4.24E+14	5.36E+12
AM-243	5.00E+14	7.10E+15	6.50E+15	6.09E+08	3.79E+15	4.00E+14	6.22E+12
CM-243	3.87E+14	6.20E+15	5.62E+15	2.26E+09	1.77E+15	4.40E+14	5.63E+12
CM-244	2.82E+14	4.43E+15	4.17E+15	7.23E+07	1.29E+15	4.40E+14	5.43E+12

Table G.6 Pathway Dose Conversion Factor - 4

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	5.99E+04	0.	5.99E+04	5.99E+04	5.99E+04	5.99E+04	5.99E+04
C-14	3.72E+05	1.86E+06	3.72E+05	3.72E+05	3.72E+05	3.72E+05	3.72E+05
FE-55	3.48E+01	2.16E+02	1.49E+02	0.	0.	8.33E+01	8.57E+01
CO-60	5.27E+03	0.	2.39E+03	0.	0.	0.	4.49E+04
NI-59	3.69E+03	2.21E+04	7.59E+03	0.	0.	0.	1.56E+03
NI-63	9.88E+03	2.95E+05	2.04E+04	0.	0.	0.	4.26E+03
SR-90	3.76E+06	1.53E+07	0.	0.	0.	0.	4.42E+05
NB-94	2.12E+00	7.08E+00	3.94E+00	0.	3.89E+00	0.	2.39E+04
TC-99	1.53E+03	3.82E+03	5.68E+03	0.	7.15E+04	4.83E+02	1.86E+05
I-129	2.19E+04	7.77E+03	6.68E+03	1.72E+07	1.44E+04	0.	1.06E+03
CS-135	9.50E+03	2.32E+04	2.14E+04	0.	8.10E+03	2.43E+03	5.01E+02
CS-137	8.49E+04	9.48E+04	1.30E+05	0.	4.40E+04	1.46E+04	2.51E+03
U-235	1.44E+04	2.38E+05	0.	0.	5.55E+04	0.	2.32E+04
U-238+D	1.35E+04	2.28E+05	0.	0.	5.20E+04	0.	1.63E+04
NP-237+D	1.64E+04	4.07E+05	3.53E+04	0.	1.22E+05	0.	2.36E+04
PU-238	1.14E+03	4.52E+04	6.37E+03	0.	4.87E+03	0.	4.85E+03
PU-239	1.27E+03	5.23E+04	7.05E+03	0.	5.39E+03	0.	4.43E+03
PU-241	2.21E+01	1.10E+03	5.61E+01	0.	1.02E+02	0.	9.31E+01
PU-242	1.22E+03	4.85E+04	6.78E+03	0.	5.19E+03	0.	4.34E+03
AM-241	3.60E+04	5.45E+05	1.92E+05	0.	2.71E+05	0.	4.94E+04
AM-243	3.53E+04	5.44E+05	1.85E+05	0.	2.65E+05	0.	5.79E+04
CM-243	1.11E+04	1.90E+05	7.15E+04	0.	5.20E+04	0.	2.32E+04
CM-244	8.52E+03	1.43E+05	6.15E+04	0.	3.98E+04	0.	2.24E+04

Table G.7 Pathway Dose Conversion Factor - 5

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	0.	0.	0.	0.	0.	0.	0.
C-14	0.	0.	0.	0.	0.	0.	0.
FE-55	0.	0.	0.	0.	0.	0.	0.
CO-60	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07
NI-59	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03
NI-63	0.	0.	0.	0.	0.	0.	0.
SR-90	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04
NB-94	9.63E+06	9.63E+06	9.63E+09	9.63E+06	9.63E+06	9.63E+06	9.63E+06
TC-99	0.	0.	0.	0.	0.	0.	0.
I-129	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04
CS-135	0.	0.	0.	0.	0.	0.	0.
CS-137	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06
U-235	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05
U-238+D	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03
NP-237+D	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.55E+04	6.56E+04
PU-238	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01
PU-239	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01
PU-241	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04
AM-243	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05
CM-243	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05
CM-244	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01

Table G.8 Pathway Dose Conversion Factor - 6

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	2.37E+06	1.42E-01	2.37E+06	2.37E+06	2.37E+06	2.37E+06	2.37E+06
C-14	1.44E+07	7.21E+07	1.44E+07	1.44E+07	1.44E+07	1.44E+07	1.44E+07
FE-55	2.73E+06	1.24E+07	8.86E+06	8.61E+05	8.61E+05	5.33E+06	5.45E+06
CO-60	1.43E+08	1.24E+08	1.33E+08	1.24E+08	1.24E+08	1.24E+08	2.89E+08
NI-59	8.54E+06	4.42E+07	1.61E+07	1.38E+06	1.38E+06	1.38E+06	4.41E+06
NI-63	1.92E+07	5.71E+08	3.96E+07	4.28E-01	4.28E-01	2.42E+02	8.26E+06
SR-90	7.61E+09	3.10E+10	8.83E+06	8.83E+06	8.83E+06	8.83E+06	9.04E+08
NB-94	3.19E+07	3.20E+07	3.19E+07	3.19E+07	3.19E+07	3.19E+07	1.47E+08
TC-99	3.60E+05	8.96E+05	1.33E+06	2.08E+00	1.68E+07	1.13E+05	4.36E+07
I-129	4.18E+07	1.72E+07	1.53E+07	2.99E+10	2.87E+07	3.64E+06	5.48E+06
CS-135	3.32E+07	8.09E+07	7.47E+07	1.39E+00	2.83E+07	8.46E+06	1.75E+06
CS-137	3.09E+08	3.44E+08	4.65E+08	1.29E+07	1.66E+08	6.39E+07	2.16E+07
U-235	2.07E+08	3.24E+09	1.18E+07	1.18E+07	7.64E+08	2.10E+07	3.26E+08
U-238+D	1.83E+08	3.09E+09	7.74E+05	7.74E+05	7.05E+08	9.32E+06	2.22E+08
NP-237+D	2.31E+08	5.55E+09	4.88E+08	7.13E+06	1.67E+09	8.11E+06	3.26E+08
PU-238	7.02E+07	2.74E+09	3.93E+08	1.03E+06	2.97E+08	1.22E+07	2.94E+08
PU-239	7.77E+07	3.17E+09	4.34E+08	3.93E+05	3.28E+08	1.09E+07	2.68E+08
PU-241	1.34E+06	6.64E+07	3.51E+06	1.31E-01	6.18E+06	1.86E+04	5.62E+06
PU-242	7.52E+07	2.94E+09	4.18E+08	7.67E+05	3.17E+08	1.09E+07	2.63E+08
AM-241	2.25E+08	3.34E+09	1.19E+09	4.19E+06	1.66E+09	5.35E+06	3.05E+08
AM-243	2.21E+08	3.34E+09	1.15E+09	4.84E+06	1.63E+09	5.93E+06	3.57E+08
CM-243	1.65E+08	2.60E+09	9.97E+08	1.30E+07	7.21E+08	1.42E+07	3.27E+08
CM-244	1.17E+08	1.95E+09	8.44E+08	9.09E+05	5.43E+08	2.12E+06	3.04E+08

Table G.9 Pathway Dose Conversion Factor - 7

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	2.37E+06	1.42E-01	2.37E+06	2.37E+06	2.37E+06	2.37E+06	2.37E+06
C-14	3.76E+07	1.88E+08	3.76E+07	3.76E+07	3.76E+07	3.76E+07	3.76E+07
FE-55	4.45E+06	2.31E+07	1.63E+07	8.61E+05	8.61E+05	9.45E+06	9.69E+06
CO-60	1.46E+08	1.24E+08	1.34E+08	1.24E+08	1.24E+08	1.24E+08	3.11E+08
NI-59	9.82E+06	5.20E+07	1.87E+07	1.38E+06	1.38E+06	1.38E+06	4.95E+06
NI-63	2.26E+07	6.74E+08	4.67E+07	4.28E-01	4.28E-01	2.42E+02	9.74E+06
SR-90	8.18E+09	3.33E+10	8.83E+06	8.83E+06	8.83E+06	8.83E+06	9.71E+08
NB-94	3.23E+07	3.32E+07	3.27E+07	3.19E+07	3.26E+07	3.19E+07	4.50E+09
TC-99	3.65E+05	9.09E+05	1.35E+06	2.08E+00	1.70E+07	1.15E+05	4.42E+07
I-129	4.28E+07	1.75E+07	1.56E+07	3.07E+10	2.93E+07	3.64E+06	5.53E+06
CS-135	1.44E+08	3.52E+08	3.25E+08	1.39E+00	1.23E+08	3.68E+07	7.60E+06
CS-137	1.30E+09	1.45E+09	1.98E+09	1.29E+07	6.81E+08	2.35E+08	5.09E+07
U-235	2.11E+08	3.29E+09	1.18E+07	1.18E+07	7.78E+08	2.10E+07	3.32E+08
U-238+D	1.87E+08	3.14E+09	7.74E+05	7.74E+05	7.18E+08	9.32E+06	2.26E+08
NP-237+D	2.57E+08	6.19E+09	5.44E+08	7.13E+06	1.87E+09	8.11E+06	3.63E+08
PU-238	7.49E+07	2.93E+09	4.19E+08	1.03E+06	3.17E+08	1.22E+07	3.14E+08
PU-239	8.29E+07	3.39E+09	4.63E+08	3.93E+05	3.51E+08	1.09E+07	2.86E+08
PU-241	1.43E+06	7.09E+07	3.74E+06	1.31E-01	6.60E+06	1.86E+04	6.00E+06
PU-242	8.02E+07	3.14E+09	4.46E+08	7.67E+05	3.38E+08	1.09E+07	2.81E+08
AM-241	3.72E+08	5.57E+09	1.97E+09	4.19E+06	2.77E+09	5.35E+06	5.07E+08
AM-243	3.65E+08	5.57E+09	1.91E+09	4.84E+06	2.72E+09	5.93E+06	5.94E+08
CM-243	2.09E+08	3.35E+09	1.28E+09	1.30E+07	9.26E+08	1.42E+07	4.18E+08
CM-244	1.51E+08	2.52E+09	1.09E+09	9.09E+05	7.00E+08	2.12E+06	3.93E+08

Table G.10 Pathway Dose Conversion Factor - 8

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	4.45E+10	5.19E+07	4.52E+10	4.45E+10	4.45E+10	4.45E+10	4.33E+10
C-14	2.66E+11	1.33E+12	2.66E+11	2.66E+11	2.66E+11	2.66E+11	2.65E+11
FE-55	4.83E+10	2.06E+11	1.54E+11	1.61E+10	1.61E+10	2.80E+11	9.36E+10
CO-60	2.68E+12	2.34E+12	2.50E+12	2.34E+12	2.34E+12	2.63E+13	5.27E+12
NI-59	1.50E+11	7.73E+11	2.84E+11	2.58E+10	2.58E+10	5.78E+10	7.65E+10
NI-63	3.34E+11	1.00E+13	6.93E+11	1.56E+08	1.56E+08	8.82E+10	1.38E+11
SR-90	1.53E+14	6.21E+11	1.67E+11	1.67E+11	1.67E+11	1.98E+11	1.53E+13
NB-94	6.10E+11	6.12E+11	6.11E+11	6.10E+11	6.11E+11	1.33E+12	2.15E+12
TC-99	5.61E+09	1.20E+10	1.87E+10	7.60E+08	2.27E+11	8.80E+09	5.45E+11
I-129	8.91E+12	3.69E+12	3.29E+12	6.33E+15	6.10E+12	8.57E+11	1.24E+12
CS-135	5.73E+11	1.44E+12	1.33E+12	5.08E+08	5.02E+11	1.55E+11	3.00E+10
CS-137	5.36E+12	6.12E+12	8.27E+12	2.42E+11	2.97E+12	1.18E+12	3.90E+11
U-235	5.37E+12	8.52E+13	2.21E+11	2.21E+11	2.00E+13	3.36E+15	5.84E+12
U-238+D	4.79E+12	8.11E+13	1.45E+10	1.45E+10	1.85E+13	3.12E+15	4.00E+12
NP-237+D	5.24E+14	1.21E+16	1.13E+15	1.34E+11	3.87E+15	3.60E+14	5.79E+12
PU-238	2.01E+14	4.13E+15	2.81E+15	1.92E+10	8.85E+14	4.08E+15	5.30E+12
PU-239	2.25E+14	4.85E+15	3.13E+15	7.40E+09	9.66E+14	3.84E+15	4.83E+12
PU-241	3.06E+12	7.55E+15	4.57E+13	4.78E+07	1.45E+13	6.80E+12	1.01E+11
PU-242	2.17E+14	4.53E+15	3.05E+15	1.44E+10	9.65E+14	3.68E+15	4.74E+12
AM-241	5.08E+14	7.18E+15	6.66E+15	7.87E+10	3.87E+15	4.24E+14	5.43E+12
AM-243	5.00E+14	7.10E+15	6.50E+15	9.10E+10	3.79E+15	4.00E+14	6.31E+12
CM-243	3.87E+14	6.20E+15	5.62E+15	2.44E+11	1.77E+15	4.40E+14	5.87E+12
CM-244	2.82E+14	4.43E+15	4.17E+15	1.71E+10	1.29E+15	4.40E+14	5.45E+12

Finally, Section 3.8 details the calculation of other impact measures considered in this appendix, including occupational exposures, land use, disposal costs, and energy use. The reference near-surface disposal facility, which was constructed to illustrate the concepts mentioned in this environmental impact statement, is discussed in Appendix E.

3.1 Disposal Technology Indices

In order to analyze the impacts from disposal of LLW, alternative disposal technology properties and their effect on the impact measure calculations must be quantified. For example, depending on specific operational procedures such as random or stacked disposal, the values of the barrier factors presented in Section 2.2 vary. In this appendix, the disposal technology properties have been expressed in the form of integer indices that refer to a specific procedure on the barrier factor computations or determine a specific value of the environmental parameters. These indices, which will be referred to as the disposal technology indices, basically denote the selection options available for a specific property. These selection options may be in the form of a specific calculation procedure or a specific value for an environmental property.

The primary rationale for handling the variations in the disposal technology properties in this manner is to provide flexibility in updating the information base associated with the alternative disposal technologies. Each value of these indices imply a value for the corresponding disposal technology property; these property values may be altered and updated with ease without changing the values of the indices or the structure of the calculations.

The disposal technology properties that have been considered in the calculation of impacts in this report are summarized in Table G.11.

3.1.1 Region Index--IR

This index, whose value is 1 or higher, is set depending upon the region considered and determines use of a specific set of environmental properties in the impact calculations. The main effect of the region index is on the site selection factor. Environmental properties that are dependent on the region index are presented in Table G.12.

The value of this index corresponding to each of the regions is as follows:

- IR=1: Northwest region
- IR=2: Southeast region
- IR=3: Midwest region
- IR=4: West region

In this EIS, the southeastern region is used for the reference disposal facility site. Variations on the values assigned for the regions (e.g., to perform sensitivity analyses) can also be triggered through use of the region index.

Table G.11 Disposal Technology Indices

Property and Index	Description
Region - IR	Geographic location of the disposal facility.
Design - ID	Two options are considered: regular trenches, and the so-called "concrete-walled" trenches.
Cover - IC	Three options on the cover between the waste and the atmosphere are considered: regular, thick, and intruder barrier.
Emplacement - IE	Three options on the emplacement of the waste are considered: random, stacked, and random combined with decontainerized disposal for compressible low activity wastes
Stabili-zation - IX	Three options on the stabilization program applied to disposal cells, which may contain structurally unstable wastes, are considered: regular, moderate, and extensive.
Layering - IL	Option on separating and putting selected waste streams (usually with higher external radiation levels) at the bottom of the disposal cell.
Segregation -IS	Option to segregate and separately dispose of wastes that are combustible/compressible and those that could contain complexing agents.
Grouting - IG	Option on filling of the interstitial spaces between the wastes with grouting material.
Hot Waste Facility - IH	Option on having a special area within the disposal facility with special procedures to handle high activity wastes.
Closure Index - IQ	This index indicates the activities during the closure period (regular or extensive).
Care Level Index - ICL	This index indicates the care level anticipated during the active institutional control period (low, moderate, and high).
Postoper-tional Period (Years) - IPO	Duration of the period between the cessation of active disposal and the transfer of the title from the site operator to the site owner.
Institu-tional Control Period (Years) - IIC	Duration between transfer of the title to the site owner and the assumed time for loss of institutional controls over the site.

Table G.12 Region Index Dependent Properties

Symbol	Scenario	Environmental Property
TPO	Accident	Air-to-air transfer factor
FSC	Construction	Soil-to-air transfer factor
FSA	Agriculture	Soil-to-air transfer factor
QFC	Ground water	Dilution factor
TTM	Ground water	Water travel time
DTTM	Ground water	Incremental water travel time
TPC	Ground water	Peclet number
DTPB	Ground water	Incremental peclet number
RGF	Ground water	Factor r_g
RET	Ground water	Retardation coefficients
PRC	Ground water	Infiltrating percolation
POP	Exposed Waste	Air-to-air and surface water transfer factors
DIST	Transportation	One-way travel distance
STPS	Transportation	Number of stops per trip
CASK	Transportation	Cask days per round trip

3.1.2 Design and Operation Index

There are four design and operation indices: design index--ID; cover index--IC; emplacement index--IE; and stabilization index--IX. The values of these indices are 1 or higher denoting the options available in the design of the disposal facility; details of the options can be found in Appendices E and F. These indices are considered below.

The Design Index--ID characterizes the disposal unit design used for radioactive waste disposal. Two options have been used in this study: regular trench disposal and concrete-walled trench disposal. This index primarily affects the site design factor.

In this appendix, three different "efficiencies" are utilized to describe the specific procedures employed in the disposal of wastes:

- the volumetric disposal efficiency which is defined as the volume of disposal space available in the disposal cell (in m^3) per unit surface area (in m^2) of the disposal cell,

- the emplacement efficiency which is the volume of waste emplaced in the disposal cell (in m^3) per unit volume (in m^3) of available disposal space, and

- the surface efficiency which is defined as the ratio of the surface area occupied by the disposal cells to the surface area occupied by the disposal cells plus the surface area between these cells that have not been utilized for disposal.

The design index determines the volumetric disposal efficiency and the surface efficiency of the design. The emplacement efficiency is discussed below. Use of a hot waste facility (see Section 3.1.3), which is defined as a special group of disposal cells used for disposal of high-activity waste, is not included in the above definitions; its efficiencies are assumed to be independent of the design index.

The Cover Index--IC can be either 1, 2, or 3, and it denotes whether a "regular" cover (denoted by 1), a "thick" cover (denoted by 2), or an engineered "intruder barrier" cover (denoted by 3) is placed over the disposed waste. A regular cover refers to 1 meter of fill below the existing grade plus a minimum of 1 meter cover above grade. A thick cover refers to the same 1 m of fill below the existing grade plus a 2-meter thick engineered cover constructed of compacted high quality clay to minimize infiltration of percolation. An engineered intruder barrier refers to the same 1 meter of fill below the existing grade plus a minimum of 5-meter thick engineered cover (e.g., low permeability layers, interbedded sand/gravel/boulder layers) to minimize infiltration and preclude intrusion.

The Emplacement Index--IE denotes the specific method used to emplace the waste in the disposal cells and primarily affects the site design factor. The three options considered and associated emplacement efficiencies are discussed below.

Random emplacement (option 1) involves simply dumping the waste directly into the disposal cell. It is the fastest method which can be used, and therefore leads to the lowest occupational exposures. However, random emplacement of waste containers may be accomplished with only about 50% emplacement efficiency (one-half the available space is empty or filled with earth or other material), and there is a higher probability of the occurrence of accidents as well as container damage during haphazard dumping.

Stacked emplacement (option 2) involves stacking waste containers in neat piles, using cranes, forklifts, etc., to accomplish this. This case may be difficult to achieve on a routine basis but represents the maximum practical volume utilization. In this case, the potential for accidents and waste container damage is much lower, and approximately 75% of the available disposal space is used--i.e., the emplacement efficiency is 0.75. However, additional fuel must be used to operate the heavy equipment used for emplacement, and occupational doses increase as more men must spend more time near the disposed waste.

Decontainerized emplacement (option 3) involves randomly disposing of all structurally stable and/or higher activity wastes, and decontainerizing and disposing low activity wastes that are, over the long term, structurally unstable. In this case, the disposal facility would be operated somewhat like a sanitary landfill. This option can substantially reduce disposal cell instability problems by accelerating the compression of unstable wastes. However, it requires a significantly increased effort by the site operator and leads to higher occupational exposures (see Appendix F). The emplacement efficiency of this option is estimated to be about 0.5 since part of the waste containers are randomly emplaced and additional soil between wastes is likely to be required during emplacement of decontainerized wastes.

The Stabilization Index--IX, whose value can be 1, 2, or 3, denotes the extent to which the disposal cells are stabilized. Such stabilization measures may be implemented during disposal operations. Past disposal experience indicates that the difficulties currently experienced at several existing disposal sites may have resulted from the natural compaction and decomposition of the wastes leading to subsidence of the disposal cell cover and increased rainwater percolation. A stabilization program with no special compaction procedures other than the use of the weight of trucks or heavy equipment is denoted by 1. A more extensive stabilization program involving sheeps-foot rollers and/or vibratory compaction during operations is denoted by 2. A program involving very extensive techniques such as dynamic compaction or similar measures is denoted by 3. This option affects the site design factor and the waste form and package factor.

3.1.3 Site Operational Options

Four operational options which may be exercised in the design of the disposal facility are considered: layering--IL, segregation--IS, grouting--IG, and use of a hot waste facility--IH. The values of all these indices are either 0, signifying that the option has not been exercised, or 1, signifying that the option has been implemented in the design. These options are briefly discussed below.

Layering Option--IL denotes whether selected waste streams (usually those with higher external radiation levels) are separated and disposed of at the bottom of the disposal cells. This practice is frequently implemented at the existing sites to minimize occupational exposures. This option, however, affects the site design factor sigificantly by limiting access of potential inadvertent intruders to the layered waste streams.

Segregation Option--IS indicates whether, during the disposal operations, the wastes are segregated and disposed of in separate disposal cells based on their compressibility/combustibility and whether they contain radionuclide-complexing chemical agents. Implementing the segregation option increases the performance capability of the disposal cell covers by limiting expected long-term waste degradation and compression after disposal to those cells containing unstable wastes. It also limits the effects of chemicals that may increase radionuclide mobility to those wastes containing these chemicals. This index primarily affects the ground-water scenario through the site design factor and the waste form factor.

Grouting Option--IG indicates whether the interstitial spaces between the waste packages are filled with a material that will improve disposal cell stability. During the grouting operation, as each layer of waste is emplaced in the disposal cell, pumpable concrete (grout) is pumped to fill all interstitial spaces between the waste containers. Some grout is also placed under the lowest layer of waste and on top of the total waste mass. Grouting is expensive, but its use is advantageous in that the waste is totally encapsulated and immobilized. There is little opportunity for infiltrating precipitation to contact the waste; the grout provides stability, and potential long-term migrational and intruder impacts are minimized. This option affects the site design factor and the waste form factor.

Hot Waste Facility Option--IH indicates use of specially designed disposal cells utilizing special operational procedures to dispose of certain high-activity waste streams. In this appendix, if a hot waste facility is used, it is located at the center of the disposal facility. Confinement of the wastes and limiting their interaction with transport agents such as wind and water are the primary considerations in hot waste facility design, and other factors such as costs and surface efficiency are secondary design objectives. Consequently, the hot waste facility represents an "idealized" confinement concept which is nonetheless achievable utilizing existing disposal technology. Various example "hot waste facility designs" are considered in Appendix F; however, to compute hot waste facility costs in this appendix, it is assumed to be a concrete-walled trench into which the waste is stacked and grouted in place. A concrete cover is then poured over the emplaced waste.

3.1.4 Postoperational Indices

There are four postoperational indices: closure index--IQ, care level index--ICL, postoperational period--IPO, and active institutional control period--IIC. These are considered below.

The Closure Index--IQ, whose value can be 1 or 2, refers to actions implemented during the closure period after the cessation of disposal operations and prior to the transfer of the site title to the site owner. An index value of 1 indicates that closure operations are assumed to last two years and involve a relatively modest level of effort by the facility operator. Closure operations are assumed to consist of dismantlement and decontamination of site buildings (except those necessary for the site owners during the active institutional control period), disposal of wastes generated during the dismantlement and decontamination operations, final contouring (including implementation of final surface drainage systems) and vegetation of the site, final radiation surveys, etc. An index value of 2 indicates that a complete site restabilization program is carried out at site closure in addition to other closure operations discussed above. This program, which is assumed to increase the closure period to four years, is intended to enhance the integrity of the disposal cell covers and therefore reduce the amount of water potentially infiltrating into the disposal cells. The restabilization program involves: (1) stripping off the existing cell covers, (2) use of vibratory compaction or similar measures to accelerate disposal cell compression, (3) backfilling the resultant compressed areas, (4) reconstruction of the cell

covers, and (5) revegetation of the covers. Implementation of these measures is assumed to be equivalent to the implementation of a stabilization program during disposal operations corresponding to an IX value of 2.

The Care Level Index--ICL, whose value can be 1, 2, or 3, refers to activities during the active institutional control period that are implemented by the site owner. Different measures may have to be implemented depending on operational parameters such as the stabilization program, whether the segregation option has been implemented, the type of disposal cell covers utilized, etc.

The level of care may range from routine surveillance and maintenance of the disposal facility (e.g., cutting the grass) which would not include any major active maintenance such as major cover engineering (low-care level denoted by 1) to extensive stabilization and remedial programs similar to those being implemented at the Maxey Flats, Kentucky disposal facility (high-care level denoted by 3). Additional information regarding the extent of long-term care activities assumed for each care level is provided in Appendix Q.

The Postoperational Period--IPO is a property of the disposal technology utilized and denotes the number of years between the cessation of active disposal of wastes and transfer of the site title to the site owner. It includes the closure period as well as any observation period implemented by the site operator, and it affects the time-delay factor. At a minimum, it would be equal to the two years required for the actions by the site operator to close the site prior to the transfer of the site title to the site owner. At a maximum, it may include four to possibly thirty years which may be required for site closure plus a number of years to verify that the site condition is suitable for the transfer of the site title to the site owner.

The Active Institutional Control Period--IIC indicates the number of years between the transfer of the site title to the site owner and the assumed loss of active institutional controls. This period also affects the time-delay factor.

3.2 Waste Form Behavior Indices

This section presents the manner in which waste form and packaging properties are handled in the impact calculational procedures. These properties are considered in the impact calculations in a manner similar to the disposal technology properties. They have been expressed through discrete indices, which are called the waste form behavior indices, that indicate a certain property of the waste form or a specific calculational procedure to be utilized in the impact calculations. The indices are summarized in Table G.13.

It has been common practice in the past to give little or no credit to waste form and packaging properties in the calculation of impacts (e.g., Refs. 24 and 25). Some credit was sometimes given to the comparative leachability of the solidification agent utilized and this effect was considered in ground-water migration impact calculations. However, a quantitative analysis of the mechanical, thermal resistance to chemical and biological attack, and other properties of the waste form and their effects on all the pathways considered has not been performed.

Table G.13 Waste Form Behavior Indices

Parameter and Symbol		Indices
Flammability	(I4)	0 = nonflammable 1 = low flammability (mixture of material with indices of 0 and 2) 2 = burns if heat supplied (does not support burning) 3 = flammable (supports burning)
Dispersibility	(I5)	0 = low 1 = low to moderate 2 = moderate 3 = severe
Leachability	(I6)	1 = unsolidified waste form 2 = solidification scenario A* 3 = solidification scenario B** 4 = solidification scenario C†
Chemical Content	(I7)	0 = no chelating agents or organic chemicals 1 = chelating agents or organic chemicals are likely to be present in the waste form
Stability	(I8)	0 = structurally unstable waste form 1 = structurally stable waste form
Accessibility	(I9)	1 = readily accessible 2 = moderately accessible 3 = accessible with difficulty

*50% urea-formaldehyde and 50% cement.
**50% cement and 50% synthetic polymer.
†100% synthetic polymer.

The primary reason for this past conservatism has been the lack of detailed data on the different types of wastes included in the impact analyses. All the LWR wastes or all the nonfuel cycle wastes, or both, were considered as one stream. A contributing reason for this conservatism has been the lack of data on the performance of the waste form over long periods of time. However, in this EIS, the waste has been separated into 36 individual waste streams and each stream is considered separately in the impact calculations. Consequently, wide variations in waste stream properties may be quantified based on the

available qualitative and comparative data on the properties of each of these waste streams. Therefore, an attempt has been made in this EIS to quantify the waste form properties and their effects on the impact calculations.

As shown in Table G.13, six indices have been assigned to each waste stream for each waste spectrum considered: a flammability index, denoted by I4, a dispersibility index, denoted by I5, a leachability index, denoted by I6; a chemical content index, denoted by I7; a stability index, denoted by I8; and an accessibility index, denoted by I9. The waste streams considered in this work and the integer values for these six indices that have been assigned to each waste stream for the four waste spectra considered are given in Appendix D.

In addition to these six indices, two more indices for each waste stream are utilized in the impact calculations: the waste processing index--denoted by I10--is explained in Section 5; and the "disposal status index"--denoted by I11--is calculated during the impacts analyses and is explained in Section 3.4.

This section discusses the procedures through which these indices are incorporated into the analysis. Specific values assigned to the waste form properties, which are denoted by the waste form behavior indices, are discussed in Appendix D, Reference 1 and Reference 6. Below is a summary of the information presented in these references.

3.2.1 Flammability Index (I4)

This index ranks waste forms according to their flammability. Waste forms which will not burn even on prolonged exposure to open flame and moderately intense heat are assigned an index of 0. These consist of waste forms that experience no evidence of combustion or decomposition upon exposure to 1000°F for 10 minutes. Those waste forms that will sustain combustion are assigned an index of 3. These consist of waste forms such as liquids with flame points around 600°F. Between these extremes are two additional flammability categories. Waste forms which show evidence of combustion and/or decomposition upon exposure for 1000°F for 10 minutes but will not sustain burning when the heat source is removed are assigned an index of 2. Waste forms consisting of a mixture of materials with flammability indices 0 and 2 are assigned an index of 1 (Ref. 1).

The only scenario in which this index is utilized is the accident-fire scenario. Each waste stream is subjected to the accident scenarios separately. The accident-fire scenario is assumed to be possible only if (1) the waste stream being tested can support combustion (i.e., I4=3) or (2) the waste stream being tested is mixed during disposal with other waste streams containing combustible material. This latter case is possible if there is no waste segregation (i.e., IS=0).

In the accident-fire scenario, the total volume of waste subjected to the fire is assumed to be 50 m^3 (about 250 55-gallon drums or equivalent volume). This volume is estimated from an assumed volume of 200 m^3 of waste received daily at the disposal site (which corresponds to about 1,000,000 m^3 of waste over

20 years). Two of the disposal cells are assumed to be in operation simultaneously, and half of the waste in one disposal cell is subjected to the accident-fire scenario.

In another study, the fraction of waste released into the atmosphere as the result of an accidental fire has been estimated to be about 10^{-2} for combustible material, and about 10^{-5} for unsolidified resins (Ref. 8). It was estimated in this study that most of the radioactivity will remain in the ashes which remain localized. In a more recent report, it has been estimated that the fraction of combustible material released from an accidental fire involving LLW is about 10^{-3} (Ref. 26).

In this EIS, all unprocessed fuel cycle compactible trash, most of the institutional streams, industrial low-specific activity waste, and industrial tritium waste have been assumed to be combustible (see Appendix D), and have been assigned a flammability index of 3. Similarly unprocessed LWR resins and cartridge filters, some of the industrial trash streams, and wastes solidified in a synthetic polymer (solidification of scenario C) have been assigned a flammability index of 2. LWR-concentrated liquids and filter sludge have been assigned an index of 1. Noncombustible trash, process waste from fuel fabrication and UF_6 conversion plants, and high-specific activity industrial waste streams (see Appendix D) have been assigned an index of 0.

In this EIS, waste streams with indices of 3 and 0 have been assumed to release a fraction of 0.1 and 1.25×10^{-5} of their activity into the air, respectively, upon being subjected to the accident-fire scenario. The waste streams with flammability indices between these two extremes have been assigned a release fraction calculated from the geometric midpoints of these two values (each index value is 20 times the adjacent lower index value). The following table gives the assumed fraction of waste released for the respective indices.

I4	f_r
0	0.0000125
1	0.00025
2	0.005
3	0.1

In other words, f_r can be expressed by the value of $0.1 \times 20^{(I4-3)}$. These assumptions are believed to be very conservative, particularly for combustible streams. Noncombustible material (I4=0) is assumed to result in 1.25×10^{-5} fraction of the waste released into the atmosphere which is greater than the value quoted for unsolidified resins (Ref. 8).

3.2.2 Dispersibility Index (I5)

This index is a measure of the degree to which individual waste streams may be suspended as respirable particles should the waste form be exposed to wind or mechanical abrasion, such as from the actions of a potential inadvertent intruder, after a significant period (on the order of 100 years). It is recognized that there is considerable uncertainty in estimating the dispersibility of various waste forms over long time periods. However, the NRC staff

believes that there is a need to consider the relative effect that improved waste forms have upon impacts to a potential inadvertent intruder. Therefore, two options exist for considering the relative effects of the dispersibility index in the calculations. In the waste form no-credit option, all waste forms are assumed to disperse into respirable fractions in a similar manner to ordinary dirt. This is the most conservative case and has been assumed by others (Refs. 24, 25). In the waste form credit option, assumptions and judgments are made regarding the comparative dispersibility of various waste forms. Then, estimates are made regarding the fraction of the waste released from the waste forms into respirable properties. This latter option is discussed below.

Waste forms which are assumed to have a low probability of becoming suspended into respirable particles are assigned an index of 0. Those waste forms which have a high potential of becoming suspended are assigned in index of 3. Waste forms which tend to crumble or fracture extensively and those forms that are subject to relatively rapid (within about 100 years) decomposition are assigned an index of 2. Waste forms consisting of a mixture of materials with dispersibility indices of 0 and 2 are assigned an index of 1.

The dispersibility of the waste form is dependent on the resistance of the waste form to chemical and biological attack (Refs. 1-6). Another property of the waste form that can be used to estimate the comparative values of this property is the compressive strengths of the waste forms (Ref. 1).

As an upper bound for this property, the most dispersible waste form (I5=3) has been assumed to be equivalent to soil, and no credit has been considered due to waste form. This value is believed to be conservative considering that the dispersed fraction of powdered PuO_2 packages in transportation accidents have been assumed to be 0.001 (Ref. 9). In comparison, wastes subjected to solidification scenario C (see Appendix D), which may be represented by the properties of waste solidified in a good synthetic polymer, are likely to resist biological and chemical attack and have significant compressive strengths (Ref. 6). These streams have been assumed to result in a low dispersible state, have been assigned an index of 0, and are assumed to have a fraction of 0.001 of the waste in a dispersible form. Other waste streams are assigned dispersibility indices in between these extremes (Ref. 1).

To summarize, for the waste form no-credit option, the fraction of the respirable dust loading in air that is contributed by each waste stream as a result of intruder activities or wind action is assumed to be equal to 1.0 for all waste forms. For the waste form credit option, this fraction is assumed to be equal to the following:

I5	f_r
3	1
2	.1
1	.01
0	.001

In other words, the factor f_r in the waste form credit option is given by the relationship $10^{(I5-3)}$. The dispersibility index is applied to the intruder-construction, intruder-agriculture, and exposed waste-wind transport scenarios.

3.2.3 Leachability Index (I6)

This index is a measure of a waste form's resistance to leaching and is primarily determined by the solidification procedures used. Unsolidified waste forms, which are assumed to be readily leached, are assigned an index of 1. Waste streams solidified according to solidification scenarios A, B, and C are assigned indices of 2, 3, and 4, respectively.

The solidification scenarios represent varying levels of performance that can be achieved through available solidification techniques. In this EIS, a level of performance designated by solidification scenario A has been simulated by assuming that half of the waste is solidified using urea-formaldehyde and the other half using cement; a level of performance designed by soldification scenario B has been simulated by assuming that half of the waste is solidifed using cement and the other half using synthetic organic polymers; and a level of performance designated by solidification scenario C has been simulated by assuming that all of the waste is solidified using synthetic organic polymers.

The primary purpose of this index is to assign values to the estimated leachability potential of solidified waste streams in comparison with unsolidified waste forms. Radionuclide-specific leaching fractions for unsolidified waste streams have been estimated based upon actual leaching data from two existing disposal facilities (see Section 3.5). The leachability index assigns values to a multiplier of these unsolidified waste stream leaching fractions. The product of the multiplier and the unsolidified waste leaching fractions gives, for each waste stream, the actual leaching fraction used in the radiological impact calculations. The multiplier is assigned a value of unity to unsolidified waste streams such as dewatered resins or trash and a value less than unity to solidified waste streams. The multiplier value assigned to solidified waste streams is dependent upon the particular solidification agent considered. Based on an analysis of the existing comparative leachability data (Ref. 1), the following values have been assigned to this multiplier:

I6	Multiplier
1	1
2	1/4
3	1/16
4	1/64

These values are applied primarily to the ground-water scenarios. Another scenario which may also be affected is the food (soil) uptake pathway of the intruder-agriculture scenario since the level of contamination in interstitial soil water available to vegetation may depend on the leachability of the waste. The use of this index as an option to help investigate the effect of waste form to reduce potential intruder impacts in these scenarios is presented in Sections 3.4 and 3.5. The value of the index, I6, however, may be further

modified depending on properties of the waste and disposal technology (see below).

3.2.4 Chemical Content Index (I7)

This index denotes whether a waste stream may contain chelating agents or organic chemicals that may increase the mobility of radionuclides during and/or after leaching. An index value of 0 indicates the likelihood that these agents or chemicals are absent in the stream, whereas an index value of 1 indicates that the stream is likely to contain chelating agents or organic chemicals.

This index, in conjunction with the segregation option index IS (see Section 3.1.3) is used to modify the multiplier values assigned to the leachability indices for the ground-water and intruder-agriculture scenarios. The following table is used in determining the fraction leached from a particular waste form:

	Mult (I6,I7,IS)	
I6	IS=1 and I7=0	IS=0 or I7=1
1	1	1
2	1/4	1
3	1/16	1/4
4	1/64	1/16

This table should be interpreted as follows. For a waste stream with a given leachability index (I6), if the waste stream either contains chelating agents (I7=1) or is disposed mixed with other waste streams containing chelating agents (IS=0), then the higher leach fraction multiplier is used. If the waste stream does not contain chelating or chemical agents (I7=0) and it is not mixed with other wastes containing chelating or chemical agents (IS=1), then the lower leach fraction multiplier is used.

A similar procedure is applied to the retardation coefficients assigned to individual radionuclides. Retardation coefficients denote the potential of the disposal site soils to retard the radionuclides during ground-water migration. If there is no waste segregation at the disposal facility, then the retardation potential of the disposal site soils is assumed to be reduced as discussed in Section 3.5.

3.2.5 Stability Index (I8)

This index denotes whether the waste form is likely to reduce in volume after disposal due to compressibility, large internal void volume, and/or chemical

and biological attack (no credit is taken for the waste containers). An index value of 0 indicates a likelihood of structural instability, whereas a value of 1 indicates a structurally stable waste form.

The stability indices have been assigned based on the physical descriptions of the waste provided in Reference 6. In general, this index has been assigned based on the void volume and/or compressibility of the waste and its biodegradability. For example, all trash waste streams are assumed to be unstable unless they are incinerated and/or solidified. Dewatered resins and filter sludges are also considered to be unstable. There is generally a 10 to 20% void volume within the disposal containers (liners). Organic resins are mostly composed of water, and water is present in the interstitial spaces between the resins. Finally, all waste forms expected to be packaged in trash or similar degradable void fillers, such as LWR noncompactible trash streams, are also assumed to be unstable. In this case, the waste form containing most of the activity can be considered to be stable. However, since this higher activity waste is packaged with compressible (degradable) material, the packaged waste stream will eventually degrade, produce voids within a disposal cell, and possibly lead to subsidence problems.

The use of this index depends on the stabilization index, IX. If IX is 3 (extensive stabilization measures are implemented), then the index I8 is ignored in the calculations. If IX is 1 (regular stabilization measures), then the segregation index IS also affects the calculational procedure. If IS=1 (segregation), then in ground water migration calculations a higher percolation estimate is adopted for wastes that are unstable (I8=0); if IS=0 (no segregation), then a higher percolation figure is adopted for all the streams (see Section 3.5).

Similarly, in the disposal cost calculations, if there is segregation, then any moderate or extensive stabilization measures (IX=2 or IX=3) are applied to only the disposal cells that contain unstable wastes; otherwise, the entire site undergoes these stabilization measures.

3.2.6 Accessibility Index (19)

The index triggers the use of a correction factor for those unsolidified waste streams that have a comparatively higher metal content. The radionuclides contained in these waste streams are not as easily accessible to transfer agents such as wind and water as are the radionuclides contained in other waste streams.

Most of the waste streams contain surface-contaminated wastes and waste containing radioactivity in readily soluble form; these streams are assigned an accessibility index of 1. The waste streams that are almost exclusively activated metals with imbedded radioactivity not readily accessible to the elements are assigned an index of 3. Only the industrial high-activity waste stream has been assigned an index of 3. Several other streams containing a significant portion of metallic waste, which have both activated and surface crud contamination, have been assigned an accessibility index of 2. The value of this index does not change depending on the waste spectrum considered.

This index is applied to all the release/transport scenarios that involve wind or water transfer agents, and to all the direct radiation scenarios. In the calculations, the degree to which a waste form resists mobilization by external transfer agents is expressed through the waste form and package factor (f_w). One of the mathematical terms in the waste form and package factor is a fractional multiplier that expresses the effect of the accessibility index. This fractional multiplier is assumed to be given by the relationship 10 (Refs. 1-19); that is:

I9	Multiplier
1	1
2	.1
3	.01

These multipliers are assumed to be applicable to the above waste streams even after a long time. Most of the equipment and metals in these waste streams are manufactured from corrosion-resistant materials. A brief comparative discussion of the waste streams for which this index is different than unity is presented below.

The main purpose of the accessibility index is to evaluate the comparative isolation from transport agents of the radioactivity contained in certain unsolidified wastes. The function of this index is similar to that of the leachability index applied to solidified wastes. The reduction of accessibility of some radioactive materials is the result of the combined physical and chemical characteristics of the waste. No reduction is considered for wastes which contain radioactivity in forms which are readily soluble or displaced. Combustible trash and absorbed liquids are examples of these types of wastes.

At the other extreme are unsolidified waste streams such as activated metals where, in the absence of surface contamination, much less of radioactivity is initially accessible to transport agents. Industrial high-activity metals are assumed to be the only waste stream of this type which is virtually free of surface contamination. Many of these activated metals are high-alloy materials (alloys with a high nonferrous metallic component) and corrode very slowly in the disposal environment. For example, a corrosion rate of 0.002 mg/100 cm^2/day (7.3×10^{-6} g/cm^2/yr) has been quoted for high-alloy stainless steel (Ref. 1). Such corrosion produces finely divided but highly insoluble oxides.

Although insoluble, these oxides may be more accessible by virtue of being finely divided. The percentage of the total activity of such waste forms converted to the oxide from in a given time is highly dependent on the geometry of the waste (i.e., surface area to mass ratio). For example, consider a high-alloy rod 100 cm long and 1 cm in diameter and having a density of 7.8 g/cm^3

with a pipe having the same external dimensions and density but with a wall thickness of 0.1 cm. The surface area to mass ratios are 0.259 cm^2/g for the rod and 2.56 cm^2/g for the pipe. Assuming that the activation products are distributed uniformly through both pieces, the fraction of the activity lost from the pipe is nearly ten times that of the rod (1.87×10^{-5}/yr versus 1.89×10^{-6}/yr). The small magnitude of both numbers illustrates the inaccessibility of the radioactivity in both cases--especially in view of the insolubility of the corrosion products. In 1,000 years, only about 2 percent of the activity becomes available. Based on this, a conservative correction factor (multiplier) of 0.01 has been applied to the dispersibility of these wastes.

The remaining unsolidified wastes fall between these two extremes. Wastes in this group include the noncompactible trash streams and nonfuel reactor core components. The noncompactible trash streams include quantities of surface-contaminated failed equipment. Many pieces of equipment are internally, rather than externally, contaminated and are sealed to prevent release of any free liquids they may contain (e.g., pumps). A pump sealed with 1 cm thick carbon steel caps (corrosion rate of 0.03 cm/yr) (Ref. 8) would isolate the radioactivity for about 30 years. After this period the release of radioactivity is controlled by the activity and amount of liquid inside the piece, the nature of the internal contamination, and the ease with which the transport agents can get in and out of the equipment.

Nonfuel core components are another case. These components are generally highly activated stainless steel (or other alloys) pieces coated with crud deposits. The accessibility of the radioactivity of these wastes depends on the thickness of the crud layer and the relative activity of the crud and underlying metal. Crud mainly consists of oxides of iron and has been found to range in thickness from 0.0003 to 6 mil on fuel roads (Ref. 1). The strong decontamination agents necessary to remove such crud deposits from LWR primary cooling systems attests to the relative inaccessibility of the radioactivity they contain. Furthermore, the transporting medium must penetrate the crud layer to begin corroding the activated metal beneath. Because the fractions of activity of these components contained in the crud and the metal itself are not well-characterized, these wastes are considered to more closely resemble noncompactible trash rather than clean-surfaced high-activity metals.

A reduction factor for the direct radiation exposure components of the scenarios is also assumed to be applicable due to the high metal content of the streams with an accessibility index greater than 1. This reduction is due to the self-shielding afforded by the higher density metals and packaging practices. For example, the uncollided gamma flux from a half-space source at the surface is inversely proportional to the density of the material; this effect alone would result in a gamma flux attenuation by a factor of about 7 (Ref. 1). Furthermore, when these noncompactible metallic wastes, which usually have irregular shapes, are packaged, other materials such as trash or soil that usually have much lower activities are placed around them to fill the voids. For the high energy gamma rays found in LLW (Co-60, Cs-137, and Nb-94), it takes only about 2 inches of metal shielding to result in an attenuation of 10. In this EIS, in view of the above effects, a reduction factor of 10 has

been applied to direct radiation exposure pathways for streams having an accessibility index greater than 1.

3.3 Waste Classification

As discussed in Section 2.2, potential long-term exposure scenarios from LLW disposal can be separated into two types: concentration scenarios and total-activity scenarios. The concentration scenarios include those involving direct human contact with the disposed waste, such as those involving exposures to a potential inadvertent intruder. In these scenarios, potential exposures are calculated considering only the radionuclide concentration in the waste streams assumed to be actually contacted by the intruder. The radionuclide concentrations and total activity in parts of the disposal facility not contacted by the potential inadvertent intruder do not enter into the calculations. On the other hand, exposures from the total activity scenarios are determined by considering the total radionuclide activity disposed at the facility. Examples of total activity scenarios include ground-water migration scenarios.

The fact that impacts from scenarios involving direct human intrusion into disposed waste are governed by the concentrations in the particular waste streams assumed to be contacted makes the intruder scenarios very useful for waste classification purposes. Assuming that a limit is placed on the exposures allowed to a potential human intruder, then the maximum allowable concentrations of radionuclides in waste streams to meet this exposure limit may be calculated.

Once concentration limits are determined, waste generators can relatively easily determine what class their waste is in by comparing the radionuclide concentrations in their wastes with the limiting concentrations determined through the intruder scenarios. Use of potential human intrusion as a means of classifying wastes for disposal has been also used by others (Refs. 24, 27).

By contrast, it is much more difficult to classify wastes through use of total activity scenarios such as ground-water migration. Comparatively speaking, impacts from ground-water migration are much more dependent on site-specific conditions than the intruder scenarios. In addition, since the potential impacts are a function of the total activity of waste disposed, it is difficult to set concentration limitations for individual radionuclides to meet a specific dose limitation criteria. It would be difficult, based upon ground-water migration considerations, to set concentration limits that can be used by a waste generator to determine the classification of this waste.

It is important to emphasize, however, that this does not mean that ground-water migration from a disposal facility is not an important consideration in LLW disposal. It does suggest that rather than establishing concentration limitations to be met by a waste generator to meet a particular ground-water exposure limitation criteria, it would probably be more useful to set an inventory limitation for a particular disposal facility (based upon site-specific information) for particular radionuclides of concern.

Then, if the waste generators were required to report the quantity of the radionuclides of concern which are contained in each shipment of waste that the waste generator ships to the particular disposal facility, the disposal facility operators could maintain a running inventory at the site of the radionuclides of concern. When the site inventory reaches the established limit for the facility, the disposal facility operator would no longer accept waste streams containing the particular radionuclides of concern. It is expected that such radionuclides of concern would include long-lived mobile isotopes such as ^{14}C, ^{99}Tc, and ^{129}I.

Potential inadvertent intruder exposures (and maximum radionuclide concentrations corresponding to a given dose conversion criteria) are a function of three general parameters: (1) the time after disposal that the intrusion occurs (the length of the active institutional control period), (2) waste form and packaging properties, and (3) disposal facility design and operating practices. Regulatory requirements can be placed upon these parameters and, depending upon the particular requirements placed upon these parameters, a classification system may be developed.

The effect of waste form and packaging properties and disposal facility design and operating practices on impacts from human intrusion is also extensively examined in Chapters 4 and 5 of this environmental impact statement. From this analysis two conclusions can be made:

- Barriers may be used to reduce the possibility of human intrusion. These barriers may include disposal at greater depths or emplacement of the waste using an engineered barrier designed to resist human intrusion (e.g., a caisson backfilled with concrete).

- If the waste is in a stable waste form that resists dispersion and if the stable waste is disposed in a disposal cell which is segregated from unstable waste forms, then potential intruder exposures would be reduced over those exposures expected if the stable wastes were disposed mixed with the unstable wastes.

Based upon establishment of a maximum time for active institutional controls and incorporating the above two conclusions, a waste classification system may be developed based on a maximum exposure limit to a potential inadvertent intruder.

The costs and relative effectiveness of various barriers against human intrusion have been analyzed in Reference 1 and Appendix F. In this work, three generic levels of intruder barriers are considered in detail, which correspond to three general levels of effectiveness against intrusion at three levels of overall costs: (1) no barrier; (2) layering; and (3) hot waste facility.

In the first case, the waste stream is assumed to be disposed in a "regular" manner without consideration of protecting a potential intruder. In the second case, the waste stream is assumed to be disposed at the bottom of the disposal cell, so that at least 5 meters of earth or other (lower activity) waste streams cover the layered waste. In the third case, the waste stream is

assumed to be disposed in a hot waste facility, which for this EIS is taken to be a concrete-walled disposal trench. The waste is stacked into the trench, grouting is poured around the waste packages, and a concrete cover is then poured over the grouted waste mass, and finally 2 meters of soil is emplaced over the concrete cover. The effectiveness of the hot waste facility is somewhat speculative, but is included to indicate an upper level of protection against inadvertent intrusion that can be achieved through near-surface disposal.

In addition and based upon the analysis in Chapters 4 and 5, it is assumed that the operational practice of segregated disposal of stable waste streams from unstable waste streams results in reduced exposures to a potential intruder contacting the stable waste streams--at least for the first several hundred years following waste disposal. Segregated disposal of the stable waste streams greatly improves the stability of the disposal cells containing the stable wastes, resulting in significantly less water infiltration and subsidence problems for these disposal cells, and less decomposition of the disposal cell contents. Exposures to a potential inadvertent intruder contacting these disposal cells at the end of the institutional control period would be limited to those acquired during discovery of the waste. It is not credible, for example, to postulate that an intruder would construct a house in, or attempt to grow vegetables in, a disposal cell composed of such wastes as 55-gallon drums filled with concrete. This scenario, which can be considered to be a subset of the intruder-construction scenario, is termed the intruder-discovery scenario.

Finally, consideration needs to be given to the length of time that intruder barriers and segregation of stable wastes would serve to reduce or eliminate potential inadvertent intruder impacts. Based on the analysis in Chapters 4 and 5, a time period of 500 years after site closure is used as a limit of the effectiveness of layering and waste segregation. Following his time period, wastes disposed through layering and/or segregation are assumed to be as accessible to an intruder as waste disposed by regular means (i.e., nonsegregated disposal). A time period of 1000 years is assumed as a maximum length of time for a hot waste facility to be effective against intrusion.

These concepts are further expanded in the following two sections which present the calculational procedures for determining intruder exposures from the two basic intruder scenarios considered in this appendix. These include the intruder-construction scenario (and its subset, the intruder-discovery scenario) presented in Section 3.4.1 and the intruder-agriculture scenario presented in Section 3.4.2.

3.4 Waste Classification Scenarios

3.4.1 Intruder-Construction Scenario

This is one of the scenarios utilized to determine the classification status of the waste streams--the other scenario being the intruder-agriculture scenario. This section considers the values of the pathway barrier factors under alternative values of the waste form behavior indices and the disposal technology indices.

This scenario assumes that at some time after the end of operations at the disposal facility, institutional controls break down temporarily and an intruder inadvertently constructs a house on the disposal facility. In so doing, the intruder is assumed to contact the disposed wastes while performing typical excavation work such as installing utilities, putting in basements, and so forth. These typical activities should not be expected to involve significant depths--e.g., in most cases no more than approximately 3 m (about 10 ft). There is, however, a much less likely chance that some excavations could proceed at a lower depth. This could occur, for example, through construction of a sub-basement for a high-rise building.

To implement this scenario, the inadvertent intruder is assumed to dig a 3-meter deep foundation hole for the house. The surface area of the house is assumed to be 20 m by 10 m (200 m^2), which is a typical surface area for a reasonably large ranch-style house. The foundation hole is assumed to be 20 m by 10 m (200 m^2) at the bottom and 26 m by 16 m at the top (giving a 1:1 slope for the sides of the hole. The top 2 meters of the foundation is assumed to be cover material and the bottom 1 meter is assumed to be waste. This excavation would result in about 232 m^3 of waste being intruded into.

The equation describing human exposure for the intruder-construction scenario is as follows:

$$H = \sum_n (f_o f_d f_w f_s)_{air} C_w \text{ PDCF-2} + \sum_n (f_o f_d f_w f_s)_{DG} C_w \text{ PDCF-5} \qquad \text{(G-8)}$$

where H is the 50-year dose commitment in mrem, PDCF-2 and PDCF-5 are the radionuclide-specific pathway dose conversion factors discussed and presented in Section 2.4, and C_w is the radionuclide concentration in the waste. Impacts are summed over all the radionuclides (n).

The first term of the equation calculates the impacts from the exposures due to suspension of contaminated dust into the air (inhalation of the contaminated dust and direct gamma exposure from the contaminated dust cloud) and the consumption of food grown nearby upon which the airborne contamination is assued to settle. The second term of the equation calculates the impacts from direct gamma exposure to the wastes during excavation. The values of the barrier factors are examined below in two subsections: regular waste disposal and disposal with barriers against intrusion.

Regular Waste Disposal

The time delay factor f_o is radionuclide-specific and is given by the following equation:

$$f_o = \exp [-\lambda T] \qquad \text{(G-4)}$$

where T is the time period between the end of active disposal operations and the initiation of the scenario (i.e., IPO plus IIC years), and λ is the decay constant of the radionuclide. This factor is the same for the air uptake

pathways and the direct gamma pathway. The assumed time period is equivalent to the assumption that the intrusion scenario involves the last disposal cell constructed at the site and conservatively neglects the possibility that the intrusion scenario may involve one of the earlier disposal cells.

The site design and operation factor (f_d) denotes the dilution of the waste due to particular disposal practices regarding waste emplacement. Its value is assumed to be 0.5, 0.75, or 0.5, depending upon whether the waste disposal is random, is stacked, or is decontainerized, respectively. The effects of other classification tests on f_d are described in Section 3.3.2.

For the air uptake pathways, two options are available for determining the waste form and package factor, f_w. These options are incorporated to help investigate the potential for improved waste forms to reduce airborne intruder impacts. As discussed in Section 3.2.2, in waste-form credit option, f_w is given by the following formula:

$$f_w = 10^{(1-I9)} \times 10^{(I5-3)} \qquad \text{(G-9)}$$

In this equation, I5 is the dispersibility index (see Section 3.2.2) and I9 is the accessibility index (see Section 3.2.6).

However, for the waste form no-credit option, no-credit is given for the waste form to reduce the dispersibility of the waste stream. In this option, the multiplier $10^{(I5-3)}$ is set equal to 1.0 for all values of I5.

For the direct gamma exposure pathway, only the self-shielding inherent to the particular waste form affects the factor f_w. In this case, f_w is set equal to the following:

$$f_w = \text{Accessibility Multiplier} \times \text{Solidification Multiplier} \qquad \text{(G-10)}$$

The modification due to accessibility results from the substantial metal component of some waste streams. For example, a reduction in direct gamma exposure intensity by a factor of 10 can be achieved through shielding of about 2 inches of metal equivalent (Ref. 1). The accessibility multiplier is taken to be 1 if the index I9 is equal to 1 and it is 0.1 if the index I9 is equal to 2 or 3. The solidification multiplier is assumed to be 0.80 for those streams that are solidified using solidifcation scenario A or B procedures which contain a significant amount of cement; otherwise, this multiplier is assumed to be unity. Since the streams with an accessibiliy index different than 1 are never solidified, the minimum value of the factor f_w for the direct gamma exposure pathway is 0.1.

The site selection factor, f_s, is different for the air and direct gamma uptake pathways of the intruder-construction scenario. For the air uptake pathways, it is the product of the soil-to-air transfer factor T_{fa} (which depends on the environmental characteristics of the region in which the disposal facility is located) with the exposure duration factor (the fraction of a year that the construction takes place). For the direct gamma exposure pathway it is equal to just the exposure duration factor. These factors are discussed below.

In this EIS, the exposure duration is assumed to be 500 working hours. This is equivalent to a construction period of 3 months, which is believed to be reasonably conservative for typical housing construction. It is believed to be very conservative for activities involving use of heavy construction equipment. This gives a value of 0.057 for f_s for the direct gamma scenario. For the air pathways, this number is multiplied by a soil-to-air transfer factor given by the formula:

$$T_{sa} = [T_{sa}]_o \times (10/v) \times (s/30) \times (50/PE)^2 \qquad (G\text{-}11)$$

where $[T_{sa}]_o$ is equal to 2.53×10^{-10} (Ref. 1), v is the average wind speed at the site in m/sec, s is the silt content of the site soils in percent, and PE is the precipitation-evaporation index of the site vicinity indicative of the antecedent moisture conditions. For the reference disposal facility, these values were determined to be v = 3.61 m/sec, s = 50%, and PE = 91, yielding a value of 3.53×10^{-10} for T_{sa} (also see Appendix J). For an exposure duration factor of 0.057, this yields a site selection factor of 2.01×10^{-11} for the air uptake component of the construction scenario.

Disposal With Barriers Against Intrusion

The barrier factors f_d and f_s are affected if the waste is disposed using intruder barriers and/or if waste segregation is implemented at the disposal facility. For the air uptake pathways, (a) for layered disposal, the factor f_d is multiplied by a factor of 0.1 to indicate the likelihood of contact of the layered wastes by the intruder; and (b) for hot waste facility disposal, f_d is multiplied by a factor of 0.01.

For the direct gamma exposure pathway, (a) for layered disposal, f_d is multiplied by a factor of 1/1200 which denotes attenuation of the radiation through a layer equivalent to 1 meter of soil; and (b) for hot waste facility disposal, f_d is multiplied by a factor of $1/1200^2$ (Ref. 2) which indicates attenuation of the radiation through a layer equivalent to 2 meters of soil.

The site selection factor, f_s, is modified only if the waste form is stable and has been disposed in a segregated manner. In this case, which is termed the intruder-discovery scenario, the exposure duration factor is reduced from 500 hours to 6 hours for all the uptake pathways (Ref. 1).

3.4.2 Intruder-Agriculture Scenario

The intruder-agriculture scenario assumes that an intruder inadvertently lives on and consumes food grown on the disposal facility.

Farming is a surface activity and generally does not involve disturbing the soil for more than a few feet. As long as a cap of one or two meters is maintained over the waste, then it is very unlikely that agricultural activities would ever contact the waste. To implement the scenario at the end of the active institutional control period, however, a portion of the soil excavated during the intruder-construction activity (232 m^3 of waste and 680 m^3 of cover

material) is assumed to be distributed around the house. After building the foundations of the house, about 312 m^3 of this soil would be backfilled outside and around the cellar walls, leaving a volume of about 600 m^3 of soil (of which about 150 m^3 is the original waste/soil mixture) involved in the agriculture scenario. The precise areal extent to which this soil is distributed is somewhat speculative. It is likely, however, that the soil will remain localized; moving even a few cubic yards of soil more than 10 meters usually requires a significant effort. It is assumed in this report that this areal extent is likely to be somewhere between 1000 m^2 and 2000 m^2. That is, the waste/soil mixture is assumed to lie within a radius of about 25 meters from the center of the house. The intruder is then assumed to live in this distributed waste/soil mixture and is also assumed to consume vegetables from a small garden located in the waste/soil mixture.

A possible alternative to this scenario is that the waste cover is stripped away by the intruder, and that the intruder lives on and grows and consumes food grown directly in the waste. This does not appear to be as reasonable as the above scenario. At current commercial rates, it costs about $1.07 to move one cubic yard of dirt from one place to an adjacent place with heavy equipment (Ref. 28). This implies that to clear 2 meters of cover from 2 acres, the intruder would have to either invest a sum of about $22,500 or perform labor equivalent to this sum. This is not a reasonable assumption since no reasonable person is likely to strip and clear away surface soil with the hope of finding better soil underneath to grow food. A noncommercial enterprise is therefore assumed for the intruder-agriculture scenario. It appears to be unreasonable to expect that a commercial operator, who would require a substantial investment for a commercial agricultural operation and therefore a clear title to the land, can be an inadvertent intruder.

The inadvertent intruder is assumed to live in the house built on the site, work at a regular job during the day, and spend some of his extra time working in a garden growing vegetables for his own use. His time during a year is assumed to be allocated between various activities as follows:

Activity	Hours/Year
At Home	4380
At Work	2000
Traveling To and From Work	250
Vacation	330
Gardening	100
Outdoors	1700
Total:	8760

In the intruder-agriculture scenario, the inadvertent intruder could be exposed principally by five pathways: (1) inhalation of contaminated dust suspended due to tilling activities as well as natural suspension, (2) direct gamma exposure from standing in the contaminated cloud, (3) consumption of food (leafy vegetables) dusted by fallout from the contaminated cloud, (4) consumption of food grown in the contaminated soil, and (5) direct gamma exposure from the disposed waste volume. For calculational convenience, the first three uptake pathways have been grouped together and denoted as the air uptake pathway. The potential exposures from these pathways are calculated in three groups: air uptake, food (soil) uptake, and direct gamma (volume) exposures. These are then added to arrive at the total potential exposures from this scenario.

In this EIS, the potential exposures from the intruder-agriculture scenario are calculated using the following equation:

$$H = \sum_n (f_o f_d f_w f_s)_{air} C_w \text{ PDCF-3} + \sum_n (f_o f_d f_w f_s)_{food} C_w \text{ PDCF-4} + \sum_n (f_o f_d f_w f_s)_{DG} C_w \text{ PDCF-5} \quad \text{(G-12)}$$

where H is the annual dose in mrem per year during the 50th year of exposure, PDCF-3, PDCF-4, and PDCF-5 are the radionuclide-specific dose conversion factors presented in Section 2.4, and C_w is the radionuclide concentration in the waste. Impacts are summed over all the radionuclides (n). The values of the barrier factors are presented below.

The time delay factor, f_o, for this scenario is identical with the construction scenario, and is given by equation (G-4). The site design and operation factor f_d is also determined in the same manner as the construction scenario. In addition, the dilution resulting from mixing the excavated waste (232 m^3) with the excavated cover soil (680 m^3), which is a factor of about 0.25, is also included in the design and operation factor.

The waste form and package factors for the air uptake and direct gamma exposure pathways composing this scenario are identical to those for the air uptake and direct gamma pathways composing the intruder-construction scenario.

For the food (soil) uptake pathway, two options are available to calculate f_w, depending upon whether credit is given for the waste form to reduce leaching of radionuclides from disposed waste and subsequent uptake by plant roots. These options are included to help investigate the potential for improved waste forms to reduce potential intruder impacts. For the waste form credit option, the following formula is utilized to calculate f_w for the food (soil) uptake pathway (also see equation G-16):

$$f_w = M_o x\ t_c \times \text{Mult}(I6, I7, IS) \times 10^{1-I9} \quad \text{(G-13)}$$

However, in the waste form no-credit option, the factor Mult(I6,I7,IS) is set equal to 1.0.

In equation G-13, M_o is the radionuclide-specific leach fraction of unsolidified waste forms (see Section 3.5). The contact time fraction t_c is the fraction of time in one year that the waste is in contact with irrigation or rainwater, while I9 is the accessibility index (see Section 3.2.6). Mult(I6,I7,IS) is the reduction due to solidification and the presence or absence of chelating chemicals (see Section 3.2.4) and is a function of leachability index (I6), the chemical content index (I7), and whether the waste streams containing chelating or chemical agents have been segregated from other waste streams (IS).

It appears to be reasonable to assume that only the fraction of radionuclides transferred from the waste to the interstitial water will be accessible to the roots. Inclusion of contact time in the above equation is consistent with this approach. The contact time fraction is conservatively assumed to equal unity in this EIS; however, this fraction may actually be a very low value in view of the soils likely to be found at most disposal locations. These locations are likely to be at topographic highs whereas the most attractive agricultural soils are found in or adjacent to flood plains.

The site selection factor f_s for the air uptake pathway is similar to the intruder-construction air uptake pathway. However, the soil-to-air transfer factor must be averaged to account for natural resuspension of the soils during part of a year. This estimate is calculated by assuming that (1) the construction scenario T_{sa} value of 3.53×10^{-10} (see Section 3.3.1) is applicable during gardening (100 hours); (2) during the time spent outdoors (1700 hours), typical natural outdoor ambient air particulate concentrations of 100 ug/m^3 are assumed to prevail (Ref. 27); and (3) during the time spent indoors (4380 hours), typical ambient indoor concentrations of 50 ug/m^3 have been assumed (Ref. 27). Utilizing a mass loading of 565 ug/m^3 for the time spent while gardening (Ref. 1), and averaging these values results in a site-selection factor value of 3.18×10^{-11}. This may be compared with the value of f_s (2.01×10^{-11}) calculated for the intruder-construction scenario.

For the food (soil) uptake pathway, f_s is taken to be the fraction of food grown onsite that is consumed by the individual. This value is assumed to be 0.5. For the direct gamma exposure pathway, f_s is equal to the exposure duration fraction multiplied by a correction factor to account for the limited areal extent of the direct gamma source that the intruder is exposed to. Moreover, the fraction of the time the intruder spends in relation to the source must be considered.

During a year, the intruder is assumed to spend 1800 hours outdoors exposed to unattenuated radiation (100 hours tilling and 1700 hours around the house). During the 4380 hours he spends indoors, he is exposed to attenuated radiation. The correction factor due to the areal extent of the source may be estimated utilizing Figure G.5. This figure shows that the intruder may be assumed to be exposed to a full disk source while outside, and an annular source while inside the house. While he is inside the house, the center of the disk

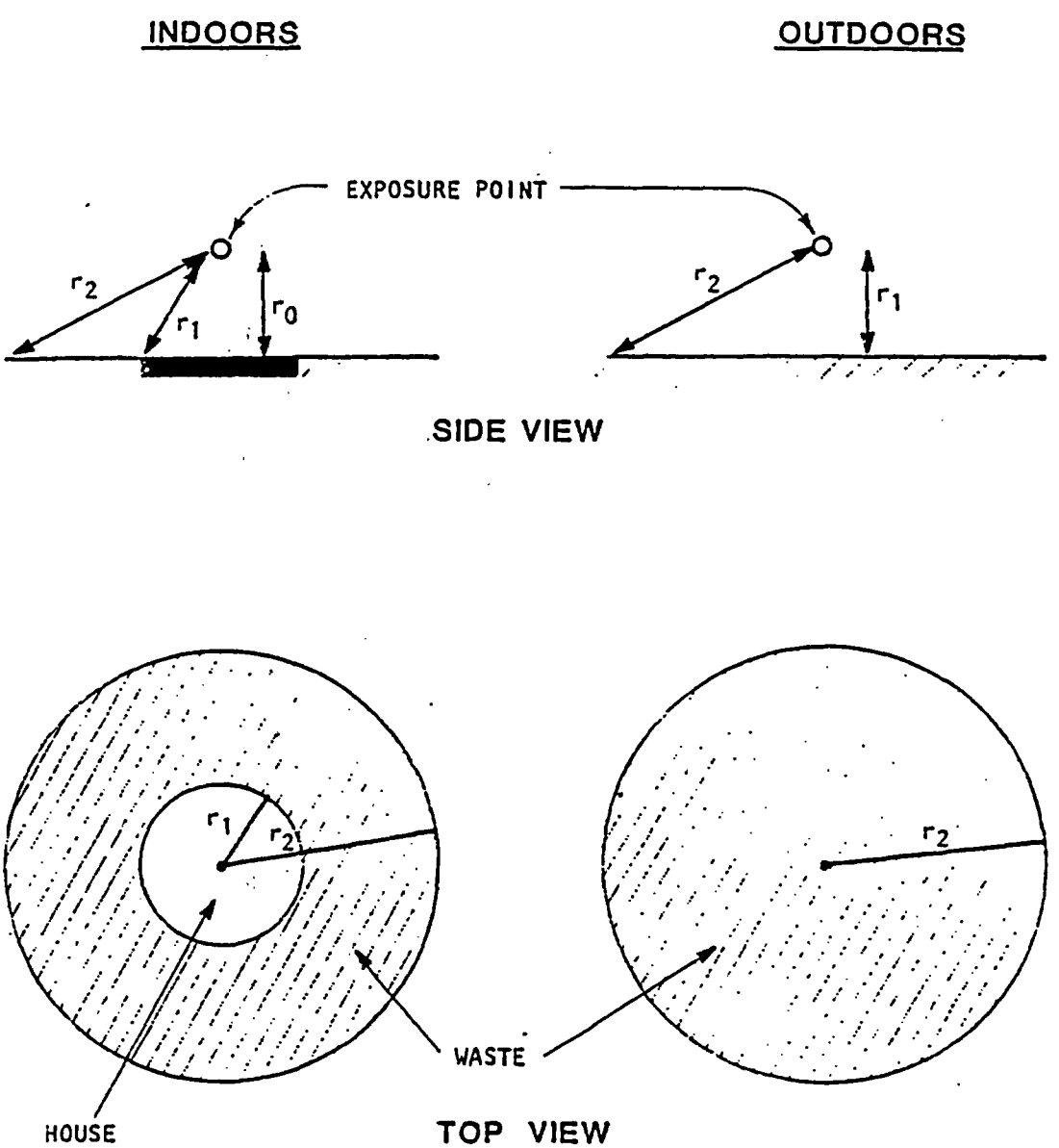


Figure G.5 Direct Gamma Exposure Geometry

represents the shielding provided by the foundation slab. The contribution to the direct gamma exposure from this center portion may be neglected in comparison with the exposure from the outside of the house. If the foundation slab is a one-foot thick concrete layer, the radiation would be attenuated to about 0.03 of its unshielded value for Cs-137 gamma rays (Ref. 1). The correction factor for the areal extent of the annular source may be represented by the following equation:

$$c = [E_1(\mu r_1) - E_1(\mu r_2)] / E_1(\mu r_o) \qquad \text{(G-14)}$$

where c is the dimensionless correction factor, $E_1(x)$ is the first order exponential integral, μ is the linear attenuation coefficient of air in units of m^{-1} (it is taken to be 0.0097 m^{-1}) and the r's are the distances indicated in Figure G.5 in meters (Ref. 1).

For a full disk source (for the time spent outdoors), the radius r_1 in equation G-14 is replaced by r_o. In order to evaluate the correction factor, the distances must be assumed. The following table gives the value of the exponential integral for some representative distances:

Distance	μr	$E_1(\mu r)$
1 m	0.0097	4.068
8 m	0.0776	2.055
20 m	0.1940	1.335
25 m	0.2425	1.068

For r_o and r_1, it is reasonable to assume 1 m and 8 m, respectively; 1 m represents the height of the exposed person, and 8 m represents the approximate radius of a 200 m^2 house floor. The value assigned to r_2, however, depends on the areal extent to which the waste/soil mixture (600 m^3) has been spread. This mixture will likely be spread unevenly within about a half acre around the house excavation, and the areal extent is likely to be between 1000 m^2 and 2000 m^2. A radius of 20 m represents an area of about 1050 m^2 over which the waste is spread, while a radius of 25 m represents an area of about 1750 m^2. A radius of 25 m is utilized in this EIS.

These assumptions yield a correction factor for the time spent outdoors of about 0.74, and a correction factor for the time spent indoors of about 0.24. Utilizing values of 1800 hours outdoors and 4380 hours indoors yields a site selection factor of about 0.27, which is the value utilized in this EIS.

3.5 Ground-Water Scenarios

These scenarios calculate the impacts resulting from ground-water migration of radionuclides from the disposed wastes to four potential biota access locations downstream in the direction of the ground-water flow: (1) a well located at the boundary of the disposal area; (2) a well located at the site boundary;

(3) a well located between the disposal facility and the surface hydrologic boundary; and (4) a stream located at the surface hydrologic boundary. Different pathway dose conversion factors are used depending on whether the access location is a well or a stream (see Section 2). An idealized map showing the geometric relationships between the disposal facility and the biota access locations are shown in Figure G.6.

As shown in this figure, the main streamline passing underneath the disposal facility has been straightened out (the longitudinal coordinates are measured along this streamline), and the disposal area (excluding the 30 m wide buffer zone), which is assumed to cover an area of 450 m x 800 m, has been divided into 10 sectors.

The following equation is used to calculate human exposures which may result from the well access ground-water scenarios:

$$H = \sum_i \sum_n (f_o f_{di} f_{wi} f_{si})\ C_w\ PDCF\text{-}6 \qquad (G\text{-}15)$$

where H is the annual dose rate in mrem per year during the 50th year of exposure, PDCF-6 is the radionuclide-specific pathway dose conversion factor presented in Section 2.4, and C_w is the radionuclide concentration of the waste stream considered. The impacts are summed over all the waste streams (i), and over all the radionuclides (n). For a surface water access location the dose conversion factor PDCF-7 is substituted instead of PDCF-6. The values of the barrier factors are presented below.

The time delay factor f_o is assumed to be 1. This merely means that the ground-water scenario is assumed to be initiated at the close of the twenty-year operational period. The site design and opration factor f_d, is utilized to incorporate modifications resulting from two of the site design options: use of a hot waste facility, and grouting (the effect of the cover is incorporated into the waste form and package factor f_w for calculational convenience--see below). If the waste is grouted, then f_d is taken to be 0.1. If the waste is placed in a concrete-walled trench or a hot waste facility, f_d is further reduced by a factor of 0.1 (Ref. 1).

3.5.1 Source Term

The source term is represented by the waste form and package factor, f_{wi}, which has units of m^3/year, and denotes the annual volume of contaminated liquid that leaves the disposal cells. This factor is given by the formula:

$$f_{wi} = f_i \times V_w \times f_c \qquad (G\text{-}16)$$

where f_i is the fraction of the disposed waste that is in the (i)th waste stream; V_w is the annual volume of water that percolates through the trench cap and contacts the disposal volume containing the waste; and f_c is the waste radionuclide concentration fraction transferred to the leachate.

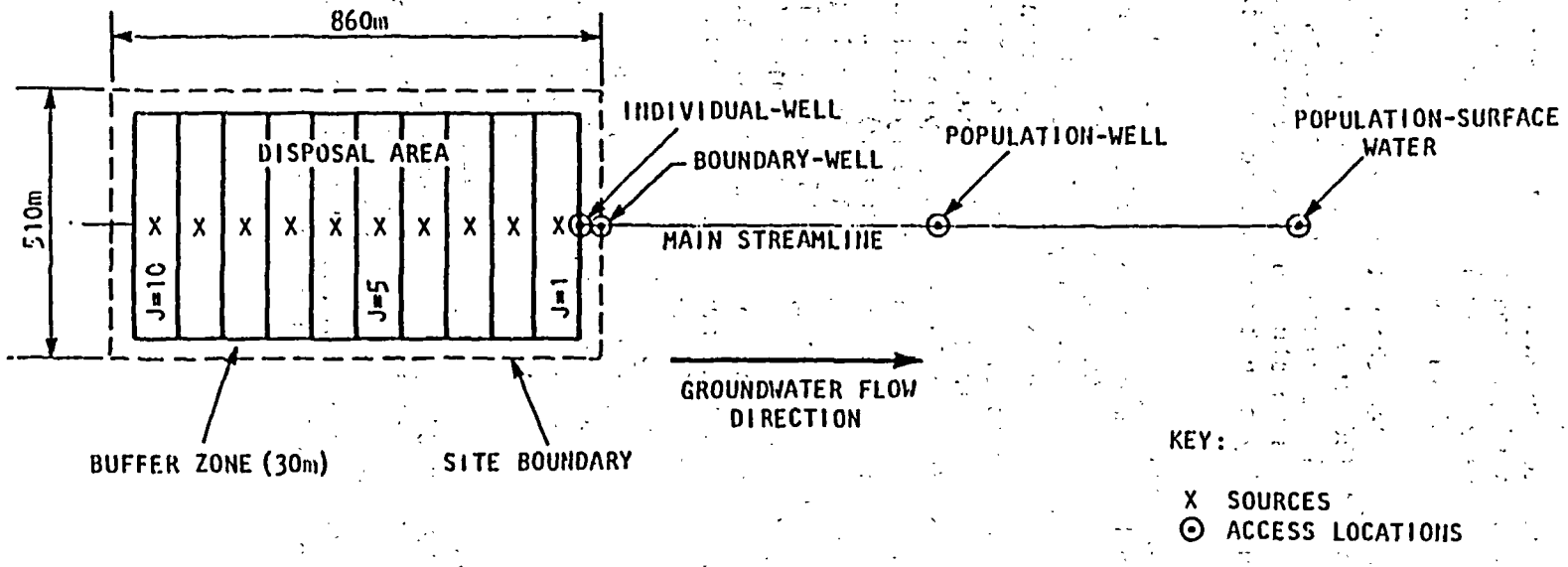


Figure G.6 Geometric Relationships of Disposal Area and Discharge Locations

The first factor f_i is self-evident; it is the ratio of the volume of the waste stream being considered to the entire volume of waste disposed at the facility. The variable (V_w) is simply the percolation (p) multiplied by the appropriate surface area. There are several different techniques for calculating the parameter (p) (also called PERC in several references).

One of these methods, usually called the water-balance technique, yields a percolation component of about 180 mm of water per year for the reference disposal facility. This value is applicable to those cases where no special effort has been made to emplace a moisture barrier over the waste and to those cases where the barrier integrity cannot be assumed due to instability of the disposed waste (Ref. 1).

For the cases where low permeability trench covers are employed and where the trench cover integrity can be assumed, the percolation component may be determined by the Darcy velocity of the least permeable stratum between the waste and the atmosphere. The Darcy velocity of a material, with hydraulic conductivity (K) in units of m/yr and unit hydraulic gradient (the most conservative assumption), has units of m^3/m^2-yr. This number, however, is modified by the fraction of each year during which there is at least 0.01 inch of precipitation. Therefore, in this latter case, (p) will be calculated from the relationship: $p = K (w/365)$, where (K) is the hydraulic conductivity of the least permeable layer covering the waste, and (w) is the mean annual number of days with 0.01 inch or more of rainfall. Assuming that a permeability of 3×10^{-7} cm/sec (about 0.3 ft/yr) is applicable for the least permeable stratum of the low permeability trench cover, and assuming (for the reference disposal facility) that w is equal to 115, yields an estimated percolation component of 30 mm. This permeability can be readily achieved through emplacement and compaction of a clay layer (materials with permeabilities in the range 10^{-7} to 10^{-9} cm/sec are commonly available) (Ref. 1). However, after the active institutional control period, it is likely that, as a result of intrusion by humans and/or by plant roots and/or burrowing animals, this low percolation rate may increase. Therefore, a time-dependent source term option has been incorporated into the calculations as discussed below in Section 3.6.3.

For the reference disposal facility, V_w is therefore assumed to be given by either $V1 = 0.180\ S_f$, or $V2 = 0.03\ S_f$ where S_f denotes the surface area involved, in m^2 (Ref. 1). However, the specific value utilized for this parameter is also determined by other factors. These include the cover index (IC), the stabilization index (IX), the waste form stability index (I8), and the segregation index (IS). The following table is utilized to arrive at the value of V_w for a given waste stream:

Cover	Cell Stabilization	Waste Stability	Infiltrating Volume: No Segregation	Infiltrating Volume: Segregation
Regular	Regular	Stable	2xV1	V1
	Regular	Unstable	2xV1	2xV1
	Moderate	Stable	1.5xV1	V1
	Moderate	Unstable	1.5xV1	1.5xV1
	Extensive	Stable	V1	V1
	Extensive	Unstable	V1	V1
Thick	Regular	Stable	2xV1	V2
	Regular	Unstable	2xV1	2xV1
	Moderate	Stable	2xV2	V2
	Moderate	Unstable	2xV2	2V2
	Extensive	Stable	V2	V2
	Extensive	Unstable	V2	V2

One more waste form behavior index affects the determination of the infiltrating volume, and that is the "disposal status" index I11. If the waste is disposed of in concrete-walled trenches or a hot waste facility (I11 = 3), the above table is ignored, and the infiltrating water volume is taken to be V2/4 multiplied by the surface area fraction of the walled trench or hot waste facility.

For the time-dependent source analysis option, an increase in the infiltration rate is assumed after the active institutional control period as follows. Only the infiltrating volumes that are less than V1 are affected. For 10 percent of the disposal area which is assumed to be disturbed by intruder activities (about 8 acres) an infiltrating volume of V1 is assumed, and for the rest of the area twice the previous value (i.e., either 4xV2 or 2xV2) is assumed. For the hot waste facility, the infiltrating volume is assumed to become V2.

The factor f_c represents the fraction of the radionuclides that are transferred from the waste to the leachate. It may be calculated using the following formula:

$$f_c = M_o \times t_c \times \text{Mult}(I6,I7,IS) \times 10^{(1-I9)} \qquad \text{(G-17)}$$

where M_o is equal to the radionuclide-specific unsolidified waste leach fraction at continuous full saturation; t_c is the fraction of a year that the infiltrating volume of water is in contact with the waste; Mult(I6,I7,IS) is the reduction in leachate concentration considering solidification methods and disposal

facility operation practices (see Section 3.2.4); and $10^{(1-I9)}$ is the accessibility factor (see Section 3.2.6). These factors are discussed below.

The factor M_o can be estimated by many theoretical methods; however, these theoretical calculations are not consistent with experimental data (Ref. 1). In this work, the average upper bounds of the leach fraction for unsolidified waste are estimated assuming that the leachate/waste conditions at the Maxey Flats, Kentucky disposal facility and the West Valley, New York disposal facility trenches (both of which can be assumed to be at continuous full saturation) may be used to approximate this bounding fraction. The above two disposal facilities, because of the presence of organic chemicals and chelating agents and because they can be assumed to be at continuous full saturation, may be assumed to represent extreme leachability conditions. Some researchers in the field believe that these types of estimates represent the best that can be achieved with the available experimental data (Refs. 1, 27).

To estimate these ratios, the measured leachate concentrations and the estimated trench inventories from several trenches for each radionuclide are utilized. This estimate takes into consideration the fraction of the leached radioactivity that may be reversibly adsorbed by the interstitial trench soils. These ratios are presented in Table G.14. Detailed calculations can be found in Reference 1.

The use of the factor M_o, however, necessitates a correction factor to take into account the transient and partially saturated conditions expected in the reference disposal facility. This correction factor is expressed through t_c. This fraction depends on the contact time between the waste and infiltrating water. Assuming that leaching at partial saturation is proportional to the moisture content, the fraction (t_c) may be expressed as the fraction of a year that the percolation component calculated above takes to pass through a given horizontal plane. That is, $t_c = p/(nv)$, where p is the precipitation (in m/yr) that infiltrates and comes into contact with the waste, n is the waste cell effective porosity, and v is the speed of the percolating water (in m/yr). The waste cell effective porosity can conservatively be assumed to be about 25% (partially compacted soils are likely to have higher porosities). The value of v depends on the interstitial soils; a very conservatively low value of 1 ft/day (corresponding to a permeability of about 1×10^{-4} cm/sec, an effective porosity of 0.25, and a hydraulic gradient of unity) will be assumed in this report for the reference disposal facility. These calculations yield the values 0.00647 and 0.00108 as the contact time factor for the above percolation cases of 0.18 m/year and 0.03 m/year, respectively (Ref. 1).

These values may be modified for soils with different permeabilities by multiplying by the ratios of the respective permeabilities; the contact time factor would increase for soils with low permeabilities, and would decrease for soils with high permeabilities by as much as a factor of 10. It should be noted that an increase or decrease in the volume of percolating water also affects the contact time.

The last two factors in equation (G-17) are the multipliers due to waste solidification and facility operating practices, and due to the relative inaccessibility of activated radioactivity in metal waste streams. The

Table G.14 Radionuclide Partition Ratios* Between Leachate and Waste

Basic Nuclide	Calculated Ratio	Other Nuclides	Assumed Ratio
H-3	1.15	Tc-99	0.115
		I-129	0.115
C-14**	5.76×10^{-3}		
Co-60	1.48×10^{-2}	Fe-55	1.48×10^{-2}
		Ni-59	1.48×10^{-2}
		Ni-63	1.48×10^{-2}
		Nb-94	1.11×10^{-2}
Sr-90	9.86×10^{-3}		
Cs-137	1.62×10^{-4}	Cs-135	1.62×10^{-4}
U-238**	1.25×10^{-4}	U-235	1.25×10^{-4}
Pu-239†	4.67×10^{-4}	Pu-238	4.67×10^{-4}
		Pu-241	4.67×10^{-4}
		Pu-242	4.67×10^{-4}
		Np-237	4.67×10^{-4}
		Cm-243	4.67×10^{-4}
		Cm-244	4.67×10^{-4}
Am-241	4.11×10^{-3}	Am-243	4.11×10^{-3}

*Ratio of the leachate concentration (in Ci/m^3) to the waste concentration in (Ci/m^3). Assumed ratios are estimated based on chemical similarities between the basic nuclide and the nuclide of concern.

**Calculated using West Valley leachate concentrations and Maxey Flats inventories.

†The calculated ratio includes Pu-238.

multiplier due to waste solidification and facility operating practices has been discussed in Section 3.2.3, and the table detailing the Mult(I6,I7,IS) factor in Section 3.2.5 is applied to this scenario. The multiplier for activated metal waste forms has been discussed in Section 3.2.6.

3.5.2 Migration Reduction Factor

The waste form and package factor, as expressed above, yields the total (in m^3/yr) source term that can be expected from a given waste stream. This source term must be related to the radionuclide concentrations at the groundwater biota access locations. This relation is expressed through the site selection factor (f_s) in units of yr/m^3. This factor, which has also been called the "confinement factor" or "reduction factor" (Ref. 3) is the groundwater migration analog of the (X/Q) term in meteorological diffusion calculations (Ref. 1).

Dozens of models, both analytical and numerical, have been developed to forecast the probable extent of radionuclide migration (sometimes called mass transport) and the associated environmental impact. A review of some of the available simulation techniques are presented in References 29 and 30. An analytical model is used in this EIS due to the generic nature of the analysis (Ref. 1).

The measurable hydrogeological parameters that should be included in an accurate simulation of mass transport are: the geometry of the problem (e.g., the travel distance and time to an access location), the decay constant of the radionuclides, the hydraulic velocities of the fluid (e.g., v), the dispersion characteristics of the medium, and the retardation coefficients of the radionuclide-medium interaction. The space- and time-averaging of the above parameters, if necessary, may be accomplished in a straightforward manner (Ref. 3). As discussed in Section 2.4, it can be shown that the time dependent site selection factor is given by (Ref. 3):

$$f_{si} = [r_g/Q] \sum_j r_{tij} \qquad \text{(G-18)}$$

where (Q) is the dilution factor in units of volume/time; the factor r_g is the time independent reduction factor due to the geometry of the problem (i.e., the spatial relationship of the disposal cells and the access location); j denotes the longitudinal sectors of the disposal facility shown in Figure G.6; and r_{tij} is the reduction factor due to migration and radioactive decay which depends on both space and time, including the duration of the source term (T_i).

The geometric reduction factor r_g is assumed to be independent of the characteristics of the waste streams. It is also independent of the longitudinal relationship of the disposal facility with the access location. A more detailed consideration of this factor is presented in Reference 1. In this EIS, it is conservatively assumed that the geometric reduction factor is unity.

The dilution factor Q is independent of the characteristics of the waste stream and the geometrical relationship of the disposal facility with respect to the access locations. The factor Q may be the pumping rate of a well or the flow rate of a stream. In this EIS, the dilution rates assumed are 7700 m^3/year (3.84 gallons per minute) for the intruder well and boundary well scenarios which represents the needs of a single person living in a rural area; 200,000 m^3/year (about 100 gpm) for the population well scenario; and 4.5×10^6 m^3/year (about 5 cubic feet per second) for the surface stream scenario (Ref. 1). Small farming communities that utilize ground water for their needs usually have wells that range from 100 gpm to 1000 gpm depending on the population (Ref. 1). A stream flow rate of about 5 cfs is selected since a stream with flow rate below this value is very unlikely to be used for human consumption. For example, Rock Lick Creek nearby the Maxey Flats, Kentucky disposal facility has an annual average flow rate of about 7 cfs, but it is not used for human consumption; it is used only for livestock (Ref. 1).

There exists a lower bound, however, for the value of the dilution factor Q, and it is given by the total volume of water infiltrating through the disposal area. This volume is calculated during the source term calculation presented in the previous section. Therefore, the value of Q is modified upward if the total volume of water infiltrating into the disposal area is greater than the above assumed values.

The migration reduction factor r_{tij} depends on the time that the exposure is assumed to occur, the duration of ground water travel between the j^{th} longitudinal section of the disposal facility and the access location, the retardation capability of the soils (radionuclide dependent), the duration of the assumed source term, and the waste stream characteristics. The longitudinal extent of the disposal facility is considered by dividing it into 10 sectors and summing the contributions (assumed to be equal) from each sector to obtain the concentrations at the discharge location. In this EIS the following formula is used for the migration reduction factor r_{tij}:

$$r_{tij} = [\exp(-\lambda t)/(J \times T_i)] \times [F_j(t) - F_j(t-T_i)] \qquad \text{(G-19)}$$

where λ is the decay constant of the nuclide, t is the time at which the migration reduction factor is applicable; J is the total number of longitudinal sectors the disposal site has been divided into, which is 10 in this EIS (see Figure G.6); T_i is the source duration factor for the i^{th} waste stream; and j denotes the sector considered. The function $F_j(t)$ is given by the following formula (Ref. 1):

$$F_j(t) = 0.5 \times U(t) \times [\operatorname{erfc}(X_-) + \exp(P_j)\operatorname{erfc}(X_+)], \text{ where} \qquad \text{(G-20)}$$

$$X_\pm = \frac{\sqrt{P_j}\,[1 - t/(Rt_{wj})]}{2\sqrt{t/(Rt_{wj})}}$$

In this equation, U(t) is the unit impulse function that is zero for a negative argument and is equal to unity otherwise; t_{wj} is the water travel time between the disposal sector being considered and the access location; P_j is the Peclet number for the distance between the disposal sector and the access location; and erfc(x) is the complement of the error function and is given by the formula (Ref. 31):

$$\text{erfc}(x) = 1 - \int_0^x (2/\sqrt{\pi}) \exp(-t^2)\, dt \qquad \text{(G-21)}$$

The retardation factors (R) that are utilized in the above equations depend on the radionuclide considered as well as the geochemistry of the soils and the transporting ground water. They are indicative of the reversible ion exchange capability of the soils and represent the ratio of the radionuclide velocities in the soil to the ground-water velocities. The cation exchange capacity of the soils is an important parameter which can be used to estimate the retardation coefficients of the soils from published data. Five sets of retardation coefficients are utilized in this EIS (Refs. 32, 33). These coefficients are presented in Table G.15.

The first set is representative of coefficients for sandy soils with low to moderate cation exchange capacities, and is assumed to represent the lower bound of retardation coefficients used in this generic analysis. The fourth set is representative of coefficients for clayey soils with moderate to high cation exchange capacities. In between these two sets, two other sets have been postulated and have been calculated utilizing the geometric midpoints of sets 1 and 4. The third set of coefficients have been assumed to be applicable to the reference disposal facility. A fifth set of coefficients have been also calculated for use in special cases.

The source duration factor T_i for the i^{th} waste stream is determined by dividing the total activity in the stream with the annual radionuclide release fraction which is given by the factor f_{wi} multiplied by the concentration. This calculation considers radionuclide decay but conservatively neglects the depletion of the radionuclide inventory at the site by previous releases. In other words, rather than having an inventory and a source term lasting for an infinite period of time with a pseudo-exponential decay (with the decay constant determined by the annual releases), all the radioactivity is released within a finite period with the annual source term determined with no depletion due to previous releases. This conservatism, which is equivalent to the assumption that waste/leachate transfer factor increases with time, is implemented for calculational convenience.

The ground-water travel times t_{wj} and Peclet numbers P_j depend on the distance between the disposal facility sector being considered and the access location. The travel time and Peclet number between the first sector and the access location are termed tw_1 and P_1, respectively, and appropriate multiples of the incremental ground-water travel time and Peclet numbers between two adjacent sectors are added to tw_1 and P_1. For the reference disposal facility, the

Table G.15 Sets of Retardation Coefficients* Used in Impacts Analysis

	Assumed Retardation Coefficients					
Nuclide	Set 1	Set 2	Set 3	Set 4	Set 5	BNWL**
H-3	1	1	1	1	1	1
C-14	10	10	10	10	10	10
Fe-55	630	1290	2640	5400	11050	3333
Ni-59†	420	860	1750	3600	7350	333
Co-60	420	860	1750	3600	7350	333
Sr-90	9	18	36	73	146	100
Nb-94	1000	2150	4640	10000	21500	10000
Tc-99	2	3	4	5	6	1
I-129	2	3	4	5	6	1
Cs-137†	85	173	350	720	1460	1000
U-235†	840	1720	3520	7200	14730	14286
Np-237	300	600	1200	2500	5000	100
Pu-238†	840	1720	3520	7200	14730	10000
Cm-243†	300	600	1200	2500	5000	3333
Am-241†	300	600	1200	2500	5000	10000

*Sets 1 and 4 are values obtained from Reference 32, except for the radionuclides Nb-94 and U-235. These values are based on comparative retardations given by the BNWL column (Ref. 33). Sets 2 and 3 are obtained as geometric midpoints of Sets 1 and 4, and Set 5 is similarly calculated, i.e.,:

Set 2 = Set 1 x Cube Root of (Set 4/Set 1),
Set 3 = Set 2 x Cube Root of (Set 4/Set 1),
Set 5 = Set 4 x Cube Root of (Set 4/Set 1).

**These values are given in Reference 30 for desert soils with a moderate cation exchange capacity of about 5 meq/100 g. They have been used as a guide to fill in missing values.

†Coefficients for other isotopes of these elements are assumed to be the same.

ground-water travel time between two adjacent sectors (a distance of 80 meters) is assumed to be 64 years (corresponding to a ground-water speed of 1.25 m/year). It is also assumed for the reference disposal facility that ground water takes 10 years to traverse the unsaturated zone. The Peclet number, P_i, is basically the distance to the access location divided by the longitudinal dispersivity of the medium. A value of 1600 is added for two adjacent sectors to the Peclet number calculated for the first sector P_1. For the reference disposal facility, the following travel times and Peclet numbers are used:

Location	Travel Time (tw_1)	Peclet Number (P_1)
Intruder Well	42 years	1,300
Boundary Well	66 years	1,900
Population Well	400 years	10,000
Surface Stream	800 years	20,000

It may be pointed out that the selection of t_{wj} and P_j as the primary variables on which the migration analysis is based implicitly allows for a sensitivity analysis. Sites with differing environmental parameters may lead to similar radionuclide concentrations at the access locations. For example, similar results would be obtained if the ground-water velocity is twice as high, and the distance to the discharge access location is twice as large. Similarly, large unsaturated zone travel times would compensate for a shorter saturated zone travel time.

3.5.3 Special Cases

This section considers variations in the ground-water migration calculational procedure for three special cases: the maximum concentration case, the time dependent source analysis, and high-integrity containers.

Maximum Concentration Case

The previous equations can be used to determine radionuclide concentrations at a particular access location as a function of time. It may also be of interest to determine the maximum concentrations of a given radionuclide at a particular access location over all time.

The maximum radionuclide concentration at the particular access location considered may occur long after the initiation of the scenario. For this special case, only the reduction factor r_{tij} is affected in the above formulation and a modification of equation (G-18) is necessary to calculate the maximum concentrations. The equation utilized in this EIS is (Ref. 1):

$$f_{si} = [r_g\ r_i]/Q \qquad \text{(G-22)}$$

where r_g and Q are as defined previously, and r_i is the time independent maximum value of the migration reduction factor r_{tij}. The parameter r_i is given by the following equation.

$$r_i = \text{maximum of } [r_{i1}, r_{i2}, \ldots, r_{i10}] \qquad \text{(G-23)}$$

where

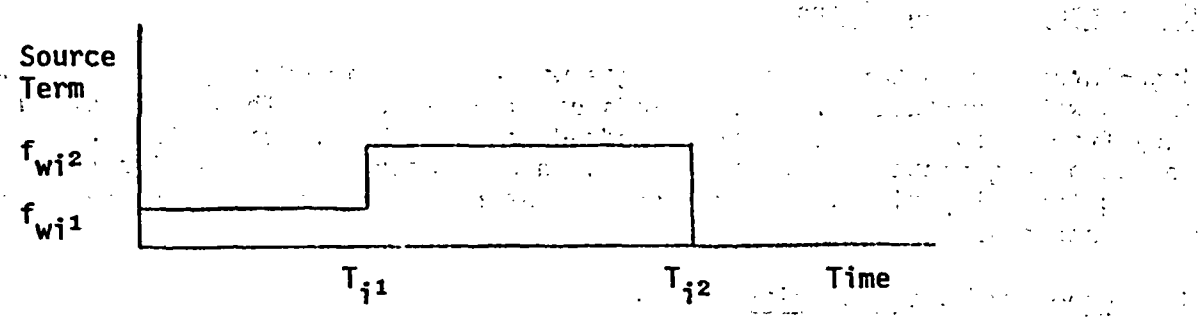
$$r_{ik} = k \times [\exp [-\lambda R t_{wk}]/(J \times T_i)] \qquad \text{(G-24)}$$

where the above variables J, T_i, λ, R, and t_{wk} denote the same parameters as were defined previously.

Time-Dependent Sources

Although a disposal facility will be designed and operated so that infiltration of rainwater will be minimized, it is possible that at some time after the disposal facility is closed, active institutional controls may break down and potential inadvertent intrusion into part of the disposed wastes may occur. Similarly, a breakdown in institutional controls may lead to an increase in infiltration of rainwater into the disposed waste and a corresponding increase in the ground-water migration source term. A calculational procedure to account for this time-dependent source-term is presented below.

For the case of the time-dependent source-term analysis, the source term is assumed to increase after the end of the active institutional control period. The source term may be represented by the following histogram:



Two source terms, denoted by f_{wi1} and f_{wi2}, are calculated using equation (G-16). These source terms are used in conjunction with two source duration times denoted by (T_{i1}) and (T_{i2}-T_{i1}). The first source term is applicable during the duration time of T_{i1} years (equal to or less than IPO+IIC - see Section 3.1), and the second source term is applicable during a duration time equal to T_{i2}-T_{i1}. The second source duration time is calculated by subtracting the radioactivity that has migrated during the first duration time from the activity inventory of the site (area under the above histogram), and dividing the remaining site activity inventory by the second source term. It is calculated by the formula:

$$T_{2i} = T_{i1} + f_{wi1} \times (TDUR - T_{i1}) / f_{wi2} \qquad \text{(G-25)}$$

where TDUR represents the source duration time if f_{wi1} were the source term during the entire period. In other words, TDUR is the duration time for the time-independent source-term analysis and TDUR times f_{wi1} times C_w is the entire site inventory of the radionuclide being considered.

For calculational convenience, the source term for this anlysis is taken to be equal to f_{wi1} and the effect of the increased source term after time T_{i1} is incorporated into the factor r_{tij}. After the definitions of these parameters, the following equation is applicable for the factor r_{tij}:

$$r_{tij} = [\exp(-\lambda t)/(J \times TDUR)] \times \left\{ F_j(t) - F_j(t-T_{i1}) + (f_{wi2}/f_{wi1}) \times [F_j(t-T_{i1}) - F_j(t-T_{e=i2})] \right\} \quad \text{(G-26)}$$

where $f_j(t)$ is the function defined previously by equation (3-19), and where the variables λ, J, TDUR, T_{i1}, T_{i2}, f_{wi1}, and f_{wi2} are as defined previously. For cases where the source is depleted within the active institutional control period (TDUR is less than IPO+IIC) or for cases where the initial percolation volume at the disposal facility is greater than or equal to V1 (see Section 3.5.1), this analysis is ignored.

High-Integrity Containers

High-integrity containers are packages which are designed to preclude waste/trench water contact for long periods of time (Ref. 1). This time period may vary from a few years to several hundred yaers. The effect of this delay due to use of high-integrity containers is incorporated into the analysis by adding the delay time to all the ground-water travel times for the selected waste streams.

3.6 Exposed-Waste Scenarios

In these scenarios, some or all of the surface area of the disposed waste is assumed to be exposed through some means. The mechanism that initiates uncovering of the waste can be either the erosion of the waste cover by surface water or wind action, or intruder activities such as housing construction. Similarly, there are two exposed waste surface scenarios depending on whether the transfer agent is wind or surface waste. Furthermore, the corresponding biota access location can be either an offsite surface water body (through surface water runoff) or offsite air (through wind suspension and transport). Therefore, there are four exposed waste scenarios: intruder-air, intruder-water, erosion-air, and erosion-water.

Only those wastes that have been disposed through regular disposal designs are considered in the erosion-initiated scenarios. Waste that is layered (disposed of at the bottom of the disposal cells), and waste that is disposed of in a hot waste facility are assumed not to be exposed to the atmosphere for the erosion-initiated scenarios. However, all the wastes are considered in the intruder-initiated scenarios. The following equations are utilized to calculate human exposures resulting from these scenarios. For the water transport and access case:

$$H = \sum_i \sum_n (f_o f_{di} f_{wi} f_{si})_{wat} C_{wi} \text{ PDCF-7} \qquad \text{(G-27)}$$

and, for air transport and access case:

$$H = \sum_i \sum_n (f_o f_{di} f_{wi} f_{si})_{air} C_{wi} \text{ PFCF-8} \qquad \text{(G-28)}$$

where H is th 50^{th} year annual dose in mrem/year after 50 years of exposure, PDCF-7 and PFCF-8 are the radionuclide-specific pathway dose conversion factors presented in Section 2.4, and C_{wi} is the radionuclide concentration in the i^{th} waste stream. The impacts are summed over all the radionuclides (n), and over all the waste streams (i). The values of the barrier factors are presented below.

The time delay barrier factor (f_o) is defined by:

$$f_o = \exp[- \lambda T] \qquad \text{(G-4)}$$

where T is the delay time, and λ is the decay constant. For the intruder-initiated exposed waste scenarios, the delay time (T) is taken to be the period between the cessation of active disposal operations and the end of the active institutional control period. For the erosion-initiated exposed waste scenarios, it is taken to be dependent on the cover thickness utilized--i.e., it is a function of the disposal technology index IC. The following table presents the values assumed for the initiation of the erosion scenario:

IC	Delay Time
1	2000 years
2	3000 years
3	10000 years

These values are believed to be extremely conservative. Previous estimates on the erosion potential of adequately emplaced cover materials have ranged from 1,000 years to 10,000 years to erode 1 meter of soil cover (Ref. 27). After consideration of the variability of this time period, Reference 13 assumes a time of 2,000 years to erode through 2 meters of cover. This is the value utilized in this EIS.

The site design factor (f_{di}) is defined as the fraction of the exposed area that is waste and will be assumed to be independent of the properties of the waste stream considered. In this EIS, it will be taken to be proportional to the emplacement efficiency of the waste; however, in this case, the percentage of the land area in between the disposal cells that have not been utilized for waste disposal must be considered--i.e., the land-surface utilization rate (see Section 3.1). Therefore, the site design factor is taken equal to the product of the emplacement efficiency (0.75 for stacked disposal and 0.5 for other emplacement cases) with the land-surface utilization rate of the design option. (For the reference disposal facility, the land surface utilization rate is conservatively estimated to be 0.90.)

The waste form and package factor (f_{wi}) denotes the total volume of the soil-waste mixture mobilized by the transfer agent per year. In this report, it may be empirically broken down into the following components.

$$f_{wi} = E \times (A/d)_i \qquad \text{(G-29)}$$

where:

E = soil-waste mixture mobilization rate (in g/m^2-yr) which will be taken to be independent of the waste stream.

A_i = total area of the soil-waste mixture (in m^2) that can be identified with the $(i)^{th}$ waste stream.

d_i = density of the soil-waste mixture (in g/m^3) that can be identified with the $(i)^{th}$ waste stream.

This equation is conservative and is applicable for both the wind transport scenario and the surface water scenario. Specific values of the above parameters and the site selection factor f_{si} are discussed below.

3.6.1 Wind Transport Scenarios

For the intruder-initiated scenarios, the factor E can be calculated based on use of the soil-to-air transfer factor (Ref. 1). It may be taken as the time-weighted average of the dust mobilization rate resulting from construction or gardening activities such as tilling and the natural wind mobilization rate (Ref. 1).

Impacts are summed over all waste streams. To calculate the amount of radioactivity released into the air from each waste stream in the intruder-initiated exposed waste scenario, either the intruder-construction or the intruder-agriculture scenarios are used depending upon the disposal status of the waste. Regular and layered unstable waste streams are subject to the agriculture scenario, while regular stable, layered stable, and hot waste facility waste streams are subject to the construction scenario. However, only 1 percent of the layered unstable wastes are assumed to contribute to the agriculture

scenario, while only 1 percent of the layered stable wastes and 0.1 percent of the hot waste facility wastes are assumed to contribute to the construction scenario. Moreover, the duration of the exposed waste scenario is modified by the duration factor of 6 hours (instead of 500 hours) for the stable wastes. Furthermore, about 1800 m^2 of waste area is assumed to be exposed continuously in the agriculture scenario with only a fraction used for gardening, and 200 m^2 of area is exposed for 500 hours for the standard construction scenario.

In order to simplify the compliacted procedure required to estimate the factor E for the above conditional cases, a basic mobilization rate is assumed to be applicable to all the cases with correction factors applied for each waste stream as appropriate for the special conditions outlined above. The basic dust mobilization rate for the intruder-initiated scenario is assumed to be 2.9×10^{-3} mg/m^2-sec (Ref. 1). For the erosion-initiated scenario, the factor E is taken as the natural wind mobilization rate of 4.1×10^{-4} mg/m^2-sec (Ref. 1).

For the erosion-initiated scenario the entire disposal site area is assumed to be exposed and A_i is calculated by dividing the volume of the waste stream being considered by the product obtained by multiplying the volumetric disposal efficiency (assumed to 6.40 m^3/m^2 for the reference disposal facility) by the surface utilization rate (0.90) and by the emplacement efficiency. The density of the soil/waste mixture is assumed to be 1.6 g/cm^3 except for those streams that are solidified using solidification scenarios A or B involving partial cement solidification. These streams are assumed to be 34% heavier.

For the wind transfer scenario, the site selection factor (f_s) is the air-to-air transfer factor (meteorological dispersion factor X/Q) (Ref. 1). For these scenarios, the number of people exposed to atmospheric releases are incorporated into the definition of the site selection factor. This results in an f_s with units of people-year/m^3.

To calculate the site selection factors, the population for the reference disposal facility (see Appendix J) is assumed to be doubled for the intruder-initiated scenario, and tripled for the erosion-initiated scenario. The number of people in each radial sector is multiplied by the corresponding atmospheric dilution factor and the results summed. The site selection factors are calculated to be 3.50×10^{-10} and 5.25×10^{-10} people-year/m^3 for the intruder-and erosion-initiated wind transfer scenarios, respectively.

3.6.2 Surface Water Scenario

Based on surface water erosion calculations (Ref. 1) the mobilization rate for the surface water scenario (i.e., the factor E in equation G-29) is calculated to be 1.84×10^2 g/m^2-year. This factor corresponds to an annual erosion rate of about 0.75 tons/acre. The other factors in the equation (i.e., A and d) remain as defined in Section 3.6.1.

The surface water site selection factor can be estimated by considering the flow rate of a nearby stream assumed to be utilized by a member of the population. In this EIS, the inverse of twice the value of the dilution factor Q previously utilized to determine ground-water impacts at the surface water access location is utilized (1.12×10^{-7} year/m^3). Twice the value is utilized to account for the increased flow conditions during heavy precipitation and subsequent heavy stream flow rates (Ref. 1).

3.7 Operational Accident Scenarios

There are two accident scenarios considered for applicability to a given stream in the impact calculations: accident-container, and accident-fire. These scenarios are described below.

3.7.1 Accident-Container Scenario

This scenario assumed that a waste container is dropped from a significant height so that the waste container breaks open and that a portion of the radioactive contents of the package is released into the air where it is transported offsite and leads to subsequent human exposure. Potential releases can be modeled as a "puff," and resulting human exposures would be over a very short time period. The potential exposures from this scenario are a strong function of the waste form--i.e., improved less dispersible waste forms lead to lower potential releases and reduced potential human exposures. The equation describing the human exposures are as follows:

$$H = \sum_{n} (f_o f_d f_w f_s)\, C_w\, PDCF\text{-}1 \qquad \text{(G-30)}$$

where H is the 50-year dose commitment in mrem, PDCF-1 is the radionuclide specifc pathway dose conversion factor presented in Section 2.4, and C_w is the radionuclide of concentration in the waste. Impacts are summed over all the radionuclides (n).

No reduction due to decay of the radionuclides is considered, and the time delay factor f_o is assumed to be one. Similarly, no reduction due to site design and operation has been assumed and the factor f_d has also been set equal to one.

The waste form and package factor f_w is affected by the dispersibility of the material at the time of disposal. An index that can be conveniently used to represent this property is the leachability index of the waste stream (see Section 3.2.3), which also represents the solidification scenario utilized for the waste stream. The waste form and package factor is given by the following equation:

$$f_w = 10^{(I-19)} \times 10^{(I-16)} \qquad \text{(G-31)}$$

The relationship $10^{(1-I9)}$ is the accessibility multiplier discussed previously. The factor $10^{(1-I6)}$ indicates the relative dispersiblity of the solidified material after a container accident. The property values for this comparative dispersibility are based on consideration of comparative mechanical strengths (measured for compressive, unnotched Izod impact, and fragmentation tests) of waste forms (Ref. 1). If the waste is not solidified, then the dispersibility factor is assumed to be unity.

The site selection factor f_s, which is dimensionless, may be calculated by assuming that the material released is a "puff," and it stays in a puff form until it reaches the exposed individual. The following equation is utilized to calculate f_s in this EIS:

$$f_s = 1.56 \times 10^{-7} \times V \times f_r \times (X/Q) \qquad \text{(G-32)}$$

where 1.56×10^{-7} is the exposure duration factor given by the fraction of air inhaled in one intake by a man performing light activity (1.25 liters) to the annual inhalation volume (8000 m^3) (Refs. 1, 34).

The source term may be represented by the product of f_r, the fraction released per second, and V, the volume of the container. For the worst case, 0.1 percent of the waste is assumed to be released into air (the case of the PuO_2 powered accident) (Ref. 9). This release fraction is modified by the solidification status of the waste stream (see above). The volume of the container involved in the accident, V, is assumed to be 170 ft^3--the size of a typical resin liner.

For puff releases, the atmospheric dispersion factor (X/Q) for a ground level release and for a person standing in the centerline of the puff is given in reference 35 by the following formula:

$$(X/Q) = [\pi \sqrt{2\pi}\, \sigma_x\, \sigma_y\, \sigma_z]^{-1} \qquad \text{(G-33)}$$

where σ_x, σ_y, and σ_z are the distance-dependent standard deviation factors of the Gaussian puff in three directions. These sigmas, in meters, indicate the spread and dilution of the plume as a function of distance from the source. Utilizing a value of $\sigma_x = \sigma_y = 3.61$ m (based on the average wind speed at the reference facility), and a value of $\sigma_z = 2.2$ m (Ref. 35), yields a (X/Q) value of 4.42×10^{-3} sec/m^3.

3.7.2 Accident-Fire Scenario

This scenario assumes that a fire starts in a disposal cell and lasts for approximately two hours. A portion of the radioactive material is released into the air where it is transported offsite and leads to subsequent exposures of humans. Potential exposures from this scenario are a strong function of the waste form and facility design and operation. For example, a waste disposal cell in which all of the wastes are composed of compressible material (e.g., segregated disposal of compressible waste) would involve larger releases (more material to burn) than a case in which the compressible material is mixed with noncombustible waste. However, most compressible waste forms have very low levels of contamination. On the other hand, improvements in the form of the compressible material would involve lower potential releases. For example, compressible material which has been processed by incineration and solidified would involve lower potential releases than compacted compressible waste.

In this work, the accident-fire scenario is used to help assess the effect of improved waste forms and site operational practices on reducing the potential exposures from an accident involving an operational fire. Each waste stream or groups of waste streams may be tested separately using this scenario.

The equation describing the human exposures is as follows:

$$H = \sum_{n} (f_o f_d f_w f_s)\, C_w\, PDCF\text{-}1 \qquad \text{(G-34)}$$

where H is the 50-year dose commitment in mrem, PDCF-1 is the radionuclide-specific pathway dose conversion factor discussed in Section 2.4 and C_w is the radionuclide concentration in the waste. Impacts are summed over all the radionuclides (n).

In a manner similar to the accident-container scenario, the time delay factor f_o and the site design and operation factor f_d are assumed to be unity. The waste form and package factor f_w is assumed to be equal to $0.1 \times 20^{(I4-3)}$ where I4 is the waste form flammability index (see Section 3.2.1).

The site selection factor f_s is determined by the atmospheric dispersion of the plume resulting from the accident. In this EIS, the plume resulting from the fire is assumed to travel in one direction and the exposed individual is assumed to stand in the centerline of the plume for a period of time. The following formula is used for f_s:

$$f_s = f_e \times f_r \times V \times (X/Q) \qquad \text{(G-35)}$$

where f_e is the exposure duration factor (dimensionless); f_r is the release fraction per second; V is the volume of the waste involved in the fire in units of m^3; and (X/Q) is the atmospheric dispersion factor in units of sec/m^3.

In this EIS, f_e is assumed to be equal to 3.63×10^{-5} based on the ratio of the air inhaled during the time period the individual is assumed to stand in the plume of the fire (10 minutes during which a man doing light activity inhales about 0.29 m^3 of air) (Ref. 34). The fraction released per second, f_r, is assumed to be 1/7200 based on the assumed duration of the fire. This is equivalent to a fire duration time of 2 hours. The volume of waste involved in the accident is assumed to be 100 m^3 based on an estimated annual disposal volume of 50,000 m^3, two disposal cells operating simultaneously, and one disposal cell involved in the fire. The atmospheric dispersion factor (X/Q) for an accident lasting from 0 to 8 hours is given by (Ref. 35):

$$(X/Q) = \exp[-h^2/(2\,\sigma_z)]/[\pi u\, \sigma_y\, \sigma_z] \qquad \text{(G-36)}$$

where h is the release height (or the effective height of the plume at the fire source), u is the wind speed assumed to be 1 m/sec with Pasquill Stability

Class F atmospheric condition (Ref. 35) and σ_y and σ_z are as defined previously. Utilizing values for σ_y and σ_z given in Reference 35 at 100 m from the fire, and conservatively assuming ground-level releases (i.e., h=0), yields a (X/q) value of 3.62×10^{-3} and a value for f_s of 1.83×10^{-9}.

3.8 Other Impact Measures

The impact measures other than individual and population exposures associated with operation of a disposal facility include occupational exposures, land use, disposal costs, and energy use. This section considers procedures for calculating these other impact measures.

3.8.1 Land Use

Calculating the land area committed for waste disposal is a straightforward function of the total volume of the waste disposed, the waste emplacement technique (i.e., whether random, stacked, or decontainerized disposal is utilized), and the volumetric efficiency of the disposal technology considered. The volumetric efficiency is a function of site design as discussed in Section 3.1.2.

For the reference disposal facility and for disposal into a regular shallow land burial trench (design case ID=1), the disposal volume (not the waste volume) per unit disposal cell area is 6.40 m^3/m^2. Therefore, for each 3.20 m^3 of waste that is disposed randomly, 1 m^2 of area is committed. However, this land-use rate should be divided by the surface utilization rate, calculated to be 0.90 for the reference disposal facility, since for all practical purposes, the land area between the disposal cells may be considered as committed land. Incorporating this correction results in 1 m^2 of land area committed for each 2.88 m^3 of waste disposed with random emplacement. Stacked emplacement would result in 1 m^2 of land area committed for each 4.32 m^3 of waste disposed.

Similarly, for the concrete-walled trench option (design case ID=2), the volumetric disposal efficiency is calculated to be 7.00 m^3 of disposal volume per unit disposal cell area (excluding walls of the trenches). Therefore, for each 5.25 m^3 of waste disposed through stacked emplacement, 1 m^2 of cell area is committed. The land-surface utilization rate in this case is calculated to be 0.35 m^2 of disposal cell area per m^2 of available land (including walls and spaces between the trenches). Therefore, the land area committed is 1 m^2 of land for each 1.84 m^3 of waste disposed.

3.8.2 Occupational Exposures

In this appendix, the calculation of the occupational exposures at the disposal facility is performed in two phases: exposures to waste handlers during unloading and emplacement of wastes, and occupational exposures to other site personnel performing routine operational and administrative functions not directly connected with waste handling.

Occupational exposures to waste handlers are strongly dependent on the packaging of the delivered waste, the shipment mode, and the disposal procedure. Therefore,

procedures for determining the occupational exposures resulting from unloading and disposal of waste are considered in the transportation impacts section of this appendix (see Section 4). Routine occupational exposures for personnel other than waste handlers are calculated in the following section.

3.8.3 Disposal Costs

Other impact measures--disposal costs, routine occupational exposures to facility personnel other than waste handlers, and energy use--are closely interrelated and are dependent on the waste volume disposed, the land-use rate, operational practices, etc. These three measures are considered in this section.

The basic unit rates (rates per unit volume or area) associated with costs (prior to multipliers to account for the cost of money, profit, inflation, etc.--see below), energy use, and routine occupational exposures at a disposal facility have been calculated in Appendices E, F, and Q. These basic unit rates are summarized in Table G.16).

The unit rates presented in Table G.16 are utilized in a computer program (OPTIONS, see Appendix H) that calculates the impact measures. Depending on the disposal facility design option selected, the status of each waste stream, I11, is determined utilizing procedures outlined in Section 3.4. Then, the volumes of waste that are unacceptable for near-surface disposal, waste disposed of through regular means, waste disposed through the layered option (if any), and waste emplaced in a hot waste facility (if any) are determined. These waste volumes, together with the selected emplacement procedure, give the respective disposal volumes required, and the disposal volumes, together with the volume utilization rates, give the respective areas involved. Then, these areas are utilized to calculate costs for design options such as alternative disposal cell covers. These unit rates are briefly discussed below.

Costs associated with the operational life of the disposal facility are divided into capital costs and operating costs as discussed in Appendix Q. Base case capital costs for the reference disposal facility are calculated from the information given in Appendix Q and include consideration of environmental investigations, licensing costs, land purchase cost, road construction, building construction, and peripheral system installation. Additional capital costs associated with implementation of a specific design option are quantified in Appendix F and added appropriately during the calculation.

The options considered during the operational life are divided into two groups: the reference system and the design options, which are subdivided into volume-dependent options and area-dependent options. For calculational convenience, these unit rates are converted to disposal volume rates since different emplacement procedures are applicable. The items considered under "other" rates include payroll, administration, equipment, etc. It is assumed that changing disposal waste volumes due to processing will not alter the rates given as "lump sum" significantly.

Table G. 16 Unit Rates for Impact Measures

Activity	Cost (thousand 1980 $)	Occupational* Exposure (person-mrem)	Energy Use (thousand gallons)	Units**
Preoperational				
Reference Base Case	7,452	--	212	Lump Sum
Additive Alternatives†				
Walled Trench	594	--	--	Lump Sum
Stacking	226	--	--	Lump Sum
Segregation	1	--	--	Lump Sum
Layering	132	--	--	Lump Sum
Decontainerized Disposal	924	--	--	Lump Sum
Hot Waste Facility	260	--	--	Lump Sum
Grouting	55	--	--	Lump Sum
Intruder Barrier	281	--	--	Lump Sum
Extreme Stabilization	10	--	--	Lump Sum
Operational				
Reference Base Case				
Trench (-Cover)	2,341	300	200	Disposal Vol.
Regular Cover	1,420	2,400	100	Disposal Area
Other Costs	63,696	1,000	200	Lump Sum
Additive Alternatives†				
Walled Trench	74,438	700	300	Disposal Vol.
Stacking	12,758	100	100	Total Waste Vol.
Segregation	3,888	100	30	Total Waste Vol.
Layering	15,400	-100	30	Volume Disp. by Layer
Decontainerized Disposal	48,975	400	100	Volume Disp. by Decon.
Hot Waste Facility	176,979	-200	450	Volume Disp. by HWF
Grouting	72,405	2,550	800	Grout Volume
Sand Backfill	2,370	--	185	Sand Volume
Cover Options				
Thick	15,524	2,400	150	Disposal Area
Intruder Barrier	103,854	2,400	300	Disposal Area
Moderate Stabilization	3,465	4,800	300	Disposal Area
Extreme Stabilization	33,345	4,800	600	Disposal Area

Table G.16 (continued)

Activity	Cost (thousand 1980 $)	Occupational* Exposure (person-mrem)	Energy Use (thousand gallons)	Units**
Postoperational				
Closure Period				
Regular Closure	1,010	500††	60	Lump Sum
Extensive Closure	3,025	1,000	60	Lump Sum
Institutional Period#				
Low Care Level				
Years 1-10	150	--	2	Per Year
Years 11-25	63	--	2	Per Year
Years 26-100	51	--	2	Per Year
Medium Care Level				
Years 1-10	303	--	6	Per Year
Years 11-25	150	--	6	Per Year
Years 26-100	63	--	6	Per Year
High Care Level				
Years 1-10	440##	--	10	Per Year
Years 11-25	303	--	10	Per Year
Years 26-100	150	--	10	Per Year

*Occupational exposures associated with operations other than waste unloading and disposal.

**Lump sum items are assumed to be independent of the waste volume; disposal volume dependency is for 1 million m^3 of disposal (not waste) volume; grout volume dependency is for 1 million m^3 of grout injected; sand volume dependency is for 1 million m^3 of sand backfill; disposal area dependency is for 1 million m^2 of trench cover area.

†All these rates for alternatives are incremental rates in addition to the rates given for the reference system.

††Regular closure is assumed to last 2 years; extensive closure is assumed to last four years. Both cases assume 5,000 person-hours of field work per year in an average radiation field of 0.05 mR/hr.

#These costs are basic costs not considering inflation or interest. Details for complete calculation of the institutional period costs, including consideration of inflation and interest, can be found in Appendix Q. The formulas given in that appendix are incorporated into the cost calculation procedure.

##To this cost, a contingency cost is added which depends on the soil conditions: $367,000 for medium-permeability soils; $168,000 for high-permeability soils; and, $1,007,000 for low-permeability soils.

The second group of options (termed additive alternatives in Table G.16) result from the application of the available design options (ID, IS, IE, IL, IH, and IG) discussed in Section 3.1 in a straightforward manner. These rates are also estimated from a wider range of design and technology options considered in Appendix F. The rates given in Appendix F are normalized, however, to one-million m^3 of waste volume for calculational convenience. Similarly, the grouting option rates are for one-million m^3 of grout injected, since the option may be exercised with either random or stacked disposal, etc. One consequence of the application of the hot waste facility option is that the total routine occupational exposures are estimated to go down as a result of increased shielding afforded by the special facility; this effect is expressed by giving a negative occupational exposure to the hot waste facility. The third group of operational options result from the application of cover-related options (IC, IX) discussed in Section 3.1. These options are area-dependent. For calculational convenience they also have been normalized to one-million m^2.

All these options are additive. As an example, the preoperational and operational costs resulting from disposal of 900,000 m^3 of waste (all found acceptable for near-surface disposal) in the reference facility with a volume efficiency of 5 m^3/m^2, with stacked emplacement (0.75), with grouting, with a thick cover, and with maximum stabilization are tabulated in Table G.17. Occupational exposures and energy use are calculated in a similar manner.

These costs, however, are multiplied with two conversion factors to account for cost of money, inflation, and other financial considerations. These multipliers are presented below. A more detailed explanation of the derivation of these multipliers can be found in Appendix Q.

For capital costs, the following items are applicable:

Item	Factor
Indirect Costs	1.73
Fixed Charge	5.00
Profit	1.20

Indirect costs result from interest during construction, contingency, and other costs such as miscellaneous overhead expenses, insurance, sales tax, etc. The fixed charge results from an assumed 25% charge on capital over the 20-year operating life of the facility. These three items result in a multiplier of 10.38 for the preoperational capital costs. For the operational costs, the following items are applicable:

Item	Factor
Contingency	1.30
Profit	1.20

This results in a multiplier of 1.56 for the operational costs. These multipliers may be illustrated through use of the example presented in Table G.17. Using these multipliers with the preoperational capital costs of $7,810,000 and the operational cost of $107,953,000 yields a total preoperational and operational cost of about $249,475,000 in 1980 dollars.

Postoperational costs (composed of closure costs and long-term care costs) are calculated using the following two equations. For the closure costs, the following equation is applied.

$$\text{Closure Costs} = C_{80} \times L \times (1+j)^L \left\{ f + \frac{i}{[(1+i)^L - 1]} \right\}$$

where C_{80} is the closure cost presented in Table G.16, L is the facility life in years, f is an annual fee for a surety bond which assures availability of closure funds (1.5% is generally used in this EIS), j is the inflation rate (9% is generally used in this EIS), and i is the interest rate (10% is generally assumed). For long-term care costs, the following equation is applicable:

$$\text{LTC Cost} = PV_{80} \times \frac{L \times (1+j)^M \times i}{[(1+i)^L - 1] \times (1+i)^C} \qquad \text{(G-37)}$$

where LTC stands for long-term care, L is the site operational life in years, C is the closure period in years, M is L+C, i is the interest rate, j is the inflation rate, and PV_{80} is given by the following equation:

$$PV_{80} = C_a \sum_{n=1}^{10} R^n + C_b \sum_{n=11}^{25} R^n + C_c \sum_{n=25}^{100} R^n \qquad \text{(G-38)}$$

where R is the ratio (1+j)/(1+i). The parameters C_a, C_b, and C_c are the annual costs given in Table G.16 for the long-term care costs during the years 0-10, 11-25, and 26-100, respectively. The cost rate C_a may include a contingency cost as referenced in Table G.16 and discussed in more detail in Appendix Q.

4.0 TRANSPORTATION IMPACTS

This section discusses the calculational procedures used to determine impacts associated with transportation of waste to the disposal facility. The impact measures developed in this report include: cost; occupational exposures associated with loading, transporation, and unloading of the waste; population exposures associated with transportation; and energy use. Section 4.1 presents the packaging and shipping assumptions utilized in the calculations. Transportation costs and other impact measures are presented in Sections 4.2 and 4.3, respectively.

Table G.17 Illustrative Calculation

Assumptions:	900,000 m^3 of waste stacked, grouted, thick cover, maximum stabilization, disposal efficiency of 5 m^3/m^2	
Disposal Volume = 900,000/0.75		= 1,200,000 m^3
Empty Disposal Space = 1,200,000x(1-0.75)		= 300,000 m^3
Disposal Area = 1,200,000/5		= 240,000 m^2
Preoperational Costs		
Reference System		$ 7,452,000
Stacking		138,000
Grouting		220,000
	Total Preoperations:	$ 7,810,000
Operational Costs		
Reference System		
Trench Construction		$ 2,810,000
Regular Cover		341,000
Other Costs		63,696,000
Additive Alternatives		
Stacking Option		7,528,500
Grouting Option		12,457,500
Thick Cover		4,224,000
Maximum Stabilization		16,896,000
	Total Operations:	$107,953,000

4.1 Packaging and Shipping Assumptions

Potential impacts (e.g., occupational exposures, population exposures, and costs) incurred during transportation of waste to the disposal facility and during subsequent unloading and emplacement operations are influenced by a number of interrelated factors. These interrelated factors increase the complexity of the impacts analyses and arise from the greatly variable nature of LLW and LLW transportation. For example, LLW can be generated in a great variety of forms and can range from wastes having very low to moderately high radioactivity concentration levels. In addition, a range of waste container types and sizes are presently available and in use.

For the purposes of this EIS, some simplifying assumptions regarding waste packaging and transportation are made based upon past experience. These assumptions include those in the following areas:

- The degree of care required for waste handling and transportation (package surface radiation levels);
- Container sizes and types; and
- The shipment mode (vehicles and overpacks used).

Additional information regarding these simplifying assumptions is provided below.

4.1.1 Surface Radiation Levels

Radiation levels at the waste package surfaces affect the care required in handling of wastes and the shielding that may be required during transportation. For the purposes of this appendix, the waste streams are generically classified into three categories according to the level of care assumed to be required to handle each waste stream:

- Regular care
- Special care
- Extreme care

Packaging sizes and packaging procedures are instrumental in determining the self-shielding afforded by some of the waste packages. However, there can be significant variations in the level of care required for each package due to variations in the specific activities of the wastes within a given stream. For this analysis, the level of care is assumed to be independent of waste package shape and volume. The relative level of care is assumed to depend only on the total specific activity contained in the waste package and the presence or absence of high-energy gamma-emitting radionuclides.

Each waste stream is denoted by an index representing the type of activity with regard to high-energy gamma-emitting radionuclides. Waste streams containing significant quantities of fission products (most notably Co-60, Nb-94, and Cs-137) are denoted as the first category. Waste streams containing very

little high-energy gamma emitters (and consequently all requiring a "regular" level of care) are denoted as the third categroy. Other streams in between these two are denoted as the second category:

Category 1 : Fission product wastes
Category 2 : Other wastes
Category 3 : All regular care wastes

In addition to these categories, the specific activity, and therefore the required level of care, for a given waste stream varies significantly. For example, surface radiation readings of similarly sized LWR resin packages varying over two or three orders of magnitude have been observed (Ref. 17). To account for this normal variation, Table G.18 is used to estimate the fraction of each waste stream that requires a specific level of care based on the total specific activity of the waste stream.

Table G.18 Distribution Between Care Level Required with Type and Specific Activity of Waste

Total Specific Activity (Ci/m^3)			Percent Waste Stream Volume in Each Handling Category		
Type 1	Type 2	Type 3	Regular	Special	Extreme
<0.01	<0.1	All	100	--	--
.01-.1	.1-1		80	20	--
.1-1	1-10		40	50	10
1-10	>10		20	60	20
10-100			10	50	40
>100			--	20	80

The values in this table are estimated guided by standard health-physics "rules of thumb" calculations for determining the surface radiation level of a waste package--e.g., the 6CEn formula (Ref. 36). For example, for waste in Category 1 with about 2 Ci/m^3 of activity, 20% of the waste volume is assumed to require regular care, 60% of the waste volume is assumed to require special care, and the remaining 20% is assumed to require extreme care. According to the 6CEn formula, assuming that all the radioactivity is Co-60 and the waste package is a 55-gallon drum, this waste may have a radiation reading of about 6 R/hour. For waste in Category 2 with about 0.2 Ci/m^3 of activity, 80% of the volume is assumed to require regular care, and the remaining 20% is assumed to require special care. All wastes in Category 3 are assumed to require regular care.

After determining the fraction of waste volume in each stream that requires a specific level of care, the waste is assumed to be packaged and shipped. The packaging and shipping assumptions for these fractions are discussed below.

4.1.2 Packaging Parameters

There are many different types of packaging currently utilized for shipment and disposal of LLW (Refs. 37, 38). These packages include wooden boxes of various sizes ranging from 10 ft^3 to 248 ft^3, 55-gallon drums, and liners (usually carbon steel) of various sizes ranging from 16 ft^3 to 200 ft^3 which fit into transport casks. For the generic analyses performed in this EIS for determining transportation and disposal impacts, these packages were generalized into five different categories:

- Large wooden boxes - 128 ft^3
- Small wooden boxes - 16 ft^3
- 55-gallon drums - 7.5 ft^3
- Small liners - 50 ft^3
- Large liners - 170 ft^3

The primary rationale for selecting these sizes is that they appear to be the most widely used sizes, and that they may be used to represent an average of other packages. For example, the 128 ft^3 box is the most commonly used (4'x4'x8') size to ship low-specific-activity (LSA) waste; the 170 ft^3 liner is the commonly available 6'x6' right-circular cylinder.

During the transportation analysis, for regular- and special-care wastes, all five methods of packaging are assumed to be acceptable. The high-activity of extreme-care wastes renders the use of boxes for packaging unacceptably inconvenient; therefore, all waste that is classified "extreme care" has been assumed to be packaged in either drums or liners which are remotely manipulated for loading and off-loading.

The distribution of these package types for each waste stream have been assumed using available shipping and survey data (Refs.1, 37-40), and are presented in Table G.19.

4.1.3 Mode of Shipment

Similar to the numerous different types of available waste packages, there may exist many different shipment modes ranging from rail and barge transport to truck transport. Many different types of overpacks may be used that depend on the handling and shielding requirements for individual waste packages (Refs. 37, 39).

In this EIS, only truck transport is considered because trucks are the most commonly used mode of transportation and truck transport is radiologically the most conservative case. Vehicles and overpacks utilized in truck shipments depend on package sizes as well as package shielding requirements. In this EIS, six different types of transport vehicles and overpacks are assumed:

1. Vans
2. Flatbed trailers
3. Shielded trailers
4. Large shielded casks
5. Small shielded casks
6. 1-drum shielded casks

Table G.19 Packaging of LLW for Waste Spectrum 1 (percent of volume packed in containers)

Waste Stream	Large Boxes	Small Boxes	55-g Drums	Small Liners	Large Liners
LWR Process Waste Group	--	--	69	15	16
Trash Group (except P- & B-NCTRASH)	23	8	69	--	--
P- & B-NCTRASH	--	--	100	--	--
Low Specific Activity Waste Group (except F- & U-PROCESS)	--	2.5	97.5	--	--
F- & U-PROCESS	--	--	100	--	--
Special Waste Group	--	--	100	--	--

*Other distributions depending on the spectrum may be imposed on the individual waste streams.

Large casks are used for transporting either large liners or fourteen 55-gallon drums, while small casks are used for transporting either small liners or six 55-gallon drums. These casks are transported to the disposal facility via flatbed trailers.

The use of particular types of vehicles and overpacks is strongly influenced by the level of care required for safe waste handling and transport of the waste packages. Vans are assumed to be suitable for all types of containers in the regular care category, with the exception of large liners which require casks. In addition, flatbed trailers are assumed to be used only for large boxes of regular-care wastes. Shielded trailers are assumed to be required for large and small boxes and drums of special-care wastes. Some of these small boxes and drums, as well as large and small liners, are assumed to require casks. Casks are assumed to be the only acceptable mode of transport for extreme-care wastes.

The percentage use of different vehicles and overpacks for each container have been estimated considering records of waste shipments delivered to the Maxey Flats, Kentucky disposal facility (Ref. 1). A tabular listing of the basic assumptions made for the transportation of wastes is presented in Table G.20. Extreme care liner shipments have been assumed to be "overweight" shipment since these require significant shielding for transportation purposes. These are also designated in Table G.20 (Refs. 1, 39).

Table G.20 Packaging and Shipment Mode Parameters

Care Level and Container	Overpack*	Per Shipment		Man-Minutes for Disposal Per Container	
		Pieces	Percent Volume	Random	Stacked
Regular Care					
Large Box	Van	3	24	200	240
	FB	4	76	74	120
Small Box	Van	36	100	16	24
Drum	Van	70	100	6	24
Small Liner	Van	11	100	136	165
Large Liner	LC	1	100	1200	1440
Special Care					
Large Box	ST	3	100	300	360
Small Box	ST	36	96	26	39
	LC	6	4	250	300
Drum	ST	70	48	10	24
	LC	14	51	86	175
	SC	6	1	200	312
Small Liner	SC	2	100	600	720
Large Liner	LC	1	100	1200	1440
Extreme Care					
Drum	SC	6	51	200	312
	1D	1	49	600	720
Smaller Liner	SC**	2	100	600	720
Large Liner	LC**	1	100	1500	1800

*FB = flatbed trailer; ST = shielded trailer; LC = large shielded cask; SC = small shilded cask; 1D = 1-drum shielded cask.

**These shipments are estimated to be overweight.

4.2 Costs

Transportation costs include a mileage charge (including fuel surcharge), a cask use charge (rental), and an overweight shipment transportation charge.

The mileage charge is calculated by estimating the total shipment miles required (including return trip mileage for casks). For the reference facility, an

average of 400 miles per one-way shipment is assumed. The basic transportation charge depends on the one-way distance and is estimated according to the following table (Ref. 1).

One-Way Distance	One-Way ($/mile)	Round Trip ($/mile)
< 400 miles	1.69	1.25
400-100 miles	1.47	1.14
> 1000 miles	1.17	1.08

Added charges, which become significant for extreme-care shipments, include a fuel surcharge (15% of the basic cost) and an overweight charge. The amount of the overweight charge depends on the maximum gross vehicle weight (GVW) allowed in states through which the shipment passes. Any overweight condition up to 85,000 lbs. is charged at about $0.21/mile plus the permit charges for each state (about $100 per 600 miles). A GVW of over 85,000 lbs. is assumed to be additionally charged $0.005 per mile per hundred pounds (cwt) over this limit. For a shipment of 96,000 lbs., which is a minimum for an extreme-care cask, the charges for an example one-way trip of 600 miles would be as follows:

Basic cost @ $1.14/mile	$1,368.00
Fuel surcharge @ 15% of charge	205.00
Overweight charge @$0.21/mile	126.00
Overweight surcharge @ $0.005/cwt/mile	330.00
Five overweight permits @ $20.00/state	100.00
Total:	$2,129.00
Per Mile:	$ 3.55

The cask-use charge calculation assumes an average turnaround time of 4 days. Cask rental rates vary depending on the size and weight of the cask required. They average $250/day for shielded casks enclosing high-activity LLW, and range down to $110/day for an unshielded 120 cubic foot capacity cask (Ref. 9). The rental rates also vary with the specific type of nuclear material the cask is licensed to carry and the accompanying performance standards the cask must satisfy.

4.3 Other Impacts

In addition to costs, three other impact measures resulting from LLW transportation are calculated in this report: energy use, occupational exposures, and population exposures. These impacts are reviewed in this section.

The energy use is calculated based on the total shipment miles, including empty cask return trips, and an average fuel consumption rate of 6 miles/gallon.

The occupational and population exposures incurred during transportation are calculated based on total loaded miles and the number of loaded shipments. The concept of loaded miles and shipments allows the miles in which the vehicle is empty because it is on a return trip to be eliminated from consideration. Occupational and population exposures are calculated separately from those resulting during transit, and those resulting from stopovers during the trip. Occupational exposures during stopovers are estimated by assuming two drivers. Each inspect the overpack for 3 minutes (10 mR/hr radiation field at the surface of the overpack), and walk around the overpack for 30 minutes (1 mR/hr radiation field at about 3 ft). This yields 2 person-mrem per stop for each shipment. The population exposure during stopovers is estimated in Reference 1, and also yields about 2 person-millirem per stop for each shipment. To estimate occupational and population exposures during transit, the values per shipment-mile given in WASH-1238 are utilized (Ref. 8). These exposure rates are summarized below.

	Population Doses (person-mrem)	Occupational Doses (person-mrem)
During Transit		
Per Shipment Mile	0.018	0.02
During Stopover		
Per Shipment	2.0	2.0

Occupational exposures resulting from the loading of the waste packages are also included in the transportation occupational exposures. These occupational exposures are calculated based on two factors: the man-minutes required to load each container, and the radiation field associated with the level of care required for each container. The man-minutes for stacked disposal shown in Table G.20 is assumed to be applicable for loading of the wastes. The radiation levels associated with the handling environment (not the package surface radiation levels) for each level of care are assumed to be as follows:

Level of Care	Radiation Level (uR/hr)
Regular	750
Special	1800
Extreme	2200

The calculation of occupational exposures to waste handlers is also straightforward based on estimates of personnel time required for unloading and disposal

of the wastes. These estimates are presented in Table G.20. Other parameters necessary for the computations are the radiation fields associated with the handling environment that the workers are exposed to. These fields are assumed to be a function of the care level of the package and whether the disposal is random or stacked. The following table presents these assumptions:

Level of Care	Radiation Level (uR/hr) Random	Stacked
Regular	500	750
Special	1200	1800
Extreme	2000	2200

Impacts calculated from these estimates are added to disposal facility occupational exposures calculated in Section 3.8.3 for disposal facility personnel other than waste handlers. Decontainerized disposal of waste is assumed to require twice the time needed for stacked handling for those packages that are to be disposed in this manner.

5. WASTE PROCESSING IMPACTS

This section discusses the calculational procedures utilized to determine the impact measures associated with processing the waste streams. These impact measures include population exposures, occupational exposures, costs, and energy use. The processing options considered in this EIS and the unit rates for costs, person-hours, and energy use for these processing options are presented in Appendix D. Based on this information and using an additional waste stream index, denoted by I10, the processing impacts are calculated for respective cases utilizing the assumptions and procedures presented in this section.

5.1 Waste Processing Index

The variations in the processing technologies applied to a given stream, which affect the calculation of the impact measures, include the volume reduction process type, the volume increase process type, the location of the processing, and the environment in which the processing takes place. For calculational convenience, the waste processing option applicable to each waste stream for each waste spectrum has been digitized and is called the waste processing index, denoted by I10 (see Section 3 for other waste form behavior indices).

The index I10 is a four-digit number with each digit denoting a specific procedure for calculation of the impact measures. These digits cumulatively correspond to a specific case. The meaning of the digits that make up the processing index are presented in Table G.21. The processing indices applied to each waste stream for each spectrum are presented in Table G.22.

The impact measures calculated represent impacts in addition to those associated with waste spectrum 1.

Table G.21 Waste Processing Index - I10

	Value	Meaning
First Digit - P	0	No Volume Reduction
	1	Regular Compaction
	2	Improved Compaction
	3	Hydraulic Press
	4	Evaporation
	5	Pathological Incineration
	6	Small Calciner
	7	Large Calciner
Second Digit - S	0	No Solidification
	1	Solidification Scenario A
	2	Solidification Scenario B
	3	Solidification Scenario C
Third Digit - L	0	No Processing
	1	Processing by the Waste Generator
	2	Processing at a Regional Processing Center
Fourth Digit - E	0	No Incineration
	1	Urban Environment
	2	Rural Environment

Table G.22 Processing Index (I10) Breakdown

Waste Streams	SPECTRUM 1				SPECTRUM 2				SPECTRUM 3				SPECTRUM 4			
	P	S	L	E	P	S	L	E	P	S	L	E	P	S	L	E
P-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
P-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-FCARTRG	0	1	1	0	0	2	1	0	0	3	1	0	0	3	1	0
B-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
B-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
B-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
P-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
B-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
B-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
F-COTRASH	0	0	0	0	1	0	1	0	6	3	1	1	6	3	1	1
F-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0
I-COTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
I+COTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-SSTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+SSTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-LOTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+LOTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
F-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I-LQSCNVL	0	0	1	0	1	0	1	0	5	3	1	1	5	3	1	1
I+LQSCNVL	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-ABSLIQD	0	0	1	0	0	2	1	0	0	3	1	0	5	3	1	1
I+ABSLIQD	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-BIOWAST	0	0	1	0	0	0	1	0	5	3	1	1	5	3	1	1
I+BIOWAST	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
N-SSWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-LOWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-NFRCOMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-DECONRS	0	3	1	0	0	3	1	0	6	3	1	2	6	3	1	2
N-ISOPROD	0	2	1	0	0	3	1	0	0	3	1	0	0	3	1	0
N-HIGHACT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TRITIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-SOURCES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TARGETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.2 Population Exposures

For the purposes of calculation of population exposures in this EIS, only incineration is assumed to result in significant atmospheric releases to the environment. The fraction of the radioactivity released depends on the type of incinerator, the controls on the off-gas system, and the radionuclide.

In this EIS, the fractions of the total input activity released to the atmosphere are assumed to be the following (Ref. 1):

	Release Fraction and Incinerator Type	
Nuclide	Pathological	Calciner
H-3	0.90	0.90
C-14	0.75	0.25
Tc-99	0.01	0.001
I-129	0.01	0.001
All Others	2.5×10^{-4}	2.5×10^{-6}

In this table, a calciner/incinerator is assumed to have better off-gas controls than a pathological incinerator. Most of the incinerated tritium is released as water vapor. Although some of the tritiated water vapor may deposit in very close vicinity of the release point due to condensation, this effect is conservatively not considered in this report. Carbon-14 is usually released as tagged CO, CO_2, and other combustion gases. Tc-99 and I-129 are usually considered as semivolatile nuclides that are harder to control than particulates. All other radionuclides are assumed to be particulates, and particulate release fractions are applied. These fractions are also used in modifying the waste concentrations for tritium and carbon-14. Release fractions for other radionuclides are conservatively assumed not to affect the radionuclide concentrations in the final product.

The final assumptions on population exposure calculations involve (1) the environment that is affected by the processing and (2) the dose conversion factors. It is assumed that institutional facilities are in an urban environment and all other facilities (including the regional processing center) are in a "rural" environment. Correspondingly, a site selection factor (sum of the products of the atmospheric diffusion factor and the number of people affected in each corresponding radial distance--see Reference 1) of 1.75×10^{-10} person-year/m^3 is applied to a rural environment, and ten times this value (i.e., 1.75×10^{-9} person-year/m^3), is applied to an urban environment.

The pathway dose conversion factor used in calculating the population doses are those applicable to the erosion-air transport scenario,--i.e., PDCG-8 presented in Table G.10.

5.3 Other Impacts

Other impacts are calculated based on the unit rates (cost, labor-hours, and energy use) that have been assumed based upon information presented in References 3 through 8 for selected waste processing options. These unit rates are summarized in Table G.23 and are discussed below.

Table G.23 Summary of Processing Unit Impact Rates

Process	Cost (1980 $)	Labor (hours)	Energy (gal of fuel)	Units
Compaction				
Regular	335	15	4.6	Per m^3
Improved	503	15	4.6	of Input
Hydraulic Press	1006	15	4.6	
Evaporation	690	4.42	56.3	Per m^3 of Input
Incineration				
Pathological	2060	8	116	Per m^3
Calciner (small)	1938	6.12	129	of Input
Calciner (large)	1039	5.35	72	
Solidification				
Scenario A	1282	24	40	Per m^3 of
Scenario B	1873	24	40	Output
Scenario C	2445	24	40	

In this EIS, the energy use is expressed in units of gallons of fuel, and the factors utilized in the calculations to convert from electrical energy and thermal energy to gallons of fuel are 40.6 kW-hr per gallon of fuel and 138.690 BTU per gallon of fuel, respectively (Ref. 5). Another assumption involving energy use is that 10 percent of the first year capital cost in 1980 dollars has been assumed to be attributable to fuel use at a rate of $1/gallon.

Occupational exposures resulting from waste processing occur primarily as a result of repair and maintenance activities on the waste processing equipment; however, it is difficult to estimate the exposures resulting from equipment repair and maintenance processing in a generic manner. This is due to the wide variations in the design of processing equipment as well as variations in the effectiveness of administrative controls on waste generators. In this EIS, all LWR waste processing is assumed to take place in a radiation field of 0.5 mR/hour, and all other waste processing is assumed to take place in a

radiation field of 0.1 mR/hour. Based on these assumed radiation fields and the labor hours required to process unit volumes of waste, it is straightforward to calculate the occupational exposures.

Another factor which affects the impact measures and which has been considered in the impact calculations is the "savings" resulting from the change in waste volume. This is represented by differential costs in packaging and storage, differential savings in occupational exposures resulting from handling less waste in storage, and differential savings in energy. These unit rates are assumed based on information presented in References 1 and 41. The "savings" applied to each stream based on per unit (m^3) net reduced volume are assumed to be $210, 4 person hours, and 0.4 gallons of fuel. If the waste processing results in additional volumes of waste (e.g., solidification), then these savings become additional impacts.

The unit rates for costs, energy use, and labor-hours assumed for the processes considered in this report--compaction, evaporation, incineration, and solidification--are presented in Reference 1.

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Appendix H

ALTERNATIVES ANALYSES CODES

This appendix presents and discusses the computer programs written to calculate the impact measures associated with the management of low-level radioactive waste (LLW). The appendix considers three phases of waste management (see Appendix G) which may result in impacts: waste processing, transportation, and disposal. The impact measures are calculated utilizing: (1) the information on the waste characteristics presented in Appendix D, (2) the data and assumptions on disposal techologies and disposal site environment presented in Appendices E, F, and J, and (3) the impact calculation methodologies presented in Appendix G.

The analyses are applied to a number of alternatives for waste form and packaging, disposal facility regional location, disposal facility design and operation, and institutional controls to determine performance objectives and technical requirements for acceptable disposal of the wastes and to determine the environmental impacts of selected alternatives. Five quantifiable impact measures have been selected for calculation in this appendix: dose to members of the public (individual and population), occupational exposures, costs, energy use, and land use (see Appendix G).

Section 1 is an introduction to the appendix and provides a discussion of the applicability of the analyses to generic versus specific disposal technologies, and presents the background rationale for separating the analyses into the components presented in the subsequent sections. Following this section, discussions of five codes which have been developed for use in this EIS are presented in Sections 2 through 5. Included in the discussions are the overall assumptions, general structures of the computer codes employed, and examples of the results of the codes. General parameters common to all the codes and a listing of the computer programs and the data bases employed are presented in Section 6. The computer codes were developed by Dr. O. I. Oztunali, et al., of the firm of Dames & Moore, and this appendix is mostly excerpted from the document "Data Base for Radioactive Waste Management, Volume 3, Impact Analysis Methodology Report," NUREG/CR-1759.

1. INTRODUCTION AND OVERVIEW

This section presents the basic assumptions for development of the codes. The discussion presented includes the purpose of the analyses; the data base and the general approach adopted in the compartmentalization of the analyses into five separate codes; and an overview of the five codes.

1.1 Purpose

The purpose of the alternatives analyses is to systematically examine the costs and impacts resulting from the management and disposal of LLW under a wide range of viable alternatives. Consideration of the costs and impacts of the various viable alternatives leads to selection of preferred performance objectives and technical criteria.

The impacts considered include long-term safety considerations, short-term safety during operations, long-term socioeconomic commitment, and long- and short-term radiological exposures--occupational exposures as well as exposures to members of the public. In view of past disposal history, long-term performance of the disposal system is stressed in the impacts analyses performed in this environmental impact statement. The long-term performance may be quantified through potential radiological impacts and long-term socioeconomic impacts.

The secondary purpose of the alternatives analyses is to generically assess the impacts of disposal according to the preferred criteria selected in the EIS. These generic results may be utilized as a first estimate of the typical impacts associated with the preferred criteria.

1.2 Summary of Data Bases

The alternatives to be considered result from the variation of parameter values associated with three major aspects of LLW management and disposal. These aspects are disposal technology properties (facility, siting, design, operations, closure, and institutional controls), waste form and packaging properties, and the dose limitation criteria applicable for specific human organs. The first two of these aspects of LLW management and disposal have been examined in Appendices D, E, F, and J, and they have been summarized in Appendix G in the form of indices.

The disposal technology properties have been quantified through thirteen indices, which are summarized in Tables H.1 and H.2 called the disposal technology indices. Each of these disposal technology indices denote a specific calculational procedure in the impact analyses or have a set of disposal properties associated with them. These indices are read into all the computer programs through an array called IRDC. The effects of all the indices and associated information, except for the region index IR, have been incorporated into the internal structure of the computer codes. The data associated with the region index is read into the program from an information file called TAPE1.

The waste form and packaging properties have similarly been quantified through use of waste form behavior indices, which are also summarized in Tables H.1 and H.3. Each index denotes a specific calculational procedure or have certain values of parameters associated with them. Waste form behavior indices have been specified for 36 different waste streams resulting from different waste generation sources, for four different waste spectra resulting from alternative waste processing methodologies which may be adopted by the waste generators or at a central processing facility. The 36 waste streams considered in this EIS are summarized in Table H.4 and the waste spectra are summarized in Table H.5.

There are two comparatively distinct information bases associated with the waste streams: one information base details the basic radiological characteristics of the waste streams, and the other details the behavior of the waste form under different waste spectra. The first information base is stored in an array called BAS, and is also read into the computer programs from TAPE1. The second information base is stored in an array called ISPC and is read into the computer programs through an information file called TAPE2.

Table H.1 Alternatives Analyses Indices

Description	Symbol	Potential Values
Disposal Technology Indices		
Region Index	IR	1 or higher
Design and Operation Indices		
Design	ID	1 or higher
Cover	IC	1, 2, or 3
Stabilization	IX	1, 2, or 3
Emplacement	IE	1, 2, or 3
Site Operational Options		
Segregation	IS	0 or 1
Layering	IL	0 or 1
Grouting	IG	0 or 1
Hot Waste Facility	IH	0 or 1
Postoperational Indices		
Closure Index	IQ	1 or 2
Care Level Index	ICL	1, 2, or 3
Postoperational Period	IPO	Years
Active Institutional Control Period	IIC	Years
Waste Form Behavior Indices		
Flammability Index	I4	0-3
Dispersibility Index	I5	0-3
Leachability Index	I6	1-4
Chemical Content Index	I7	0 or 1
Stability Index	I8	0 or 1
Accessibility Index	I9	1-3

Table H.2 Disposal Technology Indices

Property and Index	Description
Region - IR	Geographic location of the disposal facility.
Design - ID	Two options are considered: regular trenches, and the so-called "concrete walled" trenches.
Cover - IC	Three options on the cover between the waste and the atmosphere are considered: regular, thick, and intruder barrier.
Emplacement - IE	Three options on the emplacement of the waste are considered: random, stacked, and random combined with decontainerized disposal for unstable wastes.
Stabilization - IX	Three options on the stabilization program applied to disposal cells, which may contain structurally unstable wastes, are considered: regular, moderate, and extensive.
Layering - IL	Option on separating and putting selected waste streams (usually with higher external radiation levels) at the bottom of the disposal cell.
Segregation - IS	Option to segregate and separately dispose of wastes that are combustible/compressible and those that could contain complexing agents.
Grouting - IG	Option on filling of the interstitial spaces between the wastes with grouting material.
Hot waste facility - IH	Option on having a special area within the disposal facility with special procedures to handle high activity wastes.
Closure index - IQ	This index indicates the activities during the closure period (regular or extensive).
Care level index - ICL	This index indicates the care level anticipated during the active institutional control period (low, moderate, and high).
Postoperational period (years) - IPO	Duration of the period between the cessation of active disposal and the transfer of the title from the site operator to the site owner.
Institutional control period (years) - IIC	Duration between transfer of the title to the site owner and the assumed time for loss of institutional controls over the site.

Table H.3 Waste Form Behavior Indices

Parameter and Symbol		Indices
Flammability	(I4)	0 = nonflammable 1 = low flammability (mixture of material with indices of 0 and 2) 2 = burns if heat supplied (does not support burning) 3 = flammable (supports burning)
Dispersibility	(I5)	0 = near zero 1 = slight to moderate 2 = moderate 3 = severe
Leachability	(L)	1 = unsolidified waste form 2 = Type A solidification 3 = Type B solidification 4 = Type C solidification
Chemical content	(I7)	0 = no chelating agents or organic chemicals 1 = chelating agents or organic chemicals are likely to be present in the waste form
Stability	(I8)	0 = structurally unstable waste form 1 = structurally stable waste form
Accessibility	(I9)	1 = readily accessible 2 = moderately accessible 3 = accessible with difficulty

Table H.4 Waste Groups and Streams

Waste Stream	Symbol
Group I: LWR Process Wastes	
PWR Ion Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
PWR Filter Cartrides	P-FCARTRG
BWR Ion Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE
Group II: Trash	
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-COTRASH
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
Fuel Fabrication Compactible Trash	F-COTRASH
Fuel Fabrication Noncompactible Trash	F-NCTRASH
Institutional Trash (large facilities)	I-COTRASH
Institutional Trash (small facilities)	I+COTRASH
Industrial SS* Trash (large facilities)	N-SSTRASH
Industrial SS* Trash (small facilities)	N+SSTRASH
Industrial Low Trash (large facilties)	N-LOTRASH
Industrial Low Trash (small facilities)	N+LOTRASH
Group III: Low Specific Activities Wastes	
Fuel Fabrication Process Wastes	F-PROCESS
UF_6 Process Wastes	U-PROCESS
Institutional LSV** Waste (large facilities)	I-LIQSCVL
Institutional LSV** Waste (small facilities)	I+LIQSCVL
Institutional Liquid Waste (large facilities)	I-ABSLIQD
Institutional Liquid Waste (small facilities)	I+ABSLIQD
Institutional Biowaste (large facilities)	I-BIOWAST
Institutional Biowaste (small facilities)	I+BIOWAST
Industrial SS* Waste	N-SSWASTE
Industrial Low Activity Waste	N-LOWASTE
Group IV: Special Wastes	
LWR Nonfuel Reactor Components	L-NFRCOMP
LWR Decontamination Resins	L-DECONRS
Waste from Isotope Production Facilities	N-ISOPROD
Tritium Production Waste	N-TRITIUM
Accelerator Targets	N-TARGETS
Sealed Sources	N-SOURCES
High Activity Waste	N-HIGHACT

*SS = Source and special nuclear material.
**LSV = Liquid scintillation vial.

Table H.5 Summary Description of Waste Spectra

Waste Spectrum 1

This spectrum assumes a continuation of past or existing waste management practices. Some of the LWR wastes are solidified; however, no processing is done on organics, combustible wastes, or streams containing chelating agents. LWR resins and filter sludges are assumed to be shipped to disposal sites in a dewatered form. LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified with various media designated as solidification scenario A. No special effort is made to compact trash. Institutional waste streams are shipped to disposal sites after they are packaged in currently utilized absorbent materials. Resins from LWR decontamination operations are solidified in a medium with highly improved characteristics (solidification scenario C).

Waste Spectrum 2

This spectrum assumes that LWR process wastes are solidified using improved solidification techniques (solidification scenario B). LWR concentrated liquids are additionally reduced in volume, to 50 weight percent solids, through an evaporator crystallizer. In the case of cartridge filters, the solidification agent fills the voids in the packaged waste but does not increase the volume. Liquid scintillation vials are crushed at large facilities and packed in absorbent material. All compactible trash streams are compacted; most at the source of generation and some at the disposal facility. Liquids from medical isotope production facilities are solidified using solidification scenario C procedures.

Waste Spectrum 3

In this spectrum, LWR process wastes are solidified assuming that further improved solidification agents are used (solidification scenario C). LWR concentrated liquids are first evaporated to 50 weight percent solids. All possible incineration of combustible material (except LWR process wastes) is performed; some incineration is done at the source of generation and some at the disposal site. All incineration ash is solidified using solidification scenario C procedures.

Waste Spectrum 4

This spectrum assumes extreme volume reduction. All waste amenable to evaporation or incineration with fluidized bed technology are calcined and solidified using solidification scenario C procedures; LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All noncompactible wastes are reduced in volume at the disposal site or at a central processing facility using a large hydraulic press. This spectrum represents the maximum volume reduction that can be currently achieved.

The third aspect of the LLW management and disposal to be considered in the alternatives analyses--the dose limitation criteria--has been discussed in Chapters 4 and 5 of this environmental impact statement as well as in Appendix N.

Finally, the last set of basic information utilized in all the computer programs regards the characteristics of the radionuclides considered in the EIS and the pathway dose conversion factors used to determine radiological impacts when radioactivity has reached a location which may be assessed by humans. The 23 radionuclides considered in this EIS are summarized in Table H.6, while the development of and specific values for the pathway dose conversion factors are presented in Sections 1 and 2 of Appendix G. This data is stored in several arrays (see Section 6), and is also read into the computer programs from TAPE1.

A very large number of alternatives result from possible variations in values associated with these three aspects of LLW management and disposal. For example, there are 5,184 possible permutations of only ten of the disposal technology indices, for each region (IR), for each postoperational period (IPO) and for each active institutional control period (IIC). Therefore, the analyses of alternatives must utilize computer programs to rapidly calculate and assess the impacts. Furthermore, several computer programs are needed to examine and assess an isolated portion of the decision base that results from the analyses.

1.3 Overview of Computer Codes

As stated previously, long-term performance of the disposal system is stressed in this environmental impact statement. In the analyses of the radiological impacts, there are three major potential modes of exposure (see Appendix G, Section 2) two of which relate to the longer-term safety consideration: humans inadvertently contacting the waste after disposal (imputs are primarily a function of the concentration of radionuclides in the waste), and the waste entering one of several natural pathways back to biota (impacts are primarily a function of the total activity disposed of at the site).

The first step in the alternatives analyses, therefore, involves a screening of the impacts to potential inadvertent intruders. This is performed through a code called INTRUDE which determines the radiological impacts resulting from potential human inadvertent intrusion into a selected disposal facility location and design containing waste processed through one of the aforementioned waste spectra as a function of time after disposal. The results of this analysis are examined in Chapter 4.

The second step in the alternatives analyses involves determination of long-term radiological and cost impacts including those which may result from potential ground-water migration, and other radiological and nonradiological impacts. These analyses are performed through two codes called GRWATER and OPTIONS. The results of this analysis are examined in Chapter 5.

Attention is principally focused upon long-term radiological impacts of potential inadvertent intrusion into disposed wastes and potential ground-water

Table H.6 Radionuclides Considered in Waste Source Options

Isotopes	Half Life (Years)	Principal Means of Production
H-3	12.3	Fission Li-6 (n, α)
C-14	5730	N-14 (N, p)
Fe-55	2.60	Fe-54 (n, γ)
Co-60	5.26	Co-59 (n, γ)
Ni-59	80,000	Ni-58 (n, γ)
Ni-63	92	Ni-62 (n, γ)
Sr-90	28.1	Fission
Nb-94	20,000	Nb-93 (n, γ)
Tc-99	2.12×10^5	Fission; Mo-98 (n, γ), Mo-99 (β^-)
I-129	1.17×10^7	Fission
Cs-137	30.0	Fission
U-235	7.1×10^8	Natural
U-238	4.51×10^9	Natural
Np-237	2.14×10^6	U-238 (n, 2n), U-237 (β^-)
Pu-238	86.4	Np-237 (n, γ), Np-238 (β^-); daughter Cm-242
Pu-239	24,400	U-238 (n, γ), U-238 (β^-), Np-239 (β^-)
Pu-140	6,580	Multiple n-capture
Pu-241	13.2	Multiple n-capture
Pu-242	2.79×10^5	Multiple n-capture; daughter Am-242
Am-241	458	Daughter Pu-241
Am-243	7950	Multiple n-capture
Cm-243	32	Multiple n-capture
Cm-244	17.6	Multiple n-capture

migration of radionuclides, as well as potential long-term costs to a site owner for surveillance and control of a closed disposal facility. A number of alternatives for waste form and packaging, and disposal facility design and practices may be examined for means to mitigate or reduce these potential long-term radiological and cost impacts. As a byproduct of implementing these alternatives, however, there are short-term costs such as waste processing, transportation, and disposal costs as well as short-term radiological impacts such as occupational exposures during waste handling and population exposures due to waste processing.

The code GRWATER calculates the individual exposures resulting from use of contaminated water drawn from various human access locations such as a well that may become contaminated as a result of potential ground-water migration of radionuclides. These radiological impacts may be examined for several sets of disposal technology indices and a selected waste spectrum. Exposures are calculated as a function of time and may be presented as (1) total exposures from the contribution of all waste streams, (2) total exposures from a particular waste stream or group of waste streams, and (3) exposures from each of the radionuclides considered.

The code OPTIONS calculates waste volume-averaged inadvertent intruder impacts, impacts resulting from exposed waste scenarios, as well as impacts resulting from operational accidents and impacts associated with short-term considerations such as waste processing and transportation impacts, disposal costs, energy use, land use, etc.

In addition to these three codes which consider projected low-level waste characteristics, two codes have been developed to calculate limiting concentrations in waste streams and total inventories in disposal facilities for specific cases. One of these codes is called INVERSI and calculates the limiting concentrations in waste to meet a specific dose criterion for a specific disposal facility design; it may be used for waste classification purposes. The other code is called INVERSW and calculates disposal facility radionuclide inventories (or average concentrations in waste) to meet specific allowable dose criteria for ground-water migration for a specific disposal facility design and environmental characteristics.

All the codes utilized to perform the analyses are presented in Section H.6. The codes have been designed to optimize execution (running) time rather than memory. They have been executed in a CDC-6600 computer in a time sharing mode. They use just two lines of input: an IRDC(12) array which contains the disposal technology indices presented above, and a NOTE(6) array which is a 60 character descriptive title that can be arbitrarily set. The rest of the data is input to the codes through two tapes: TAPE1, which contains most of the generic data (see Section 6) and TAPE2 which contains waste spectrum specific information. A listing of these tapes are also presented in Section 6.

Alteration of the codes for other systems should be relatively easy since they use only standard FORTRAN functions that are commonly used. Output formats and statements, however, should be closely checked, since they can vary significantly from one computer system to the next.

1.4 Waste Classification Test Procedure

Based upon the analysis performed in Chapters 4 and 5, a waste classification test procedure was developed. The test procedure is used in the OPTIONS and GRWATER computer codes to determine radiological, economic, and other impacts from LLW disposal.

In the claculations, the disposal status of each waste stream, denoted by the status index I11, is determined and is used internally in the computer codes. It denotes if any special procedures are required to dispose of the waste stream in a near-surface disposal facility or if the waste is unacceptable for near-surface disposal.

The index, I11, is 1 if the waste is disposable through "regular means." It is 2 if layering of the waste is required, and 3 if the waste is disposed of in a hot waste facility. For disposal by regular means, no special consideration is given to providing barriers against potential inadvertent intruder exposures. Layering of waste streams provides a barrier against an intruder contacting the layered waste streams. Disposal into a hot waste facility provides additional barriers against intrusion. An index value of 0 indicates that the waste is unacceptable for near-surface disposal. The testing procedure utilized in the determination of the disposal status index is presented in Figure H.1.

Each test consists of successively subjecting a given waste stream to the intruder-construction and the intruder-agriculture scenarios after a given period of time, and determining if the calculated radiological impacts in each scenario for each human organ due to all the radionuclides in the waste stream meet given organ-specific dose limitation criteria. Therefore, there are four basic variables in these tests: (1) the waste status (regular or layered or hot waste test), (2) the type of test (standard or modified), (3) the time after the transfer of the site title to site owner at which the test is applied (after the active institutional control period--denoted by IIC years, or after 500 years, or after 1000 years), and (4) the dose limitation criteria which is applied to all the tests. The first three variables are discussed below.

For a given waste stream, first the regular disposal test is applied at IIC years. This regular disposal test may be either a standard or a modified test depending on whether the waste form is stable (I8=1) and the waste streams are being segregated (IS=1) at the disposal site (see Figure H.1). If the waste is found acceptable during the standard test, then it is classified as regular waste. If the waste passes a modified test, it must also pass a regular standard waste test at 500 years before being classified as regular.

If the waste stream fails any of the above three tests, then it is not regular waste. In this case, the layered disposal tests are applied to the waste stream at IIC years if the layering option is available to the disposal technology case being considered--i.e., if IL is equal to unity. The layered test can also be a standard or modified test depending on the values assigned to

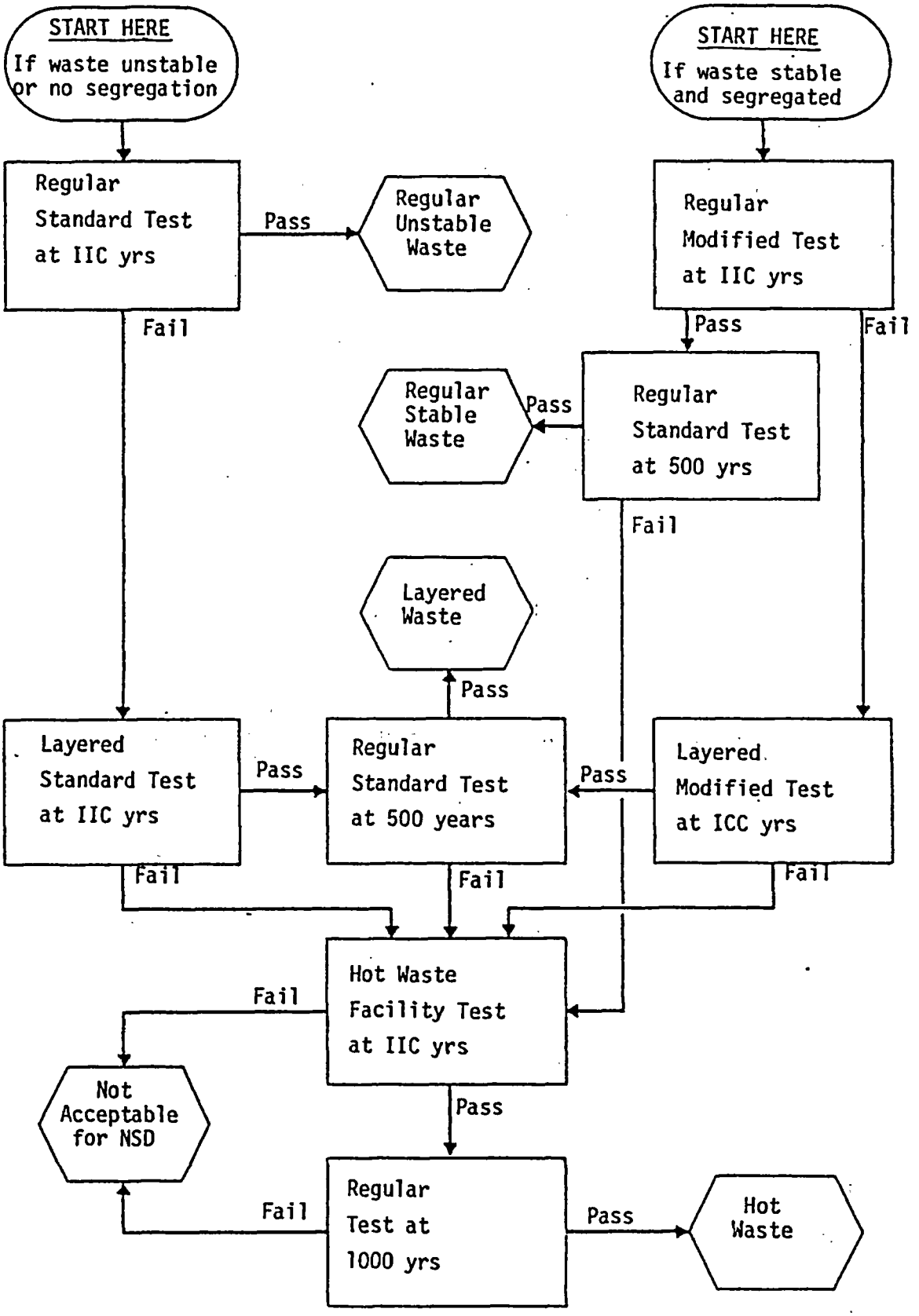

Figure H.1 Waste Classification Test Procedure

the waste stability index (I8) and the segregation index (IS). In both of these cases, a waste stream that passes either of the layered tests is tested again in a regular standard waste test at 500 years before being classified as layered waste.

If the layering option is not available or if the waste stream is found not to be acceptable for layered disposal (i.e., it fails one of the above three tests), then hot waste facility disposal is attempted if that option is available to the disposal case technology being considered--i.e., if IH is equal to 1. There are two tests for the hot waste facility option: one is a special hot waste test at IIC years, and the other is a regular standard test at 1000 years. If the waste is found to be unacceptable in any of these options--there may be no option but regular disposal, i.e., IL = 0 and IH = 0--then the waste is considered unacceptable for near-surface disposal for the disposal technology under consideration and for the dose limitation criteria being applied. In this manner the status index I11 is determined and utilized in the total activity scenarios as briefly summarized below and described in Sections G.3.5 and G.3.6 of Appendix G.

If the disposal status of the waste stream is 1 or 2 (regular or layered waste), then no special reduction factors are applied to the ground-water scenarios. However, if the disposal status is 3, then the percolation component of the ground-water scenario is reduced to 25 percent of its minimum value (Section G.3.5). This reduction is due to the special measures adopted in the design of a hot waste facility.

If the disposal status of the waste is 1, then no special reduction factors are applied to the exposed waste scenarios. However, if the disposal status is 2, then the wastes are exempted from the erosion-initiated exposed waste scenarios (they are beneath a minimum of 6 to 7 meters of other material) and only 1 percent of the waste is assumed to contribute to the intruder-initiated exposed waste scenarios (Appendix G, Section G.3.6). For a disposal status of 3, the wastes are exempted from the erosion-initiated exposed waste scenarios and only 0.1 percent of the wastes are assumed to contribute to the intruder-initiated exposed waste scenarios (Appendix G, Section G.3.6).

As described above, there are five distinct classification tests: regular standard, regular modified, layered standard, layered modified, and hot waste facility. These tests are briefly described below.

Regular Standard Test

In this test, no additional reduction factors are applied to either the intruder-construction or intruder-agriculture scenario. This test may be exercised for regular wastes at the end of ICC years, or to wastes that have passed layered waste tests at the end of 500 years, or to wastes that have passed the hot waste facility test at the end of 100 years.

Regular Modified Test

The modified test is applied only at the end of IIC years, and it assumes that the waste stream is stable and segregated from unstable waste streams. Therefore,

an inadvertent intruder initiating the intruder-construction scenario will clearly realize that wastes are being intruded into, and will not continue any further (termed intruder-discovery scenario). This results in a substantially reduced contact time for the intruder-construction scenario. The regular standard test uses a contact time of 500 hours, however, in a regular modified test this contact time is reduced to 6 hours (the actual contact time is likely to be no more than half a working day plus 2 hours to account for direct gamma exposure of the intruder through a reduced thickness of cover material). As a consequence of the discovery that wastes are being intruded into, the intruder-agriculture scenario is eliminated in this test.

For the layered standard test, a contact time of 500 hours is assumed. However, for the layered modified test, a contact time of 6 hours is assumed based on the same rationale given for the regular modified test. It should be pointed out that all the waste streams that pass these layered tests undergo a regular standard test at the end of 500 years at which time no credit is assumed for layering.

Hot Waste Facility Test

This test is also applied only at the end of IIC years. The rationale presented above for the layered tests is applicable for the hot waste facility which is designed to confine the wastes regardless of cost or land use considerations. Moreover, it in effect takes unstable wastes, and through disposal design makes them into stable wastes for intrusion purposes. The agriculture scenario is not considered in the hot waste facility test. For the construction scenario a reduction factor of 0.01 is applied to the site design factor for the air uptake component, and a reduction factor of $1/1200^2$ is applied for the direct gamma exposure. Again, it should be pointed out that the waste streams that pass the hot waste facility test are subjected to a regular standard test at the end of 1000 years.

Layered Standard and Modified Tests

In the layered tests, the intruder-agriculture scenario is not applied since the wastes are likely to be disposed of beneath a minimum of 2 meters of cover and 4 to 5 meters of other regular wastes. No reasonable mechanism after only IIC years can be envisioned that would permit the interaction of these wastes with the environment through an intruder-agriculture scenario. For the intruder-construction scenario, different reduction factors are applied to the different uptake pathways: air uptake and the direct gamma exposure pathways.

For the air uptake pathway, only 10 percent of the layered wastes are assumed to be accessible to the intruder. This is a very conservative assumption; it is unlikely that even 1 percent of the area exposed during construction will be the layer of waste underneath 6 to 7 meters of other material. For the direct gamma exposure uptake pathway, the intruder is assumed to be shielded from the layered wastes by at least one meter of soil or equivalent material resulting in a reduction of about 1200 in the radiation intensity.

2. INTRUDE CODE

In determining performance objectives and technical requirements for LLW disposal, an important consideration is the potential for human intrusion into the disposed waste. Such intrusion may act to increase the potential for ground-water migration by increasing the infiltration of precipitation into the waste and it may also bring wastes to the surface where they may potentially be dispersed by wind or water. These actions may result in radiation doses to the surrounding population. However, the largest radiation exposures by far would be to the intruders themselves.

There are four basic scenarios considered for potential intruder exposure:

- o the intruder-construction scenario, which involves potential excavation into a closed disposal facility site and construction of a house;
- o the intruder-discovery scenario, which is a subset of the intruder-construction scenario and also involves excavation into a closed disposal facility site; however, the time over which excavation activities continue is reduced relative to the intruder-construction scenario;
- o the intruder-agriculture scenario, which involves persons potentially living in a house located in contaminated soil and consuming vegetables grown in an onsite garden; and
- o the intruder-well scenario, which involves use of contaminated water from an onsite well.

This section and code considers the first three of these scenarios: intruder-construction, intruder-discovery, and intruder-agriculture scenarios. The third scenario, the intruder-well scenario, is considered in the next section on ground-water impacts analyses (the GRWATER code). The potential exposures to the surrounding population as a result of the actions of an intruder, the exposed waste scenarios, are considered in the following section on the OPTIONS codes.

There are three principal means of controlling potential exposures to an intruder: use of institutional controls, use of natural and/or engineered barriers which would make it more difficult for an intruder to contact the waste, and use of less dispersible waste forms. None of these controls can be assumed to be functional forever. However, an important decision to be made at the time of disposal for a given waste stream is whether it requires special considerations with regard to institutional controls, waste form, and natural and/or engineered barriers. INTRUDE performs a screening analyses to determine which waste stream (or streams when mixed and disposed together) requires special consideration.

The code calculates seven human organ doses as a function of time. Also calculated are the ICRP weighted exposure sum over all the organ doses indicative of

the total impact of the exposures. The output of the INTRUDE code can be illustrated through an example.

The disposal technology indices (see Tables H.1 and H.2) selected for this example are presented below:

IR = 2	IS = 0
ID = 1	IL = 0
IC = 1	IG = 0
IX = 1	IH = 0
IE = 1	IQ = 1

In addition, the closure period (i.e., IPO) is assumed to be 2 years, and the active institutional control period (i.e., IIC) is varied from 50 years to 2,000 years.

In the analyses, all four waste spectra (see Table H.4) are considered one by one. A number of different analyses may be performed for different groups of waste streams for a given waste spectrum. Four such potential groupings are as follows:

- Each waste stream separately (36 separate analyses);
- Waste streams in four macroscopic groups;
- Waste streams in five major waste generation sources;
- All the waste streams together.

An example output of the code is presented in Table H.7 for the above reference set of disposal technology indices. The waste spectrum considered is waste spectrum 2, and impacts are presented for the first group of 7 waste streams (LWR process waste streams) shown on Table H.4.

3. GRWATER CODE

This section discusses GRWATER which is a code written to perform an assessment of the impacts from ground-water migration of radionuclides with emphasis on waste form and packaging performance parameters, and site selection and design parameters. After classification of the waste streams into categories in accordance with the test procedure outlined in Section H.1.4 and the dose limitation criteria specified in the code as acceptable, the code computes seven human organ doses as a function of time after closure of the disposal facility for selected biota access locations.

There are three basic scenarios for direct or indirect exposure of humans to radioactivity from potential ground-water migration: an individual-well scenario which envisions drilling of a well either adjacent to a disposal cell or at the site boundary; a population-well scenario which envisions pumping water from a well to satisfy the needs of a small community located between the disposal facility and an open water location receiving ground water passing underneath the site; and a population-surface water scenario which assumes that population exposures result from consumption and utilization of open water that has received discharge from contaminated ground water passing underneath the site.

Table H.7 Example INTRUDE Output (Spectrum 2)

```
APP H
IR = 2  ID = 1  IC = 1  IX = 1
IE = 1  IS = 0  IL = 0  IG = 0
IH = 0  ICL=12  IPO= 2 YEARS  100


GROUP NO = 1

YR =  50,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  1.409E+04 1.412E+04 1.412E+04 1.409E+04 1.410E+04 1.410E+04 1.409E+04 2.044E+04
 INT=AGRI  1.670E+04 1.675E+04 1.670E+04 1.671E+04 1.669E+04 1.669E+04 1.669E+04 2.422E+04

YR = 100,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  4.347E+03 4.371E+03 4.367E+03 4.345E+03 4.355E+03 4.354E+03 4.344E+03 6.308E+03
 INT=AGRI  5.150E+03 5.174E+03 5.155E+03 5.166E+03 5.149E+03 5.148E+03 5.145E+03 7.471E+03

YR = 150,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  1.373E+03 1.395E+03 1.391E+03 1.372E+03 1.381E+03 1.379E+03 1.371E+03 1.996E+03
 INT=AGRI  1.626E+03 1.640E+03 1.632E+03 1.645E+03 1.628E+03 1.627E+03 1.624E+03 2.361E+03

YR = 200,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  4.362E+02 4.562E+02 4.526E+02 4.357E+02 4.438E+02 4.418E+02 4.348E+02 6.369E+02
 INT=AGRI  5.160E+02 5.264E+02 5.223E+02 5.360E+02 5.186E+02 5.177E+02 5.151E+02 7.507E+02

YR = 300,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  4.790E+01 6.511E+01 6.203E+01 4.769E+01 5.447E+01 5.271E+01 4.675E+01 7.327E+01
 INT=AGRI  5.595E+01 6.372E+01 6.154E+01 7.643E+01 5.856E+01 5.777E+01 5.556E+01 8.336E+01

YR = 400,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  9.193E+00 2.445E+01 2.164E+01 9.121E+00 1.494E+01 1.361E+01 8.187E+00 1.672E+01
 INT=AGRI  1.018E+01 1.677E+01 1.512E+01 3.076E+01 1.250E+01 1.189E+01 9.876E+00 1.679E+01

YR = 500,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  5.214E+00 1.897E+01 1.634E+01 5.252E+00 1.027E+01 9.460E+00 4.317E+00 1.064E+01
 INT=AGRI  5.549E+00 1.137E+01 9.953E+00 2.618E+01 7.598E+00 7.192E+00 5.290E+00 9.932E+00

YR =1000,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  4.287E+00 1.361E+01 1.137E+01 4.657E+00 7.189E+00 6.384E+00 3.722E+00 8.403E+00
 INT=AGRI  4.705E+00 8.605E+00 7.501E+00 2.547E+01 5.897E+00 6.295E+00 4.579E+00 8.336E+00

YR =2000,     BODY      BONE      LIVER     THYROID    KIDNEY    LUNG      G-I TRACT   ICRP
 INT=CONS  3.859E+00 1.010E+01 8.141E+00 4.459E+00 5.261E+00 7.874E+00 3.582E+00 7.165E+00
 INT=AGRI  4.373E+00 7.020E+00 6.056E+00 2.583E+01 4.966E+00 5.931E+00 4.337E+00 7.605E+00
```

An idealized map of the disposal facility showing the areal relationships of the disposal site and the ground-water access locations was shown in Figure G.6. As indicated in the figure, the transverse (i.e., perpendicular to the ground-water flow direction) dispersion of the contaminants before and after they reach the saturated zone is measured through the geometric reduction factor (r_g). However, the dispersion of the contaminants in the direction of ground-water flow is dependent on the longitudinal (parallel to the ground-water flow direction) extent of the disposal facility.

The longitudinal extent of the disposal facility is taken into account in the analysis by dividing the disposal facility into 10 sectors and applying the point-source equations given in Appendix G to each of the 10 sectors. In this manner, the transverse distribution is taken into account through the factor (r_g), and the longitudinal distribution of the source is numerially integrated.

In this calculation, water starting from each of the sectors has different travel times to the access locations. This travel time is calculated in the computer code through the use of an incremental travel time and Peclet number between the sectors (the DTTM and DTPC arrays), through dividing the source term into 10 equal parts, and placing this source at the center of each sector. The rest of the ground-water migration assumptions have been presented in Appendix G.

The code has several options built into it:

1. it can consider different dose limitation criteria in the initial classification of the wastes into regular, layered, or hot waste facility wastes;

2. it can exclude a waste stream or group of waste streams from the analysis through the use of the NDX(36) array;

3. it can consider a waste stream or group of waste streams packaged in high integrity containers thereby postponing the initiation of the ground-water migration scenario for those streams for a specified period of time;

4. it has the option to perform a time dependent source term calculation, and increase the released source term after an intruder and/or time causes percolation values to increase;

5. it can provide the total exposures from the contribution of all the radionuclides in all the streams, total exposures from all the radionuclides from a particular waste stream or group of streams, or exposures from each of the radionuclides considered in all or some of the waste streams.

A portion of an example output of GRWATER is presented in Table H.8 for the case of waste spectrum 2, and the following disposal facility indices:

IR = 2 ID = 1 IC = 2 IX = 2 IE = 1
IS = 1 IL = 1 IG = 0 IH = 1 IQ = 1
ICL = 2 IPO = 2 years IIC = 100 years

Table H.8 Example GRWATER Output (Spectrum 2)

```
APP H
SPECTRUM  2
IR = 2  ID = 1  IC = 2  IX = 2
IE = 1  IS = 1  IL = 1  IG = 0
IH = 1  ICL=12  IPO= 2 YEARS  100
VREG = 6.78E+05 VLAY = 0.       VHOT = 0.       VNOT = 1.94E+04

YR =   40.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   50.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   60.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  3.536E-03 2.125E-10 3.536E-03 3.536E-03 3.536E-03 3.536E-03 3.536E-03 4.703E-03
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   70.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  1.111E+00 6.672E-08 1.111E+00 1.111E+00 1.111E+00 1.111E+00 1.111E+00 1.477E+00
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   80.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  6.543E-01 3.931E-08 6.543E-01 6.543E-01 6.543E-01 6.543E-01 6.543E-01 8.702E-01
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   90.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  3.726E-01 2.238E-08 3.726E-01 3.726E-01 3.726E-01 3.726E-01 3.726E-01 4.956E-01
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =  100.     BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT     ICRP
 BOU-WELL  2.122E-01 1.275E-08 2.122E-01 2.122E-01 2.122E-01 2.122E-01 2.122E-01 2.822E-01
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.
```

Table H.8 (continued)

YR = 700.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	3.913E-03	1.282E-02	2.996E-03	1.056E+00	3.716E-03	2.567E-03	3.335E-03	3.803E-02
POP-WELL	4.609E-15	2.769E-22	4.609E-15	4.609E-15	4.609E-15	4.609E-15	4.609E-15	6.131E-15
POP-SURF	0.	0.	0.	0.	0.	0.	0.	0.

YR = 800.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	1.502E-02	6.762E-02	1.400E-02	1.181E+00	1.480E-02	1.353E-02	1.438E-02	6.278E-02
POP-WELL	2.193E-17	1.317E-24	2.193E-17	2.193E-17	2.193E-17	2.193E-17	2.193E-17	2.917E-17
POP-SURF	1.149E-20	6.898E-28	1.149E-20	1.149E-20	1.149E-20	1.149E-20	1.149E-20	1.528E-20

YR = 900.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	1.587E-02	6.931E-02	1.450E-02	1.577E+00	1.557E-02	1.387E-02	1.500E-02	7.387E-02
POP-WELL	1.065E-19	6.399E-27	1.065E-19	1.065E-19	1.065E-19	1.065E-19	1.065E-19	1.417E-19
POP-SURF	4.003E-22	2.404E-29	4.003E-22	4.003E-22	4.003E-22	4.003E-22	4.003E-22	5.324E-22

YR = 1000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	1.580E-02	6.853E-02	1.438E-02	1.646E+00	1.549E-02	1.371E-02	1.491E-02	7.773E-02
POP-WELL	2.871E-17	4.410E-17	6.240E-17	9.454E-15	7.337E-16	6.014E-16	1.884E-15	4.792E-16
POP-SURF	5.323E-24	3.197E-31	5.323E-24	5.323E-24	5.323E-24	5.323E-24	5.323E-24	7.080E-24

YR = 2000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	3.290E-02	1.390E-01	2.943E-02	4.014E+00	3.214E-02	2.780E-02	3.067E-02	1.789E-01
POP-WELL	4.959E-04	2.075E-04	1.875E-04	3.548E-01	4.339E-04	4.260E-05	3.121E-04	1.122E-02
POP-SURF	3.209E-26	4.901E-26	6.928E-26	1.066E-23	8.141E-25	6.660E-27	2.091E-24	5.369E-25

YR = 4000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	6.181E-02	2.757E-01	5.727E-02	5.265E+00	6.079E-02	5.515E-02	5.882E-02	2.701E-01
POP-WELL	2.655E-03	2.731E-03	1.821E-03	1.647E+00	2.332E-03	5.514E-04	1.709E-03	5.278E-02
POP-SURF	4.889E-05	8.038E-05	1.839E-05	3.506E-02	4.248E-05	4.105E-06	2.997E-05	1.109E-03

YR = 6000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	7.346E-02	3.339E-01	6.892E-02	5.277E+00	7.243E-02	6.680E-02	7.044E-02	2.925E-01
POP-WELL	1.039E-02	4.140E-02	8.955E-03	1.659E+00	1.006E-02	8.286E-03	9.436E-03	6.771E-02
POP-SURF	1.047E-04	4.357E-05	3.927E-05	7.507E-02	8.959E-05	8.780E-06	6.063E-05	2.374E-03

YR = 8000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	6.522E-02	2.927E-01	6.068E-02	5.268E+00	6.418E-02	5.857E-02	6.218E-02	2.766E-01
POP-WELL	1.477E-02	6.329E-02	1.333E-02	1.659E+00	1.444E-02	1.266E-02	1.381E-02	7.615E-02
POP-SURF	1.414E-04	2.275E-04	7.606E-05	7.510E-02	1.243E-04	4.558E-05	9.712E-05	2.445E-03

YR =10000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	5.277E-02	2.305E-01	4.823E-02	5.255E+00	5.172E-02	4.611E-02	4.971E-02	2.526E-01
POP-WELL	1.661E-02	7.249E-02	1.517E-02	1.661E+00	1.627E-02	1.450E-02	1.564E-02	7.969E-02
POP-SURF	6.848E-04	2.943E-03	6.194E-04	7.563E-02	6.695E-04	5.889E-04	6.402E-04	3.493E-03

4. OPTIONS CODE

The previous two codes, INTRUDE and GRWATER, concentrate on the long-term radiological impacts resulting from the disposal of LLW. This section presents a code for calculating all the impact measures other than ground-water impacts.

The calculated results include five major components: (1) the volumes of waste requiring different disposal practices--i.e., the volumes in each disposal status which vary depending on the disposal technology indices and waste form behavior parameters determined by the waste spectrum assumed; (2) disposed waste-volume-averaged inadvertent intruder impacts; (3) radiological impacts resulting from potential exposed waste scenarios; (4) exposures which may result from abnormal operating conditions (accident scenarios); and finally (5) the impact measures applicable to the different phases associated with LLW management and disposal (i.e., waste processing, transportation, disposal) consisting of costs, occupational exposures, population exposures, energy use, and land use. OPTIONS code calculates these five items. All radiological impacts (except occupational exposures and population exposures from waste transportation which are total body exposures) calculated include seven human organs.

The volumes of waste in each disposal status, however, have further been divided within each major category--i.e., regular, layered, and hot waste facility wastes--into four subcategories: stable with no chemical agents (NCH-STAB), stable with chemical agents (CH-STAB), unstable with no chemical agents (NCH-STAB) and unstable with chemical agents (NCH-STAB).

The code has most of the same capabilities in the GRWATER code. For example, it can consider different dose limitation criteria in the initial classification of the wastes, it can exclude streams from the analysis, etc.

A portion of an example output of OPTIONS is presented in Tables H.9 through H.11 for the case considered in the GRWATER code example.

5. INVERSI AND INVERSW CODES

The inverse codes calculate the maximum average concentrations (or inventories) that may be disposed within the radiological guidelines considered (maximum exposure limits) and various disposal technology properties. There are two inverse codes: intruder (INVERSI), and ground water (INVERSW). In each case, the maximum average concentrations for a given set of disposal technology parameters are calculated for 1 million m^3 of waste disposed in the facility.

For these two codes the basic data matrices BAS and ISPC are not utilized. The waste form parameters, however, are input into the calculation through the array ISPC, and the disposal technology indices are input through the IRDC array.

The major option available in the running of these codes is to set dose limitation criteria to different sets of values. In addition, INVERSI code calculates and prints the results of all seven distinct waste classification tests--i.e.,

Table H.9 Example Options Output - 1

```
DISPOSAL TECHNOLOGY INDICES
IN = 2  ID = 1  IC = 2  IX = 2
IE = 1  IS = 1  IL = 1  IG = 0
IH = 1  ICL=12  IPO= 2  IIC= 100

REGULAR WASTE :                                  6.756E+05 M**3
     CH=STAB     I=LOSCNVL 3.182E+04
                 I=ABSLIQD 2.586E+03
                 I+ABSLIGD 4.628E+03
                 N=TRITIUM 9.616E+02
                 TOTAL VOLUME :          3.995E+04 M**3
     CH=UNSTAB   I+LOSCNVL 4.072E+04
                 I=SIDWAST 8.332E+03
                 I+SIDWAST 8.332E+03
                 N=LOWASTE 1.665E+04
                 TOTAL VOLUME :          7.404E+04 M**3
     NCH=STAB    P=IXRESIN 1.578E+04
                 P=CONCLIQ 2.040E+04
                 P=FSLUDGE 1.950E+03
                 P=FCARTRG 6.014E+03
                 B=IXRESIN 3.475E+04
                 B=CONCLIQ 3.774E+04
                 B=FSLUDGE 7.703E+04
                 P=NCTRASH 6.017E+04
                 F=NCTRASH 2.734E+04
                 F=PROCESS 2.159E+04
                 N=PROCESS 7.765E+03
                 A=SSWASTE 1.751E+04
                 L=NFRCOMP 7.975E+02
                 N=HIGHACT 7.204E+02
                 N=TARGETS 5.702E+02
                 TOTAL VOLUME :          3.299E+05 M**3
     NCH=UNSTAB  P=COTRASH 5.862E+04
                 B=COTRASH 2.881E+04
                 F=COTRASH 4.344E+04
                 F=NCTRASH 1.152E+04
                 I=COTRASH 1.943E+04
                 I+COTRASH 9.717E+03
                 N=SSTRASH 3.308E+04
                 N+SSTRASH 1.650E+04
                 N=LOTRASH 6.994E+03
                 N+LOTRASH 3.497E+03
                 TOTAL VOLUME :          2.317E+05 M**3

LAYERED WASTE :                                  2.871E+03 M**3
     CH=STAB     N=ISOPROD 2.871E+03
                 TOTAL VOLUME :          2.871E+03 M**3

NOT ACCEPTABLE:                                  1.938E+04 M**3
                 L=DECONRS 1.933E+04
                 N=SOURCES 5.152E+01
```

Table H.10 Example OPTIONS Output - 2

		BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INTRUDER IMPACTS									
	INT-CONS	3.259E+01	3.360E+01	3.266E+01	3.234E+01	3.250E+01	3.253E+01	3.236E+01	4.735E+01
	INT-AGRI	2.151E+01	2.606E+01	2.024E+01	2.019E+01	2.020E+01	2.021E+01	2.051E+01	3.132E+01
	INT-CONS	1.925E+00	6.251E+00	5.404E+00	1.921E+00	3.508E+00	3.745E+00	1.644E+00	3.815E+00
	INT-AGRI	2.205E+00	4.668E+00	3.987E+00	8.307E+00	2.839E+00	2.905E+00	2.120E+00	3.876E+00
	INT-CONS	3.226E-01	3.241E+00	2.836E+00	4.227E-01	1.231E+00	2.097E+00	1.456E-01	1.211E+00
	INT-AGRI	3.725E-01	2.032E+00	1.247E+00	6.526E+00	7.463E-01	1.064E+00	3.350E-01	1.080E+00
EXPOSE/ACC IMPACTS									
	INT-AIR	1.194E+03	2.161E+04	1.233E+04	3.781E+03	7.798E+03	9.787E+03	2.626E+01	6.284E+03
	ERO-AIR	6.111E+00	1.198E+02	7.940E+01	6.451E+01	2.750E+01	1.086E+02	3.549E-01	4.189E+01
	INT-WAT	1.848E-03	5.512E-03	1.433E-03	1.069E-04	5.557E-04	2.366E-04	2.544E-04	2.674E-03
	ERO-WAT	8.866E-02	7.030E-01	1.413E-01	9.939E-01	1.075E-01	5.408E-02	1.612E-01	2.351E-01
	ACC-SNGC	1.460E-01	4.595E-01	2.437E-01	8.174E-02	1.568E-01	9.680E-01	7.052E-02	3.480E-01
	ACC-FIRE	5.894E+00	1.881E+01	9.769E+00	3.185E+00	6.287E+00	2.841E+01	2.491E+00	1.277E+01
	ACC-AVG	3.020E+00	9.635E+00	5.006E+00	1.633E+00	3.222E+00	1.469E+01	1.281E+00	6.559E+00

Table H.11 Example OPTIONS Output - 3

OTHER IMPACTS	WASTE PROCESSING GENERAT	WASTE PROCESSING DISPOSAL	TRANSP	DISPOSAL	LT CARE	.100 .090		
COST ($)	5.80E+08	3.63E+07	1.85E+08	1.97E+08	1.81E+07	3.67E+06	0.	1.44E+07
UNIT COST ($/M3)	8.54E+02	5.35E+01	2.72E+02	2.90E+02	2.67E+01	5.42E+00	0.	2.13E+01
POP DOSE (MREM)	0.	0.	5.01E+05	0.				
OCC DOSE (MREM)	3.91E+06	1.25E+05	5.43E+06	2.34E+06				
LAND USE (M**2)	0.	0.	0.	2.36E+05				
ENERGY USE (GAL)	1.73E+07	4.42E+05	1.33E+07	1.22E+06				

regular standard test at IIC years, regular modified test at IIC years, layered standard test at IIC years, layered modified test at IIC years, hot waste facility test at IIC years, regular standard test at 500 years, and regular standard test at 1000 years. INVERSW code also performs two sensitivity analyses: (1) it varies the percolation value associated with the given region index IR by assuming 50 percent of the value, the value given, and twice the value given, and (2) it varies the retardation characteristics of the soils by calculating the limiting concentrations for all five sets of retardation coefficients considered in this work (see Appendix G).

These codes use a modified version of TAPE1 containing the pathway dose conversion factors and the environmental parameters associated with the given region index IR.

6. LISTING OF THE CODES AND DATA FILES

Table H.8 presents symbolic definitions of the data utilized in the analyses which have been presented in the previous chapters. Also given are the computer code definitions of most of the parameters, and some of the assumed values for the analyses.

Almost all the codes use two tapes (some do not need to use all the information contained in these tapes) for input information: TAPE1 contains waste spectrum independent information such as radionuclide concentrations of unprocessed waste, nuclide specific parameters, and environmental parameters; and TAPE2 contains information on the waste spectrum being considered--e.g., volume reduction and increase factors, and waste form behavior indices. In addition, INPUT (query by the code at the terminal the code is being run from) is utilized for reading in the disposal technology indices and descriptive "header" information.

The listing of the codes are presented following Table H.12. These include the following:

Codes	Data files	
INTRUDE	DATA	SPC1
GRWATER	DATAD	SPC2
OPTIONS	NUCS	SPC3
INVERSI		SPC4
INVERSW		

Table H.12 General Data Definitions

CONTROL INTEGERS AND VALUES (Read from Tape 1)

NS: Number of Waste Streams - 36
Individual streams are usually denoted by ISTR.

NNUC: Number of Radionuclides - 23
Individual nuclides are usually denoted by INUC.

FICRP(7): This array, which is located in BAST Common Block and read from Tape 1, contains ICRP body equivalent factors for the seven human organs being considered in the analysis. The values are 1.0, 0.12, 0.06, 0.03, 0.06, 0.12, and 0.06 for total body, bone, liver, thyroid, kidney, lung, and GI tract, respectively.

WASTE STREAM DEPENDENT ARRAYS

BAS(36,32): Basic Data Matrix
Location: BAST Common Block
Read From: Tape 1

This matrix contains most of the waste stream dependent basic information. The first index of this array refers to the 36 waste streams assumed for the analysis. The second index refers to the following:

Index	Description
1	Waste Stream Name - Alphanumeric.
2	(Reserved)
3	When input, it is the untreated volume of the waste stream in m^3 generated between 1980 and 2000 for a region or for the entire country. This may then be replaced with the normalized disposed waste volume in subroutine COMBYN. For waste spectrum 1, the sum of this value over all streams is one million m^3. For other waste spectra it is referenced to spectrum 1.
4	Gross undecayed activity of the untreated waste (Ci/m^3). This value is used only in transportation calculations; it is not modified in the program.
5-27	Radionuclide concentrations of the waste streams decayed to year 2000 for the 23 radionuclides in the stream (Ci/m^3). The concentrations are modified by volume reduction and increase factors (if applicable) and stored on top of the old concentrations in subroutine COMBYN.
28	Transported waste volume in m^3 which is calculated in subroutine COMBYN. Depending on where the waste processing takes place, this value may be different from the disposed waste volume, i.e., BAS(ISTR,3).

Table H.12 (continued)

Index	Description
29-32	Waste processing impacts: costs ($), occupational dose (mrem), energy use (gallons of fuel), and population dose (mrem), respectively, for the waste stream volume given in BAS(ISTR,3). These impacts are calculated in subroutine COMBYN.

ISPC(36,11): Waste Spectrum Matrix
Location: BAST Common Block
Read From: Tape 2

This matrix is read for each waste spectrum and contains all the information that distinguishes waste spectra from each other. The first index of the matrix refers to the waste stream. The second index refers to the following:

Index	Description
1	Waste Packaging Index, which is used in the transportation calculations, and is composed of two digits representing packaging characteristics and the gamma emission characteristics of waste.
2	Volume Reduction Factor multiplied by 100 (to make it an integer).
3	Volume Increase Factor similarly multiplied by 100.
4	Flammability Index - I4
5	Dispersibility Index - I5
6	Leachability Index - I6
7	Chemical Content Index - I7
8	Stability Index - I8
9	Accessibility Index - I9
10	Overall Waste Processing Index (I10) (see Section 5 of Appendix G) which is composed of four processing indices (digits) that are unscrambled and utilized in subroutine COMBYN to calculate BAS(ISTR,29) through BAS(ISTR,32).
11	Waste Disposal Status Index (I11) (see Section H.1.4) which is computed in subroutine RCLAIM.

RADIONUCLIDE DEPENDENT ARRAYS

DCF(23,7,8): Pathway Dose Conversion Factor Matrix
Location: BAST Common Block
Read From: Tape 1

This matrix contains the multiple pathway dose conversion factors discussed in Section 2.4 of Appendix G. DCF(I,J,K) is the pathway dose conversion factor

Table H.12 (continued)

for the radionuclide (I), human organ (J), and pathway (K). Human organs considered (as given for the FICRP array) are total body, bone, liver, thyroid, kidney, lung, and GI tract, respectively. Pathways considered are those resulting from the following release scenarios: accident, construction (air uptake pathway), agriculture (air uptake pathway), agriculture (food (soil) uptake pathway), direct-gamma (volume) exposure), well water, open water, and air (see Section 2.4 of Appendix G). This matrix is not modified by the code.

NUC(23): Radionuclide Names
Location: NUCS Common Block
Read From: Tape 1

This array contains the alphanumeric names of the radionuclides considered in the analysis: H-3, C-14, FE-55, NI-59, CO-60, NI-63, SR-90, NB-94, TC-99, I-129, CS-135, CS-137, U-235, U-238, NP-237, PU-238, PU-239/240, PU-241, PU-242, AM-241, AM-243, CM-243, CM-244.

AL(23): Decay Constants
Location: NUCS Common Block
Read From: Tape 1

This array contains the decay constants of the 23 selected radionuclides in units of year $^{-1}$.

FMF(23): Leachate Partition Ratios
Location: NUCS Common Block
Read From: Tape 1

This array contains the radionuclide dependent partition ratios between the radionuclide concentrations in the trench leachate and in the unsolidified waste (see Appendix G).

RET(23,5): Retardation Coefficients
Location: NUCS Common Block
Read From: Tape 1

This array contains the retardation coefficients of the radionuclides for five different soil conditions (see Appendix G). Only RET(I,1) and RET(I,4) are read in from Tape 1, the rest of the coefficients are calculated from RET(I,1) and RET(I,4) and stored in subroutine COMBYN.

ENVIRONMENT DEPENDENT ARRAYS

Most of the codes utilized provide for six different disposal environments, each of which is denoted by a specific value of IR in the discussion below. The first four cases correspond to the regional characteristics outlined in Appendix J: northeast, southeast, midwest, and southwest. For most of the analysis only the second set of environmental parameters (IR=2), which represen

Table H.12 (continued)

the reference disposal facility environment, are utilized. The fifth and sixth sets of environmental parameters (IR=5 and IR=6) are variations of the reference facility environment and are utilized for the ground-water migration analyses.

FSC(6): Construction Dust Mobilization Factor
Location: DTIS Common Block
Read From: Tape 1

This array (denoting f_s-construction) contains the dust mobilization factor, which depends on environmental parameters such as antecedent moisture conditions and soil particle size distribution and annual average wind speed, for the air uptake pathway of the intruder-construction scenario.

FSA(6): Agriculture Dust Mobilization Factor
Location: DTIS Common Block
Read From: Tape 1

This array (denoting f_s-agriculture) contains the dust mobilization factor, which depends on environmental parameters such as antecedent moisture conditions and soil particle size distribution and annual average wind speed, for the air uptake pathway of the intruder-agriculture scenario.

PRC(6,2): Percolation Matrix
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the potential infiltration into the disposal cell modified by the anticipated waste-water contact time given in units of meters for two different conditions: PRC(IR,1) is the no special cover condition, and PRC(IR,2) is the thick cover condition. These percolation values are given in Appendix J.

QFC(6,3): Dilution Factors
Location: DTIS Common Block
Read From: Tape 1

This array contains the dilution factors (Q) in units of (m^3/year) for the three ground-water discharge locations: boundary-well, population-well, and population-surface water discharge locations.

TTM(6,3): Ground-water Travel Time Matrix
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the ground-water travel times in years (t_w) between the sector of the disposal site (see Section 3.6 of Appendix G) closest to the discharge locations and the three ground-water discharge locations mentioned above in QFC(6,3).

Table H.12 (continued)

TPC(6,3): Peclet Number Matrix
Location: DTIS Common Block
Read From: Tape 1

This array contains the dimensionless Peclet Numbers (P) for the ground-water travel times given by the above matrix TTM(6,3).

RGG(6,3): Geometric Migration Reduction Factor
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the geometric reduction factor (r_g) resulting from the transverse relationship of the discharge location and the disposal facility for the three ground-water discharge locations considered in the analysis. These values are assumed to be unity.

POP(6,3): Exposed Waste Site Selection Factors
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the exposed waste site selection factors (f_s): POP(IR,1) and POP(IR,2), in units of person-m^3/year, correspond to the factors for exposed waste-intruder-air and exposed waste-erosion-air scenarios, respectively; and POP(IR,3) corresponds to the exposed waste-surface water (intruder and erosion) scenarios.

DTTM(6): Incremental Travel Times
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the incremental travel times between the sectors of the disposal facility in units of years (see Section 3.6 of Appendix G).

DTPC(6): Incremental Peclet Numbers
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the incremental Peclet numbers between the sectors of the disposal facility (see Section 3.6 of Appendix G).

TPO(6,2): Atmospheric Dispersion Factor Array
Location: DTIS Common Block
Read From: Tape 1

This array contains the atmospheric dispersion factors utilized in the accident scenarios for the disposal facility site location. These factors have units of person-year/m^3 and are the atmospheric (X/Q) factors for a given radial distance multiplied by the population at that distance summed over all distances. TPO(IR,1) is for the accident-fire scenario, and TPO(IR,2) is for the single-container accident scenario.

Table H.12 (continued)

NRET(6):	Retardation Status Array
Location:	DTIS Common Block
Read From:	Tape 1

The values in this array indicate the condition of the soils in the vicinity of the disposal site with regard to the retardation of radionuclides. It determines which RET(23,5) will be used in the ground-water migration analysis, i.e., RET(23,NRET(IR)) is used.

Listing for INTRUDE Computer Code

```
00100       PROGRAM  INTRUDE (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
00110C
00120C      TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
00130C        FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCK.
00140C      TAPE2 CONTAINS ISPC(SPECTRAL) FILE.
00150C      INPUT IS USED TO READ IRDC - DISPOSAL TECHNOLOGY INDICES.
00160C      TAPE3 CONTAINS DETAILED OUTPUT - FROM SUBROUTINE RCLAIM.
00170C      TAPE4 CONTAINS MAIN PROGRAM OUTPUT (INTRUDER IMPACTS).
00180C
00190       COMMON/PAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
00200+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
00210+            /DTIS/FSC(6),FSA(6),PRC(6,2),OFC(6,3),TTM(6,3),TPC(6,3),
00220+            RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
00230+            /IMPS/DZD(7,2),DZ(7,2,9)
00240C
00250C      MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
00260C
00270       DIMENSION NOTE(6),TYM(9),DES(2),IGRP(36),DEC(23,2)
00280       DATA NTYM/9/,TYM/50.,100.,150.,200.,300.,400.,500.,1.E3,2.E3/,
00290C           NGNX/36/,IGRP/1,2,3,4,5,6,7,8,9,10,11,12,13,14,
00300C                        15,16,17,18,19,20,21,22,23,24,25,
00310C                        26,27,28,29,30,31,32,33,34,35,36/
00320C           NGNX/4/,IGRP/7*1,12*2,10*3,7*4/
00330C           NGNX/5/,IGRP/11*1,2,2,3,3,4*4,2,2,6*3,4,4,7*5/
00340+           NGNX/1/,IGRP/36*1/
00350       DATA DES/10H REC-CONS ,10H REC-AGRI /,DEC/.9,.75,6*2.5E-3,
00360+      2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,2*1.E-4,13*2.5E-5/
00370C
00380C      THE ABOVE MATRICES AND ARRAYS ARE:
00390C      NOTE(6)   : HEADER LABEL FOR OUTPUT IDENTIFICATION.
00400C      TYM(9)    : NINE TIME STEPS AT WHICH INTRUDER IMPACTS
00410C                  ARE CALCULUATED.
00420C      DES(2)    : DESCRIPTION OF INTRUDER PATHWAYS.
00430C      IGRP(36)  : ARRAY USED TO DEFINE GROUPING OF WASTE STREAMS.
00440C      DEC(23,2): DECON FACTORS FOR INCINERATOR AND CALCINER.
00450C
00460       READ(1,101)NSTR,NNUC,FICRP
00470       DO 10 I=1,NSTR
00480       READ(1,102)(BAS(I,J),J=1,27)
00490    10 READ(2,103)(ISPC(I,J),J=1,10)
00500       DO 20 I=1,NNUC
00510       READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
00520       DO 15 K=1,8
00530    15 READ(1,106)(DCF(I,J,K),J=1,7)
00540    20 CONTINUE
00550C
00560C      INPUT ENVIRONMENTAL PARAMETERS
00570C
00580       DO 25 I=1,6
00590       READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(OFC(I,J),J=1,3),
00600+                 (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
00610+                 (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
00620+                 DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
00630    25 CONTINUE
```

Listing for INTRUDE Computer Code (continued)

```
00640   101 FORMAT(2I5,7F5.2)
00650   102 FORMAT(A10,2F10.3/10X,6F10.3/10X,6F10.3/10X,6F10.3/10X,6F10.3)
00660   103 FORMAT(10X,10I5)
00670   104 FORMAT(A10,4E10.3)
00680   105 FORMAT(10X,7E10.3/10X,6F10.3/10X,6F10.3,I5/10X,4F10.3)
00690   106 FORMAT(10X,7F10.3)
00700C
00710       DO 35 ISTR=1,NSTR
00720       A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
00730       A2=BAS(ISTR,3) $ A3=A2/(A1*3.62) $ BAS(ISTR,3)=A3
00740       DO 30 I=5,27
00750    30 BAS(ISTR,I)=BAS(ISTR,I)*A1
00760       J=ISPC(ISTR,10)
00770       IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
00780       IH=J-IP*1000-IS*100-IL*10 $ IF(IL.EQ.0)GO TO 35
00790       IF(IP.LT.5)GO TO 35
00800       J=1 $ IF(IP.GT.5)J=2
00810       BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
00820       BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
00830    35 CONTINUE
00840C
00850C      NEXT LINE READS IN - THRU INPUT - THE 12 DISPOSAL
00860C      TECHNOLOGY INDICES AND HEADER INFORMATION.
00870C
00880       READ,IRDC $ READ 1002,NOTE $ WRITE(4,1003) NOTE,IRDC
00890       DO 70 IGNX=1,NGNX
00900       NX=0 $ VDIS=0. $ CALL ZERO(DZ,126)
00910C
00920C      DO 70 INTERPRETS IGRP(GROUPING) ARRAY
00930C      DO 50 IS THE MAIN LOOP IN CALCULATING INTRUDER IMPACTS
00940C      DO 45 LOOP DISTINGUISHES BETWEEN THE TIME STEPS
00950C
00960       DO 50 ISTR=1,NSTR
00970       IF(IGNX.NE.IGRP(ISTR))GO TO 50
00980       DO 45 ITYM=1,NTYM
00990       IRDC(12)=TYM(ITYM)+0.1 $ CALL RCLAIM(ISTR,NNUC)
01000       DO 40 I=1,7
01010       DO 40 J=1,2
01020    40 DZ(I,J,ITYM)=DZ(I,J,ITYM)+BAS(ISTR,3)*DZD(I,J)
01030    45 CONTINUE
01040       NX=1 $ VDIS=VDIS+BAS(ISTR,3)
01050    50 CONTINUE
01060       IF(NX.EQ.0)GO TO 70
01070       DO 55 I=1,NTYM
01080       DO 55 J=1,7
01090       DO 55 K=1,2
01100    55 DZ(J,K,I)=DZ(J,K,I)/VDIS
01110       IF(NGNX.EQ.36)WRITE(4,1004) BAS(IGNX,1)
01120       IF(NGNX.NE.36)WRITE(4,1005) IGNX
01130       DO 65 I=1,NTYM
01140       WRITE(4,1006) TYM(I)
01150       DO 65 K=1,2
01160       A1=0.
01170       DO 60 J=1,7
01180    60 A1=A1+DZ(J,K,I)*FICPP(J)
01190    65 WRITE(4,1007) DES(K),(DZ(J,K,I),J=1,7),A1
01200    70 CONTINUE
```

Listing for INTRUDE Computer Code (continued)

```
01210C
01220 1001 FORMAT(12I3)
01230 1002 FORMAT(6A10)
01240 1003 FORMAT(1H1/2X,6A10/2X*IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
01250+                        *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
01260+                        *IH =*I2*  ICL=*I2*  IPO=*I2* YEARS*I5)
01270 1004 FORMAT(//2X,A10)
01280 1005 FORMAT(//2X*GROUP NO =*I2)
01290 1006 FORMAT(/2X*YR =*F5.0*    BODY       BONE       LIVER*
01300+     *    THYROID    KIDNEY    LUNG    G-I TRACT    ICRP*)
01310 1007 FORMAT(2X,A10,8E10.3)
01320      STOP $ END
01330C
01340C
01350      SUBROUTINE RCLAIM(ISTR,NNUC)
01360      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
01370+          /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
01380+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
01390+           /DTIS/FSC(6),FSA(6)/IMPS/DZ(7,2)
01400      DIMENSION EMP(3),DMY(7,5)
01410      DATA EMP/.5,.75,.5/
01420C
01430C     EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
01440C     DMY(7,5)  : MATRIX TO HOLD 5 SUB-PATHWAYS WHICH WILL LATER
01450C                 BE ADDED TOGETHER TO DEFINE CONSTRUCTION AND%@
01460C                 AGRICULTURE PATHWAYS.
01470C
01480   10 I5=ISPC(ISTR,5) $ I7=ISPC(ISTR,7) $ I9=ISPC(ISTR,9)
01490      I6=ISPC(ISTR,6) $ FDES=EMP(IE)*(1.-0.9*IG)
01500      A8=ISPC(ISTR,8)
01510      A8=1. $ IF(I6.EQ.2.OR.I6.EQ.3)A8=0.8
01520      IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
01530C
01540C     GDEL DEFINES YEAR OF SCENARIO INITIATION
01550C
01560      GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
01570      IF(I9.EQ.3) A8=A8*10.
01580      A5=1. $ IF(I5.LT.3)A5=10.**(I5-3)
01590      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
01600      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
01610      I12=1
01620      IF(IL.EQ.0.AND.IS.EQ.1.AND.IR.EQ.1) I12=2
01630      IF(IL.EQ.1.AND.IS.EQ.0) I12=3
01640      IF(IL.EQ.1.AND.IS.EQ.1.AND.I8.EQ.1) I12=4
01650      IF(IH.EQ.1.OR.ID.EQ.2) I12=5
01660      GO TO (11,12,13,14,15),I12
01670   11 A4C=1. $ A4A=1. $ A8C=A8 $ A8A=A8 $ GO TO 20
01680   12 A4C=0.012 $ A4A=0. $ A8C=0.012*A8 $ A8A=0. $ GO TO 20
01690   13 A4C=0.1 $ A4A=0. $ A8C=A8/1200. $ A8A=0. $ GO TO 20
01700   14 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A8/1200. $ A8A=0. $ GO TO 20
01710   15 A4C=0.01 $ A4A=0. $ A8C=0.1*A8/1.44E+6 $ A8A=0.
01720      IF(IG.EQ.0) A8C=A8C*0.1
01730   20 CONTINUE
01740      CALL ZERO(DZ,14) $ WRITE(3,101) BAS(ISTR,1),BAS(ISTR,3),ISTR
01750  101 FORMAT(/2X,A10,E10.3,I5)
01760C
```

Listing for INTRUDE Computer Code (continued)

```
01770C      MAIN LOOP IN CALCULATING DOSFS FROM ALL NUCLIDES FOR
01780C      SEVEN ORGANS.
01790C
01800       DO 40 INUC=1,NNUC
01810       A1=A9*FDES*FXM(AL(INUC)*GDEL)*BAS(ISTR,INUC+4)
01820       DO 30 I=1,7
01830       A2=DCF(INUC,I,5)
01840       DMY(I,1)=A1*0.057*A2*A8C $ DMY(I,3)=A1*0.27*A2*0.25*ARA
01850       DMY(I,2)=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
01860       DMY(I,4)=A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)*0.25
01870       DMY(I,5)=0.25*0.5*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
01880C      DMY(I,2)=A1*A4C*FSC(IR)*DCF(INUC,I,2)
01890C      DMY(I,4)=A1*A4A*FSA(IR)*DCF(INUC,I,3)*0.25
01900C      DMY(I,5)=0.25*0.5*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
01910       DZ(I,1)=DZ(I,1)+DMY(I,1)+DMY(I,2)
01920       DZ(I,2)=DZ(I,2)+DMY(I,3)+DMY(I,4)+DMY(I,5)
01930    30 CONTINUE
01940       IF(ISTR.LT.30)GO TO 40
01950C      WRITE(3,102) NUC(INUC),((DMY(I,J),I=1,7),J=1,5)
01960   102 FORMAT(2X,A10,7E9.2/(12X,7E9.2))
01970    40 CONTINUE
01980       RETURN $ END
01990C
02000       SUBROUTINE ZERO(A,N)
02010       DIMENSION A(N)
02020       DO 10 I=1,N
02030    10 A(I)=0.
02040       RETURN $ END
02050       FUNCTION FXM(A1)
02060       A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
02070       FXM=A2
02080       RETURN $ END
```

Listing for GRWATER Computer Code

```
00100       PROGRAM GRWATER(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
00110C
00120C      TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
00130C        FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCK.
00140C      TAPE2 CONTAINS THE SPECTRAL (ISPC) FILE.
00150C      INPUT IS USED TO READ IRDC - DISPOSAL TECHNOLOGY INDICES.
00160C      TAPE3 CONTAINS DETAILED OUTPUT - FROM SUBROUTINE GWATER.
00170C      TAPE4 CONTAINS THE MAIN PROGRAM OUTPUT (GROUNDWATER IMPACTS).
00180C
00190       COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
00200+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
00210+            /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
00220+            RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
00230+            /IMPS/DZO(23,18,21)/DHIC/IHIC(36),THIC
00240C
00250C      MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
00260C      DTNX BLOCK CONTAINS DISPOSAL TECHNOLGY INDICES.
00270C      IMPS BLOCK  - DZO(23,18,21) - WILL CONTAIN RESULTS OF GWATER
00280C      - DOSES FOR 23 NUCLIDES, 18 TIME STEPS, 7 ORGAN FOR 3 LOCATIONS.
00290C      DHIC BLOCK CONCERNS THE USE OF HIGH INTEGRITY CONTAINERS;
00300C      IHIC INDICATES WHICH STREAMS USE HIGH INTEGRITY CONTAINERS
00310C      AND THIC IS TIME ATTRIBUTE ASSOCIATED WITH CONTAINER.
00320C
00330       DIMENSION TIMP(6),TYM(18),DES(3),DZ(7,3,18),NDX(36)
00340       DATA NDX/36*1/
00350       DATA IHIC/36*0/,THIC/100./
00360       DATA TYM/40.,50.,60.,100.,200.,300.,400.,500.,600.,700.,
00370+      800.,900.,1000.,2000.,4000.,6000.,8000.,10000./,NTYM/18/
00380       DATA DES/10H REC-WELL ,10H POP-WELL ,10H POP-SURF /
00390C
00400C         NDX(36)     : INDEX TO INCLUDE OR EXCLUDE PARTICULAR
00410C                       STREAMS IN ANAYSIS (1=INCLUDE, 0=EXCLUDE).
00420C         TYM(18)     : 18 TIME STEPS TO BE CONSIDERED IN GROUNDWATER
00430C                       ANALYSIS.
00440C         DES(3)      : DESCRIPTION OF 3 PATHWAYS OF CONCERN.
00450C         DZ(7,3,18)  : DOSES SUMMED OVER ALL NUCLIDES.
00460C
00470       READ,IRDC $ READ 1002,TIMP $ WRITE(4,1003) TIMP,IRDC
00480       CALL COMBYN(NSTR,NNUC)
00490       VNOT=0. $ VREG=0. $ VLAY=0. $ VHOT=0.
00500C
00510C      LOOP 30 CLASSIFIES WASTE STREAMS AND ACCUMULATES THEIR
00520C      VOLUME AS NOT ACCEPTABLE, REGULAR, LAYERED, OR HOT.
00530C
00540       DO 30 ISTR=1,NSTR
00550       IF(IRDC(1).EQ.4) ISPC(ISTR,5)=ISPC(ISTR,5)-1
00560       IMOD=1 $ CALL RCLAIM(ISTR,NNUC,IMOD)
00570       IF(NDX(ISTR).NE.1)ISPC(ISTR,11)=0
00580       II=ISPC(ISTR,11)+1 $ GO TO(10,15,20,25),II
00590    10 VNOT=VNOT+BAS(ISTR,3) $ GO TO 30
00600    15 VREG=VREG+BAS(ISTR,3) $ GO TO 30
00610    20 VLAY=VLAY+BAS(ISTR,3) $ GO TO 30
00620    25 VHOT=VHOT+BAS(ISTR,3)
00630    30 CONTINUE
00640       WRITE(4,1004) VREG,VLAY,VHOT,VNOT
00650C
```

Listing for GRWATER Computer Code (continued)

```
00660       CALL GWATER(NSTR,NNUC,NTYM,TYM) $ CALL ZERO(DZ,378)
00670C
00680C      LOOP 40 SUMS DOSES OVER ALL NUCLIDES
00690C
00700       DO 40 ITYM=1,NTYM
00710       DO 40 K=1,3
00720       KK=(K-1)*7
00730       DO 40 J=1,7
00740       DO 40 INUC=1,NNUC
00750    40 DZ(J,K,ITYM)=DZ(J,K,ITYM)+DZD(INUC,ITYM,KK+J)
00760C
00770C      LOOP 70 OUTPUTS GROUNDWATER DOSES FOR 7 ORGANS, 3 PATHWAYS,
00780C      AND 18 TIMES.
00790C
00800       DO 70 ITYM=1,NTYM
00810       TYMD=TYM(ITYM) $ WRITE(4,1005) TYMD
00820       DO 60 K=1,3
00830       A1=0.
00840       DO 50 J=1,7
00850    50 A1=A1+DZ(J,K,ITYM)*FICRP(J)
00860    60 WRITE(4,1006) DES(K),(DZ(J,K,ITYM),J=1,7),A1
00870    70 CONTINUE
00880C
00890C      LOOP 80 OUTPUTS DOSES FOR EACH TIME CONSIDERED FOR EACH NUCLIDE
00900C
00910       DO 80 INUC=1,12
00920       WRITE(4,1007) NUC(INUC)
00930       DO 80 ITYM=1,NTYM
00940       DO 80 K=1,3
00950       KK=(K-1)*7
00960    80 WRITE(4,1008) TYM(ITYM),DES(K),(DZD(INUC,ITYM,KK+J),J=1,7)
00970C
00980 1001 FORMAT(12I3)
00990 1002 FORMAT(6A10)
01000 1003 FORMAT(2X,6A10/2X*IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
01010+                    *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
01020+                    *IH =*I2*  ICL=*I2*  IPO=*I2* YEARS*I5)
01030 1004 FORMAT(2X*VREG =*E9.2* VLAY =*E9.2* VHOT =*E9.2* VNOT =*E9.2)
01040 1005 FORMAT(/2X*YR =*F5.0*    BODY      BONE      LIVER*
01050+     *    THYROID    KIDNEY    LUNG    G-I TRACT    ICRP*)
01060 1006 FORMAT(2X,A10,8E10.3)
01070 1007 FORMAT(/2X,A10,10X*BODY       BONE       LIVER*
01080+     *    THYROID    KIDNEY    LUNG    G-I TRACT*)
01090 1008 FORMAT(2X,F6.0,2X,A10,7E10.3)
01100       STOP $ END
01110C
01120C
01130       SUBROUTINE COMRYN(NSTR,NNUC)
01140       COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
01150+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTIS/FSC(6),FSA(6),
01160+            PPC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),RGF(6,3),POP(6,3),DTTM(6)
01170+            DTPC(6),TPO(6,2),NRET(6)
01180       DIMENSION DEC(23,2)
01190       DATA DEC/.9,.75,6*2.5E-3,2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,
01200+      2*1.E-4,13*2.5E-5/
```

Listing for GRWATER Computer Code (continued)

```
01210       READ(1,101)NSTR,NNUC,FICRP
01220       DO 70 I=1,NSTR
01230       READ(1,102)(BAS(I,J),J=1,27)
01240       READ(2,103)(ISPC(I,J),J=1,10)
01250    70 CONTINUE
01260       DO 80 I=1,NNUC
01270       READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
01280       DO 75 K=1,8
01290       READ(1,106)(DCF(I,J,K),J=1,7)
01300    75 CONTINUE
01310    80 CONTINUE
01320       DO 90 I=1,6
01330       READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(DFC(I,J),J=1,3),
01340+      (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),(RGF(I,J),J=1,3),(POP(I,J),J=1,3),
01350+      NRET(I),DTTM(I),DTPC(I),(TPD(I,J),J=1,2)
01360    90 CONTINUE
01370   101 FORMAT(2I5,7F5.2)
01380   102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
01390   103 FORMAT(10X,10I5)
01400   104 FORMAT(A10,4E10.3)
01410   105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6F10.3,I5/10X,4F10.3)
01420   106 FORMAT(10X,7E10.3)
01430       DO 50 ISTR=1,NSTR
01440       A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
01450       A2=BAS(ISTR,3) $ A3=A2/(A1*3.62) $ BAS(ISTR,3)=A3
01460       DO 20 I=5,27
01470    20 BAS(ISTR,I)=BAS(ISTR,I)*A1
01480       J=ISPC(ISTR,10)
01490       IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
01500       IH=J-IP*1000-IS*100-IL*10 $ IF(IL.EQ.0)GO TO 50
01510       IF(IP.LT.5)GO TO 50
01520       J=1 $ IF(IP.GT.5)J=2
01530       BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
01540       BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
01550    50 CONTINUE
01560       DO 60 INUC=1,NNUC
01570       A2=RET(INUC,4) $ A1=(A2/RET(INUC,1))**0.334
01580       RET(INUC,5)=A2*A1 $ RET(INUC,3)=A2/A1
01590    60 RET(INUC,2)=RET(INUC,1)*A1
01600       RETURN $ END
01610C
01620C
01630       SUBROUTINE RCLAIM(ISTR,NNUC,IMOD)
01640C
01650C      THIS SUBROUTINE IS USED TO CLASSIFY EACH WASTE STREAM AS:
01660C          (1) NOT ACCEPTABLE, (2) REGULAR,
01670C          (3) LAYERED, OR (4) HOT
01680C
01690       COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
01700+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
01710+            /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,ITC
01720+            /DTIS/FSC(6),FSA(6)/IMPS/D7(7,2)/DHIC/IHIC(34),THIC
01730C
01740C      D7(7,2) : INTRUDER DOSES USED IN CLASSIFICATION TESTS
01750C
```

Listing for GRWATER Computer Code (continued)

```
01760       DIMENSION EMP(5),DLC(7)
01770       DATA EMP/.5,.75,.5,.5,.75/,DLC/500.,500.,1500.,3000.,3*1500./
01780C
01790C      EMP(5) : VOLUME EMPLACEMENT EFFICIENCIES
01800C      DLC(7) : DOSE LIMITING CRITERIA FOR 7 ORGANS
01810C
01820       I5=ISPC(ISTR,5) $ I6=ISPC(ISTR,6) $ I7=ISPC(ISTR,7)
01830       I8=ISPC(ISTR,8) $ I9=ISPC(ISTR,9)
01840       IF(IHIC(ISTR).GT.0) I8=1
01850       A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
01860       IF(I7.EQ.1.OR.I5.EQ.0) I6=I6-1
01870       EDES=EMP(IE)*(1.-.9*I6)
01880       IF(I9.EQ.3) A7=A7*10.
01890       A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
01900       A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
01910       A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
01920       I3=1 $ IF(I5.EQ.1.AND.I8.EQ.1)I3=2
01930       IF(ID.EQ.2)I3=2
01940C
01950C      TESTING ROUTINE FOR CLASSIFING WASTE, BASED ON INTRUDER
01960C      CONSTRUCTION AND AGRICULTURE PATHWAYS.
01970C
01980    10 GDEL=IP0+TIC $ IF(IC.EQ.3) GDEL=IP0+500.
01990       CALL ZERO(97,14) $ GO TO (11,12,13,14,15,16,17,18),I3
02000    11 A4C=1. $ A4A=1. $ ARC=A7 $ ARA=A7 $ GO TO 20
02010    12 A4C=0.012 $ A4A=0. $ ARC=0.012*A7 $ ARA=0. $ GO TO 20
02020    13 GDEL=IP0+500. $ A4C=1. $ A4A=1. $ ARC=A7 $ ARA=A7 $ GO TO 20
02030    14 A4C=0.1 $ A4A=0. $ ARC=A7/1200. $ ARA=0. $ GO TO 20
02040    15 A4C=0.0012 $ A4A=0. $ ARC=0.0012*A7/1200. $ ARA=0. $ GO TO 20
02050    16 GDEL=IP0+500. $ A4C=1. $ A4A=1. $ ARC=A7 $ ARA=A7 $ GO TO 20
02060    17 ARC=0.1*A7/1.44E6 $ IF(IG.EQ.0)ARC=ARC*0.1
02070       A4C=0.01 $ A4A=0. $ ARA=0. $ GO TO 20
02080    18 GDEL=IP0+1000. $ ARC=A7 $ IF(IG.EQ.0)ARC=0.1*A7
02090       A4C=1. $ A4A=1. $ ARA=ARC
02100C
02110C      MAIN LOOP FOR CALCULATING DOSES
02120C
02130    20 DO 40 INUC=1,NNUC
02140       A1=A9*EDES*EXM(AL(INUC)*GDEL)*RAS(ISTR,INUC+4)
02150       DO 30 I=1,7
02160       A2=DCF(INUC,I,5)
02170       B1=A1*A4C*A5*ESC(IR)*DCF(INUC,I,2)
02180       B2=A1*ARC*A2*0.057
02190       B3=0.25*A1*A4A*A5*ESA(IR)*DCF(INUC,I,3)
02200       B4=0.5*0.25*A1*A4A*A6*EMF(INUC)*DCF(INUC,I,4)
02210C      B1=A1*A4C*ESC(IR)*DCF(INUC,I,2)
02220C      B3=0.25*A1*A4A*ESA(IR)*DCF(INUC,I,3)
02230C      B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)*EMF(INUC)
02240       B5=0.25*A1*ARA*A2*0.27
02250       D7(I,1)=D7(I,1)+B1+B2
02260    30 D7(I,2)=D7(I,2)+B3+B4+B5
02270    40 CONTINUE
02280C
```

Listing for GRWATER Computer Code (continued)

```
02290C      TEST DOSES AGAINST DLC
02300C
02310       DO 50 IORG=1,7
02320       DO 50 IPTH=1,2
02330       IF(DZ(IORG,IPTH).GT.DLC(IORG)) GO TO 60
02340    50 CONTINUE
02350       GO TO (51,52,51,53,53,54,55,56),I3
02360    51 ISPC(ISTR,11)=1 $ RETURN
02370    52 I3=3 $ GO TO 10
02380    53 I3=6 $ GO TO 10
02390    54 ISPC(ISTR,11)=2 $ RETURN
02400    55 I3=8 $ GO TO 10
02410    56 ISPC(ISTR,11)=3 $ RETURN
02420    60 GO TO (61,62,63,63,63,63,70,70),I3
02430    61 IF(IL.EQ.0)GO TO 63
02440       I3=4 $ GO TO 10
02450    62 IF(IL.EQ.0)GO TO 63
02460       I3=5 $ GO TO 10
02470    63 IF(IH.EQ.0)GO TO 70
02480       I3=7 $ GO TO 10
02490    70 ISPC(ISTR,11)=0
02500C
02510C      ISPC(ISTR,11) CONTAINS WASTE CLASSIFICATION INDEX
02520       RETURN $ END
02530C
02540       FUNCTION ERFS(A1,A2)
02550       A3=0.5*SQPT(A2/A1)
02560       A4=A3*(1.-A1) $ A5=A3*(1.+A1)
02570       IF(A4.GT.0)GO TO 10
02580       ERFS=2.+EXM(A4*A4)*(POLY(A5)-POLY(-A4)) $ RETURN
02590    10 ERFS=EXM(A4*A4)*(POLY(A4)+POLY(A5))
02600       RETURN $ END
02610C
02620C
02630       FUNCTION POLY(X1)
02640       DATA A1,A2,A3,A4,A5,P/.254829592,-.284496736,1.421413741,
02650+                            -1.453152027,1.061405429,.3275911/
02660       T1=1./(1.+P*X1)
02670       POLY=T1*(A1+T1*(A2+T1*(A3+T1*(A4+T1*A5))))
02680       RETURN $ END
02690       FUNCTION EXM(A1)
02700       A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
02710       EXM=A2
02720       RETURN $ END
02730C
02740C
02750       SUBROUTINE GWATER(NSTR,NNUC,NTYM,TYMD)
02760       COMMON/BAST/RAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
02770+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
02780+            /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
02790+            /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
02800+            TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
02810+            /IMPS/DZ(23,18,21)/DHIC/IHIC(36),THIC
02820       DIMENSION EMP(5),EFF(2),SEFF(2),DMY(3,20),TYMD(18),RES(18,3)
02830       DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,SEFF/0.9,0.35/,NOPT/1/
02840       TVOL=0. $ GINS=IPO+IIC $ NSEC=10 $ CALL ZERO(DZ,8694)
```

Listing for GRWATER Computer Code (continued)

```
02850C
02860C      NEXT SECTION DETERMINES PERCOLATION VALUE AND
02870C      LOWER LIMIT FOR THE DILUTION FACTOR
02880C
02890       PRC1=PRC(IR,1) $ PRC2=PRC(IR,2)
02900       IF(IG.EQ.1.OR.ID.EQ.2) GO TO 5
02910       IF(IE.GT.3) PRC1=PRC(IR,1)/10.
02920       IF(IE.GT.3) PRC2=PRC(IR,2)/10.
02930     5 CONTINUE
02940       IF(IC.EQ.1)PRCD=PRC1
02950       IF(IC.GT.1)PRCD=PRC2
02960       IF(IX.EQ.1)PRCD=4.*PRC1
02970       IF(IC.EQ.1.AND.IX.EQ.2) PRCD=2.25*PRC1
02980       IF(IC.EQ.2.AND.IX.EQ.2) PRCD=4.0*PRC2
02990       TVOL=352000.*SQRT(PRC(IR,1)*27.8)
03000       IF(TVOL.LT.7700.) TVOL=7700.
03010C
03020C      MAIN LOOP OF GROUNDWATER PATHWAY EQUATION
03030C           ************************************
03040C           SOME OF THE MAIN VARIABLE NAMES ARE:
03050C           PERC  : SOURCE TERMS
03060C           PER2
03070C           FMF   : RADIONUCLIDE PARTITION RATIOS
03080C           QFC   : DILUTION FACTOR
03090C           TDUR  : DURATION TIME OF RADIONUCLIDE
03100C           RES   : MIGRATION REDUCTION FACTOR
03110C           RGF   : GEOMETRICAL REDUCTION FACTOR
03120C           ************************************
03130C
03140       DO 90 ISTR=1,NSTR
03150       I11=ISPC(ISTR,11) $ IF(I11.EQ.0)GO TO 90
03160       WRITE(3,101) BAS(ISTR,1),BAS(ISTR,3),ISTR,I11
03170       I6=ISPC(ISTR,6) $ VUR=0.9/(EMP(IE)*FFF(ID))
03180       I7=ISPC(ISTR,7) $ IF(I11.EQ.3)VUR=0.19
03190       I8=ISPC(ISTR,8) $ IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
03200       I9=ISPC(ISTR,9) $ GDFL=0. $ IF(IHIC(ISTR).EQ.1)GDEI=THIC
03210       IF(IHIC(ISTR).GT.0) I8=1
03220       PERC=PRCD $ IF(I8.NE.1.OR.IS.NE.1)GO TO 10
03230       IF(IC.EQ.1)PERC=PRC1
03240       IF(IC.GT.1)PERC=PRC2
03250    10 IF(I11.EQ.3.OR.ID.EQ.2)PERC=PRC2/16.
03260       PERC=PERC*(1.0-0.9*IG) $ PER2=3.6*PERC+0.1*PRC1
03270       IF(ID.EQ.2)PER2=0.9*PERC+0.1*PRC2
03280       NX=0 $ IF(PERC.LT.PRC1)NX=1
03290       A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
03300       A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
03310       I1=NRET(IR) $ IF(IS.EQ.0.OR.I7.EQ.1)I1=I1-1
03320       TDUM=1.0/(PERC*VUR*A6*A9) $ IF(I1.LE.0)I1=1
03330       DO 80 INUC=1,12
03340       IF(BAS(ISTR,INUC+4).LT.1.E-14)GO TO 80
03350       TDUR=TDUM/FMF(INUC) $ CALL ZERO(DMY,60)
03360       C1=TDUR $ IF(NX.EQ.0.OR.NOPT.EQ.0)GO TO 15
03370       IF(C1.LT.GINS)C1=GINS
03380C
```

Listing for GRWATER Computer Code (continued)

```
03390C      SUBROUTINE RTIJ CALCULATES THE MIGRATION REDUCTION FACTOR
03400C      RESULTS ARE RETURNED IN RES MATRIX.
03410C
03420    15 CALL RTIJ(TYMD,NTYM,INUC,IR,I1,C1,0.,RES,GDFL)
03430       B1=BAS(ISTR,3)*BAS(ISTR,INUC+4)/TDUR
03440       DO 30 IPTH=1,3
03450       B2=B1*RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC)
03460       IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
03470       I3=(IPTH-1)*7 $ I2=6 $ IF(IPTH.EQ.3)I2=7
03480       DO 25 ITYM=1,NTYM
03490       A3=EXM(AL(INUC)*TYMD(ITYM))
03500       DO 20 I=1,7
03510       A4=A3*RES(ITYM,IPTH)*B2*DCF(INUC,I,I2)
03520       DMY(IPTH,ITYM)=DMY(IPTH,ITYM)+A4*FICRP(I)
03530    20 DZ(INUC,ITYM,I3+I)=DZ(INUC,ITYM,I3+I)+A4
03540    25 CONTINUE
03550    30 CONTINUE
03560C
03570C      THE NEXT SECTION CONSIDERS (OPTIONAL BY NOPT) THE SECOND
03580C      SOURCE TERM OF A 2-STEP ANALYSIS WITH AN INCREASED SOURCE
03590C      TERM (PER2) AFTER THE INSTITTUTIONAL CONTROL PERIOD.
03600C
03610       IF(NX.EQ.0.OR.NOPT.EQ.0)GO TO 60
03620       IF(TDUR.LE.GINS)GO TO 60
03630       T1=GINS $ T2=T1+PERC*(TDUR-T1)/PER2
03640       CALL RTIJ(TYMD,NTYM,INUC,IR,I1,T2,T1,RES,GDFL)
03650       B1=B1*PER2/PERC
03660       DO 50 IPTH=1,3
03670       B2=B1*RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC)
03680       IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
03690       I3=(IPTH-1)*7 $ I2=6 $ IF(IPTH.EQ.3)I2=7
03700       DO 45 ITYM=1,NTYM
03710       A3=EXM(AL(INUC)*TYMD(ITYM))
03720       DO 40 I=1,7
03730       A4=A3*RES(ITYM,IPTH)*B2*DCF(INUC,I,I2)
03740       DMY(IPTH,ITYM)=DMY(IPTH,ITYM)+A4*FICRP(I)
03750    40 DZ(INUC,ITYM,I3+I)=DZ(INUC,ITYM,I3+I)+A4
03760    45 CONTINUE
03770    50 CONTINUE
03780    60 WRITE(3,102) NUC(INUC)
03790       WRITE(3,103) ((DMY(I,J),J=1,NTYM),I=1,3)
03800    80 CONTINUE
03810    90 CONTINUE
03820C
03830C      END OF MAIN LOOP
03840C
03850   101 FORMAT(2X,A10,E10.3,2I5)
03860   102 FORMAT(2X,A7)
03870   103 FORMAT(9X,9F9.2)
03880       RETURN $ END
03890C
03900C
03910       SUBROUTINE RTIJ(TYMD,NTYM,INUC,IR,I1,TDUR,TMIN,RES,GDFL)
03920       COMMON/NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
03930+            /DTIS/FSCA(42),TTM(6,3),TPC(6,3),RGFP(36),DTTM(6),DTPC(6)
03940       DIMENSION TYMD(NTYM),RES(IR,3),RTTM(6),RTPC(6)
```

Listing for GRWATER Computer Code (continued)

```
      DATA BTTM/350.,66.,175.,283.,56.,116./,
     +     BPTC/700.,1900.,700.,1600.,1900.,1900./,NOPTW/0/
C
C     NOPTW=0 SIGNIFIES INTRUDER WELL
C     NOPTW=1 SIGNIFIES BOUNDARY WELL (BTTM,BTPC)
C
      CALL ZERO(RES,54)
      DO 30 IPTH=1,3
      A1=RET(INUC,I1)*TTM(IR,IPTH)+GDEL
      IF(IPTH.EQ.1.AND.NOPTW.EQ.1) A1=RET(INUC,I1)*BTTM(IR)+GDEL
      DO 20 ITYM=1,NTYM
      TYM=TYMD(ITYM)-TMIN $ A2=TYMD(ITYM)-TDUR
      DO 10 ISEC=1,10
      B3=1.0/(A1+RET(INUC,I1)*(ISEC-1)*DTTM(IR))
      IF(TYM*1.1*B3.LT.1.0) GO TO 20
      B4=TPC(IR,IPTH)+(ISEC-1)*DTPC(IR)
      IF(IPTH.EQ.1.AND.NOPTW.EQ.1) B4=BTPC(IR)+(ISEC-1)*DTPC(IR)
      A3=0.5*ERFS(B3*TYM,B4)
      IF(A2.GT.0.)A3=A3-0.5*ERFS(B3*A2,B4)
      IF(A3.LT.0.)A3=0.
   10 RES(ITYM,IPTH)=RES(ITYM,IPTH)+A3
   20 CONTINUE
   30 CONTINUE
      RETURN $ END
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
```

Listing for OPTIONS Computer Code

```
00100      PROGRAM OPTIONS(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
00110C
00120C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
00130C     FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCKS.
00140C     TAPE2 CONTAINS ISPC(SPECTRAL) FILE.
00150C     TAPE3 READS IN THE DISPOSAL TECHNOLOGY CASES
00160C     TAPE4 CONTAINS PROGRAM OUTPUT.
00170C
00180      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
00190+          /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/TRDC(12)
00200+          /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
00210+               RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
00220+          /VOL/VREG,VLAY,VHOT
00230+          /IMPS/DZ(8,7,2),DZO(4,7,2),DZA(7,7),DZS(36,7,2)
00240C
00250C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
00260C     DTNX BLOCK CONTAINS THE DISPOSAL TECHNOLOGY INDICES.
00270C     VOL BLOCK CONTAINS TOTAL REGULAR, LAYERED, AND HOT WASTE VOLUMES.
00280C     IMPS IS EXPLAINED BELOW:
00290C     DZ(8,7,2)   = OUTPUT FROM SUBROUTINE RCLAIM TO MAIN PROGRAM
00300C                   CONTAINING INTRUDER IMPACTS FOR SEVEN ORGANS
00310C                   AND TWO PATHWAYS UNDER EIGHT TESTING CONDITIONS.
00320C     DZO(4,7,2) = THIS MATRIX IS USED TO VOLUME AVERAGE THE OUTPUT
00330C                   DOSES FROM RCLAIM. FINAL VALUES ARE FOR SEVEN ORGANS
00340C                   AND TWO PATHWAYS AT THREE TIME STEPS (100, 500,
00350C                   1000 YEARS) AND SUBSEQUENTLY PRINTED OUT TO TAPE4.
00360C     DZA(7,7)    = OUTPUT FROM SUBROUTINE ACCEXP TO MAIN PROGRAM
00370C                   CONTAINING THE ACCIDENT AND EXPOSURE DOSES FOR
00380C                   SEVEN ORGAN AND SEVEN PATHWAYS.
00390C     DZS(36,7,2) = OUTPUT FROM SUBROUTINE ACCEXP FOR THE TWO
00400C                    ACCIDENT PATHWAYS CONSIDERED BY ALL STREAMS (36)
00410C                    AND 7 ORGANS.
00420      DIMENSION IQR(36),IQL(36),IQH(36),IQN(36),G(4),D(4)
00430      DIMENSION NOTE(6),DES(9),TIMP(6),COST(5),UN(5),NDX(36)
00440C
00450C     THESE ARRAYS ARE EXPLAINED BELOW:
00460C     IQR(36), IQL(36) = INDICES OF STREAMS BELONGING TO EACH
00470C     IQH(36), IQN(36)   OF THE FOUR WASTE TYPES (REGULAR, LAYERED,
00480C                        HOT, AND NOT ACCEPTABLE)
00490C     NOTE(6)          = HEADER INFORMATION READ IN THRU INPUT AND
00500C                        PRINTED OUT ON TOP OF OUTPUT FOR IDENTIFICATION.
00510C     DES(9)           = DESCRIPTION OF 9 PATHWAYS CONSIDERED.
00520C     TIMP(6)          = TRANSPORTATION IMPACTS CALCULATED IN SUBROUTINE
00530C                        TRANSP AND PASSED TO MAIN PROGRAM.
00540C     COST(5)          = DISPOSAL IMPACTS CALCULATED IN SUBROUTINE ECON.
00550C     G(4),D(4)        = LOCAL ARRAYS WHICH ACCUMULATES PROCESSING IMPACTS.
00560C                        G FOR PROCESSING AT GENERATOR AND D FOR PROCESSING
00570C                        AT THE DISPOSAL SITE
00580C     UN(5)            = UNIT COSTS ($/M3) FOR PROCESSING, TRANSPORTATION,
00590C                        DISPOSAL DURING OPERATIONAL PERIOD, AND DISPOSAL
00600C                        DURING POST CLOSURE PERIOD.
00610C     NDX              = STREAM CONTROL ARRAY
00620C                          0 = DELETE STREAM FROM CONSIDERATION
00630C                          1 = PROCEED AS NORMAL
00640C                          2 = HIGH INTEGRITY CONTAINER
00650C                          3 = STABLIZED
```

Listing for OPTIONS Computer Code (continued)

```
00660C
00670       DATA DES/10H REC-CONS ,10H REC-AGRI ,
00680+            10H REC-AIR  ,10H ERO-AIR  ,10H REC-WAT  ,
00690+            10H ERO-WAT  ,10H ACC-SNGC ,10H ACC-FTRF ,10H ACC-AVG
00700       DATA RI,RJ/.1,.09/
00710       DATA NDX/36*1/
00720C
00730C      SUBROUTINE COMBYN READS IN MOST OF THE INPUT DATA
00740C      AND CALCULATES THE PROCESSING IMPACTS. PROCESSING IMPACTS
00750C      ARE RETURNED IN BAS(ISTR,29) THRU BAS(ISTR,32).
00760C
00770       CALL COMBYN(NSTR,NNUC,NDX)
00780C
00790       READ(3,)NCASE
00800       DO 300 NC=1,NCASE
00810       READ(3,1002)NOTE $ READ(3,)IRDC
00820       WRITE(4,1003)NOTE,IRDC
00830       CALL ZERO(D7,721)
00840       VREG=0. $ VLAY=0. $ VHOT=0. $ VNOT=0.
00850       NREG=0  $ NLAY=0  $ NHOT=0  $ NNOT=0
00860C
00870C
00880C      NEXT SECTION CALCULATES THE INTRUDER IMPACTS AND DETERMINES
00890C      THE WASTE STREAM STATUS - ISPC(ISTR,11).
00900C
00910C
00920       DO 50 ISTR=1,NSTR
00930       IF(IRDC(1).EQ.4) ISPC(ISTR,5)=ISPC(ISTR,5)-1
00940       IDX=NDX(ISTR) $ IMOD=1 $ CALL RCLAIM(ISTR,NNUC,IMOD,IDX)
00950       II=ISPC(ISTR,11)+1 $ GO TO (10,20,30,40),II
00960    10 NNOT=NNOT+1              $ IQN(NNOT)=ISTR
00970       VNOT=VNOT+BAS(ISTR,3) $ GO TO 50
00980    20 NREG=NREG+1              $ IQR(NREG)=ISTR
00990       DO 25 I=1,7
01000       DO 25 J=1,2
01010       DZQ(1,I,J)=DZQ(1,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
01020       DZQ(2,I,J)=DZQ(2,I,J)+BAS(ISTR,3)*DZ(3,I,J)
01030    25 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
01040       VREG=VREG+BAS(ISTR,3) $ GO TO 50
01050    30 NLAY=NLAY+1              $ IQL(NLAY)=ISTR
01060       DO 35 I=1,7
01070       DO 35 J=1,2
01080       DZQ(4,I,J)=DZQ(4,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
01090       DZQ(2,I,J)=DZQ(2,I,J)+BAS(ISTR,3)*DZ(3,I,J)
01100    35 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
01110       VLAY=VLAY+BAS(ISTR,3) $ GO TO 50
01120    40 NHOT=NHOT+1              $ IQH(NHOT)=ISTR
01130       DO 45 I=1,7
01140       DO 45 J=1,2
01150       DZQ(1,I,J)=DZQ(1,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
01160    45 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
01170       VHOT=VHOT+BAS(ISTR,3)
01180    50 CONTINUE
01190       IF(VLAY.EQ.0.) VLAY=1.
```

Listing for OPTIONS Computer Code (continued)

```
01200       DO 55 J=1,7
01210       DO 55 K=1,2
01220       DZO(1,J,K)=DZO(I,J,K)/(VREG+VHOT)
01230       IF(VLAY.GT.1.) DZO(1,J,K)=DZO(1,J,K)+DZO(4,J,K)/VLAY
01240       DZO(2,J,K)=DZO(2,J,K)/(VREG+VLAY)
01250    55 DZO(3,J,K)=DZO(3,J,K)/(VREG+VLAY+VHOT)
01260C
01270C      THE MATRIX DZO NOW CONTAINS THE VOLUME AVERAGED INTRUDER IMPACTS.
01280C
01290       IF(VLAY.EQ.1.) VLAY=0.
01300       IF(NREG.GT.0) CALL PRT(VREG,IOR,NREG,1,NDX)
01310       IF(NLAY.GT.0) CALL PRT(VLAY,IOL,NLAY,2,NDX)
01320       IF(NHOT.GT.0) CALL PRT(VHOT,IOH,NHOT,3,NDX)
01330       IF(NNOT.GT.0) CALL PRT(VNOT,ION,NNOT,4,NDX)
01340       WRITE(4,1008)
01350       DO 70 I=1,3
01360       DO 65 K=1,2
01370       A1=0.
01380       DO 60 J=1,7
01390    60 A1=A1+DZO(I,J,K)*FICRP(J)
01400    65 WRITE(4,1009) DES(K),(DZO(I,J,K),J=1,7),A1
01410    70 CONTINUE
01420C
01430C      NEXT SECTION CALCULATES THE DOSES FOR THE ACCIDENT AND EXPOSURE
01440C      SCENARIOS - CONSISTS OF SEVEN PATHWAYS FOR SEVEN ORGANS.
01450C
01460       CALL ACCEXP(NSTR,NNUC,NDX)
01470       WRITE(4,1014)
01480       DO 100 K=1,7
01490       KK=K+2 $ A1=0.
01500       DO 95 J=1,7
01510    95 A1=A1+DZA(J,K)*FICRP(J)
01520   100 WRITE(4,1015)DES(KK),(DZA(J,K),J=1,7),A1
01530C
01540C      NEXT SECTION CALCULATES THE TRANSPORTATION IMPACTS AND THE
01550C      DISPOSAL IMPACTS THRU SUBROUTINES TRANSP AND ECON, RESPECTIVELY.
01560C
01570       CALL TRANSP(TIMP,NSTR)
01580       CALL ZERO(G,4) $ CALL ZERO(D,4)
01590       DO 110 I=1,NSTR
01600       I1=ISPC(I,10) $ I2=I1/100
01610       I3=(I1/10)-I2*10 $ IF(I3.EQ.0) GO TO 110
01620C
01630C      SEPERATE GENERATOR AND DISPOSAL PROCESSING IMPACTS
01640C
01650       IF(I3.EQ.2) GO TO 105
01660       G(1)=G(1)+BAS(I,29) $ G(2)=G(2)+BAS(I,30)
01670       G(3)=G(3)+BAS(I,31) $ G(4)=G(4)+BAS(I,32)
01680       GO TO 110
01690   105 D(1)=D(1)+BAS(I,29) $ D(2)=D(2)+BAS(I,30)
01700       D(3)=D(3)+BAS(I,31) $ D(4)=D(4)+BAS(I,32)
01710   110 CONTINUE
01720C
01730       CALL ECON(NSTR,RI,PJ,COST,NDX)
01740C
```

Listing for OPTIONS Computer Code (continued)

```
01750C
01760C     PROCESSING, TRANSPORTATION, AND DISPOSAL IMPACTS ARE NOW BROUGHT
01770C     TOGETHER AND PRINTED OUT.
01780C
01790      VT=VREG+VLAY+VHOT
01800      UN(1)=G(1)/VT $ UN(2)=D(1)/VT
01810      UN(3)=TIMP(1)/VT $ UN(4)=COST(1)/VT $ UN(5)=COST(5)/VT
01820      COST(2)=COST(2)+TIMP(5) $ X=0.
01830      TIMP(3)=TIMP(3)+TIMP(6)
01840      WRITE(4,1013)RI,RJ,G(1),D(1),TIMP(1),COST(1),COST(5),
01850+     UN(1),UN(2),UN(3),UN(4),UN(5),G(4),D(4),TIMP(4),X,
01860+     G(3),D(3),TIMP(3),COST(2),X,X,X,COST(4),G(2),D(2),TIMP(2),COST(3)
01870C
01880      DO 120 K=1,2
01890      IF(K.EQ.1)WRITE(4,1016)
01900      IF(K.EQ.2)WRITE(4,1017)
01910      WRITE(4,1018)
01920      DO 120 I=1,NSTP
01930      A1=0.
01940      DO 115 J=1,7
01950  115 A1=A1+D7S(I,J,K)*FICRP(J)
01960      WRITE(4,1020)BAS(I,1),(D7S(I,J,K),J=1,7),A1
01970  120 CONTINUE
01980  300 CONTINUE
01990 1001 FORMAT(12I3)
02000 1002 FORMAT(6A10)
02010 1003 FORMAT(1H1/2X,6A10//2X*DISPOSAL TECHNOLOGY INDICES*/2X,
02020+                        *IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
02030+                        *IF =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
02040+                        *IH =*I2*  ICL=*I2*  IPO=*I2*  IIC=*I4)
02050 1008 FORMAT(1H1/2X,*INTRUDER IMPACTS*,7X,*BODY      BONE      LIVER*
02060+     *    THYROID    KIDNEY    LUNG    G-I TRACT    ICRP*)
02070 1009 FORMAT(12X,A10,8E10.3)
02080 1013 FORMAT(/2X*OTHER IMPACTS      WASTE PROCESSING    TRANSP    *,
02090+     *DISPOSAL   LT CARE*,2X,2F5.3/16X*     GENERAT  DISPOSAL*/2X,
02100+     *COST ($)*8X,5E10.2/2X*UNIT COST ($/M3)*5E10.2/2X*POP DOSE (MREM) *,
02110+     4E10.2/2X*OCC DOSE (MREM) *4F10.2/2X,16HLAND USE (M**2) ,4F10.2/2X,
02120+     *ENERGY USE (GAL)*4F10.2)
02130 1014 FORMAT(/2X*EXPOSE/ACC IMPACTS*)
02140 1015 FORMAT(12X,A10,8E10.3)
02150 1016 FORMAT(//2X*SINGLE CONTAINER ACCIDENT - ALL STREAMS*)
02160 1017 FORMAT(//2X*ACCIDENT BY FIRE - ALL STREAMS*)
02170 1018 FORMAT(14X,*STREAM*,5X,*BODY      BONE      LIVER    THYROID    *
02180+     *KIDNEY    LUNG    G-I TRACT    ICRP*)
02190 1020 FORMAT(12X,A10,8E10.3)
02200      STOP $ END
02210C
```

Listing for OPTIONS Computer Code (continued)

```
02220C
02230       SUBROUTINE COMRYN(NSTR,NNUC,NDX)
02240C
02250C      THIS SUBROUTINE READS THE DATA FILES, TAPE1 AND TAPE2, AND
02260C      PERFORMS SEVERAL BASIC CALCULATIONS TO INTEGRATE SOME OF
02270C      THE INFORMATION.  IT PERFORMS THE FOLLOWING:
02280C      1 : READ THE COMMON BLOCKS BAST, NUCS, AND DTIS
02290C      2 : USING THE VRF AND VIF GIVEN IN ISPC MATRIX MODIFIES
02300C          VOLUMES AND CONCENTRATIONS
02310C      3 : CALCULATES TRANSPORTED VOLUME AND STORES IT ON BAS(ISTR,2B)
02320C      4 : CALCULATES THE WASTE PROCESSING IMPACTS
02330C      5 : MODIFIES H-3 AND C-14 CONC IF WASTE IS INCINERATED
02340C      6 : CALCULATES THE RET(23,5) MATRIX FROM GIVEN INFORMATION.
02350C
02360       COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
02370+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTIS/FSC(6),FSA(6),
02380+            PRC(6,2),OFC(6,3),TTM(6,3),TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),
02390+            DTPC(6),TPO(6,2),NRET(6)
02400       DIMENSION AZR(36),UPRS(7,3),USOL(3,3),USAV(3),
02410+                 DEC(23,2),TPOP(2),NDX(36)
02420C
02430C
02440C      ADDITIONAL INFORMATION NECESSARY FOR THIS ROUTINE ARE GIVEN
02450C      IN THE ARRAYS AND DATA STATEMENTS.  THE ARRAYS ARE FOLLOWING:
02460C      AZR(36)    = SPECTRUM 1 VIF/VRF RATIOS
02470C      UPRS(7,3)  = VOLUME REDUCTION UNIT IMPACTS
02480C      USOL(3,3)  = SOLIDIFICATION UNIT IMPACTS
02490C      USAV(3)    = UNIT SAVINGS RESULTING FROM VOLUME REDUCTION
02500C      DEC(23,1)  = DECON FACTORS FOR PATHOLOGICAL INCINERATOR,
02510C                   AND DEC(23,2) IS THE DECON FACTORS FOR CALCINER.
02520C      TPOP(2)    = PERSON-YEAR/M3 ATMOSPHERIC DISPERSION FACTORS
02530C      FOR POPULATION EXPOSURE CALCULATION FOR URBAN AND RURAL AREAS.
02540C
02550       DATA AZR/1.,1.4,3*1.,1.4,15*1.,4*3.,2*1.92,3*1.,2.,1.3,4*1./
02560       DATA UPRS/335.,503.,1006.,690.,2060.,1938.,1039.,3*4.6,
02570+            56.3,116.,129.,72.,3*15.,4.42,8.,6.12,5.35/,
02580+       USOL/1282.,1873.,2445.,3*40.,3*24./,
02590+       USAV/210.,.4,4./,TPOP/1.56E-8,1.56E-10/,DEC/.9,.75,6*2.5E-3,
02600+            2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,2*1.E-4,13*2.5E-5/
02610       READ(1,101)NSTR,NNUC,FICRP
02620       DO 70 I=1,NSTR
02630       READ(1,102)(BAS(I,J),J=1,27)
02640       READ(2,103)(ISPC(I,J),J=1,10)
02650    70 CONTINUE
02660       DO 80 I=1,NNUC
02670       READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
02680       DO 75 K=1,8
02690       READ(1,106)(DCF(I,J,K),J=1,7)
02700    75 CONTINUE
02710    80 CONTINUE
02720       DO 90 I=1,6
02730       READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(OFC(I,J),J=1,3),
02740+      (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),(RGF(I,J),J=1,3),(POP(I,J),J=1,3),
02750+      NRET(I),DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
02760    90 CONTINUE
```

Listing for OPTIONS Computer Code (continued)

```
02770   101 FORMAT(2I5,7F5.2)
02780   102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
02790   103 FORMAT(10X,10I5)
02800   104 FORMAT(A10,4E10.3)
02810   105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4E10.3)
02820   106 FORMAT(10X,7E10.3)
02830       DO 50 ISTR=1,NSTR
02840       A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
02850       A2=BAS(ISTR,3)/3.62 $ A3=A2/A1 $ BAS(ISTR,3)=A3
02860       DO 20 I=5,27
02870    20 BAS(ISTR,I)=BAS(ISTR,I)*A1
02880       BAS(ISTR,28)=BAS(ISTR,3) $ J=ISPC(ISTR,10)
02890C
02900C      THE FACTOR 3.62 IS THE NORMALIZATION VALUE
02910C      FOR ONE MILLION CUBIC METERS.
02920C      THE NEXT SECTION UNSCRAMBLES THE PROCESSING INDEX AND GETS
02930C      THE VOLUME REDUCTION METHOD - IP, SOLIDIFICATION - IS,
02940C      LOCATION - IL, AND ENVIRONMENT - IH.  IF IL=0 THEN THERE IS
02950C      NO PROCESSING AND THE SECTION IS SKIPPED, IF IL=2 THEN
02960C      THE DISPOSAL AND TRANSPORTATION VOLUMES ARE DIFFERENT
02970C
02980       BAS(ISTR,4)=BAS(ISTR,4)*A1
02990       IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
03000       IH=J-IP*1000-IS*100-IL*10 $ IF(NDX(ISTR).EQ.2)GO TO 31
03010       IF(IL.EQ.0) GO TO 50
03020       IF(IL.NE.2) GO TO 25
03030       BAS(ISTR,28)=A2 $ BAS(ISTR,4)=BAS(ISTR,4)/A1
03040    25 A5=0.5 $ IF(ISTR.GT.11)A5=0.1
03050C
03060C      NEXT DO LOOP CALCULATES WASTE PROCESSING IMPACTS
03070C
03080       DO 30 J=1,3
03090       A4=-A3*(AZR(ISTR)*A1-1.)*USAV(J)
03100       IF(IP.GT.0)A4=A4+A2*UPRS(IP,J)
03110       IF(IS.GT.0)A4=A4+A3*USOL(IS,J)
03120       IF(J.EQ.3)A4=A4*A5
03130    30 BAS(ISTR,28+J)=A4
03140C
03150C      NEXT SECTION FOR STREAMS PUT IN HIGH INTEGRITY CONTAINERS
03160C
03170    31 IF(NDX(ISTR).NE.2) GO TO 32
03180       A4=A2*450.
03190       BAS(ISTR,29)=A4
03200       IF(IL.EQ.0) GO TO 50
03210    32 CONTINUE
03220C
03230C      NEXT SECTION SKIPPED IF WASTE IS NOT INCINERATED
03240C      OTHERWISE, LOCATION DEPENDENT POP DOSES ARE CALCULATED
03250C
03260       IF(IP.LT.5)GO TO 50
03270       A5=0. $ J=2 $ IF(IP.EQ.5)J=1
03280       IF(IH.NE.1.AND.IH.NE.2)IH=1
03290       DO 40 INUC=1,NNUC
03300       A4=BAS(ISTR,3)*BAS(ISTR,INUC+4)*DEC(INUC,J)*TPOP(IH)
03310       DO 40 I=1,7
03320    40 A5=A5+A4*FICRP(I)*DCF(INUC,I,R)
03330       BAS(ISTR,32)=A5
```

Listing for OPTIONS Computer Code (continued)

```
03340C
03350C      ONLY ICRP WEIGHTED POPULATION IMPACTS ARE CALCULATED
03360C      ABOVE, TWO STATEMENTS BELOW MODIFY H-3 AND C-14
03370C      CONCENTRATIONS TO ACCOUNT FOR LOSS UP THE STACK.
03380C
03390       BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
03400       BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
03410    50 CONTINUE
03420       RETURN $ END
03430C
03440C
03450       SUBROUTINE RCLAIM(ISTR,NNUC,IMOD,IDX)
03460C
03470C      THIS ROUTINE CALCULATES THE INTRUDER IMPACTS FOR TWO PATHWAYS
03480C      - CONTRUCTION AND AGRICULTURE - AND DETERMINES THE STATUS OF
03490C      EACH WASTE STREAM ISPC(ISTR,11) AND DETERMINING TEST
03500C      CONDITION (IMOD).
03510C
03520       COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
03530+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
03540+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
03550+           /DTIS/FSC(6),FSA(6)/IMPS/DZ(8,7,2)
03560       DIMENSION EMP(5),DLC(7)
03570C
03580       DATA EMP/.5,.75,.5,.5,.75/,DLC/2*500.,1500.,3000.,3*1500./
03590       I5=ISPC(ISTR,5) $ I6=ISPC(ISTR,6) $ I7=ISPC(ISTR,7)
03600       I8=ISPC(ISTR,8) $ I9=ISPC(ISTR,9)
03610       IF(IDX.GT.1) I8=1
03620       A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
03630       CALL ZERO(DZ,112) $ IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
03640       FDES=EMP(IE)*(1.-.9*IG)
03650       A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
03660       A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
03670       A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
03680C
03690C      NEXT SECTION CALCULATES INTRUDER IMPACTS UNDER EIGHT
03700C      CONDITIONS (LOOP 35) AND SUBSEQUENTLY TESTS FOR STATUS ASSIGNMENT.
03710C      ULTIMATELY WASTE STREAM WILL BE CLASSIFIED AS EITHER NOT
03720C      ACCEPTABLE,REGULAR,LAYERED, OR HOT.
03730C
03740       DO 35 I3=1,8
03750       GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
03760       GO TO (11,12,13,14,15,16,17,18),I3
03770    11 A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
03780    12 A4C=0.012 $ A4A=0. $ A8C=0.012*A7 $ A8A=0. $ GO TO 20
03790    13 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
03800    14 A4C=0.1 $ A4A=0. $ A8C=A7/1200. $ A8A=0. $ GO TO 20
03810    15 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A7/1200. $ A8A=0. $ GO TO 20
03820    16 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
03830    17 A8C=0.1*A7/1.44E6 $ IF(IG.EQ.0)A8C=A8C*0.1
03840       A4C=0.01 $ A4A=0. $ A8A=0. $ GO TO 20
03850    18 GDEL=IPO+1000. $ A8C=A7 $ IF(IG.EQ.0)A8C=0.1*A7
03860       A4C=1. $ A4A=1. $ A8A=A8C
```

Listing for OPTIONS Computer Code (continued)

```
03870    20 DO 30 INUC=1,NNUC
03880       A1=A9*FDES*EXM(AL(INUC)*GDEL)*BAS(ISTR,INUC+4)
03890       DO 25 I=1,7
03900       A2=DCF(INUC,I,5)
03910       B1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
03920       B2=A1*A8C*A2*0.057
03930       B3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
03940       B4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
03950C      B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
03960C      B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
03970C      B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)
03980       B5=0.25*A1*ARA*A2*0.27
03990       DZ(I3,I,1)=DZ(I3,I,1)+B1+B2
04000    25 DZ(I3,I,2)=DZ(I3,I,2)+B3+B4+B5
04010    30 CONTINUE
04020    35 CONTINUE
04030C
04040C      ALL CONDITIONS TESTED - NOW DETERMINE WASTE STATUS
04050C
04060       I3=1 $ IF(IS.EQ.1.AND.IR.EQ.1) I3=2
04070       IF(ID.EQ.2) I3=2
04080       I30=I3
04090       IF(IDX.EQ.0) GO TO 70
04100    40 DO 50 IORG=1,7
04110       DO 50 IPTH=1,2
04120       IF(DZ(I3,IORG,IPTH).GT.DLC(IORG)) GO TO 60
04130    50 CONTINUE
04140       GO TO (51,52,51,53,53,54,55,56),I3
04150    51 ISPC(ISTR,11)=1
04160       IMOD=1 $ IF(I30.EQ.2) IMOD=2
04170       RETURN
04180    52 I3=3 $ GO TO 40
04190    53 I3=6 $ GO TO 40
04200    54 ISPC(ISTR,11)=2
04210       IMOD=4 $ IF(I30.EQ.2) IMOD=5
04220       RETURN
04230    55 I3=8 $ GO TO 40
04240    56 ISPC(ISTR,11)=3 $ IMOD=7
04250       RETURN
04260    60 GO TO (61,62,63,63,63,63,70,70),I3
04270    61 IF(IL.EQ.0)GO TO 63
04280       I3=4 $ GO TO 40
04290    62 IF(IL.EQ.0)GO TO 63
04300       I3=5 $ GO TO 40
04310    63 IF(IH.EQ.0)GO TO 70
04320       I3=7 $ GO TO 40
04330    70 ISPC(ISTR,11)=0
04340       RETURN $ END
04350C
04360C
```

Listing for OPTIONS Computer Code (continued)

```
04370       SUBROUTINE ACCEXP(NSTR,NNUC,NDX)
04380C
04390C      THIS ROUTINE CALCULATES THE EXPOSURE AND ACCIDENT IMPACTS
04400C      FOR 7 PATHWAYS (4 EXPOSURE AND 3 ACCIDENT) AND 7 ORGANS.
04410C
04420       COMMON/RAST/RAS(36,32),ISPC(36,11),DCF(23,7,8)
04430+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
04440+            /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
04450+            /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
04460+            TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6
04470+            /IMPS/DZDM(168),DZA(7,7),DZS(36,7,2)
04480       DIMENSION EMP(5),EFF(2),SEFF(2),NDX(36)
04490       DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,SEFF/0.9,0.35/
04500       VTOP=0. $ VTOT=0. $ VHOT=0. $ GREC=IPO+IIC
04510C
04520C      EROSION TIME SCALE DEPENDENT ON COVER USED AT DISPOSAL SITE
04530C
04540       GERO=IPO+2000.
04550       IF(IC.EQ.2) GERO=IPO+3000.
04560       IF(IC.EQ.3) GERO=IPO+10000.
04570       IF(ID.EQ.2) GERO=IPO+10000.
04580       DO 10 ISTR=1,NSTR
04590       II=ISPC(ISTR,11)
04600       IF(II.EQ.1)VTOP=VTOP+RAS(ISTR,3)
04610       IF(II.EQ.1.OR.II.EQ.2)VTOT=VTOT+RAS(ISTR,3)
04620       IF(II.EQ.3)VHOT=VHOT+RAS(ISTR,3)
04630    10 CONTINUE
04640C
04650C      VTOP IS JUST REGULAR WASTE
04660C      VTOT IS REGULAR + LAYERED WASTE
04670C
04680C
04690C      NEXT SECTION ESTABLISHES AREAL FACTORS FOR 4 EXPOSURE PATHWAYS
04700C
04710       FRA=5.72E-5*POP(IR,1)*1.8E+3 $ VUR=EMP(IE)*EFF(ID)*SEFF(ID)
04720       FEA=8.09E-6*POP(IR,2)*VTOT/VUR
04730       FRW=1.15E-4*POP(IR,3)*1.8E+3
04740       FEW=1.15E-4*POP(IR,3)*VTOT/VUR
04750C
04760C      MAIN LOOP FOR EXPOSURE IMPACTS
04770C
04780       DO 40 ISTR=1,NSTR
04790       A1=0.25 $ I11=ISPC(ISTR,11) $ IF(I11.EQ.0)GO TO 40
04800       I5=ISPC(ISTR,5) $ A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
04810       I9=ISPC(ISTR,9) $ A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
04820       I8=ISPC(ISTR,8) $ IF(NDX(ISTR).GT.1) I8=1
04830       IF(I8.EQ.1.AND.IS.EQ.1)A1=0.012/9.
04840       IF(I11.EQ.2.OR.ID.EQ.2)A1=A1*0.01
04850       IF(I11.EQ.3)A1=1.2E-5/9.
04860       A2=EMP(IE)*SEFF(ID)*BAS(ISTR,3)/VTOP
04870       A3=A2*VTOP/(VTOT+VHOT) $ IF(I11.GT.1)A2=0.
04880       IF(ID.EQ.2.AND.I11.NE.2) A2=A3
```

Listing for OPTIONS Computer Code (continued)

```
04890       DO 30 INUC=1,NNUC
04900       A6=EXM(GREC*AL(INUC)) $ A7=EXM(GERO*AL(INUC))
04910       A8=BAS(ISTR,INUC+4)
04920       B1=FRA*A1*A3*A6*A8*A5     $ B2=FEA*A2*A7*A8
04930       B3=FRW*A1*A3*A6*A8*A9     $ B4=FEW*A2*A7*A8
04940       DO 20 IORG=1,7
04950       DZA(IORG,1)=DZA(IORG,1)+B1*DCF(INUC,IORG,8)
04960       DZA(IORG,2)=DZA(IORG,2)+B2*DCF(INUC,IORG,8)
04970       DZA(IORG,3)=DZA(IORG,3)+B3*DCF(INUC,IORG,7)
04980       DZA(IORG,4)=DZA(IORG,4)+B4*DCF(INUC,IORG,7)
04990    20 CONTINUE
05000    30 CONTINUE
05010    40 CONTINUE
05020C
05030C      END EXPOSURE LOOP
05040C
05050       VSC=0. $ VFR=0.
05060C
05070C      MAIN LOOP OF ACCIDENT IMPACTS
05080C
05090       DO 80 ISTR=1,NSTR
05100       I3=ISPC(ISTR,11) $ IF(I3.EQ.0.OR.I3.EQ.3)GO TO 80
05110       I4=ISPC(ISTR,4) $ I6=ISPC(ISTR,6) $ I9=ISPC(ISTR,9)
05120       A5=BAS(ISTR,3) $ IF(I9.GT.1) GO TO 80
05130       FAF=TPO(IR,1) $ FAS=TPO(IR,2)
05140       IF(I6.GT.1) FAS=FAS*(10.**(1-I6))
05150       IF(I4.LT.3) FAF=FAF*(20.**(I4-3))
05160       IF(IS.EQ.1.AND.I4.NE.3) FAF=0.
05170C
05180C      DISTINGUISH BETWEEN SINGLE CONTAINER AND FIRE ACCIDENTS
05190C
05200       VFR=VFR+A5
05210       VSC=VSC+A5
05220       DO 70 INUC=1,NNUC
05230       A1S=FAS*BAS(ISTR,INUC+4)*A5
05240       A1F=FAF*BAS(ISTR,INUC+4)*A5
05250       DO 70 IORG=1,7
05260       DZS(ISTR,IORG,1)=DZS(ISTR,IORG,1)+A1S*DCF(INUC,IORG,1)/A5
05270       DZS(ISTR,IORG,2)=DZS(ISTR,IORG,2)+A1F*DCF(INUC,IORG,1)/A5
05280       DZA(IORG,5)=DZA(IORG,5)+A1S*DCF(INUC,IORG,1)
05290    70 DZA(IORG,6)=DZA(IORG,6)+A1F*DCF(INUC,IORG,1)
05300    80 CONTINUE
05310C
05320C      END OF ACCIDENT LOOP
05330C
05340C
05350C      LAST PATHWAY IS AVERAGED ACCIDENT
05360C
05370       DO 90 IORG=1,7
05380       DZA(IORG,7)=(DZA(IORG,5)+DZA(IORG,6))/(VSC+VFR)
05390       IF(VSC.GT.0.) DZA(IORG,5)=DZA(IORG,5)/VSC
05400       IF(VFR.GT.0.) DZA(IORG,6)=DZA(IORG,6)/VFR
05410    90 CONTINUE
05420       RETURN $ END
05430C
```

Listing for OPTIONS Computer Code (continued)

```
05440C
05450       SUBROUTINE TRANSP(TIMP,NSTR)
05460C
05470C      THIS ROUTINE DETERMINES THE TRANSPORTATION SCHEME FOR ALL
05480C      WASTE STREAMS BASED PRIMARILY ON THE PACKAGING INDEX OF
05490C      THE SPECTRUM FILES AND THE ACTIVITY CONCENTRATIONS OF THE
05500C      INDIVIDUAL STREAMS. ULTIMATE RESULT IS THE TRANSPORTATION
05510C      IMPACTS (TIMP).
05520C
05530       COMMON/BAST/BAS(36,32),ISPC(36,11)/DTNX/IR,ID,IC,IX,IF
05540       DIMENSION PCAR(6,3),PPAK(8,6),KON(18),TYM(2,18),KWT(18),
05550+      PDZ(2,3),PKV(5),TDZ(2,2),TCST(2,3),TIMP(6),TVOL(5,3),
05560+      DUM1(3),DUM2(3),DUM3(3,3),DIST(6),STPS(6),CASK(6)
05570C
05580C      THE ABOVE ARRAYS AND MATRICES ARE EXPLAINED BELOW:
05590C           PCAR(6,3)    : CONTAINS 6 DISTRIBUTIONS OF 3 CARE TYPES.
05600C           PPAK(8,6)    : CONTAINS 8 DISTRIBUTIONS OF 5 PACKING
05610C                          CONTAINERS + A POSITIONING INDEX.
05620C           KON(18)      : MULTIPLE INDEX WHICH DESCRIBES PACKING
05630C                          CAPABILITIES FOR 3 CARE TYPES AND 5
05640C                          CONTAINERS.
05650C           TYM(2,18)    : TIME IN MINUTES FOR UNLOADING OF WASTE
05660C                          (CONTACT TIME) - CORRESPONDING TO THE
05670C                          18 KON INDICES ABOVE.
05680C           TCST(2,3)    : TRANSPORTATION COST ($) PER MILE.
05690C           RDZ(2,3)     : RADIOLOGICAL COST (DOSE) PER HOUR OF
05700C                          CONTACT TIME WITH WASTE.
05710C           TDZ(2,2)     : TWO PART TRANSPORTATION DOSE: PER MILE,
05720C                          AND LUMP SUM PARAMETERS.
05730C           PKV(5)       : VOLUME CAPACITY FOR EACH OF 5 CONTAINERS.
05740C           KWT(18)      : INDEX TO RELATE TRANSPORT VEHICLE OVER-
05750C                          WEIGHT STATUS TO EACH OF KON INDICES.
05760C           DIST(6)      : TRAVEL DISTANCE TO DISPOSAL SITE IN
05770C                          VARIOUS REGIONS.
05780C           STPS(6)      : STATE INSPECTION STOPS TO BE EXPECTED
05790C                          WITHIN A PARTICULAR REGION.
05800C           CASK(6)      : NUMBER OF DAYS A CASK WOULD BE REQUIRED
05810C                          IN A PARTICULAR REGION.
05820C           OTHER ARRAYS AND MATRICES DESCRIBED FURTHER ON IN PROGRAM.
05830C
05840       DATA PCAR/1.,.8,.4,.2,.1,0.,0.,.2,.5,.6,.5,.2,0.,0.,.1,.2,.4,.8/
05850       DATA PPAK/0.,.23,5*0.,.1,.0,.,.08,.025,5*0.,.69,.69,.975,.2,1.,
05860+      3*0.,.15,0.,0.,.8,0.,.5,2*0.,.16,4*0.,.5,1.,0.,3.,1.,2.,4*3.,1./
05870       DATA KON/1103024,1104076,1236100,1370100,1411100,-1501100,
05880+           2103100,2236096,-2206004,2370048,-2314051,-2306001,
05890+           -2402100,-2501100,-3306051,-3301049,-3402100,-3501100/
05900       DATA TYM/200.,240.,74.,120.,16.,24.,6.,24.,136.,165.,1200.,1440.,
05910+           300.,360.,26.,39.,250.,300.,10.,24.,86.,175.,200.,312.,
05920+           600.,720.,1200.,1440.,200.,312.,600.,720.,600.,720.,
05930+           1500.,1800./,TCST/1.69,1.25,1.47,1.14,1.17,1.08/
05940       DATA RDZ/500.,750.,1200.,1800.,2200.,2200./,TDZ/1.8E-2,
05950+           2.0E-2,2.,2./,PKV/3.625,.453,.208,1.416,4.814/
05960       DATA KWT/16*0,2*1/,DIST/300.,400.,600.,1000.,2*400./,
05970+           STPS/2*1.,2.,3.,2*1./,CASK/2.,3.,5.,8.,2*3./
05980       CALL ZERO(TIMP,6) $ CALL ZERO(TVOL,15)
05990C
```

Listing for OPTIONS Computer Code (continued)

```
06000C      THIS SECTION -DO LOOP 160- DISTRIBUTES THE WASTE INTO THREE
06010C      CARE TYPES AND AMONG FIVE PACKING CONTAINERS. (3 CONTAINERS
06020C      ARE CONSIDERED IN EACH LOOP - IF APPLICABLE TO THAT STREAM.)
06030C
06040       DO 160 IPAK=1,8
06050       NX=0 $ CALL ZERO(DUM1,3)
06060C
06070C      DO LOOP 70 DISTRIBUTES WASTE AMONG CARE TYPES
06080C
06090       DO 70 ISTR=1,NSTR
06100       IF(ISPC(ISTR,11).EQ.0)GO TO 70
06110       I2=IABS(ISPC(ISTR,1))
06120       I1=I2/10 $ IF(I1.NE.IPAK)GO TO 70
06130       I3=I2-I1*10 $ A1=BAS(ISTR,28)
06140C
06150C      I1 = PACKAGING INDEX      I3 = CARE TYPE INDEX
06160C
06170C      FOLLOWING SECTION DETERMINES I4 - INDEX FOR CARE TYPE
06180C      DISTRIBUTION - BASED ON UNDECAYED TOTAL ACTIVITY OF STREAM.
06190C
06200       A2=BAS(ISTR,4)*100. $ IF(I3.EQ.2) A2=BAS(ISTR,4)*10.
06210       NX=1 $ IF(I3.GT.2) GO TO 40
06220       I5=ALOG10(A2)
06230       IF(I3.EQ.2) GO TO 30
06240       IF(A2.LT.1.) I4=1
06250       IF(A2.GE.1.) I4=I5+2
06260       IF(I4.GT.6) I4=6
06270       GO TO 50
06280    30 IF(A2.LT.1.) I4=1
06290       IF(A2.GE.1.) I4=I5+2
06300       IF(I4.GT.4) I4=4
06310       GO TO 50
06320    40 I4=I3-2
06330    50 DO 60 I=1,3
06340    60 DUM1(I)=DUM1(I)+PCAR(I4,I)*A1
06350    70 CONTINUE
06360C
06370C      DUM1 CONTAINES WASTE VOLUME IN EACH OF 3 CARE TYPES
06380C
06390       IF(NX.EQ.0) GO TO 160
06400       A1=DUM1(1)+DUM1(2)+DUM1(3)
06410       I2=PPAK(IPAK,6)+0.1
06420C
06430C      DO LOOP 80 DISTRIBUTES WASTE AMONG CONTAINERS
06440C
06450       DO 80 I=1,3
06460       II=I-1
06470    80 DUM2(I)=PPAK(IPAK,I2+II)*A1
06480C
06490C      DUM2 CONTAINS WASTE VOLUME IN EACH OF 3 CONTAINERS CONSIDERED
06500C      IN THIS LOOP OF 160
06510C
06520       CALL ZERO(DUM3,9)
06530C
```

Listing for OPTIONS Computer Code (continued)

```
06540C      DO LOOP 130 DETERMINES PACKAGING STRATEGY FOR 3 CARE TYPES AND
06550C      3 CONTAINERS CONSIDERED FOR THIS LOOP OF IPAK. RESULTS ARE
06560C      PLACED IN DUM3.
06570C
06580       DO 130 J=1,3
06590       DO 120 I=1,3
06600       IF(DUM1(J).LE.0.0) GO TO 130
06610       IF(DUM2(I).LE.0.0) GO TO 120
06620       IF(DUM1(J)-DUM2(I))90,100,110
06630    90 DUM3(I,J)=DUM1(J)
06640       DUM2(I)=DUM2(I)-DUM1(J)
06650       DUM1(J)=-1.0 $ GO TO 130
06660   100 DUM3(I,J)=DUM1(J)
06670       DUM2(I)=-1.0 $ DUM1(J)=-1.0 $ GO TO 130
06680   110 DUM3(I,J)=DUM2(I)
06690       DUM1(J)=DUM1(J)-DUM2(I)
06700       DUM2(I)=-1.0
06710   120 CONTINUE
06720   130 CONTINUE
06730       DO 150 I=1,3
06740       II=I-1
06750       DO 150 J=1,3
06760   150 TVOL(I2+II,J)=TVOL(I2+II,J)+DUM3(I,J)
06770   160 CONTINUE
06780C
06790C      TVOL CONTAINS TOTAL WASTE VOLUME DISTRIBUTED FOR 3 CARE TYPES
06800C      AND 5 CONTAINERS FOR ALL WASTE STREAMS.
06810C
06820C
06830C      THIS SECTION -DO LOOP 240- CALCULATES THE TRANSPORTATION
06840C      IMPACTS RESULTING FROM TVOL DISTRIBUTION. (18 LOOPS REQUIRED
06850C      FOR CHARACTERIZING THE 3 CARE TYPES AND 5 CONTAINERS USED
06860C      IN THIS PROGRAM)
06870C      RESULTS ARE PLACED IN TIMP ARRAY, WHERE:
06880C           TIMP(1) = DOLLARS
06890C           TIMP(2) = ENERGY USE
06900C           TIMP(3) = TRANSPORTATION OCCUPATIONAL DOSE
06910C           TIMP(4) = TRANSPORTATION POPULATION DOSE
06920C           TIMP(5) = DISPOSAL SITE OCCUPATIONAL DOSE (UNLOADING)
06930C           TIMP(6) = TRANSPORTATION OCCUPATIONAL DOSE (LOADING)
06940C
06950C
06960       DO 240 IKON=1,18
06970       II=KON(IKON) $ NX=1 $ FRC=1.0
06980C
06990C      IF KON INDEX IS NEGATIVE THEN RETURN TRIP IS NECESSARY.
07000C
07010       IF(II.GT.0) GO TO 210
07020       II=-II $ NX=2
07030   210 I3=II/100000 $ I2=I3/10 $ I1=I3-I2*10
07040       I5=II-I3*100000 $ I3=I5/1000 $ I4=I5-I3*1000
07050C
07060C      IN ABOVE SECTION KON BROKEN UP INTO:
07070C      I1 = PACKAGE TYPE      I3 = NO. OF PACKAGES THIS SHIPMENT
07080C      I2 = CARE TYPE         I4 = PCT. OF WASTE SENT THIS SHIPMENT
07090C
```

Listing for OPTIONS Computer Code (continued)

```
07100       IF((I2.EQ.1).OR.(I2.EQ.2.AND.NX.EQ.2)) FRC=0.1
07110       FRS=I4/100 $ A1=TVOL(I1,I2)*FRS
07120       IF(A1.LT.1.E-06) GO TO 240
07130       KSHP=A1/(I3*PKV(I1))+1.0
07140       A2=KSHP*DIST(IR) $ A3=A2*NX
07150       TIMP(2)=TIMP(2)+A3/6.
07160C
07170C      IN ABOVE EQUATION 6 REPRESENTS MILES PER GALLON FUEL CONSUMPTION.
07180C
07190       TIMP(4)=TIMP(4)+(A2*TDZ(1,1)+KSHP*TDZ(1,2)*STPS(IR))*FRC
07200       TIMP(3)=TIMP(3)+(A2*TDZ(2,1)+KSHP*TDZ(2,2)*STPS(IR))*FRC
07210       NC=2 $ IF(DIST(IR).GT.400..AND.DIST(IR).LT.1000.) NC=2
07220       IF(DIST(IR).LE.400.) NC=1
07230       TIMP(1)=TIMP(1)+A3*TCST(NX,NC)*1.15
07240C
07250C      IN NEXT SECTION CASK RENTAL FEE AND OVERWEIGHT FEE ADDED -
07260C      IF APPLICABLE.
07270C
07280       IF(NX.EQ.1) GO TO 220
07290       TIMP(1)=TIMP(1)+KSHP*CASK(IR)*250.
07300       IF(KWT(IKON).GT.0)TIMP(1)=TIMP(1)+A2*0.76+60.*STPS(IR)
07310   220 KPAK=A1/PKV(I1)+1.0
07320       NX=2 $ IF(IF.EQ.1.OR.IE.EQ.4) NX=1
07330       FRC=1.0 $ IF(IE.EQ.3) FRC=2.0
07340       A2=KPAK*TYM(NX,IKON)/60.
07350       TIMP(5)=TIMP(5)+A2*FRC*RDZ(NX,I2)*1.E-3
07360       TIMP(6)=TIMP(6)+A2*RDZ(2,I2)*1.E-3
07370   240 CONTINUE
07380       RETURN $ END
07390C
07400C
07410       SUBROUTINE ECON(NSTR,RI,RJ,COST,NDX)
07420C
07430C      THIS ROUTINE CALCULATES THE DISPOSAL IMPACTS BASED LARGELY
07440C      ON THE INPUTED VALUES FOR THE DISPOSAL TECHNOLOGY INDICES.
07450C      THE RESULTS OF THIS ROUTINE ARE PLACED IN ARRAY COST, WHERE:
07460C           COST(1) = PRE-OP AND OPERATIONAL DOLLARS
07470C           COST(2) = OCCUPATIONAL DOSE
07480C           COST(3) = ENERGY USE
07490C           COST(4) = LAND USE
07500C           COST(5) = POST-OP DOLLARS
07510C
07520       COMMON/BAST/BAS(36,32),ISPC(36,11)
07530       COMMON/DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
07540       COMMON/VOL/VREG,VLAY,VHOT
07550       DIMENSION EMP(5),EFF(2),AMULT(2),CONT(6),COST(5),SEFF(2)
07560       DIMENSION NDX(36)
07570C
07580C      THE SIGNIFICANT ARRAYS ABOVE ARE:
07590C      AMULT(2)    = CAPITAL AND OPERATIONS COST ($) MULTIPLIERS.
07600C      CONT(3)     = CONTINGENCY COST FOR SOIL PERMEABILITY CONDITIONS.
07610C      COST(5)     = CONTAINS RESULTANT IMPACTS - IN TERMS OF $,
07620C                    OCCUPATIONAL DOSE, ENERGY USE, LAND USE, AND
07630C                    POST OPERATIONAL $.
07640C
07650C
```

Listing for OPTIONS Computer Code (continued)

```
07660C      RI AND RJ PARAMETERS ARE INTEREST AND INFLATION RATES, RESPECTIVELY.
07670C
07680       DATA CONT/1007.,367.,367.,0.,168.,1007./,ITO,F/20,.015/
07690       DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,AMULT/10.38,1.56/,
07700+           SEFF/.9,.35/
07710       CALL ZERO(COST,5)
07720       VSTAB=0. $ VUNS=0. $ DECON=0.
07730       DO 5 ISTR=1,NSTR
07740       I11=ISPC(ISTR,11)  $ I2=ISPC(ISTR,8)
07750       IF(NDX(ISTR).GT.1) I2=1
07760       IF(I11.EQ.0.OR.I11.EQ.3) GO TO 5
07770       IF(IE.EQ.3.AND.I2.EQ.0) DECON=DECON+BAS(ISTR,3)
07780       IF(I2.EQ.0) VSTAB=VSTAB+BAS(ISTR,3)
07790       IF(I2.EQ.1) VUNS=VUNS+BAS(ISTR,3)
07800     5 CONTINUE
07810       IF(IE.EQ.3) IS=1
07820C
07830C      VSTAB &_ VUNS CONTAIN STABLE AND UNSTABLE WASTE VOLUMES,RESPECTIVELY
07840C
07850       DREG=(VREG+VLAY)*1.E-06 $ DHOT=VHOT*1.E-06
07860       DLAY=VLAY*1.E-06        $ DECON=DECON*1.E-06
07870       DVOL=DREG/EMP(IE)       $ DAREA=DVOL/(EFF(ID)*SEFF(ID))
07880       GV=(1.-EMP(IE))*DVOL $ VTOT=VREG+VLAY+VHOT
07890       SV=DREG*((1.1567/EMP(IE))-1.)
07900C
07910C      VOLUME AND AREA VALUES ARE EXPRESSED IN UNITS OF MILLION M3 OR M2
07920C      FOR USE IN COST EVALUATIONS. GV IS GROUT VOLUME. SV IS SAND VOLUME.
07930C
07940       COST(4)= (DAREA           +(DHOT/1.84))*1.E6
07950       S1=(VSTAB/VREG)*DAREA $ S2=(VUNS/VREG)*DAREA
07960C
07970C      IN FOLLOWING SECTION C1,C2, AND C3 WILL ACCUMULATE THE DOLLAR,
07980C      DOSE, AND ENERGY COSTS THROUGH THE VARIOUS PHASES OF THE SITE LIFE.
07990C
08000C
08010C      PRE-OPERATIONAL (CAPITAL) COSTS
08020C
08030C      ******** REFERENCE BASE CASE ********
08040       C1=7452. $ COST(3)=212.
08050C      ******** ADDITIVE ALTERNATIVES ******
08060       IF(ID.EQ.2) C1=C1+593.5
08070       IF(IE.EQ.2 .OR.IE.EQ.5) C1=C1+225.5
08080       IF(IS.EQ.1) C1=C1+0.99
08090       IF(IL.EQ.1) C1=C1+132.
08100       IF(IE.EQ.3) C1=C1+924.3
08110       IF(IH.EQ.1) C1=C1+259.4
08120       IF(IG.EQ.1) C1=C1+55.
08130       IF(IC.EQ.3) C1=C1+280.5
08140       IF(IX.EQ.3) C1=C1+9.9
08150       CAP=C1*AMULT(1)
08160C
08170C
```

Listing for OPTIONS Computer Code (continued)

```
08180C      OPERATIONAL COSTS
08190C
08200C      ******** REFERENCE BASE CASE ********
08210       C1=2341.*DVOL $ C2=300.*DVOL $ C3=200.*DVOL
08220       C1=C1+1420.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+100.*DAREA
08230       C1=C1+63696. $ C2=C2+1000. $ C3=C3+200.
08240C
08250C      ******** ADDITIVE ALTERNATIVES ******
08260       IF(ID.NE.2) GO TO 20
08270       C1=C1+74438.*DVOL $ C2=C2+700.*DVOL $ C3=C3+300.*DVOL
08280    20 IF(IE.LT.5.AND.NE.2) GO TO 25
08290       C1=C1+12758.*DREG $ C2=C2+100.*DREG $ C3=C3+100.*DREG
08300    25 IF(IS.NE.1) GO TO 30
08310       C1=C1+3888.*DREG $ C2=C2+100.*DREG $ C3=C3+30.*DREG
08320    30 IF(IL.NE.1) GO TO 35
08330       C1=C1+15400.*DLAY $ C2=C2+100.*DLAY $ C3=C3+30.*DLAY
08340    35 IF(IE.NE.3) GO TO 40
08350       C1=C1+48975.*DECON $ C2=C2+400.*DECON $ C3=C3+100.*DECON
08360    40 IF(IH.NE.1) GO TO 45
08370       C1=C1+176979.*DHOT $ C2=C2+(-200.)*DHOT $ C3=C3+450.*DHOT
08380    45 IF(IG.NE.1) GO TO 46
08390       C1=C1+72405.*GV $ C2=C2+2550.*GV $ C3=C3+800.*GV
08400    46 IF(IE.LT.4) GO TO 50
08410       C1=C1+3270.*SV $ C3=C3+150.*DAREA
08420    50 IF(IC.NE.2) GO TO 55
08430       C1=C1+15524.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+150.*DAREA
08440    55 IF(IC.NE.3) GO TO 60
08450       C1=C1+103854.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+300.*DAREA
08460    60 IF(IX.EQ.1) GO TO 75
08470       S3=S2
08480       IF(IS.EQ.0) S3=S1+S2
08490       IF(ID.EQ.2) S3=0.
08500       IXX=IX-1 $ GO TO (65,70),IXX
08510    65 C1=C1+3465.*S3 $ C2=C2+4800.*S3 $ C3=C3+300.*S3
08520       GO TO 75
08530    70 C1=C1+33345.*S3 $ C2=C2+4800.*S3 $ C3=C3+600.*S3
08540    75 OPS=C1*AMULT(2)
08550       COST(2)=COST(2)+C2 $ COST(3)=COST(3)+C3
08560C
08570C
08580C      POST-OPERATIONAL COSTS
08590C
08600C      ICL IS BROKEN INTO TWO PARTS TO INDICATE THE LEVEL OF
08610C      CLOSURE AND INSTITUTIONAL CARE, RESPECTIVELY.
08620C
08630C      ******** CLOSURE PERIOD ********
08640       ICL1=ICL/10 $ ICL2=ICL-ICL1*10
08650       C1=1010. $ C2=500. $ C3=15.
08660       IF(ICL1.NE.2) GO TO 76
08670       C1=3025. $ C2=1000. $ C3=60.
08680C
```

Listing for OPTIONS Computer Code (continued)

```
08690C      ******** INSTITUTIONAL PERIOD ****
08700C
08710C      DOLLAR COST SECTION
08720C
08730    76 CA=150. $ CB=63. $ CC=51.
08740       IF(ICL2.NE.2) GO TO 77
08750       CA=303. $ CB=150. $ CC=63.
08760    77 IF(ICL2.NE.3) GO TO 78
08770       CA=440.+CONT(IR) $ CB=303. $ CC=150.
08780    78 S1=0. $ S2=0. $ S3=0.
08790       DO 80 N=1.10
08800       E=N
08810       D1=(1.+RJ)**E $ D2=(1.+RI)**E
08820    80 S1=S1+D1/D2
08830       DO 85 N=11.25
08840       E=N
08850       D1=(1.+RJ)**E $ D2=(1.+RI)**E
08860    85 S2=S2+D1/D2
08870       DO 90 N=26.IIC
08880       E=N
08890       D1=(1.+RJ)**E $ D2=(1.+RI)**E
08900    90 S3=S3+D1/D2
08910       PV80=CA*S1+CB*S2+CC*S3
08920       M=IPO+ITO
08930       EM=M $ EITO=ITO $ EIPO=IPO
08940       D1=(1.+RJ)**EITO $ D2=(1.+RJ)**EM
08950       D3=(1.+RI)**EITO $ D4=(1.+RI)**EIPO
08960       U3=(EITO*PV80*D2*RI)/((D3-1.)*D4)
08970       U3=(EITO*C1*D1*F) + U3
08980       COST(1)=CAP+OPS $ COST(5)=U3
08990C
09000C       ENERGY USE SECTION
09010C
09020       IICC=(IIC-26)+1
09030       GO TO (100,110,120),ICL2
09040   100 C3=C3+10*5.+15*3.+IICC*1.
09050       GO TO 125
09060   110 C3=C3+10*10.+15*5.+IICC*3.
09070       GO TO 125
09080   120 C3=C3+10*12.+15*10.+IICC*5.
09090   125 CONTINUE
09100       COST(1)=COST(1)*1000.
09110       COST(2)=COST(2)+C2 $ COST(5)=COST(5)*1000.
09120       COST(3)=COST(3)+C3 $ COST(3)=COST(3)*1000.
09130       RETURN $ END
09140C
09150C      UTILITY SUBROUTINES
09160C
09170       SUBROUTINE ZERO(A,N)
09180       DIMENSION A(N)
09190       DO 10 I=1,N
09200    10 A(I)=0.
09210       RETURN $ END
09220C
```

Listing for OPTIONS Computer Code (continued)

```
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END
      SUBROUTINE PRT(V,IQ,N,ID,NDX)
      COMMON/BAST/BAS(36,32),ISPC(36,11)
      DIMENSION IQ(36),LAB(4),NDX(36)
      DATA LAB/10HCH-STAB   ,10HCH-UNSTAB ,10HNCH-STAB  ,10HNCH-UNSTAB/
      IF(N.EQ.0)RETURN
      GO TO (10,10,50,70),ID
   10 IF(ID.EQ.1)WRITE(4,410)V
      IF(ID.EQ.2)WRITE(4,420)V
      DO 25 K=1,4
      IT=0 $ VTOT=0.
      DO 20 I=1,N
      ISTR=IQ(I)
      I8=ISPC(ISTR,8) $ I7=ISPC(ISTR,7)
      IF(NDX(ISTR).GT.1) I8=1
      IF(K.NE.1.AND.I7.EQ.1.AND.I8.EQ.1) GO TO 20
      IF(K.NE.2.AND.I7.EQ.1.AND.I8.EQ.0) GO TO 20
      IF(K.NE.3.AND.I7.EQ.0.AND.I8.EQ.1) GO TO 20
      IF(K.NE.4.AND.I7.EQ.0.AND.I8.EQ.0) GO TO 20
      IF(IT.EQ.0)WRITE(4,430)LAB(K),BAS(ISTR,1),BAS(ISTR,3)
      IF(IT.EQ.1)WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
      IT=1 $ VTOT=VTOT+BAS(ISTR,3)
   20 CONTINUE
      IF(IT.EQ.1) WRITE(4,470)VTOT
   25 CONTINUE
      RETURN
   50 WRITE(4,450)V
      DO 55 I=1,N
      ISTR=IQ(I)
   55 WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
      RETURN
   70 WRITE(4,460)V
      DO 75 I=1,N
      ISTR=IQ(I)
   75 WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
  410 FORMAT(/2X*REGULAR WASTE :*,21X,E10.3,5H M**3)
  420 FORMAT(/2X*LAYERED WASTE :*,21X,E10.3,5H M**3)
  430 FORMAT(7X,A10,A10,E10.3)
  440 FORMAT(17X,A10,E10.3)
  450 FORMAT(/2X*HOT WASTE     :*,21X,E10.3,5H M**3)
  460 FORMAT(/2X*NOT ACCEPTABLE:*,21X,E10.3,5H M**3)
  470 FORMAT(1BX*TOTAL VOLUME  :*5X,E10.3,5H M**3)
      RETURN $ END
```

Listing for INVERSI Computer Code

```
00100       PROGRAM INVERSI(INPUT,OUTPUT,TAPE1,TAPE2)
00110C
00120C      THIS IS THE INVERSE INTRUDER AND ACCIDENT CODE.  IT FINDS
00130C      THE INDIVIDUAL NUCLIDE CONCENTRATIONS NECESSARY TO REACH
00140C      DOSES ASSIGNED BY THE DLC (DOSE LIMITING CRITERIA).
00150C
00160       COMMON/BAST/DCF(23,7,8),FICRP(7)/DTNX/IRDC(12)
00170+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
00180+            /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3)
00190+                  RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6
00200+            /IMPS/DMY(23,8,14)
00210C
00220C      MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
00230C      DTNX BLOCK CONTAINS THE DISPOSAL TECHNOLOGY INDICES.
00240C      DMY(23,8,14) WILL CONTAIN THE CONCENTRATIONS FOR ALL NUCLIDES,
00250C      7 ORGANS, AND SEVERAL PATHWAYS.
00260C
00270       DIMENSION DES(20),ORGAN(8),ISPC(11)
00280       DATA ORGAN/10H   BODY   ,10H   BONE   ,10H   LIVER  ,10H  THYROID
00290+                 10H  KIDNEY  ,10H   LUNG   ,10H  GI-LLI  ,10H  MINIMUM
00300       DATA DES/10H UNS1-CON ,10H UNS1-AGR ,10H STA1-CON ,10H STA1-AGR ,
00310+              10H UNSL-CON ,10H UNSL-AGR ,10H STAL-CON ,10H STAL-AGR ,
00320+              10H GEN5-CON ,10H GEN5-AGR ,10H HWF1-CON ,10H HWF1-AGR ,
00330+              10H HWF2-CON ,10H HWF2-AGR ,10H INT-AIR  ,10H ERO-AIR  ,
00340+              10H INT-WAT  ,10H ERO-WAT  ,10H ACC-CONT ,10H ACC-FIRE /
00350C
00360C      THE ABOVE ARRAYS ARE:
00370C          DES(20)    : DESCRIPTION OF PATHWAYS USED IN BOTH INTRUDER
00380C                       AND ACCIDENT SCENARIOS.
00390C          ORGAN(8)   : DESCRIPTION OF 7 ORGANS + A MINIMUM COLUMN.
00400C          ISPC(11)   : SPECTRUM INDICES READ IN THRU INPUT.
00410C
00420       DATA AL240/1.05E-4/
00430C
00440C      NEXT SECTION READS IN - THRU TAPE1 - THE NUCLIDE AND REGIONAL
00450C      DATA NECESSARY FOR THIS PROGRAM.
00460C
00470       READ(1,101)NSTR,NNUC,FICRP
00480       DO 20 I=1,NNUC
00490       READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
00500       DO 10 K=1,8
00510       READ(1,106)(DCF(I,J,K),J=1,7)
00520    10 CONTINUE
00530    20 CONTINUE
00540       DO 30 I=1,6
00550       READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
00560+                 (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
00570+                 (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
00580+                 DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
00590    30 CONTINUE
00600   101 FORMAT(2I5,7F5.2)
00610   104 FORMAT(A10,4E10.3)
00620   105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4F10.3)
00630   106 FORMAT(10X,7E10.3)
00640C
```

Listing for INVERSI Computer Code (continued)

```
00650C      NEXT, THE 12 DISPOSAL TECHNOLOGY AND 6 SPECTRUM INDICES ARE
00660C      READ IN THRU INPUT.
00670C
00680       READ,IRDC
00690       READ,(ISPC(J),J=4,9)
00700       WRITE(2,1010)IRDC $ WRITE(2,1020)(ISPC(J),J=4,9)
00710       CALL ZERO(DMY,2576) $ CALL RINV(ISPC,NNUC) $ CALL MIN(DMY,14)
00720C
00730C      ABOVE SUBROUTINE RINV WAS CALLED TO CALCULATE CONCENTRATIONS
00740C      WHICH ARE RETURNED IN DMY MATRIX. SUBROUTINE MIN FINDS
00750C      SMALLEST CONCENTRATION FOR EACH NUCLIDE - OVER ALL 7 ORGANS.
00760C
00770C      LOOP 40 CONSIDERS DAUGHTER IN-GROWTH AND PRINTS OUT INTRUDER
00780C      CONCENTRATIONS TO TAPE2.
00790C
00800       DO 40 K=1,14
00810       A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
00820       IF(A1.GT.A2) DMY(17,8,K)=A2
00830       A1=DMY(17,9,K) $ A2=DMY(23,8,K)*AL240/AL(23)
00840       IF(A1.GT.A2) DMY(17,8,K)=A2
00850       A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
00860       IF(A1.GT.A2) DMY(20,8,K)=A2
00870       WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
00880       WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
00890    40 CONTINUE
00900       IF(I.NE.-1)GO TO 80
00910C
00920C      NEXT SECTION SIMILAR TO ONE ABOVE - ONLY NOW FOR ACCIDENT
00930C      SCENARIOS.
00940C
00950       CALL ZERO(DMY,1840) $ CALL AINV(ISPC,NNUC) $ CALL MIN(DMY,6)
00960       DO 50 K=1,6
00970       KK=K+14
00980       WRITE(2,1003) DES(KK),(ORGAN(J),J=1,8)
00990       WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
01000    50 CONTINUE
01010    80 CONTINUE
01020 1003 FORMAT(//2X,A9,2X,8A10)
01030 1004 FORMAT(2X,A10,8E10.2)
01040 1010 FORMAT(1H1/2X,*DISPOSAL TECHNOLOGY INDICES*/2X
01050+                *IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
01060+                *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
01070+                *IH =*I2*  ICL=*I2*  IPO=*I2*  IIC=*I4)
01080 1020 FORMAT(/2X*SPECTRAL INDICES*/2X
01090+                *FLAM  =*I2*   DISP  =*I2/2X
01100+                *LEACH =*I2*   CHEM  =*I2/2X
01110+                *STABI =*I2*   ACCES =*I2/)
01120       STOP $ END
01130C
01140C
01150       SUBROUTINE RINV(ISPC,NNUC)
01160C
01170C      THIS ROUTINE DOES MOST OF THE WORK IN CALCULATING THE
01180C      CONCENTRATIONS. IT IS SIMILAR TO SUBROUTINE RCLAIM IN
01190C      THE OPTIONS CODE EXCEPT THE PATHWAY EQUATIONS HAVE BEEN
01200C      MODIFIED TO FIND THE CONCENTRATIONS WHEN THE DOSES ARE
01210C      GIVEN.
```

Listing for INVERSI Computer Code (continued)

```
01220C
01230       COMMON/BAST/DCF(23,7,8)/DTIS/FSC(6),FSA(6)/IMPS/DMY(23,8,14)
01240+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
01250+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
01260       DIMENSION EMP(3),ISPC(11),DLC(7)
01270       DATA EMP/.5,.75,.5/,DLC/2*500.,1500.,3000.,3*1500./
01280C
01290C      THE ABOVE ARRAYS ARE:
01300C          EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
01310C          ISPC(11)  : SPECTRUM INDICES PASSED FROM MAIN PROGRAM
01320C          DLC(7)    : DOSE LIMITING CRITERIA FOR 7 ORGANS
01330C
01340       I5=ISPC(5) $ I6=ISPC(6) $ I7=ISPC(7)
01350       I8=ISPC(8) $ I9=ISPC(9) $ NSTB=0
01360       IF(I8.EQ.1.AND.IS.EQ.1)NSTB=1
01370       A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
01380       IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
01390       FDES=EMP(IE)*(1.-.9*IG)
01400       A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
01410       A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
01420       A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
01430C
01440C      OUTSIDE LOOP IN CONCENTRATION CALCULATIONS - SETS UP
01450C      PARAMETERS NEEDED FOR TESTING WASTE STREAMS AT ALL THREE
01460C      CLASSIFICATION LEVELS:REGULAR, LAYERED, AND HOT.
01470C
01480       DO 50 I3=1,7
01490       GO TO (11,12,13,14,15,16,17),I3
01500    11 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
01510       A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
01520    12 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
01530       A4C=0.012 $ A4A=0. $ A8C=0.012*A7 $ A8A=0. $ GO TO 20
01540    13 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
01550       A4C=0.1 $ A4A=0. $ A8C=A7/1200. $ A8A=0. $ GO TO 20
01560    14 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
01570       A4C=0.0012 $ A4A=0. $ A8C=0.0012*A7/1200. $ A8A=0. $ GO TO 20
01580    15 GDEL=IPO+500.
01590       A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
01600    16 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
01610       A4C=0.01 $ A8C=0.1*A7/1.44E6 $ IF(IG.EQ.0)A8C=0.1*A8C
01620       A4A=0. $ A8A=0. $ GO TO 20
01630    17 GDEL=IPO+1000.
01640       A4C=1. $ A8C=A7 $ IF(IG.EQ.0)A8C=0.1*A8C
01650       A4A=1. $ A8A=A8C
01660C
01670C      MAIN CALCULATION LOOP
01680C
01690    20 DO 40 INUC=1,NNUC
01700       A1=A9*FDES*EXM(AL(INUC)*GDEL)
01710       DO 30 I=1,7
01720       A2=DCF(INUC,I,5)
01730       R1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
01740       R2=A1*A8C*A2*0.057
01750       R3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
01760       R4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
```

Listing for INVERSI Computer Code (continued)

```
01770C      B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
01780C      B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
01790C      B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
01800       B5=0.25*A1*A8A*A2*0.27
01810       J=(I3-1)*2 $ A2=B1+B2 $ A3=B3+B4+B5
01820       IF(A2.NE.0.)DMY(INUC,I,J+1)=DLC(I)/A2
01830       IF(A3.NE.0.)DMY(INUC,I,J+2)=DLC(I)/A3
01840C
01850C      DMY CONTAINS CONCENTRATIONS FOR 2 INTRUDER PATHWAYS
01860C           (J+1) : CONSTRUCTION
01870C           (J+2) : AGRICULTURE
01880C
01890    30 CONTINUE
01900    40 CONTINUE
01910    50 CONTINUE
01920       RETURN $ END
01930C
01940C
01950       SUBROUTINE AINV(ISPC,NNUC)
01960C
01970C      THIS ROUTINE PERFORMS FUNCTION SIMILAR TO THE PRECEDING
01980C      SUBROUTINE - ONLY NOW FOR THE ACCIDENT SCENARIOS.
01990C
02000       COMMON/BAST/DCF(23,7,8)/IMPS/DMY(23,8,10)
02010+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
02020+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
02030+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
02040+           TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
02050       DIMENSION EMP(3),EFF(2),SEFF(2),ISPC(11),
02060+                 DLCEA(7),DLCEW(7),DLCAC(7)
02070       DATA EMP/.5,.75,.5/,EFF/6.4,7.0/,SEFF/0.9,0.35/,
02080+           DLCEA/7*100./,DLCEW/7*4./,DLCAC/7*500./
02090C
02100C      THE ABOVE ARRAYS ARE:
02110C          EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
02120C          EFF(2)    : LAND USE VOLUME EFFICIENCIES
02130C          SEFF(2)   : LAND USE SURFACE AREA EFFICIENCIES
02140C          ISPC(11)  : SPECTRUM INDICES PASSED FROM MAIN PROGRAM
02150C          DLCEA(7)  : DOSE LIMITING CRITERIA FOR EROSION AIR
02160C          DLCEW(7)  : DOSE LIMITING CRITERIA FOR EROSION WATER
02170C
02180       GREC=IPO+IIC $ GERO=IPO+2000.
02190       IF(IC.EQ.2)GERO=IPO+3000.
02200       IF(IC.EQ.3)GERO=IPO+10000.
02210       AREA=1.8E3*EMP(IE)/4.0
02220C      AREA=200.*EMP(IE)*0.012
02230C      AREA=18.*EMP(IE)/4.0
02240C      AREA=2.*EMP(IE)*0.012
02250C      AREA=0.2*EMP(IE)
02260C
02270C      NEXT SECTION ESTABLISHES AREAL FACTORS FOR 4 EXPOSURE PATHWAYS
02280C
02290       FRA=5.72E-5*POP(IR,1)*AREA   $ VUR=EFF(ID)*1.E-6
02300       FEA=8.09E-6*POP(IR,2)/VUR
02310       FRW=1.15E-4*POP(IR,3)*AREA
02320       FEW=1.15E-4*POP(IR,3)/VUR
02330       I5=ISPC(5) $ A5=1. $ IF(I5.LT.3)A5=10.**(I5-3)
02340       I9=ISPC(9) $ A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
```

Listing for INVERSI Computer Code (continued)

```
02350C
02360C      MAIN LOOP FOR EXPOSURE CONCENTRATION CALCULATIONS
02370C
02380       DO 20 INUC=1,NNUC
02390       A6=EXM(GREC*AL(INUC)) $ A7=EXM(GERO*AL(INUC))
02400       DO 10 IORG=1,7
02410       F1=FRA*A6*DCF(INUC,IORG,8)*A5*A9 $ F2=FEA*A7*DCF(INUC,IORG,8)
02420       F3=FRW*A6*DCF(INUC,IORG,7)*A5    $ F4=FEW*A7*DCF(INUC,IORG,7)
02430       IF(F1.NE.0.) DMY(INUC,IORG,1)=DLCEA(IORG)/F1
02440       IF(F3.NE.0.) DMY(INUC,IORG,3)=DLCEW(IORG)/F3
02450       IF(F2.NE.0.) DMY(INUC,IORG,2)=DLCEA(IORG)/F2
02460       IF(F4.NE.0.) DMY(INUC,IORG,4)=DLCEW(IORG)/F4
02470    10 CONTINUE
02480    20 CONTINUE
02490C
02500C      NEXT SECTION SETS UP PARAMETERS FOR FIRE(FAF) AND SINGLE
02510C      CONTAINER(FAS) ACCIDENTS.
02520C
02530       FAF=TPO(IR,1) $ FAS=TPO(IR,2)
02540       I6=ISPC(6) $ IF(I6.GT.1) FAS=FAS*(10.**(1-I6))
02550       I4=ISPC(4) $ IF(I4.LT.3) FAF=FAF*(20.**(I4-3))
02560       A9=1. $ I9=ISPC(9) $ IF(I9.GT.1)A9=10.**(1-I9)
02570       IF(IS.EQ.1.AND.I4.NE.3) FAF=0.
02580C
02590C      MAIN LOOP FOR ACCIDENT CONCENTRATION CALCULATIONS
02600C
02610       DO 70 INUC=1,NNUC
02620       DO 70 IORG=1,7
02630C
02640       A1=A9*FAS*DCF(INUC,IORG,1)
02650       A2=A9*FAF*DCF(INUC,IORG,1)
02660       IF(A1.NE.0.) DMY(INUC,IORG,5)=DLCAC(IORG)/A1
02670       IF(A2.NE.0.) DMY(INUC,IORG,6)=DLCAC(IORG)/A2
02680    70 CONTINUE
02690       RETURN $ END
02700C
02710       SUBROUTINE ZERO(A,N)
02720       DIMENSION A(N)
02730       DO 10 I=1,N
02740    10 A(I)=0.
02750       RETURN $ END
02760C
02770       FUNCTION EXM(A1)
02780       A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
02790       EXM=A2
02800       RETURN $ END
02810C
02820       SUBROUTINE MIN(D,N)
02830       DIMENSION D(23,8,14),X(7)
02840       DO 10 I=1,23
02850       DO 10 K=1,N
02860       DO 5 J=1,7
02870       X(J)=D(I,J,K)
02880       IF(X(J).EQ.0.) X(J)=1.E+99
02890     5 CONTINUE
02900       D(I,8,K)=AMIN1(X(1),X(2),X(3),X(4),X(5),X(6),X(7))
02910    10 CONTINUE
02920       RETURN $ END
```

Listing for INVERSW Computer Code

```
00100       PROGRAM INVERSW(INPUT,OUTPUT,TAPE1,TAPE2)
00110C
00120C      THIS IS THE INVERSE GROUNDWATER CODE.  IT FINDS INDIVIDUAL
00130C      NUCLIDE CONCENTRATIONS NECESSARY TO REACH DOSES ASSIGNED IN
00140C      THE DLC (DOSE LIMITING CRITERIA) STATEMENT.
00150C
00160       COMMON/PAST/DCF(23,7,8),FICRP(7)/DTNX/IRDC(12)
00170+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
00180+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
00190+                RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
00200+           /IMPS/DMY(23,8,5)
00210C
00220C      MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
00230C      DMY(23,8,5) WILL CONTAIN THE CONCENTRATIONS OUTPUTED FROM
00240C      SUBROUTINE GINV.
00250C
00260       DIMENSION DES(3),ORGAN(8),ISPC(11),LIM(3),CP(3)
00270       DATA ORGAN/10H   BODY   ,10H   BONE   ,10H   LIVER  ,10H  THYROID ,
00280+              10H  KIDNEY  ,10H   LUNG   ,10H  GI-LLI  ,10H  MINIMUM  /
00290       DATA DES/10H INT-WELL ,10H ROU-WELL ,10H POP-WELL /
00300       DATA LIM/8H ACTUAL ,8H  LOWER ,8H HIGHER /,CP/1.,.5,4./
00310C
00320C      THE ABOVE ARRAYS ARE:
00330C         DES(3)     : DESCRIPTION OF 3 GROUNDWATER PATHWAYS.
00340C         ORGAN(8)   : DESCRIPTION OF 7 ORGAN + A MINIMUM COLUMN.
00350C         ISPC(11)   : SPECTRUM INDICES READ IN THRU INPUT.
00360C         LIM(3)     : DESCRIPTION OF 3 RETARDATION LEVELS.
00370C         CP(3)      : MULTIPLIER USED IN MODIFING RETARDATION LEVEL.
00380C
00390       DATA AL240/1.05E-4/
00400C
00410C      NEXT SECTION READS IN - THRU TAPE1 - THE NUCLIDE AND
00420C      REGIONAL DATA NECESSARY FOR THIS PROGRAM.
00430C
00440       READ(1,101)NSTR,NNUC,FICRP
00450       DO 10 I=1,NNUC
00460       READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
00470       DO  5 K=1,8
00480     5 READ(1,106)(DCF(I,J,K),J=1,7)
00490    10 CONTINUE
00500       DO 15 I=1,6
00510       READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
00520+                 (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
00530+                 (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
00540+                 DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
00550    15 CONTINUE
00560   101 FORMAT(2I5,7F5.2)
00570   104 FORMAT(A10,4E10.3)
00580   105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4F10.3)
00590   106 FORMAT(10X,7E10.3)
00600C
00610C      REMAINING RETARDATION COEFFICIENTS ARE NOW COMPUTED
00620C
00630       DO 20 INUC=1,NNUC
00640       A2=RET(INUC,4) $ A1=(A2/RET(INUC,1))**0.334
00650       RET(INUC,5)=A2*A1 $ RET(INUC,3)=A2/A1
00660    20 RET(INUC,2)=RET(INUC,1)*A1
```

Listing for INVERSW Computer Code (continued)

```
00670C
00680C      THE 12 DISPOSAL TECHNOLOGY INDICES AND 6 NECESSARY SPECTRUM
00690C      INDICES ARE READ IN THRU INPUT.
00700C
00710       READ,IRDC $ READ,(ISPC(J),J=4,9)
00720       WRITE(2,1010)IRDC $ WRITE(2,1020)(ISPC(J),J=4,9)
00730C
00740C      LOOP 35 FINDS THE GROUNDWATER CONCENTRATIONS FOR EACH OF
00750C      THE 5 RETARDATION COEFFICIENTS. SUBROUTINE GINV DOES MOST OF
00760C      CALCULATIONS INVOLVED. DAUGHTER IN-GROWTH IS ALSO TAKEN
00770C      INTO CONSIDERATION.
00780C
00790       DO 35 IRET=1,5
00800       WRITE(2,1005) IRET $ CALL ZERO(DMY,920)
00810       CALL GINV(ISPC,NNUC,IRET) $ CALL MIN(DMY,3)
00820       DO 30 K=1,3
00830       A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
00840       IF(A1.GT.A2) DMY(17,8,K)=A2
00850       A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
00860       IF(A1.GT.A2) DMY(17,8,K)=A2
00870       A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
00880       IF(A1.GT.A2) DMY(20,8,K)=A2
00890       WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
00900       WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
00910    30 CONTINUE
00920    35 CONTINUE
00930C
00940    40 IR=IRDC(1) $ NR=NRET(IR)
00950C
00960C      LOOP 60 FINDS THE GROUNDWATER CONCENTRATIONS FOR THE
00970C      RETARDATION COEFFICIENT AS IMPLIED BY THE IR INDEX OF
00980C      DISPOSAL TECHNOLOGY. THIS LOOP HOWEVER VARIES THE PERCOLATION
00990C      VALUE. IT USES THE VALUE IMPLIED BY IR AS WELL AS HALF THIS
01000C      VALUE AND DOUBLE THIS VALUE.
01010C
01020       DO 60 KN=1,3
01030       A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
01040       IF(A1.GT.A2) DMY(17,8,K)=A2
01050       A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
01060       IF(A1.GT.A2) DMY(17,8,K)=A2
01070       A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
01080       IF(A1.GT.A2) DMY(20,8,K)=A2
01090       WRITE(2,1006) LIM(KN) $ CALL ZERO(DMY,920)
01100       PRC(IR,1)=PRC(IR,1)*CP(KN) $ PRC(IR,2)=PRC(IR,2)*CP(KN)
01110       CALL GINV(ISPC,NNUC,NR) $ CALL MIN(DMY,3)
01120       DO 50 K=1,3
01130       WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
01140       WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
01150    50 CONTINUE
01160    60 CONTINUE
01170C
01180 1001 FORMAT(12I3)
01190 1003 FORMAT(//2X,A9,8A10)
01200 1004 FORMAT(A10,8E10.2)
01210 1005 FORMAT(//2X,'RETARDATION COEFF. ',I2)
01220 1006 FORMAT(//2X,A7,'PERCOLATION VALUE')
```

Listing for INVERSW Computer Code (continued)

```
01230 1010 FORMAT(2X,*DISPOSAL TECHNOLOGY INDICES*/2X,
01240+               *IR =*,I2,*  ID =*,I2,*  IC =*,I2,*  IX =*,I2/2X,
01250+               *IE =*,I2,*  IS =*,I2,*  IL =*,I2,*  IG =*,I2/2X,
01260+               *IH =*,I2,*  ICL=*,I2,*  IPO=*,I2,*  IIC=*,I4)
01270 1020 FORMAT(/2X,*SPECTRAL INDICES*/2X,
01280+               *FLAM  =*,I2,*   DISP  =*,I2/2X,
01290+               *LEACH =*,I2,*   CHEM  =*,I2/2X,
01300+               *STARI =*,I2,*   ACCES =*,I2)
01310      STOP $ END
01320C
01330C
01340      SUBROUTINE GINV(ISPC,NNUC,NRT)
01350C
01360C     THIS ROUTINE CONTAINS THE ACTUAL CALCULATION OF THE
01370C     CONCENTRATIONS.
01380C
01390      COMMON/BAST/DCF(23,7,8)/IMPS/DMY(23,8,5)
01400+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
01410+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
01420+           /DTIS/FSC(6),FSA(6),PRC(6,2),OFC(6,3),TTM(6,3),
01430+           TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
01440      DIMENSION EMP(3),EFF(2),SEFF(2),DLC(7,3),ISPC(11)
01450      DATA NSEC/10/,DLC/2*500.,1500.,3000.,3*1500.,3*25.,75.,3*25.,7*4./
01460      DATA EMP/.5,.75,.5/,EFF/6.4,7.0/,SEFF/0.9,0.35/
01470C
01480C     THE MATRICES AND ARRAYS ABOVE ARE:
01490C         EMP(3)     : VOLUME EMPLACEMENT EFFICIENCIES
01500C         EFF(2)     : LAND USE VOLUME EFFICIENCIES
01510C         SEFF(2)    : LAND USE SURFACE AREA EFFICIENCIES
01520C         DLC(7,3)   : DOSE LIMITING CRITERIA FOR 7 ORGANS
01530C                      AND 3 PATHWAYS.
01540C                      PARTITIONED INTO.
01550C
01560      GDEL=0. $ VOR=1.0/(EMP(IE)*EFF(ID))
01570      IF(IC.EQ.1)PRCD=PRC(IR,1)
01580      IF(IC.GT.1)PRCD=PRC(IR,2)
01590      IF(IX.EQ.1)PRCD=4.*PRC(IR,1)
01600      IF(IX.GT.1)PRCD=2.25*PRCD
01610      I6=ISPC(6) $ I7=ISPC(7) $ I8=ISPC(8) $ I9=ISPC(9)
01620      PERC=PRCD $ IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
01630      IF(I8.NE.1.OR.IS.NE.1)GO TO 20
01640      IF(IC.EQ.1)PERC=PRC(IR,1)
01650      IF(IC.GT.1)PERC=PRC(IR,2)
01660   20 TVOL=352000.*SQRT(PRC(IR,1)*27.8)
01670      IF(ID.EQ.2.OR.IH.EQ.1)PERC=PRC(IR,2)/16.
01680      PERC=PERC*(1.0-0.9*IG)
01690      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
01700      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
01710      I1=NPT $ IF(IS.EQ.0.OR.I7.EQ.1)I1=I1-1
01720      TDUM=1.0/(PERC*VOR*A6*A9) $ IF(I1.LE.0)I1=1
01730C
```

Listing for INVERSW Computer Code (continued)

```
01740C      MAIN LOOP - GROUNDWATER PATHWAY EQUATIONS MANIPULATED SO
01750C                  AS TO FIND CONCENTRATIONS WHEN THE DOSE IS GIVEN.
01760C
01770       DO 80 INUC=1,NNUC
01780       TDUR=TDUM/FMF(INUC)
01790       DO 70 IPTH=1,3
01800       I2=4 $ IF(IPTH.EQ.3) I2=7
01810       R2=RGF(IR,IPTH)/(QFC(IR,IPTH)*NSFC*TDUR)
01820       IF(TVOL.GT.QFC(IR,IPTH))R2=R2*QFC(IR,IPTH)/TVOL
01830       A3=0. $ TNRT=RET(INUC,I1)*TTM(IR,IPTH)
01840       DO 40 ISEC=1,NSEC
01850       R3=TNRT+RET(INUC,I1)*(ISEC-1)*DTTM(IR)
01860       IF(R3.GE.TNRT+TDUR)GO TO 50
01870       A4=ISEC*EXM(AL(INUC)*R3)
01880       A3=AMAX1(A3,A4)
01890    40 CONTINUE
01900    50 DO 60 IORG=1,7
01910       AD=1.E6*A3*R2*DCF(INUC,IORG,I2)
01920       A1=0. $ IF(AD.NE.0.) A1=DLC(IORG,IPTH)/AD
01930    60 DMY(INUC,IORG,IPTH)=A1
01940    70 CONTINUE
01950    80 CONTINUE
01960       RETURN $ END
01970C
01980C
01990       SUBROUTINE ZERO(A,N)
02000       DIMENSION A(N)
02010       DO 10 I=1,N
02020    10 A(I)=0.
02030       RETURN $ END
02040C
02050       FUNCTION EXM(A1)
02060       A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
02070       EXM=A2
02080       RETURN $ END
02090C
02100       SUBROUTINE MIN(D,N)
02110C
02120C      THIS ROUTINE RETURNS THE SMALLEST CONCENTRATION - OVER
02130C      ALL 7 ORGANS - FOR EACH NUCLIDE.
02140C
02150       DIMENSION D(23,8,5),X(7)
02160       DO 10 I=1,23
02170       DO 10 K=1,N
02180       DO 5 J=1,7
02190       X(J)=D(I,J,K)
02200       IF(X(J).EQ.0.) X(J)=1.E+99
02210     5 CONTINUE
02220       D(I,8,K)=AMIN1(X(1),X(2),X(3),X(4),X(5),X(6),X(7))
02230    10 CONTINUE
02240       RETURN $ END
```

Listing of DATA Data File

```
  36   231.000 .120 .060 .030 .060 .120 .060
P-IXRESIN 1.100E-01 3.463E+04
         1 3.360E-02 2.660E-03 9.740E-05 2.340E-03 2.790E-06 4.530E-03
         1 8.610E-04 8.840E-08 1.940E-04 8.230E-07 2.440E-06 8.230E-07
         1 2.190E-02 4.710E-08 3.710E-07 9.060E-12 2.600E-05 1.820E-05
         1 7.940E-04 3.990E-08 4.154E-05 1.260E-06 9.920E-09 1.380E-05
P-CONCLIQ 1.100E-01 2.435E+05
         2 1.090E-01 3.450E-03 1.270E-04 2.270E-02 2.710E-05 4.400E-02
         2 8.360E-03 8.580E-07 2.520E-04 1.070E-06 3.160E-06 1.070E-06
         2 2.850E-02 6.150E-08 4.840E-07 1.180E-11 5.120E-05 3.310E-05
         2 1.440E-03 7.250E-08 7.132E-05 2.020E-06 1.170E-08 1.920E-05
P-FSLUDGE 1.100E-01 4.279E+03
         3 1.060E+00 2.590E-03 9.550E-05 3.100E-01 3.710E-04 6.000E-01
         3 1.140E-01 1.170E-05 1.890E-04 8.030E-07 2.370E-06 8.030E-07
         3 2.140E-02 1.460E-07 1.150E-06 2.810E-11 4.760E-05 1.550E-04
         3 6.750E-03 3.390E-07 4.581E-04 1.780E-05 3.100E-07 1.770E-04
P-FCARTRG 1.100E-01 2.177E+04
         4 1.860E+00 1.150E-03 4.250E-05 5.550E-01 6.600E-04 1.070E+00
         4 2.040E-01 2.090E-05 8.400E-05 3.580E-07 1.060E-06 3.580E-07
         4 9.540E-03 3.640E-07 2.870E-06 7.020E-11 2.510E-04 3.800E-04
         4 1.660E-02 8.340E-07 6.414E-04 1.100E-05 1.930E-07 1.100E-04
B-IXRESIN 1.200E-01 7.623E+04
         5 4.630E+00 1.920E-02 1.190E-03 9.480E-01 9.800E-04 1.590E+00
         5 2.150E-02 3.090E-05 3.640E-03 7.650E-05 2.040E-04 7.650E-05
         5 2.040E+00 5.330E-08 4.200E-07 1.020E-11 8.340E-05 5.340E-05
         5 2.600E-03 1.170E-07 9.798E-05 1.570E-06 2.700E-08 1.820E-05
B-CONCLIQ 1.200E-01 2.102E+05
         6 2.870E-01 6.240E-04 3.890E-05 7.940E-02 8.210E-05 1.330E-01
         6 1.800E-03 2.590E-06 1.180E-04 2.500E-06 6.650E-06 2.500E-06
         6 6.650E-02 3.440E-08 2.710E-07 6.610E-12 1.990E-04 9.430E-05
         6 4.600E-03 2.060E-07 2.523E-04 8.100E-06 2.590E-07 2.050E-04
B-FSLUDGE 1.200E-01 1.690E+05
         7 5.240E+00 1.260E-02 7.780E-04 1.440E+00 1.490E-03 2.410E+00
         7 3.250E-02 4.700E-05 2.370E-03 5.000E-05 1.330E-04 5.000E-05
         7 1.330E+00 3.320E-07 2.610E-06 6.380E-11 4.660E-04 2.360E-04
         7 1.150E-02 5.180E-07 4.868E-04 1.050E-05 2.970E-07 2.240E-04
P-COTRASH 2.100E-01 4.244E+05
         8 2.280E-02 3.040E-04 1.120E-05 5.970E-03 7.110E-06 1.150E-02
         8 2.190E-03 2.250E-07 2.220E-05 9.420E-08 2.780E-07 9.420E-08
         8 2.510E-03 7.890E-09 6.220E-08 1.520E-12 5.970E-06 5.530E-06
         8 2.410E-04 1.210E-08 1.089E-05 2.670E-07 2.740E-09 2.610E-06
P-NCTRASH 2.100E-01 2.178E+05
         9 5.250E-01 6.990E-03 2.570E-04 1.370E-01 1.640E-04 2.650E-01
         9 5.050E-02 5.180E-06 5.110E-04 2.170E-06 6.410E-06 2.170E-06
         9 5.780E-02 1.820E-07 1.430E-06 3.490E-11 1.380E-04 1.270E-04
         9 5.550E-03 2.790E-07 2.508E-04 6.150E-06 6.300E-08 6.000E-05
B-COTRASH 2.200E-01 2.086E+05
        10 2.350E-02 6.750E-05 4.170E-06 6.010E-03 6.210E-06 1.010E-02
        10 1.360E-04 1.960E-07 1.270E-05 2.680E-07 7.140E-07 2.680E-07
        10 7.140E-03 1.220E-09 9.600E-09 2.350E-13 2.300E-06 1.160E-06
        10 5.630E-05 2.530E-09 2.586E-06 6.520E-08 1.930E-09 1.490E-06
B-NCTRASH 2.200E-01 9.896E+04
        11 3.790E+00 1.090E-02 6.730E-04 9.690E-01 1.000E-03 1.620E+00
        11 2.190E-02 3.160E-05 2.050E-03 4.330E-05 1.150E-04 4.330E-05
        11 1.150E+00 1.970E-07 1.550E-06 3.780E-11 3.710E-04 1.860E-04
        11 9.080E-03 4.080E-07 4.172E-04 1.050E-05 3.120E-07 2.410E-04
F-COTRASH 2.110E-01 2.359E+05
        12 5.580E-06      0.          0.          0.          0.          0.
        12      0.        0.          0.          0.          0.          0.
        12      0.  1.180E-06 4.400E-06          0.          0.          0.
        12      0.        0.          0.          0.          0.          0.
F-NCTRASH 2.110E-01 4.171E+04
        13 5.330E-06      0.          0.          0.          0.          0.
        13      0.        0.          0.          0.          0.          0.
        13      0.  1.130E-06 4.200E-06          0.          0.          0.
        13      0.        0.          0.          0.          0.          0.
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Listing of DATA Data File (Continued)

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..          ..          ..          ..          ..          ..          ..
I-COTRASH 2.030E-01 1.407E+05
        14 1.130E-01 9.130E-02 5.260E-03       0.          0.    1.040E-02
        14       0.          0. 1.450E-03 3.390E-09          0.          0.
        14 4.560E-03          0.          0.          0.          0.          0.
        14       0.          0. 4.820E-06          0.          0.          0.
I+COTRASH 2.030E-01 1.407E+05
        15 1.130E-01 9.130E-02 5.260E-03       0.          0.    1.040E-02
        15       0.          0. 1.450E-03 3.390E-09          0.          0.
        15 4.560E-03          0.          0.          0.          0.          0.
        15       0.          0. 4.820E-06          0.          0.          0.
N-SSTRASH 2.060E-01 1.796E+05
        16 1.120E-05          0.          0.          0.          0.          0.
        16       0.          0.          0.          0.          0.          0.
        16       0. 2.360E-06 8.800E-06          0.          0.          0.
        16       0.          0.          0.          0.          0.          0.
N+SSTRASH 2.060E-01 1.796E+05
        17 1.120E-05          0.          0.          0.          0.          0.
        17       0.          0.          0.          0.          0.          0.
        17       0. 2.360E-06 8.800E-06          0.          0.          0.
        17       0.          0.          0.          0.          0.          0.
N-LOTRASH 2.070E-01 5.064E+04
        18 3.530E-02 2.850E-02 1.640E-03       0.          0.    3.250E-03
        18       0.          0. 4.530E-04 1.060E-09          0.          0.
        18 1.420E-03          0.          0.          0.          0.          0.
        18       0.          0. 1.510E-06          0.          0.          0.
N+LOTRASH 2.070E-01 5.064E+04
        19 3.530E-02 2.850E-02 1.640E-03       0.          0.    3.250E-03
        19       0.          0. 4.530E-04 1.060E-09          0.          0.
        19 1.420E-03          0.          0.          0.          0.          0.
        19       0.          0. 1.510E-06          0.          0.          0.
F-PROCESS 3.110E-01 7.816E+04
        20 1.080E-04          0.          0.          0.          0.          0.
        20       0.          0.          0.          0.          0.          0.
        20       0. 2.300E-05 8.540E-05          0.          0.          0.
        20       0.          0.          0.          0.          0.          0.
U-PROCESS 3.120E-01 2.811E+04
        21 3.800E-04          0.          0.          0.          0.          0.
        21       0.          0.          0.          0.          0.          0.
        21       0. 1.650E-05 3.640E-04          0.          0.          0.
        21       0.          0.          0.          0.          0.          0.
I-LQSCNVL 3.030E-01 4.914E+04
        22 9.600E-03 5.010E-03 2.510E-04       0.          0.          0.
        22       0.          0. 4.340E-03          0.          0.          0.
        22       0.          0.          0.          0.          0.          0.
        22       0.          0.          0.          0.          0.          0.
I+LQSCNVL 3.030E-01 4.914E+04
        23 9.600E-03 5.010E-03 2.510E-04       0.          0.          0.
        23       0.          0. 4.340E-03          0.          0.          0.
        23       0.          0.          0.          0.          0.          0.
        23       0.          0.          0.          0.          0.          0.
I-ABSLIQD 3.030E-01 5.585E+03
        24 1.990E-01 1.420E-01 8.160E-03       0.          0.    3.120E-02
        24       0.          0. 4.340E-03 1.020E-08          0.          0.
        24 1.370E-02          0.          0.          0.          0.          0.
        24       0.          0.          0.          0.          0.          0.
I+ABSLIQD 3.030E-01 5.585E+03
        25 1.990E-01 1.420E-01 8.160E-03       0.          0.    3.120E-02
        25       0.          0. 4.340E-03 1.020E-08          0.          0.
        25 1.370E-02          0.          0.          0.          0.          0.
        25       0.          0.          0.          0.          0.          0.
I-BIOWAST 3.030E-01 1.571E+04
        26 2.060E-01 1.750E-01 1.010E-02       0.          0.    3.990E-03
        26       0.          0. 8.330E-03 6.510E-09          0.          0.
        26 8.760E-03          0.          0.          0.          0.          0.
        26       0.          0.          0.          0.          0.          0.
I+BIOWAST 3.030E-01 1.571E+04
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Listing of DATA Data File (Continued)

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        27 2.060E-01 1.750E-01 1.010E-02      0.       0.    3.990E-03
        27      0.       0.    8.330E-03 6.510E-09      0.       0.
        27 8.760E-03      0.       0.       0.       0.       0.
        27      0.       0.       0.       0.       0.       0.
N-SSWASTE 3.060E-01 6.339E+04
        28 2.170E-04      0.       0.       0.       0.       0.
        28      0.       0.       0.       0.       0.       0.
        28      0.  4.600E-05 1.710E-04      0.       0.       0.
        28      0.       0.       0.       0.       0.       0.
N-LOWASTE 3.070E-01 6.027E+04
        29 2.110E-02 1.630E-02 9.360E-04      0.       0.    1.470E-03
        29      0.       0.    1.310E-03 7.760E-10      0.       0.
        29 1.040E-03      0.       0.       0.       0.       0.
        29      0.       0.       0.       0.       0.       0.
L-NFRCOMP 4.300E-01 2.887E+03
        30 4.040E+03      0.    2.590E-01 2.230E+03 1.400E+00 1.600E+03
        30 2.090E+02 8.190E-03      0.       0.       0.       0.
        30      0.       0.       0.       0.       0.       0.
        30      0.       0.       0.       0.       0.       0.
L-DECONRS 4.400E-01 3.498E+04
        31 1.560E+02 1.080E-02 6.880E-04 4.050E+01 4.490E-02 7.280E+01
        31 3.690E+00 1.420E-03 4.280E-02 1.200E-05 3.340E-05 1.200E-05
        31 3.180E-01 6.840E-05 5.400E-04 1.320E-08 1.340E+00 1.770E+00
        31 3.550E+01 3.870E-03 1.026E+00 3.590E-04 3.460E-04 3.270E-03
N-ISOPROD 4.040E-01 5.196E+03
        32 1.500E+01 4.200E-02 4.510E-05      0.       0.       0.
        32      0.       0.    6.270E+00 3.270E-04 2.720E-06 3.270E-04
        32 8.730E+00 1.020E-05 3.810E-05 5.330E-13 1.970E-04 5.550E-05
        32 7.100E-03 9.570E-08 2.152E-04 1.250E-06 1.650E-04 2.880E-07
N-HIGHACT 4.030E-01 2.608E+03
        33 2.100E+02      0.    1.320E-02 1.150E+02 6.560E-02 8.480E+01
        33 1.060E+01 4.470E-04      0.       0.       0.       0.
        33      0.       0.       0.       0.       0.       0.
        33      0.       0.       0.       0.       0.       0.
N-TRITIUM 4.050E-01 3.481E+03
        34 2.330E+03 2.330E+03      0.       0.       0.       0.
        34      0.       0.       0.       0.       0.       0.
        34      0.       0.       0.       0.       0.       0.
        34      0.       0.       0.       0.       0.       0.
N-SOURCES 4.030E-01 1.865E+02
        35 5.760E+03 2.090E+03 3.190E-03      0.       0.    8.120E+01
        35 1.050E+01      0.    2.870E+01      0.       0.       0.
        35 3.540E+03      0.       0.       0.       0.       0.
        35      0.       0.    1.600E+01      0.       0.       0.
N-TARGETS 4.030E-01 1.340E+03
        36 8.040E+01 8.040E+01      0.       0.       0.       0.
        36      0.       0.       0.       0.       0.       0.
        36      0.       0.       0.       0.       0.       0.
        36      0.       0.       0.       0.       0.       0.
H-3     5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3  /ACC 1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3  /CON 1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3  /AGR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3  /FOO 5.995E+04      0.    5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3  /DGM      0.       0.       0.       0.       0.       0.       0.
H-3  /WWT 2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3  /SWT 2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3  /AIR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14    1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14 /ACC 3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14 /CON 6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14 /AGR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14 /FOO 3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14 /DGM      0.       0.       0.       0.       0.       0.       0.
C-14 /WWT 1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14 /SWT 3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
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Listing of DATA Data File (Continued)

C-14	/AIR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
FE-55		2.670E-01	1.480E-02	6.300E+02	5.400E+03			
FE-55	/ACC	1.805E+10	1.885E+10	2.413E+10	1.613E+10	1.613E+10	2.081E+11	1.925E+10
FE-55	/CON	9.283E+09	4.816E+10	3.941E+10	5.080E+07	5.080E+07	2.095E+11	2.116E+10
FE-55	/AGR	3.219E+10	1.903E+11	1.376E+11	5.080E+07	5.080E+07	2.644E+11	7.752E+10
FE-55	/FOO	3.492E+01	2.161E+02	1.493E+02	0.	0.	8.331E+01	8.566E+01
FE-55	/DGM	0.	0.	0.	0.	0.	0.	0.
FE-55	/WWT	2.727E+06	1.244E+07	8.863E+06	8.609E+05	8.609E+05	5.326E+06	5.452E+06
FE-55	/SWT	4.450E+06	2.314E+07	1.625E+07	8.609E+05	8.609E+05	9.449E+06	9.692E+06
FE-55	/AIR	4.827E+10	2.064E+11	1.537E+11	1.613E+10	1.613E+10	2.804E+11	9.360E+10
NI-59		8.660E-06	1.480E-02	4.200E+02	3.600E+03			
NI-59	/ACC	3.698E+10	9.378E+10	5.058E+10	2.578E+10	2.578E+10	5.778E+10	2.850E+10
NI-59	/CON	3.872E+10	2.325E+11	8.130E+10	5.980E+07	5.980E+07	3.206E+10	1.441E+10
NI-59	/AGR	1.247E+11	7.476E+11	2.581E+11	5.980E+07	5.980E+07	3.206E+10	5.082E+10
NI-59	/FOO	3.693E+03	2.211E+04	7.590E+03	0.	0.	0.	1.563E+03
NI-59	/DGM	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03
NI-59	/WWT	8.537E+06	4.425E+07	1.609E+07	1.377E+06	1.377E+06	1.377E+06	4.408E+06
NI-59	/SWT	9.825E+06	5.196E+07	1.874E+07	1.377E+06	1.377E+06	1.377E+06	4.953E+06
NI-59	/AIR	1.505E+11	7.733E+11	2.838E+11	2.578E+10	2.578E+10	5.778E+10	7.654E+10
CO-60		1.320E-01	1.480E-02	4.200E+02	3.600E+03			
CO-60	/ACC	2.358E+12	2.336E+12	2.353E+12	2.336E+12	2.336E+12	2.634E+13	2.504E+12
CO-60	/CON	1.237E+11	2.280E+10	7.599E+10	2.280E+10	2.280E+10	2.402E+13	8.593E+11
CO-60	/AGR	3.695E+11	2.280E+10	1.874E+11	2.280E+10	2.280E+10	2.402E+13	2.953E+12
CO-60	/FOO	5.274E+03	0.	2.391E+03	0.	0.	0.	4.492E+04
CO-60	/DGM	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07
CO-60	/WWT	1.432E+08	1.238E+08	1.326E+08	1.238E+08	1.238E+08	1.239E+08	2.893E+08
CO-60	/SWT	1.458E+08	1.238E+08	1.338E+08	1.238E+08	1.238E+08	1.239E+08	3.112E+08
CO-60	/AIR	2.683E+12	2.336E+12	2.500E+12	2.336E+12	2.336E+12	2.634E+13	5.266E+12
NI-63		7.530E-03	1.480E-02	4.200E+02	3.600E+03			
NI-63	/ACC	3.056E+10	9.602E+11	6.576E+10	1.560E+08	1.560E+08	8.816E+10	7.436E+09
NI-63	/CON	1.040E+11	3.150E+12	2.176E+11	1.560E+08	1.560E+08	8.816E+10	3.911E+10
NI-63	/AGR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NI-63	/FOO	9.878E+03	2.945E+05	2.041E+04	0.	0.	0.	4.259E+03
NI-63	/DGM	0.	0.	0.	0.	0.	0.	0.
NI-63	/WWT	1.915E+07	5.711E+08	3.958E+07	4.276E-01	4.276E-01	2.416E+02	8.258E+06
NI-63	/SWT	2.260E+07	6.738E+08	4.670E+07	4.276E-01	4.276E-01	2.416E+02	9.743E+06
NI-63	/AIR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NB-94		3.470E-05	1.110E-02	1.000E+03	1.000E+04			
NB-94	/ACC	6.102E+11	6.114E+11	6.108E+11	6.095E+11	6.107E+11	1.330E+12	6.839E+11
NB-94	/CON	1.389E+10	1.515E+10	1.454E+10	1.320E+10	1.446E+10	7.332E+11	4.432E+11
NB-94	/AGR	1.399E+10	1.548E+10	1.472E+10	1.320E+10	1.464E+10	7.332E+11	1.557E+12
NB-94	/FOO	2.116E+00	7.078E+00	3.937E+00	0.	3.892E+00	0.	2.390E+04
NB-94	/DGM	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06
NB-94	/WWT	3.193E+07	3.196E+07	3.194E+07	3.192E+07	3.194E+07	3.192E+07	1.466E+08
NB-94	/SWT	3.232E+07	3.324E+07	3.266E+07	3.192E+07	3.265E+07	3.192E+07	4.496E+09
NB-94	/AIR	6.103E+11	6.118E+11	6.111E+11	6.095E+11	6.110E+11	1.330E+12	2.153E+12
SR-90		2.470E-02	9.860E-03	9.000E+00	7.300E+01			
SR-90	/ACC	2.417E+13	9.617E+13	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.892E+11
SR-90	/CON	6.394E+13	2.588E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	4.727E+12
SR-90	/AGR	1.891E+14	7.686E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	1.946E+13
SR-90	/FOO	6.407E+07	2.611E+08	0.	0.	0.	0.	7.543E+06
SR-90	/DGM	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04
SR-90	/WWT	9.564E+09	3.895E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.134E+09
SR-90	/SWT	1.014E+10	4.128E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.201E+09
SR-90	/AIR	1.892E+14	7.688E+14	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.962E+13
TC-99		3.270E-06	1.150E-01	2.000E+00	5.000E+00			
TC-99	/ACC	1.176E+09	9.680E+08	2.280E+09	7.600E+08	1.996E+10	7.400E+09	7.880E+09
TC-99	/CON	2.960E+09	5.411E+09	8.890E+09	7.600E+08	1.031E+11	7.962E+09	2.240E+11
TC-99	/AGR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.720E+09	9.008E+11
TC-99	/FOO	6.566E+03	1.635E+04	2.433E+04	0.	3.061E+05	2.067E+03	7.953E+05
TC-99	/DGM	0.	0.	0.	0.	0.	0.	0.
TC-99	/WWT	4.186E+05	1.042E+06	1.551E+06	2.083E+00	1.951E+07	1.318E+05	5.069E+07
TC-99	/SWT	4.240E+05	1.056E+06	1.571E+06	2.083E+00	1.976E+07	1.335E+05	5.135E+07
TC-99	/AIR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.721E+09	9.008E+11
I-129		4.080E-08	1.150E-01	2.000E+00	5.000E+00			
I-129	/ACC	9.139E+11	8.515E+11	8.515E+11	5.128E+13	8.515E+11	8.572E+11	8.521E+11

Listing of DATA Data File (Continued)

I-129 /CON	2.068E+12	7.124E+11	6.123E+11	1.624E+15	1.315E+12	6.366E+09	9.787E+10
I-129 /AGR	8.346E+12	2.942E+12	2.528E+12	6.553E+15	5.433E+12	6.366E+09	4.006E+11
I-129 /FOO	6.019E+04	2.137E+04	1.836E+04	4.725E+07	3.947E+04	0.	2.901E+03
I-129 /DGM	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04
I-129 /WWT	4.289E+07	1.758E+07	1.562E+07	3.081E+10	2.938E+07	3.644E+06	5.536E+06
I-129 /SWT	4.389E+07	1.793E+07	1.592E+07	3.160E+10	3.004E+07	3.644E+06	5.584E+06
I-129 /AIR	9.197E+12	3.792E+12	3.379E+12	6.554E+15	6.284E+12	8.572E+11	1.251E+12
CS-135	2.310E-07	1.620E-04	8.500E+01	7.200E+02			
CS-135/ACC	2.371E+10	9.651E+10	8.851E+10	5.080E+08	3.331E+10	1.491E+10	1.004E+09
CS-135/CON	1.566E+11	4.209E+11	3.879E+11	5.080E+08	1.466E+11	4.884E+10	8.007E+09
CS-135/AGR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-135/FOO	8.836E+03	2.157E+04	1.991E+04	0.	7.531E+03	2.256E+03	4.656E+02
CS-135/DGM	0.	0.	0.	0.	0.	0.	0.
CS-135/WWT	3.318E+07	8.098E+07	7.475E+07	1.392E+00	2.828E+07	8.472E+06	1.748E+06
CS-135/SWT	1.442E+08	3.520E+08	3.250E+08	1.392E+00	1.229E+08	3.683E+07	7.600E+06
CS-135/AIR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-137	2.310E-02	1.620E-04	8.500E+01	7.200E+02			
CS-137/ACC	4.499E+11	6.339E+11	7.779E+11	2.419E+11	4.259E+11	3.299E+11	2.444E+11
CS-137/CON	1.397E+12	1.719E+12	2.351E+12	1.530E+09	9.010E+11	2.941E+11	3.919E+10
CS-137/AGR	5.117E+12	5.872E+12	8.030E+12	1.530E+09	2.729E+12	9.350E+11	1.491E+11
CS-137/FOO	7.896E+04	8.814E+04	1.205E+05	0.	4.092E+04	1.360E+04	2.333E+03
CS-137/DGM	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06
CS-137/WWT	3.094E+08	3.438E+08	4.655E+08	1.287E+07	1.665E+08	6.394E+07	2.163E+07
CS-137/SWT	1.302E+09	1.452E+09	1.981E+09	1.287E+07	6.808E+08	2.349E+08	5.096E+07
CS-137/AIR	5.358E+12	6.112E+12	8.270E+12	2.419E+11	2.969E+12	1.175E+12	3.895E+11
U-235	9.760E-10	1.250E-04	8.400E+02	7.200E+03			
U-235 /ACC	2.062E+12	3.062E+13	2.214E+11	2.214E+11	7.262E+12	3.360E+15	5.175E+11
U-235 /CON	2.643E+12	4.361E+13	1.590E+09	1.590E+09	1.013E+13	3.360E+15	1.586E+12
U-235 /AGR	5.154E+12	8.500E+13	1.590E+09	1.590E+09	1.979E+13	3.360E+15	5.621E+12
U-235 /FOO	1.443E+04	2.378E+05	0.	0.	5.552E+04	0.	2.319E+04
U-235 /DGM	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05
U-235 /WWT	2.073E+08	3.235E+09	1.177E+07	1.177E+07	7.643E+08	2.098E+07	3.261E+08
U-235 /SWT	2.109E+08	3.294E+09	1.177E+07	1.177E+07	7.781E+08	2.098E+07	3.318E+08
U-235 /AIR	5.374E+12	8.522E+13	2.214E+11	2.214E+11	2.001E+13	3.360E+15	5.841E+12
U-238	1.540E-10	1.250E-04	8.400E+02	7.200E+03			
U-238 /ACC	1.695E+12	2.882E+13	1.454E+10	1.454E+10	6.575E+12	3.120E+15	2.546E+11
U-238 /CON	2.429E+12	4.145E+13	8.570E+07	8.570E+07	9.447E+12	3.120E+15	1.147E+12
U-238 /AGR	4.774E+12	8.108E+13	8.570E+07	8.570E+07	1.849E+13	3.120E+15	3.989E+12
U-238 /FOO	1.348E+04	2.277E+05	0.	0.	5.196E+04	0.	1.633E+04
U-238 /DGM	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03
U-238 /WWT	1.835E+08	3.087E+09	7.739E+05	7.739E+05	7.050E+08	9.325E+06	2.221E+08
U-238 /SWT	1.868E+08	3.144E+09	7.739E+05	7.739E+05	7.179E+08	9.325E+06	2.262E+08
U-238 /AIR	4.789E+12	8.109E+13	1.454E+10	1.454E+10	1.850E+13	3.120E+15	4.003E+12
NP-237	3.240E-07	4.670E-04	3.000E+02	2.500E+03			
NP-237/ACC	5.202E+14	1.200E+16	1.120E+15	1.340E+11	3.840E+15	3.602E+14	3.740E+11
NP-237/CON	5.209E+14	1.202E+16	1.122E+15	8.400E+08	3.847E+15	3.600E+14	1.550E+12
NP-237/AGR	5.238E+14	1.209E+16	1.128E+15	8.400E+08	3.868E+15	3.600E+14	5.652E+12
NP-237/FOO	1.645E+04	4.067E+05	3.533E+04	0.	1.223E+05	0.	2.357E+04
NP-237/DGM	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04
NP-237/WWT	2.312E+08	5.546E+09	4.885E+08	7.126E+06	1.674E+09	8.113E+06	3.263E+08
NP-237/SWT	2.572E+08	6.189E+09	5.443E+08	7.126E+06	1.867E+09	8.113E+06	3.635E+08
NP-237/AIR	5.239E+14	1.209E+16	1.128E+15	1.340E+11	3.868E+15	3.602E+14	5.785E+12
PU-238	8.020E-03	4.670E-04	8.400E+02	7.200E+03			
PU-238/ACC	2.000E+14	4.080E+15	2.800E+15	1.924E+10	8.801E+14	4.080E+15	3.313E+11
PU-238/CON	2.003E+14	4.091E+15	2.802E+15	8.870E+07	8.812E+14	4.080E+15	1.514E+12
PU-238/AGR	2.012E+14	4.126E+15	2.807E+15	8.870E+07	8.850E+14	4.080E+15	5.277E+12
PU-238/FOO	1.137E+03	4.522E+04	6.371E+03	0.	4.868E+03	0.	4.855E+03
PU-238/DGM	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01
PU-238/WWT	7.019E+07	2.741E+09	3.931E+08	1.025E+06	2.972E+08	1.221E+07	2.940E+08
PU-238/SWT	7.485E+07	2.926E+09	4.192E+08	1.025E+06	3.171E+08	1.221E+07	3.139E+08
PU-238/AIR	2.012E+14	4.126E+15	2.807E+15	1.924E+10	8.850E+14	4.080E+15	5.297E+12
PU-239	2.840E-05	4.670E-04	8.400E+02	7.200E+03			
PU-239/ACC	2.240E+14	4.800E+15	3.120E+15	7.400E+09	9.601E+14	3.840E+15	3.034E+11
PU-239/CON	2.243E+14	4.813E+15	3.122E+15	5.170E+07	9.613E+14	3.840E+15	1.392E+12
PU-239/AGR	2.253E+14	4.854E+15	3.127E+15	5.170E+07	9.655E+14	3.840E+15	4.826E+12
PU-239/FOO	1.270E+03	5.234E+04	7.049E+03	0.	5.393E+03	0.	4.429E+03

Listing of DATA Data File (Continued)

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PU-239/DGM 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01
PU-239/WWT 7.765E+07 3.172E+09 4.343E+08 3.934E+05 3.285E+08 1.092E+07 2.676E+08
PU-239/SWT 8.286E+07 3.386E+09 4.632E+08 3.934E+05 3.506E+08 1.092E+07 2.858E+08
PU-239/AIR 2.253E+14 4.854E+15 3.127E+15 7.400E+09 9.656E+14 3.840E+15 4.833E+12
PU-241     5.250E-02 4.670E-04 8.400E+02 7.200E+03
PU-241/ACC 3.040E+12 7.440E+13 4.560E+13 4.780E+07 1.440E+13 6.800E+12 5.568E+09
PU-241/CON 3.046E+12 7.467E+13 4.561E+13 4.780E+07 1.443E+13 6.800E+12 2.861E+10
PU-241/AGR 3.063E+12 7.552E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-241/FOO 2.208E+01 1.097E+03 5.613E+01      0. 1.017E+02      0. 9.310E+01
PU-241/DGM 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01
PU-241/WWT 1.341E+06 6.642E+07 3.512E+06 1.310E-01 6.179E+06 1.864E+04 5.618E+06
PU-241/SWT 1.431E+06 7.091E+07 3.742E+06 1.310E-01 6.596E+06 1.864E+04 5.999E+06
PU-241/AIR 3.053E+12 7.553E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-242     2.480E-06 4.670E-04 8.400E+02 7.200E+03
PU-242/ACC 2.160E+14 4.480E+15 3.040E+15 1.441E+10 9.601E+14 3.680E+15 2.944E+11
PU-242/CON 2.163E+14 4.492E+15 3.042E+15 6.930E+07 9.613E+14 3.680E+15 1.355E+12
PU-242/AGR 2.173E+14 4.530E+15 3.047E+15 6.930E+07 9.653E+14 3.680E+15 4.722E+12
PU-242/FOO 1.224E+03 4.848E+04 6.783E+03      0. 5.194E+03      0. 4.343E+03
PU-242/DGM      0.      0.      0.      0.      0.      0.      0.
PU-242/WWT 7.520E+07 2.938E+09 4.184E+08 7.674E+05 3.168E+08 1.085E+07 2.628E+08
PU-242/SWT 8.021E+07 3.137E+09 4.462E+08 7.674E+05 3.381E+08 1.085E+07 2.806E+08
PU-242/AIR 2.173E+14 4.530E+15 3.047E+15 1.441E+10 9.654E+14 3.680E+15 4.736E+12
AM-241     1.510E-03 4.110E-03 3.000E+02 2.500E+03
AM-241/ACC 5.041E+14 7.120E+15 6.640E+15 7.869E+10 3.840E+15 4.241E+14 3.587E+11
AM-241/CON 5.049E+14 7.134E+15 6.645E+15 3.800E+08 3.847E+15 4.240E+14 1.508E+12
AM-241/AGR 5.077E+14 7.176E+15 6.660E+15 3.800E+08 3.868E+15 4.240E+14 5.355E+12
AM-241/FOO 3.599E+04 5.448E+05 1.916E+05      0. 2.707E+05      0. 4.936E+04
AM-241/DGM 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04
AM-241/WWT 2.247E+08 3.340E+09 1.199E+09 4.192E+06 1.663E+09 5.354E+06 3.047E+08
AM-241/SWT 3.721E+08 5.372E+09 1.974E+09 4.192E+06 2.772E+09 5.354E+06 5.069E+08
AM-241/AIR 5.078E+14 7.176E+15 6.660E+15 7.869E+10 3.868E+15 4.241E+14 5.434E+12
AM-243     8.720E-05 4.110E-03 3.000E+02 2.500E+03
AM-243/ACC 4.961E+14 7.040E+15 6.480E+15 9.096E+10 3.760E+15 4.001E+14 3.630E+11
AM-243/CON 4.969E+14 7.054E+15 6.485E+15 6.090E+08 3.767E+15 4.000E+14 1.713E+12
AM-243/AGR 4.996E+14 7.096E+15 6.499E+15 6.090E+08 3.787E+15 4.000E+14 6.223E+12
AM-243/FOO 3.525E+04 5.441E+05 1.849E+05      0. 2.654E+05      0. 5.787E+04
AM-243/DGM 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05
AM-243/WWT 2.208E+08 3.337E+09 1.148E+09 4.837E+06 1.631E+09 5.933E+06 3.572E+08
AM-243/SWT 3.653E+08 5.566E+09 1.906E+09 4.837E+06 2.718E+09 5.933E+06 5.942E+08
AM-243/AIR 4.997E+14 7.096E+15 6.499E+15 9.096E+10 3.788E+15 4.001E+14 6.313E+12
CM-243     2.170E-02 4.670E-04 3.000E+02 2.500E+03
CM-243/ACC 3.843E+14 6.161E+15 5.601E+15 2.444E+11 1.760E+15 4.403E+14 5.484E+11
CM-243/CON 3.846E+14 6.171E+15 5.604E+15 2.260E+09 1.763E+15 4.400E+14 1.594E+12
CM-243/AGR 3.866E+14 6.204E+15 5.616E+15 2.260E+09 1.772E+15 4.400E+14 5.629E+12
CM-243/FOO 1.113E+04 1.897E+05 7.155E+04      0. 5.195E+04      0. 2.319E+04
CM-243/DGM 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05
CM-243/WWT 1.647E+08 2.598E+09 9.970E+08 1.296E+07 7.212E+08 1.417E+07 3.269E+08
CM-243/SWT 2.087E+08 3.347E+09 1.280E+09 1.296E+07 9.264E+08 1.417E+07 4.184E+08
CM-243/AIR 3.868E+14 6.204E+15 5.617E+15 2.444E+11 1.772E+15 4.403E+14 5.871E+12
CM-244     3.940E-02 4.670E-04 3.000E+02 2.500E+03
CM-244/ACC 2.800E+14 4.400E+15 4.160E+15 1.706E+10 1.280E+15 4.400E+14 3.051E+11
CM-244/CON 2.805E+14 4.408E+15 4.163E+15 7.230E+07 1.282E+15 4.400E+14 1.533E+12
CM-244/AGR 2.820E+14 4.433E+15 4.174E+15 7.230E+07 1.289E+15 4.400E+14 5.434E+12
CM-244/FOO 8.520E+03 1.434E+05 6.145E+04      0. 3.978E+04      0. 2.241E+04
CM-244/DGM 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01
CM-244/WWT 1.170E+08 1.954E+09 8.443E+08 9.093E+05 5.430E+08 2.115E+06 3.044E+08
CM-244/SWT 1.507E+08 2.521E+09 1.087E+09 9.093E+05 7.001E+08 2.115E+06 3.929E+08
CM-244/AIR 2.820E+14 4.433E+15 4.174E+15 1.706E+10 1.289E+15 4.400E+14 5.451E+12
REGION 1   9.180E-12 2.960E-11 1.970E-04 4.930E-05 7.700E+03 2.000E+05 4.500E+06
           2.000E+02 5.000E+03 1.000E+04 4.000E+02 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 1.010E-09 1.510E-09 1.120E-07      3
           4.000E+02 8.000E+02 1.830E-10 2.610E-12
REGION 2   2.010E-11 3.180E-11 1.160E-03 3.240E-05 7.700E+03 2.000E+05 4.500E+06
           4.200E+01 4.000E+02 8.000E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.500E-10 5.250E-10 1.120E-07      3
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of DATA Data File (Continued)

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REGION 3  2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
          1.400E+02 2.900E+03 5.800E+03 4.000E+02 1.250E+04 2.500E+04
          1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07    4
          1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4  2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
          1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
          1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07    2
          8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5  2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
          3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
          1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07    2
          6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6  2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
          9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
          1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07    4
          6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of DATAD Data File

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  36   231.000 .120 .060 .030 .060 .120 .060
P-IXRESIN 1.100E-01 3.463E+04
         1 3.360E-02 1.840E-03 9.730E-05 7.300E-04 2.790E-06 2.170E-03
         1 8.150E-04 8.840E-08 1.630E-04 8.230E-07 2.440E-06 8.230E-07
         1 1.860E-02 4.710E-08 3.710E-07 9.060E-12 2.450E-05 1.820E-05
         1 5.630E-04 3.990E-08 4.134E-05 1.260E-06 8.520E-09 1.060E-05
P-CONCLIQ 1.100E-01 2.435E+05
         2 1.090E-01 2.390E-03 1.270E-04 7.080E-03 2.710E-05 2.110E-02
         2 7.920E-03 8.580E-07 2.120E-04 1.070E-06 3.160E-06 1.070E-06
         2 2.430E-02 6.150E-08 4.840E-07 1.180E-11 4.830E-05 3.310E-05
         2 1.020E-03 7.250E-08 7.102E-05 2.020E-06 1.010E-08 1.470E-05
P-FSLUDGE 1.100E-01 4.279E+03
         3 1.060E+00 1.790E-03 9.540E-05 9.670E-02 3.710E-04 2.880E-01
         3 1.080E-01 1.170E-05 1.590E-04 8.030E-07 2.370E-06 8.030E-07
         3 1.820E-02 1.460E-07 1.150E-06 2.810E-11 4.490E-05 1.550E-04
         3 4.790E-03 3.390E-07 4.551E-04 1.780E-05 2.660E-07 1.360E-04
P-FCARTRG 1.100E-01 2.177E+04
         4 1.860E+00 7.970E-04 4.250E-05 1.730E-01 6.600E-04 5.140E-01
         4 1.930E-01 2.090E-05 7.070E-05 3.580E-07 1.060E-06 3.580E-07
         4 8.120E-03 3.640E-07 2.870E-06 7.020E-11 2.370E-04 3.800E-04
         4 1.180E-02 8.340E-07 6.394E-04 1.100E-05 1.660E-07 8.440E-05
B-IXRESIN 1.200E-01 7.623E+04
         5 4.630E+00 1.340E-02 1.190E-03 2.990E-01 9.800E-04 7.700E-01
         5 2.040E-02 3.090E-05 3.080E-03 7.650E-05 2.040E-04 7.650E-05
         5 1.740E+00 5.330E-08 4.200E-07 1.020E-11 7.880E-05 5.340E-05
         5 1.850E-03 1.170E-07 9.768E-05 1.570E-06 2.330E-08 1.400E-05
B-CONCLIQ 1.200E-01 2.102E+05
         6 2.870E-01 4.350E-04 3.890E-05 2.500E-02 8.210E-05 6.440E-02
         6 1.710E-03 2.590E-06 9.970E-05 2.500E-06 6.650E-06 2.500E-06
         6 5.670E-02 3.440E-08 2.710E-07 6.610E-12 1.880E-04 9.430E-05
         6 3.280E-03 2.060E-07 2.513E-04 8.090E-06 2.230E-07 1.580E-04
B-FSLUDGE 1.200E-01 1.690E+05
         7 5.240E+00 8.780E-03 7.770E-04 4.540E-01 1.490E-03 1.170E+00
         7 3.080E-02 4.700E-05 2.000E-03 5.000E-05 1.330E-04 5.000E-05
         7 1.130E+00 3.320E-07 2.610E-06 6.380E-11 4.400E-04 2.360E-04
         7 8.200E-03 5.180E-07 4.848E-04 1.050E-05 2.560E-07 1.720E-04
P-COTRASH 2.100E-01 4.244E+05
         8 2.280E-02 2.110E-04 1.120E-05 1.860E-03 7.110E-06 5.520E-03
         8 2.070E-03 2.250E-07 1.870E-05 9.420E-08 2.780E-07 9.420E-08
         8 2.140E-03 7.890E-09 6.220E-08 1.520E-12 5.640E-06 5.530E-06
         8 1.710E-04 1.210E-08 1.085E-05 2.670E-07 2.350E-09 2.000E-06
P-NCTRASH 2.100E-01 2.178E+05
         9 5.250E-01 4.840E-03 2.570E-04 4.270E-02 1.640E-04 1.270E-01
         9 4.780E-02 5.180E-06 4.300E-04 2.170E-06 6.410E-06 2.170E-06
         9 4.920E-02 1.820E-07 1.430E-06 3.490E-11 1.300E-04 1.270E-04
         9 3.930E-03 2.790E-07 2.498E-04 6.140E-06 5.410E-08 4.600E-05
B-COTRASH 2.200E-01 2.086E+05
        10 2.350E-02 4.700E-05 4.170E-06 1.890E-03 6.210E-06 4.890E-03
        10 1.290E-04 1.960E-07 1.070E-05 2.680E-07 7.140E-07 2.680E-07
        10 6.090E-03 1.220E-09 9.600E-09 2.350E-13 2.170E-04 1.160E-06
        10 4.010E-05 2.530E-09 2.575E-06 6.510E-08 1.660E-09 1.150E-06
B-NCTRASH 2.200E-01 9.896E+04
        11 3.790E+00 7.600E-03 6.720E-04 3.050E-01 1.000E-03 7.840E-01
        11 2.080E-02 3.160E-05 1.730E-03 4.330E-05 1.150E-04 4.330E-05
        11 9.810E-01 1.970E-07 1.550E-06 3.780E-11 3.510E-04 1.860E-04
        11 6.470E-03 4.080E-07 4.152E-04 1.050E-05 2.690E-07 1.860E-04
F-COTRASH 2.110E-01 2.359E+05
        12 5.580E-06      0.          0.          0.          0.          0.
        12      0.        0.          0.          0.          0.          0.
        12      0.  1.180E-06 4.400E-06          0.          0.          0.
        12      0.        0.          0.          0.          0.          0.
F-NCTRASH 2.110E-01 4.171E+04
        13 5.330E-06      0.          0.          0.          0.          0.
        13      0.        0.          0.          0.          0.          0.
        13      0.  1.130E-06 4.200E-06          0.          0.          0.
        13      0.        0.          0.          0.          0.          0.
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Listing of DATAD Data File (Continued)

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I-COTRASH 2.030E-01 1.407E+05
       14 1.130E-01 5.950E-02 5.250E-03      0.        0.    4.410E-03
       14      0.        0.    1.190E-03 3.390E-09      0.        0.
       14 3.780E-03      0.         0.        0.        0.        0.
       14      0.        0.    4.760E-06      0.        0.        0.
I+COTRASH 2.030E-01 1.407E+05
       15 1.130E-01 5.950E-02 5.250E-03      0.        0.    4.410E-03
       15      0.        0.    1.190E-03 3.390E-09      0.        0.
       15 3.780E-03      0.         0.        0.        0.        0.
       15      0.        0.    4.760E-06      0.        0.        0.
N-SSTRASH 2.060E-01 1.796E+05
       16 1.120E-05      0.         0.        0.        0.        0.
       16      0.        0.         0.        0.        0.        0.
       16      0.   2.360E-06 8.800E-06      0.        0.        0.
       16      0.        0.         0.        0.        0.        0.
N+SSTRASH 2.060E-01 1.796E+05
       17 1.120E-05      0.         0.        0.        0.        0.
       17      0.        0.         0.        0.        0.        0.
       17      0.   2.360E-06 8.800E-06      0.        0.        0.
       17      0.        0.         0.        0.        0.        0.
N-LOTRASH 2.070E-01 5.064E+04
       18 3.530E-02 1.860E-02 1.640E-03      0.        0.    1.380E-03
       18      0.        0.    3.710E-04 1.060E-09      0.        0.
       18 1.180E-03      0.         0.        0.        0.        0.
       18      0.        0.    1.490E-06      0.        0.        0.
N+LOTRASH 2.070E-01 5.064E+04
       19 3.530E-02 1.860E-02 1.640E-03      0.        0.    1.380E-03
       19      0.        0.    3.710E-04 1.060E-09      0.        0.
       19 1.180E-03      0.         0.        0.        0.        0.
       19      0.        0.    1.490E-06      0.        0.        0.
F-PROCESS 3.110E-01 7.816E+04
       20 1.080E-04      0.         0.        0.        0.        0.
       20      0.        0.         0.        0.        0.        0.
       20      0.   2.300E-05 8.540E-05      0.        0.        0.
       20      0.        0.         0.        0.        0.        0.
U-PROCESS 3.120E-01 2.811E+04
       21 3.800E-04      0.         0.        0.        0.        0.
       21      0.        0.         0.        0.        0.        0.
       21      0.   1.650E-05 3.640E-04      0.        0.        0.
       21      0.        0.         0.        0.        0.        0.
I-LOSCNVL 3.030E-01 4.914E+04
       22 9.600E-03 3.270E-03 2.510E-04      0.        0.        0.
       22      0.        0.    3.550E-03      0.        0.        0.
       22      0.        0.         0.        0.        0.        0.
       22      0.        0.         0.        0.        0.        0.
I+LOSCNVL 3.030E-01 4.914E+04
       23 9.600E-03 3.270E-03 2.510E-04      0.        0.        0.
       23      0.        0.    3.550E-03      0.        0.        0.
       23      0.        0.         0.        0.        0.        0.
       23      0.        0.         0.        0.        0.        0.
I-ABSLIQD 3.030E-01 5.585E+03
       24 1.990E-01 9.260E-02 8.150E-03      0.        0.    1.320E-02
       24      0.        0.    3.550E-03 1.020E-08      0.        0.
       24 1.140E-02      0.         0.        0.        0.        0.
       24      0.        0.         0.        0.        0.        0.
I+ABSLIQD 3.030E-01 5.585E+03
       25 1.990E-01 9.260E-02 8.150E-03      0.        0.    1.320E-02
       25      0.        0.    3.550E-03 1.020E-08      0.        0.
       25 1.140E-02      0.         0.        0.        0.        0.
       25      0.        0.         0.        0.        0.        0.
I-BIOWAST 3.030E-01 1.571E+04
       26 2.060E-01 1.140E-01 1.010E-02      0.        0.    1.690E-03
       26      0.        0.    6.820E-03 6.510E-09      0.        0.
       26 7.260E-03      0.         0.        0.        0.        0.
       26      0.        0.         0.        0.        0.        0.
I+BIOWAST 3.030E-01 1.571E+04
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Listing of DATAD Data File (Continued)

```
          27 2.060E-01 1.140E-01 1.010E-02      0.       0.     1.690E-03
          27      0.       0.     6.820E-03 6.510E-09      0.       0.
          27 7.260E-03      0.          0.       0.       0.       0.
          27      0.       0.          0.       0.       0.       0.
N-SSWASTE 3.060E-01 6.339E+04
          28 2.170E-04      0.          0.       0.       0.       0.
          28      0.       0.          0.       0.       0.       0.
          28      0.  4.600E-05 1.710E-04      0.       0.       0.
          28      0.       0.          0.       0.       0.       0.
N-LOWASTE 3.070E-01 6.027E+04
          29 2.110E-02 1.060E-02 9.350E-04      0.       0.     6.230E-04
          29      0.       0.     1.070E-03 7.760E-10      0.       0.
          29 8.620E-04      0.          0.       0.       0.       0.
          29      0.       0.          0.       0.       0.       0.
L-NFRCOMP 4.300E-01 2.887E+03
          30 4.040E+03      0.     2.590E-01 6.980E+02 1.400E+00 7.700E+02
          30 1.980E+02 8.190E-03      0.       0.       0.       0.
          30      0.       0.          0.       0.       0.       0.
          30      0.       0.          0.       0.       0.       0.
L-DECONRS 4.400E-01 3.498E+04
          31 1.560E+02 7.510E-03 6.870E-04 1.270E+01 4.490E-02 3.500E+01
          31 3.490E+00 1.420E-03 3.610E-02 1.200E-05 3.340E-05 1.200E-05
          31 2.710E-01 6.840E-05 5.400E-04 1.320E-08 1.260E+00 1.770E+00
          31 2.520E+01 3.870E-03 1.026E+00 3.590E-04 2.980E-04 2.510E-03
N-ISOPROD 4.040E-01 5.196E+03
          32 1.500E+01 2.740E-02 4.510E-05      0.       0.       0.
          32      0.       0.     5.140E+00 3.270E-04 2.720E-06 3.270E-04
          32 7.240E+00 1.020E-05 3.810E-05 5.330E-13 1.840E-04 5.550E-05
          32 4.750E-03 9.570E-08 2.151E-04 1.250E-06 1.380E-04 2.110E-07
N-HIGHACT 4.030E-01 2.608E+03
          33 2.100E+02      0.     1.320E-02 2.970E+01 6.560E-02 3.600E+01
          33 9.950E+00 4.470E-04      0.       0.       0.       0.
          33      0.       0.          0.       0.       0.       0.
          33      0.       0.          0.       0.       0.       0.
N-TRITIUM 4.050E-01 3.481E+03
          34 2.330E+03 1.520E+03      0.       0.       0.       0.
          34      0.       0.          0.       0.       0.       0.
          34      0.       0.          0.       0.       0.       0.
          34      0.       0.          0.       0.       0.       0.
N-SOURCES 4.030E-01 1.865E+02
          35 5.760E+03 1.360E+03 3.190E-03      0.       0.     3.440E+01
          35 9.860E+00      0.     2.350E+01      0.       0.       0.
          35 2.930E+03      0.          0.       0.       0.       0.
          35      0.       0.     1.580E+01      0.       0.       0.
N-TARGETS 4.030E-01 1.340E+03
          36 8.040E+01 5.240E+01      0.       0.       0.       0.
          36      0.       0.          0.       0.       0.       0.
          36      0.       0.          0.       0.       0.       0.
          36      0.       0.          0.       0.       0.       0.
H-3       5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3   /ACC 1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3   /CON 1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3   /AGR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3   /FOO 5.995E+04      0.     5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3   /DGM      0.       0.          0.       0.       0.       0.       0.
H-3   /WWT 2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3   /SWT 2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3   /AIR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14      1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14  /ACC 3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14  /CON 6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14  /AGR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14  /FOO 3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14  /DGM      0.       0.          0.       0.       0.       0.       0.
C-14  /WWT 1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14  /SWT 3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
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Listing of DATAD Data File (Continued)

C-14	/AIR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
FE-55		2.670E-01	1.480E-02	6.300E+02	5.400E+03			
FE-55	/ACC	1.805E+10	1.885E+10	2.413E+10	1.613E+10	1.613E+10	2.081E+11	1.925E+10
FE-55	/CON	9.283E+09	4.816E+10	3.941E+10	5.080E+07	5.080E+07	2.095E+11	2.116E+10
FE-55	/AGR	3.219E+10	1.903E+11	1.376E+11	5.080E+07	5.080E+07	2.644E+11	7.752E+10
FE-55	/FOO	3.482E+01	2.161E+02	1.493E+02	0.	0.	8.331E+01	8.566E+01
FE-55	/DGM	0.	0.	0.	0.	0.	0.	0.
FE-55	/WWT	2.727E+06	1.244E+07	8.863E+06	8.609E+05	8.609E+05	5.326E+06	5.452E+06
FE-55	/SWT	4.450E+06	2.314E+07	1.625E+07	8.609E+05	8.609E+05	9.449E+06	9.692E+06
FE-55	/AIR	4.827E+10	2.064E+11	1.537E+11	1.613E+10	1.613E+10	2.804E+11	9.360E+10
NI-59		8.660E-06	1.480E-02	4.200E+02	3.600E+03			
NI-59	/ACC	3.698E+10	9.378E+10	5.058E+10	2.578E+10	2.578E+10	5.778E+10	2.850E+10
NI-59	/CON	3.872E+10	2.325E+11	8.130E+10	5.980E+07	5.980E+07	3.206E+10	1.441E+10
NI-59	/AGR	1.247E+11	7.476E+11	2.581E+11	5.980E+07	5.980E+07	3.206E+10	5.082E+10
NI-59	/FOO	3.693E+03	2.211E+04	7.590E+03	0.	0.	0.	1.563E+03
NI-59	/DGM	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03
NI-59	/WWT	8.537E+06	4.425E+07	1.609E+07	1.377E+06	1.377E+06	1.377E+06	4.408E+06
NI-59	/SWT	9.825E+06	5.196E+07	1.874E+07	1.377E+06	1.377E+06	1.377E+06	4.953E+06
NI-59	/AIR	1.505E+11	7.733E+11	2.838E+11	2.578E+10	2.578E+10	5.778E+10	7.654E+10
CO-60		1.320E-01	1.480E-02	4.200E+02	3.600E+03			
CO-60	/ACC	2.358E+12	2.336E+12	2.353E+12	2.336E+12	2.336E+12	2.634E+13	2.504E+12
CO-60	/CON	1.237E+11	2.280E+10	7.599E+10	2.280E+10	2.280E+10	2.402E+13	8.593E+11
CO-60	/AGR	3.695E+11	2.280E+10	1.874E+11	2.280E+10	2.280E+10	2.402E+13	2.953E+12
CO-60	/FOO	5.274E+03	0.	2.391E+03	0.	0.	0.	4.492E+04
CO-60	/DGM	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07
CO-60	/WWT	1.432E+08	1.239E+08	1.326E+08	1.238E+08	1.238E+08	1.239E+08	2.893E+08
CO-60	/SWT	1.458E+08	1.238E+08	1.338E+08	1.238E+08	1.238E+08	1.239E+08	3.112E+08
CO-60	/AIR	2.683E+12	2.336E+12	2.500E+12	2.336E+12	2.336E+12	2.634E+13	5.266E+12
NI-63		7.530E-03	1.480E-02	4.200E+02	3.600E+03			
NI-63	/ACC	3.056E+10	9.602E+11	6.576E+10	1.560E+08	1.560E+08	8.816E+10	7.436E+09
NI-63	/CON	1.040E+11	3.150E+12	2.176E+11	1.560E+08	1.560E+08	8.816E+10	3.911E+10
NI-63	/AGR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NI-63	/FOO	9.878E+03	2.945E+05	2.041E+04	0.	0.	0.	4.259E+03
NI-63	/DGM	0.	0.	0.	0.	0.	0.	0.
NI-63	/WWT	1.915E+07	5.711E+08	3.958E+07	4.276E-01	4.276E-01	2.416E+02	8.258E+06
NI-63	/SWT	2.260E+07	6.738E+08	4.670E+07	4.276E-01	4.276E-01	2.416E+02	9.743E+06
NI-63	/AIR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NB-94		3.470E-05	1.110E-02	1.000E+03	1.000E+04			
NB-94	/ACC	6.102E+11	6.114E+11	6.108E+11	6.095E+11	6.107E+11	1.330E+12	6.839E+11
NB-94	/CON	1.389E+10	1.515E+10	1.454E+10	1.320E+10	1.446E+10	7.332E+11	4.432E+11
NB-94	/AGR	1.399E+10	1.548E+10	1.472E+10	1.320E+10	1.464E+10	7.332E+11	1.557E+12
NB-94	/FOO	2.116E+00	7.078E+00	3.937E+00	0.	3.892E+00	0.	2.390E+04
NB-94	/DGM	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06
NB-94	/WWT	3.193E+07	3.196E+07	3.194E+07	3.192E+07	3.194E+07	3.192E+07	1.466E+08
NB-94	/SWT	3.232E+07	3.324E+07	3.266E+07	3.192E+07	3.265E+07	3.192E+07	4.496E+09
NB-94	/AIR	6.103E+11	6.118E+11	6.111E+11	6.095E+11	6.110E+11	1.330E+12	2.153E+12
SR-90		2.470E-02	9.860E-03	9.000E+00	7.300E+01			
SR-90	/ACC	2.417E+13	9.617E+13	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.892E+11
SR-90	/CON	6.394E+13	2.588E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	4.727E+12
SR-90	/AGR	1.891E+14	7.686E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	1.946E+13
SR-90	/FOO	6.407E+07	2.611E+08	0.	0.	0.	0.	7.543E+06
SR-90	/DGM	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04
SR-90	/WWT	9.564E+09	3.895E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.134E+09
SR-90	/SWT	1.014E+10	4.128E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.201E+09
SR-90	/AIR	1.892E+14	7.688E+14	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.962E+13
TC-99		3.270E-06	1.150E-01	2.000E+00	5.000E+00			
TC-99	/ACC	1.176E+09	9.680E+08	2.280E+09	7.600E+08	1.996E+10	7.400E+09	7.880E+09
TC-99	/CON	2.960E+09	5.411E+09	8.890E+09	7.600E+08	1.031E+11	7.962E+09	2.240E+11
TC-99	/AGR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.720E+09	9.008E+11
TC-99	/FOO	6.566E+03	1.635E+04	2.433E+04	0.	3.061E+05	2.067E+03	7.953E+05
TC-99	/DGM	0.	0.	0.	0.	0.	0.	0.
TC-99	/WWT	4.186E+05	1.042E+06	1.551E+06	2.083E+00	1.951E+07	1.318E+05	5.069E+07
TC-99	/SWT	4.240E+05	1.056E+06	1.571E+06	2.083E+00	1.976E+07	1.335E+05	5.135E+07
TC-99	/AIR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.721E+09	9.008E+11
I-129		4.080E-08	1.150E-01	2.000E+00	5.000E+00			
I-129	/ACC	9.139E+11	8.515E+11	8.515E+11	5.128E+13	8.515E+11	8.572E+11	8.521E+11

Listing of DATAD Data File (Continued)

I-129 /CON	2.068E+12	7.124E+11	6.123E+11	1.624E+15	1.315E+12	6.366E+09	9.787E+10
I-129 /AGR	8.346E+12	2.942E+12	2.528E+12	6.553E+15	5.433E+12	6.366E+09	4.006E+11
I-129 /FOO	6.019E+04	2.137E+04	1.836E+04	4.725E+07	3.947E+04	0.	2.901E+03
I-129 /DGM	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04
I-129 /WWT	4.289E+07	1.758E+07	1.562E+07	3.081E+10	2.938E+07	3.644E+06	5.536E+06
I-129 /SWT	4.389E+07	1.793E+07	1.592E+07	3.160E+10	3.004E+07	3.644E+06	5.584E+06
I-129 /AIR	9.197E+12	3.792E+12	3.379E+12	6.554E+15	6.284E+12	8.572E+11	1.251E+12
CS-135	2.310E-07	1.620E-04	8.500E-01	7.200E+02			
CS-135/ACC	2.371E+10	9.651E+10	8.851E+10	5.080E+08	3.331E+10	1.491E+10	1.004E+09
CS-135/CON	1.566E+11	4.209E+11	3.879E+11	5.080E+08	1.466E+11	4.884E+10	8.007E+09
CS-135/AGR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-135/FOO	8.836E+03	2.157E+04	1.991E+04	0.	7.531E+03	2.256E+03	4.656E+02
CS-135/DGM	0.	0.	0.	0.	0.	0.	0.
CS-135/WWT	3.318E+07	8.098E+07	7.475E+07	1.392E+00	2.828E+07	8.472E+06	1.748E+06
CS-135/SWT	1.442E+08	3.520E+08	3.250E+08	1.392E+00	1.229E+08	3.683E+07	7.600E+06
CS-135/AIR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-137	2.310E-02	1.620E-04	8.500E-01	7.200E+02			
CS-137/ACC	4.499E+11	6.339E+11	7.779E+11	2.419E+11	4.259E+11	3.299E+11	2.444E+11
CS-137/CON	1.397E+12	1.719E+12	2.351E+12	1.530E+09	8.010E+11	2.941E+11	3.919E+10
CS-137/AGR	5.117E+12	5.872E+12	8.030E+12	1.530E+09	2.729E+12	9.350E+11	1.491E+11
CS-137/FOO	7.896E+04	8.814E+04	1.205E+05	0.	4.092E+04	1.360E+04	2.333E+03
CS-137/DGM	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06
CS-137/WWT	3.094E+08	3.438E+08	4.655E+08	1.287E+07	1.665E+08	6.394E+07	2.163E+07
CS-137/SWT	1.302E+09	1.452E+09	1.981E+09	1.287E+07	6.808E+08	2.349E+08	5.096E+07
CS-137/AIR	5.358E+12	6.112E+12	8.270E+12	2.419E+11	2.969E+12	1.175E+12	3.895E+11
U-235	9.760E-10	1.250E-04	8.400E+02	7.200E+03			
U-235 /ACC	2.062E+12	3.062E+13	2.214E+11	2.214E+11	7.262E+12	3.360E+15	5.175E+11
U-235 /CON	2.643E+12	4.361E+13	1.590E+09	1.590E+09	1.013E+13	3.360E+15	1.586E+12
U-235 /AGR	5.154E+12	8.500E+13	1.590E+09	1.590E+09	1.979E+13	3.360E+15	5.621E+12
U-235 /FOO	1.443E+04	2.378E+05	0.	0.	5.552E+04	0.	2.319E+04
U-235 /DGM	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05
U-235 /WWT	2.073E+08	3.235E+09	1.177E+07	1.177E+07	7.643E+08	2.098E+07	3.261E+08
U-235 /SWT	2.109E+08	3.294E+09	1.177E+07	1.177E+07	7.781E+08	2.098E+07	3.318E+08
U-235 /AIR	5.374E+12	8.522E+13	2.214E+11	2.214E+11	2.001E+13	3.360E+15	5.841E+12
U-238	1.540E-10	1.250E-04	8.400E+02	7.200E+03			
U-238 /ACC	1.695E+12	2.882E+13	1.454E+10	1.454E+10	6.575E+12	3.120E+15	2.546E+11
U-238 /CON	2.429E+12	4.145E+13	8.570E+07	8.570E+07	9.447E+12	3.120E+15	1.147E+12
U-238 /AGR	4.774E+12	8.108E+13	8.570E+07	8.570E+07	1.849E+13	3.120E+15	3.989E+12
U-238 /FOO	1.348E+04	2.277E+05	0.	0.	5.196E+04	0.	1.633E+04
U-238 /DGM	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03
U-238 /WWT	1.835E+08	3.087E+09	7.739E+05	7.739E+05	7.050E+08	9.325E+06	2.221E+08
U-238 /SWT	1.868E+08	3.144E+09	7.739E+05	7.739E+05	7.179E+08	9.325E+06	2.262E+08
U-238 /AIR	4.789E+12	8.109E+13	1.454E+10	1.454E+10	1.850E+13	3.120E+15	4.003E+12
NP-237	3.240E-07	4.670E-04	3.000E+02	2.500E+03			
NP-237/ACC	5.202E+14	1.200E+16	1.120E+15	1.340E+11	3.840E+15	3.602E+14	3.740E+11
NP-237/CON	5.209E+14	1.202E+16	1.122E+15	8.400E+08	3.847E+15	3.600E+14	1.550E+12
NP-237/AGR	5.238E+14	1.209E+16	1.128E+15	8.400E+08	3.868E+15	3.600E+14	5.652E+12
NP-237/FOO	1.645E+04	4.067E+05	3.533E+04	0.	1.223E+05	0.	2.357E+04
NP-237/DGM	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04
NP-237/WWT	2.312E+08	5.546E+09	4.885E+08	7.126E+06	1.674E+09	8.113E+06	3.263E+08
NP-237/SWT	2.572E+08	6.189E+09	5.443E+08	7.126E+06	1.867E+09	8.113E+06	3.635E+08
NP-237/AIR	5.239E+14	1.209E+16	1.128E+15	1.340E+11	3.868E+15	3.602E+14	5.785E+12
PU-238	8.020E-03	4.670E-04	8.400E+02	7.200E+03			
PU-238/ACC	2.000E+14	4.080E+15	2.800E+15	1.924E+10	8.801E+14	4.080E+15	3.313E+11
PU-238/CON	2.003E+14	4.091E+15	2.802E+15	8.870E+07	8.812E+14	4.080E+15	1.514E+12
PU-238/AGR	2.012E+14	4.126E+15	2.807E+15	8.870E+07	8.850E+14	4.080E+15	5.277E+12
PU-238/FOO	1.137E+03	4.522E+04	6.371E+03	0.	4.868E+03	0.	4.855E+03
PU-238/DGM	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01
PU-238/WWT	7.019E+07	2.741E+09	3.931E+08	1.025E+06	2.972E+08	1.221E+07	2.940E+08
PU-238/SWT	7.485E+07	2.926E+09	4.192E+08	1.025E+06	3.171E+08	1.221E+07	3.139E+08
PU-238/AIR	2.012E+14	4.126E+15	2.807E+15	1.924E+10	8.850E+14	4.080E+15	5.297E+12
PU-239	2.840E-05	4.670E-04	8.400E+02	7.200E+03			
PU-239/ACC	2.240E+14	4.800E+15	3.120E+15	7.400E+09	9.601E+14	3.840E+15	3.034E+11
PU-239/CON	2.243E+14	4.813E+15	3.122E+15	5.170E+07	9.613E+14	3.840E+15	1.392E+12
PU-239/AGR	2.253E+14	4.854E+15	3.127E+15	5.170E+07	9.655E+14	3.840E+15	4.826E+12
PU-239/FOO	1.270E+03	5.274E+04	7.049E+03	0.	5.397E+03	0.	4.429E+03

Listing of DATAD Data File (Continued)

PU-239/DGM	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01
PU-239/WWT	7.765E+07	3.172E+09	4.343E+08	3.934E+05	3.285E+08	1.092E+07	2.676E+08
PU-239/SWT	8.286E+07	3.386E+09	4.632E+08	3.934E+05	3.506E+08	1.092E+07	2.858E+08
PU-239/AIR	2.253E+14	4.854E+15	3.127E+15	7.400E+09	9.656E+14	3.840E+15	4.833E+12
PU-241	5.250E-02	4.670E-04	8.400E+02	7.200E+03			
PU-241/ACC	3.040E+12	7.440E+13	4.560E+13	4.780E+07	1.440E+13	6.800E+12	5.568E+09
PU-241/CON	3.046E+12	7.467E+13	4.561E+13	4.780E+07	1.443E+13	6.800E+12	2.861E+10
PU-241/AGR	3.063E+12	7.552E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-241/FOO	2.208E+01	1.097E+03	5.613E+01	0.	1.017E+02	0.	9.310E+01
PU-241/DGM	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01
PU-241/WWT	1.341E+06	6.642E+07	3.512E+06	1.310E-01	6.179E+06	1.864E+04	5.618E+06
PU-241/SWT	1.431E+06	7.091E+07	3.742E+06	1.310E-01	6.596E+06	1.864E+04	5.999E+06
PU-241/AIR	3.063E+12	7.553E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-242	2.480E-06	4.670E-04	8.400E+02	7.200E+03			
PU-242/ACC	2.160E+14	4.480E+15	3.040E+15	1.441E+10	9.601E+14	3.680E+15	2.944E+11
PU-242/CON	2.163E+14	4.492E+15	3.042E+15	6.930E+07	9.613E+14	3.680E+15	1.355E+12
PU-242/AGR	2.173E+14	4.530E+15	3.047E+15	6.930E+07	9.653E+14	3.680E+15	4.722E+12
PU-242/FOO	1.224E+03	4.848E+04	6.783E+03	0.	5.194E+03	0.	4.343E+03
PU-242/DGM	0.	0.	0.	0.	0.	0.	0.
PU-242/WWT	7.520E+07	2.938E+09	4.184E+08	7.674E+05	3.168E+08	1.085E+07	2.628E+08
PU-242/SWT	8.021E+07	3.137E+09	4.462E+08	7.674E+05	3.381E+08	1.085E+07	2.806E+08
PU-242/AIR	2.173E+14	4.530E+15	3.047E+15	1.441E+10	9.654E+14	3.680E+15	4.736E+12
AM-241	1.510E-03	4.110E-03	3.000E+02	2.500E+03			
AM-241/ACC	5.041E+14	7.120E+15	6.640E+15	7.869E+10	3.840E+15	4.241E+14	3.587E+11
AM-241/CON	5.049E+14	7.134E+15	6.645E+15	3.800E+08	3.847E+15	4.240E+14	1.508E+12
AM-241/AGR	5.077E+14	7.176E+15	6.660E+15	3.800E+08	3.868E+15	4.240E+14	5.355E+12
AM-241/FOO	3.599E+04	5.448E+05	1.916E+05	0.	2.707E+05	0.	4.936E+04
AM-241/DGM	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04
AM-241/WWT	2.247E+08	3.340E+09	1.189E+09	4.192E+06	1.663E+09	5.354E+06	3.047E+08
AM-241/SWT	3.721E+08	5.572E+09	1.974E+09	4.192E+06	2.772E+09	5.354E+06	5.069E+08
AM-241/AIR	5.078E+14	7.176E+15	6.660E+15	7.869E+10	3.868E+15	4.241E+14	5.434E+12
AM-243	8.720E-05	4.110E-03	3.000E+02	2.500E+03			
AM-243/ACC	4.961E+14	7.040E+15	6.480E+15	9.096E+10	3.760E+15	4.001E+14	3.630E+11
AM-243/CON	4.969E+14	7.054E+15	6.485E+15	6.090E+08	3.767E+15	4.000E+14	1.713E+12
AM-243/AGR	4.996E+14	7.096E+15	6.499E+15	6.090E+08	3.787E+15	4.000E+14	6.223E+12
AM-243/FOO	3.525E+04	5.441E+05	1.849E+05	0.	2.654E+05	0.	5.787E+04
AM-243/DGM	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05
AM-243/WWT	2.208E+08	3.337E+09	1.148E+09	4.837E+06	1.631E+09	5.933E+06	3.572E+08
AM-243/SWT	3.653E+08	5.566E+09	1.906E+09	4.837E+06	2.718E+09	5.933E+06	5.942E+08
AM-243/AIR	4.997E+14	7.096E+15	6.499E+15	9.096E+10	3.788E+15	4.001E+14	6.313E+12
CM-243	2.170E-02	4.670E-04	3.000E+02	2.500E+03			
CM-243/ACC	3.843E+14	6.161E+15	5.601E+15	2.444E+11	1.760E+15	4.403E+14	5.484E+11
CM-243/CON	3.846E+14	6.171E+15	5.604E+15	2.260E+09	1.763E+15	4.400E+14	1.594E+12
CM-243/AGR	3.866E+14	6.204E+15	5.616E+15	2.260E+09	1.772E+15	4.400E+14	5.629E+12
CM-243/FOO	1.113E+04	1.897E+05	7.155E+04	0.	5.195E+04	0.	2.319E+04
CM-243/DGM	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05
CM-243/WWT	1.647E+08	2.598E+09	9.970E+08	1.296E+07	7.212E+08	1.417E+07	3.269E+08
CM-243/SWT	2.087E+08	3.347E+09	1.280E+09	1.296E+07	9.264E+08	1.417E+07	4.184E+08
CM-243/AIR	3.868E+14	6.204E+15	5.617E+15	2.444E+11	1.772E+15	4.403E+14	5.871E+12
CM-244	3.940E-02	4.670E-04	3.000E+02	2.500E+03			
CM-244/ACC	2.800E+14	4.400E+15	4.160E+15	1.706E+10	1.280E+15	4.400E+14	3.051E+11
CM-244/CON	2.805E+14	4.408E+15	4.163E+15	7.230E+07	1.282E+15	4.400E+14	1.533E+12
CM-244/AGR	2.820E+14	4.433E+15	4.174E+15	7.230E+07	1.289E+15	4.400E+14	5.434E+12
CM-244/FOO	8.520E+03	1.434E+05	6.145E+04	0.	3.978E+04	0.	2.241E+04
CM-244/DGM	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01
CM-244/WWT	1.170E+08	1.954E+09	8.443E+08	9.093E+05	5.430E+08	2.115E+06	3.044E+08
CM-244/SWT	1.507E+08	2.521E+09	1.087E+09	9.093E+05	7.001E+08	2.115E+06	3.929E+08
CM-244/AIR	2.820E+14	4.433E+15	4.174E+15	1.706E+10	1.289E+15	4.400E+14	5.451E+12
REGION 1	9.180E-12	2.960E-11	1.970E-04	4.930E-05	7.700E+03	2.000E+05	4.500E+06
	2.000E+02	5.000E+03	1.000E+04	4.000E+02	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	1.010E-09	1.510E-09	1.120E-07	3
	4.000E+02	8.000E+02	1.830E-10	2.610E-12			
REGION 2	2.010E-11	3.180E-11	1.160E-03	3.240E-05	7.700E+03	2.000E+05	4.500E+06
	4.200E+01	4.000E+02	8.000E+02	1.300E+03	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	3.500E-10	5.250E-10	1.120E-07	3
	6.400E+01	1.600E+03	1.830E-10	3.323E-12			

Listing of DATAD Data File (Continued)

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REGION 3   2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
           1.400E+02 2.900E+03 5.800E+03 4.000E+02 1.250E+04 2.500E+04
           1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07    4
           1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4   2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
           1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
           1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07    2
           8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5   2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
           3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07    2
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6   2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
           9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07    4
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of NUCS Data File

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   36    23 1.00   .12   .06   .03   .06   .12   .06
H-3          5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3    /ACC  1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3    /CON  1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3    /AGR  4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3    /FOO  5.995E+04      0.   5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3    /DGM        0.        0.        0.        0.        0.        0.        0.
H-3    /WWT  2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3    /SWT  2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3    /AIR  4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14         1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14   /ACC  3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14   /CON  6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14   /AGR  2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14   /FOO  3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14   /DGM        0.        0.        0.        0.        0.        0.        0.
C-14   /WWT  1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14   /SWT  3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
C-14   /AIR  2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
FE-55        2.670E-01 1.480E-02 6.300E+02 5.400E+03
FE-55  /ACC  1.805E+10 1.885E+10 2.413E+10 1.613E+10 1.613E+10 2.081E+11 1.925E+10
FE-55  /CON  9.283E+09 4.816E+10 3.941E+10 5.080E+07 5.080E+07 2.095E+11 2.116E+10
FE-55  /AGR  3.219E+10 1.903E+11 1.376E+11 5.080E+07 5.080E+07 2.644E+11 7.752E+10
FE-55  /FOO  3.482E+01 2.161E+02 1.493E+02      0.        0.   8.331E+01 8.566E+01
FE-55  /DGM        0.        0.        0.        0.        0.        0.        0.
FE-55  /WWT  2.727E+06 1.244E+07 8.863E+06 8.609E+05 8.609E+05 5.326E+06 5.452E+06
FE-55  /SWT  4.450E+06 2.314E+07 1.625E+07 8.609E+05 8.609E+05 9.449E+06 9.692E+06
FE-55  /AIR  4.827E+10 2.064E+11 1.537E+11 1.613E+10 1.613E+10 2.804E+11 9.360E+10
NI-59        8.660E-06 1.480E-02 4.200E+02 3.600E+03
NI-59  /ACC  3.698E+10 9.378E+10 5.058E+10 2.578E+10 2.578E+10 5.778E+10 2.850E+10
NI-59  /CON  3.872E+10 2.325E+11 8.130E+10 5.980E+07 5.980E+07 3.206E+10 1.441E+10
NI-59  /AGR  1.247E+11 7.476E+11 2.581E+11 5.980E+07 5.980E+07 3.206E+10 5.082E+10
NI-59  /FOO  3.693E+03 2.211E+04 7.590E+03      0.        0.        0.   1.563E+03
NI-59  /DGM  6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03
NI-59  /WWT  8.537E+06 4.425E+07 1.609E+07 1.377E+06 1.377E+06 1.377E+06 4.408E+06
NI-59  /SWT  9.825E+06 5.196E+07 1.874E+07 1.377E+06 1.377E+06 1.377E+06 4.953E+06
NI-59  /AIR  1.505E+11 7.733E+11 2.838E+11 2.578E+10 2.578E+10 5.778E+10 7.654E+10
CO-60        1.320E-01 1.480E-02 4.200E+02 3.600E+03
CO-60  /ACC  2.358E+12 2.336E+12 2.353E+12 2.336E+12 2.336E+12 2.634E+13 2.504E+12
CO-60  /CON  1.237E+11 2.280E+10 7.599E+10 2.280E+10 2.280E+10 2.402E+13 8.593E+11
CO-60  /AGR  3.695E+11 2.280E+10 1.874E+11 2.280E+10 2.280E+10 2.402E+13 2.953E+12
CO-60  /FOO  5.274E+03      0.   2.391E+03      0.        0.        0.   4.492E+04
CO-60  /DGM  1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07
CO-60  /WWT  1.432E+08 1.238E+08 1.326E+08 1.238E+08 1.238E+08 1.239E+08 2.893E+08
CO-60  /SWT  1.458E+08 1.238E+08 1.338E+08 1.238E+08 1.238E+08 1.239E+08 3.112E+08
CO-60  /AIR  2.683E+12 2.336E+12 2.500E+12 2.336E+12 2.336E+12 2.634E+13 5.266E+12
NI-63        7.530E-03 1.480E-02 4.200E+02 3.600E+03
NI-63  /ACC  3.056E+10 9.602E+11 6.576E+10 1.560E+08 1.560E+08 8.816E+10 7.436E+09
NI-63  /CON  1.040E+11 3.150E+12 2.176E+11 1.560E+08 1.560E+08 8.816E+10 3.911E+10
NI-63  /AGR  3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NI-63  /FOO  9.878E+03 2.945E+05 2.041E+04      0.        0.        0.   4.259E+03
NI-63  /DGM        0.        0.        0.        0.        0.        0.        0.
NI-63  /WWT  1.915E+07 5.711E+08 3.958E+07 4.276E-01 4.276E-01 2.416E+02 8.258E+06
NI-63  /SWT  2.260E+07 6.738E+08 4.670E+07 4.276E-01 4.276E-01 2.416E+02 9.743E+06
NI-63  /AIR  3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NB-94        3.470E-05 1.110E-02 1.000E+03 1.000E+04
NB-94  /ACC  6.102E+11 6.114E+11 6.108E+11 6.095E+11 6.107E+11 1.330E+12 6.839E+11
NB-94  /CON  1.389E+10 1.515E+10 1.454E+10 1.320E+10 1.446E+10 7.332E+11 4.432E+11
NB-94  /AGR  1.399E+10 1.548E+10 1.472E+10 1.320E+10 1.464E+10 7.332E+11 1.557E+12
NB-94  /FOO  2.116E+00 7.078E+00 3.937E+00      0.   3.892E+00      0.   2.390E+04
NB-94  /DGM  9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06
NB-94  /WWT  3.193E+07 3.196E+07 3.194E+07 3.192E+07 3.194E+07 3.192E+07 1.466E+08
NB-94  /SWT  3.232E+07 3.324E+07 3.266E+07 3.192E+07 3.265E+07 3.192E+07 4.496E+09
NB-94  /AIR  6.103E+11 6.118E+11 6.111E+11 6.095E+11 6.110E+11 1.330E+12 2.153E+12
SR-90        2.470E-02 9.860E-03 9.000E+00 7.300E+01
SR-90  /ACC  2.417E+13 9.617E+13 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.892E+11
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Listing of NUCS Data File (Continued)

SR-90 /CON	6.394E+13	2.588E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	4.727E+12
SR-90 /AGR	1.891E+14	7.686E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	1.946E+13
SR-90 /FOO	6.407E+07	2.611E+08	0.	0.	0.	0.	7.543E+06
SR-90 /DGM	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04
SR-90 /WWT	9.564E+09	3.895E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.134E+09
SR-90 /SWT	1.014E+10	4.128E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.201E+09
SR-90 /AIR	1.892E+14	7.688E+14	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.962E+13
TC-99	3.270E-06	1.150E-01	2.000E+00	5.000E+00			
TC-99 /ACC	1.176E+09	9.680E+08	2.280E+09	7.600E+08	1.996E+10	7.400E+09	7.880E+09
TC-99 /CON	2.960E+09	5.411E+09	8.890E+09	7.600E+08	1.031E+11	7.962E+09	2.240E+11
TC-99 /AGR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.720E+09	9.008E+11
TC-99 /FOO	6.566E+03	1.635E+04	2.433E+04	0.	3.061E+05	2.067E+03	7.953E+05
TC-99 /DGM	0.	0.	0.	0.	0.	0.	0.
TC-99 /WWT	4.186E+05	1.042E+06	1.551E+06	2.083E+00	1.951E+07	1.318E+05	5.069E+07
TC-99 /SWT	4.240E+05	1.056E+06	1.571E+06	2.083E+00	1.976E+07	1.335E+05	5.135E+07
TC-99 /AIR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.721E+09	9.008E+11
I-129	4.080E-08	1.150E-01	2.000E+00	5.000E+00			
I-129 /ACC	9.139E+11	8.515E+11	8.515E+11	5.128E+13	8.515E+11	8.572E+11	8.521E+11
I-129 /CON	2.068E+12	7.124E+11	6.123E+11	1.624E+15	1.315E+12	6.366E+09	9.787E+10
I-129 /AGR	8.346E+12	2.942E+12	2.528E+12	6.553E+15	5.433E+12	6.366E+09	4.006E+11
I-129 /FOO	6.019E+04	2.137E+04	1.836E+04	4.725E+07	3.947E+04	0.	2.901E+03
I-129 /DGM	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04
I-129 /WWT	4.289E+07	1.758E+07	1.562E+07	3.081E+10	2.938E+07	3.644E+06	5.536E+06
I-129 /SWT	4.389E+07	1.793E+07	1.592E+07	3.160E+10	3.004E+07	3.644E+06	5.584E+06
I-129 /AIR	9.197E+12	3.792E+12	3.379E+12	6.554E+15	6.284E+12	8.572E+11	1.251E+12
CS-135	2.310E-07	1.620E-04	8.500E+01	7.200E+02			
CS-135/ACC	2.371E+10	9.651E+10	8.851E+10	5.080E+08	3.331E+10	1.491E+10	1.004E+09
CS-135/CON	1.566E+11	4.209E+11	3.879E+11	5.080E+08	1.466E+11	4.884E+10	8.007E+09
CS-135/AGR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-135/FOO	8.836E+03	2.157E+04	1.991E+04	0.	7.531E+03	2.256E+03	4.656E+02
CS-135/DGM	0.	0.	0.	0.	0.	0.	0.
CS-135/WWT	3.318E+07	8.098E+07	7.475E+07	1.392E+00	2.828E+07	8.472E+06	1.748E+06
CS-135/SWT	1.442E+08	3.520E+08	3.250E+08	1.392E+00	1.229E+08	3.683E+07	7.600E+06
CS-135/AIR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-137	2.310E-02	1.620E-04	8.500E+01	7.200E+02			
CS-137/ACC	4.499E+11	6.339E+11	7.779E+11	2.419E+11	4.259E+11	3.299E+11	2.444E+11
CS-137/CON	1.397E+12	1.719E+12	2.351E+12	1.530E+09	8.010E+11	2.941E+11	3.919E+10
CS-137/AGR	5.117E+12	5.872E+12	8.030E+12	1.530E+09	2.729E+12	9.350E+11	1.491E+11
CS-137/FOO	7.896E+04	8.814E+04	1.205E+05	0.	4.092E+04	1.360E+04	2.333E+03
CS-137/DGM	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06
CS-137/WWT	3.094E+08	3.438E+08	4.655E+08	1.287E+07	1.665E+08	6.394E+07	2.163E+07
CS-137/SWT	1.302E+09	1.452E+09	1.981E+09	1.287E+07	6.808E+08	2.349E+08	5.096E+07
CS-137/AIR	5.358E+12	6.112E+12	8.270E+12	2.419E+11	2.969E+12	1.175E+12	3.895E+11
U-235	9.760E-10	1.250E-04	8.400E+02	7.200E+03			
U-235 /ACC	2.062E+12	3.062E+13	2.214E+11	2.214E+11	7.262E+12	3.360E+15	5.175E+11
U-235 /CON	2.643E+12	4.361E+13	1.590E+09	1.590E+09	1.013E+13	3.360E+15	1.586E+12
U-235 /AGR	5.154E+12	8.500E+13	1.590E+09	1.590E+09	1.979E+13	3.360E+15	5.621E+12
U-235 /FOO	1.443E+04	2.378E+05	0.	0.	5.552E+04	0.	2.319E+04
U-235 /DGM	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05
U-235 /WWT	2.073E+08	3.235E+09	1.177E+07	1.177E+07	7.643E+08	2.098E+07	3.261E+08
U-235 /SWT	2.109E+08	3.294E+09	1.177E+07	1.177E+07	7.781E+08	2.098E+07	3.318E+08
U-235 /AIR	5.374E+12	8.522E+13	2.214E+11	2.214E+11	2.001E+13	3.360E+15	5.841E+12
U-238	1.540E-10	1.250E-04	8.400E+02	7.200E+03			
U-238 /ACC	1.695E+12	2.882E+13	1.454E+10	1.454E+10	6.575E+12	3.120E+15	2.546E+11
U-238 /CON	2.429E+12	4.145E+13	8.570E+07	8.570E+07	9.447E+12	3.120E+15	1.147E+12
U-238 /AGR	4.774E+12	8.108E+13	8.570E+07	8.570E+07	1.849E+13	3.120E+15	3.989E+12
U-238 /FOO	1.348E+04	2.277E+05	0.	0.	5.196E+04	0.	1.633E+04
U-238 /DGM	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03
U-238 /WWT	1.835E+08	3.087E+09	7.739E+05	7.739E+05	7.050E+08	9.325E+06	2.221E+08
U-238 /SWT	1.868E+08	3.144E+09	7.739E+05	7.739E+05	7.179E+08	9.325E+06	2.262E+08
U-238 /AIR	4.789E+12	8.109E+13	1.454E+10	1.454E+10	1.850E+13	3.120E+15	4.003E+12
NP-237	3.240E-07	4.670E-04	3.000E+02	2.500E+03			
NP-237/ACC	5.202E+14	1.200E+16	1.120E+15	1.340E+11	3.840E+15	3.602E+14	3.740E+11
NP-237/CON	5.209E+14	1.202E+16	1.122E+15	8.400E+08	3.847E+15	3.600E+14	1.550E+12
NP-237/AGR	5.238E+14	1.209E+16	1.128E+15	8.400E+08	3.868E+15	3.600E+14	5.652E+12
NP-237/FOO	1.645E+04	4.067E+05	3.533E+04	0.	1.223E+05	0.	2.357E+04

Listing of NUCS Data File (Continued)

NP-237/DGM	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04
NP-237/WWT	2.312E+08	5.546E+09	4.885E+08	7.126E+06	1.674E+09	8.113E+06	3.263E+08
NP-237/SWT	2.572E+08	6.189E+09	5.443E+08	7.126E+06	1.867E+09	8.113E+06	3.635E+08
NP-237/AIR	5.239E+14	1.209E+16	1.128E+15	1.340E+11	3.868E+15	3.602E+14	5.785E+12
PU-238	8.020E-03	4.670E-04	8.400E+02	7.200E+03			
PU-238/ACC	2.000E+14	4.080E+15	2.800E+15	1.924E+10	8.801E+14	4.080E+15	3.313E+11
PU-238/CON	2.003E+14	4.091E+15	2.802E+15	8.870E+07	8.812E+14	4.080E+15	1.514E+12
PU-238/AGR	2.012E+14	4.126E+15	2.807E+15	8.870E+07	8.850E+14	4.080E+15	5.277E+12
PU-238/FOO	1.137E+03	4.522E+04	6.371E+03	0.	4.868E+03	0.	4.855E+03
PU-238/DGM	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01
PU-238/WWT	7.019E+07	2.741E+09	3.931E+08	1.025E+06	2.972E+08	1.221E+07	2.940E+08
PU-238/SWT	7.485E+07	2.926E+09	4.192E+08	1.025E+06	3.171E+08	1.221E+07	3.139E+08
PU-238/AIR	2.012E+14	4.126E+15	2.807E+15	1.924E+10	8.850E+14	4.080E+15	5.297E+12
PU-239	2.940E-05	4.670E-04	8.400E+02	7.200E+03			
PU-239/ACC	2.240E+14	4.800E+15	3.120E+15	7.400E+09	9.601E+14	3.840E+15	3.034E+11
PU-239/CON	2.243E+14	4.813E+15	3.122E+15	5.170E+07	9.613E+14	3.840E+15	1.392E+12
PU-239/AGR	2.253E+14	4.854E+15	3.127E+15	5.170E+07	9.655E+14	3.840E+15	4.826E+12
PU-239/FOO	1.270E+03	5.234E+04	7.049E+03	0.	5.393E+03	0.	4.429E+03
PU-239/DGM	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01
PU-239/WWT	7.765E+07	3.172E+09	4.343E+08	3.934E+05	3.285E+08	1.092E+07	2.676E+08
PU-239/SWT	8.286E+07	3.386E+09	4.632E+08	3.934E+05	3.506E+08	1.092E+07	2.858E+08
PU-239/AIR	2.253E+14	4.854E+15	3.127E+15	7.400E+09	9.656E+14	3.840E+15	4.833E+12
PU-241	5.250E-02	4.670E-04	8.400E+02	7.200E+03			
PU-241/ACC	3.040E+12	7.440E+13	4.560E+13	4.780E+07	1.440E+13	6.800E+12	5.568E+09
PU-241/CON	3.046E+12	7.467E+13	4.561E+13	4.780E+07	1.443E+13	6.800E+12	2.861E+10
PU-241/AGR	3.063E+12	7.552E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-241/FOO	2.208E+01	1.097E+03	5.613E+01	0.	1.017E+02	0.	9.310E+01
PU-241/DGM	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01
PU-241/WWT	1.341E+06	6.642E+07	3.512E+06	1.310E-01	6.179E+06	1.864E+04	5.618E+06
PU-241/SWT	1.431E+06	7.091E+07	3.742E+06	1.310E-01	6.596E+06	1.864E+04	5.999E+06
PU-241/AIR	3.063E+12	7.553E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-242	2.480E-06	4.670E-04	8.400E+02	7.200E+03			
PU-242/ACC	2.160E+14	4.480E+15	3.040E+15	1.441E+10	9.601E+14	3.680E+15	2.944E+11
PU-242/CON	2.163E+14	4.492E+15	3.042E+15	6.930E+07	9.613E+14	3.680E+15	1.355E+12
PU-242/AGR	2.173E+14	4.530E+15	3.047E+15	6.930E+07	9.653E+14	3.680E+15	4.722E+12
PU-242/FOO	1.224E+03	4.848E+04	6.783E+03	0.	5.194E+03	0.	4.343E+03
PU-242/DGM	0.	0.	0.	0.	0.	0.	0.
PU-242/WWT	7.520E+07	2.938E+09	4.184E+08	7.674E+05	3.168E+08	1.085E+07	2.628E+08
PU-242/SWT	8.021E+07	3.137E+09	4.462E+08	7.674E+05	3.381E+08	1.085E+07	2.806E+08
PU-242/AIR	2.173E+14	4.530E+15	3.047E+15	1.441E+10	9.654E+14	3.680E+15	4.736E+12
AM-241	1.510E-03	4.110E-03	3.000E+02	2.500E+03			
AM-241/ACC	5.041E+14	7.120E+15	6.640E+15	7.869E+10	3.840E+15	4.241E+14	3.587E+11
AM-241/CON	5.049E+14	7.134E+15	6.645E+15	3.800E+08	3.847E+15	4.240E+14	1.508E+12
AM-241/AGR	5.077E+14	7.176E+15	6.660E+15	3.800E+08	3.868E+15	4.240E+14	5.355E+12
AM-241/FOO	3.599E+04	5.448E+05	1.916E+05	0.	2.707E+05	0.	4.936E+04
AM-241/DGM	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04
AM-241/WWT	2.247E+08	3.340E+09	1.189E+09	4.192E+06	1.663E+09	5.354E+06	3.047E+08
AM-241/SWT	3.721E+08	5.572E+09	1.974E+09	4.192E+06	2.772E+09	5.354E+06	5.069E+08
AM-241/AIR	5.078E+14	7.176E+15	6.660E+15	7.869E+10	3.868E+15	4.241E+14	5.434E+12
AM-243	8.720E-05	4.110E-03	3.000E+02	2.500E+03			
AM-243/ACC	4.961E+14	7.040E+15	6.480E+15	9.096E+10	3.760E+15	4.001E+14	3.630E+11
AM-243/CON	4.969E+14	7.054E+15	6.485E+15	6.090E+08	3.767E+15	4.000E+14	1.713E+12
AM-243/AGR	4.996E+14	7.096E+15	6.499E+15	6.090E+08	3.787E+15	4.000E+14	6.223E+12
AM-243/FOO	3.525E+04	5.441E+05	1.849E+05	0.	2.654E+05	0.	5.787E+04
AM-243/DGM	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05
AM-243/WWT	2.208E+08	3.337E+09	1.148E+09	4.837E+06	1.631E+09	5.933E+06	3.572E+08
AM-243/SWT	3.653E+08	5.566E+09	1.906E+09	4.837E+06	2.718E+09	5.933E+06	5.942E+08
AM-243/AIR	4.997E+14	7.096E+15	6.499E+15	9.096E+10	3.788E+15	4.001E+14	6.313E+12
CM-243	2.170E-02	4.670E-04	3.000E+02	2.500E+03			
CM-243/ACC	3.843E+14	6.161E+15	5.601E+15	2.444E+11	1.760E+15	4.403E+14	5.484E+11
CM-243/CON	3.846E+14	6.171E+15	5.604E+15	2.260E+09	1.763E+15	4.400E+14	1.594E+12
CM-243/AGR	3.866E+14	6.204E+15	5.616E+15	2.260E+09	1.772E+15	4.400E+14	5.629E+12
CM-243/FOO	1.113E+04	1.897E+05	7.155E+04	0.	5.195E+04	0.	2.319E+04
CM-243/DGM	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05
CM-243/WWT	1.647E+08	2.598E+09	9.970E+08	1.296E+07	7.212E+08	1.417E+07	3.269E+08
CM-243/SWT	2.087E+08	3.347E+09	1.280E+09	1.296E+07	9.264E+08	1.417E+07	4.184E+08

Listing of NUCS Data File (Continued)

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CM-243/AIR 3.868E+14 6.204E+15 5.617E+15 2.444E+11 1.772E+15 4.403E+14 5.871E+12
CM-244     3.940E-02 4.670E-04 3.000E+02 2.500E+03
CM-244/ACC 2.800E+14 4.400E+15 4.160E+15 1.706E+10 1.280E+15 4.400E+14 3.051E+11
CM-244/CON 2.805E+14 4.408E+15 4.163E+15 7.230E+07 1.282E+15 4.400E+14 1.533E+12
CM-244/AGR 2.820E+14 4.433E+15 4.174E+15 7.230E+07 1.289E+15 4.400E+14 5.434E+12
CM-244/FOO 8.520E+03 1.434E+05 6.145E+04      0.    3.978E+04      0.    2.241E+04
CM-244/DGM 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01
CM-244/WWT 1.170E+08 1.954E+09 8.443E+08 9.093E+05 5.430E+08 2.115E+06 3.044E+08
CM-244/SWT 1.507E+08 2.521E+09 1.087E+09 9.093E+05 7.001E+08 2.115E+06 3.929E+08
CM-244/AIR 2.820E+14 4.433E+15 4.174E+15 1.706E+10 1.289E+15 4.400E+14 5.451E+12
REGION 1   9.180E-12 2.960E-11 1.970E-04 4.930E-05 7.700E+03 2.000E+05 4.500E+06
           2.000E+02 5.000E+03 1.000E+04 4.000E+02 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 1.010E-09 1.510E-09 1.120E-07    3
           4.000E+02 8.000E+02 1.830E-10 2.610E-12
REGION 2   2.010E-11 3.180E-11 1.160E-03 3.240E-05 7.700E+03 2.000E+05 4.500E+06
           4.200E+01 4.000E+02 8.000E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.500E-10 5.250E-10 1.120E-07    3
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 3   2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
           1.400E+02 2.900E+03 5.300E+03 4.000E+02 1.250E+04 2.500E+04
           1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07    4
           1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4   2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
           1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
           1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07    2
           8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5   2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
           3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07    2
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6   2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
           9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07    4
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
```

SPC1 Data File

P-IXRESIN	11	100	100	2	1	1	0	1	1 0010	0
P-CONCLIQ	11	100	140	1	1	2	0	1	1 0110	0
P-FSLUDGE	11	100	100	1	3	1	0	1	1 0010	0
P-FCARTRG	11	100	100	2	2	1	0	0	1 0110	0
B-IXRESIN	11	100	100	2	1	1	0	1	1 0010	0
B-CONCLIQ	11	100	140	1	1	2	0	1	1 0110	0
B-FSLUDGE	11	100	100	1	3	1	0	1	1 0010	0
P-COTRASH	21	100	100	3	2	1	0	0	1 0000	0
P-NCTRASH	51	100	100	0	0	1	0	0	2 0000	0
B-COTRASH	21	100	100	3	2	1	0	0	1 0000	0
B-NCTRASH	51	100	100	0	0	1	0	0	2 0000	0
F-COTRASH	22	100	100	3	2	1	0	0	1 0000	0
F-NCTRASH	22	100	100	0	0	1	0	0	2 0000	0
I-COTRASH	23	100	100	3	2	1	0	0	1 0000	0
I+COTRASH	23	100	100	3	2	1	0	0	1 0000	0
N-SSTRASH	22	100	100	2	2	1	0	0	1 0000	0
N+SSTRASH	22	100	100	2	2	1	0	0	1 0000	0
N-LOTRASH	22	100	100	3	2	1	0	0	1 0000	0
N+LOTRASH	22	100	100	3	2	1	0	0	1 0000	0
F-PROCESS	52	100	100	0	3	1	0	1	1 0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1 0000	0
I-LQSCNVL	33	100	300	3	3	1	1	0	1 0010	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1 0010	0
I-ABSLIQD	33	100	300	3	3	1	1	1	1 0010	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1 0010	0
I-BIOWAST	33	100	192	2	3	1	1	0	1 0010	0
I+BIOWAST	33	100	192	2	3	1	1	0	1 0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1 0000	0
N-LOWASTE	31	100	100	3	3	1	1	0	1 0000	0
L-NFRCOMP	51	100	100	0	0	1	0	0	2 0000	0
L-DECONRS	51	100	200	2	0	4	1	1	1 0310	0
N-ISOPROD	51	100	130	1	1	3	1	0	1 0210	0
N-HIGHACT	52	100	100	0	0	1	0	0	3 0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1 0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2 0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1 0000	0

SPC2 Data File

P-IXRESIN	11	100	165	1	1	3	0	1	1	0210	0
P-CONCLIQ	11	600	182	1	1	3	0	1	1	4210	0
P-FSLUDGE	11	100	165	1	1	3	0	1	1	0210	0
P-FCARTRG	11	100	100	1	1	3	0	1	1	0210	0
B-IXRESIN	11	100	165	1	1	3	0	1	1	0210	0
B-CONCLIQ	11	240	156	1	1	3	0	1	1	4210	0
B-FSLUDGE	11	100	165	1	1	3	0	1	1	0210	0
P-COTRASH	21	200	100	3	2	1	0	0	1	1010	0
P-NCTRASH	51	100	100	0	0	1	0	1	2	0000	0
B-COTRASH	21	200	100	3	2	1	0	0	1	1010	0
B-NCTRASH	51	100	100	0	0	1	0	1	2	0000	0
F-COTRASH	22	150	100	3	2	1	0	0	1	1010	0
F-NCTRASH	22	100	100	0	0	1	0	0	2	0000	0
I-COTRASH	23	200	100	3	2	1	0	0	1	1010	0
I+COTRASH	23	400	100	3	2	1	0	0	1	2020	0
N-SSTRASH	22	150	100	2	2	1	0	0	1	1010	0
N+SSTRASH	22	300	100	2	2	1	0	0	1	2020	0
N-LOTRASH	22	200	100	3	2	1	0	0	1	1010	0
N+LOTRASH	22	400	100	3	2	1	0	0	1	2020	0
F-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
I-LQSCNVL	33	128	300	3	3	1	1	1	1	1010	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I-ABSLIQD	33	100	165	3	3	3	0	1	1	0210	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I-BIOWAST	33	100	192	2	3	1	1	0	1	0010	0
I+BIOWAST	33	100	192	2	3	1	1	0	1	0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1	0000	0
N-LOWASTE	31	100	100	3	3	1	1	0	1	0000	0
L-NFRCOMP	51	100	100	0	0	1	0	1	2	0000	0
L-DECONRS	51	100	200	2	0	4	1	1	1	0310	0
N-ISOPROD	51	100	200	1	0	4	1	1	1	0310	0
N-HIGHACT	52	100	100	0	0	1	0	1	3	0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1	0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2	0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1	0000	0

SPC3 Date File

P-IXRESIN	11	100	200	2	0	4	0	1	1 0310	0
P-CONCLIQ	11	600	200	2	0	4	0	1	1 4310	0
P-FSLUDGE	11	100	200	1	0	4	0	1	1 0310	0
P-FCARTRG	11	100	100	2	0	4	0	1	1 0310	0
B-IXRESIN	11	100	200	2	0	4	0	1	1 0310	0
B-CONCLIQ	11	240	200	1	0	4	0	1	1 4310	0
B-FSLUDGE	11	100	200	1	0	4	0	1	1 0310	0
P-COTRASH	61	8000	200	0	0	4	0	1	1 6312	0
P-NCTRASH	51	100	100	0	0	1	0	1	2 0000	0
B-COTRASH	61	8000	200	0	0	4	0	1	1 6312	0
B-NCTRASH	51	100	100	0	0	1	0	1	2 0000	0
F-COTRASH	62	4000	200	0	0	4	0	1	1 6311	0
F-NCTRASH	22	100	100	0	0	1	0	0	2 0000	0
I-COTRASH	23	2000	200	0	0	4	0	1	1 5311	0
I+COTRASH	23	8000	200	3	0	4	0	1	1 7322	0
N-SSTRASH	22	1000	200	0	0	4	0	1	1 5311	0
N+SSTRASH	22	4000	200	2	0	4	0	1	1 7322	0
N-LOTRASH	22	2000	200	0	0	4	0	1	1 5311	0
N+LOTRASH	22	8000	200	3	0	4	0	1	1 7322	0
F-PROCESS	52	100	100	0	3	1	0	1	1 0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1 0000	0
I-LQSCNVL	33	452	200	0	0	4	0	1	1 5311	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1 0010	0
I-ABSLIQD	33	100	200	0	0	4	0	1	1 0310	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1 0010	0
I-BIOWAST	33	1500	200	0	0	4	0	1	1 5311	0
I+BIOWAST	33	100	192	2	0	1	1	0	1 0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1 0000	0
N-LOWASTE	31	100	100	3	3	1	1	0	1 0000	0
L-NFRCOMP	51	100	100	0	0	1	0	1	2 0000	0
L-DECONRS	51	1800	200	1	0	4	0	1	1 6312	0
N-ISOPROD	51	100	200	1	0	4	1	1	1 0310	0
N-HIGHACT	52	100	100	0	0	1	0	1	3 0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1 0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2 0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1 0000	0

SPC4 Data File

P-IXRESIN	71	1800	200	1	0	4	0	1	1	6312	0
P-CONCLIQ	71	800	200	1	0	4	0	1	1	6312	0
P-FSLUDGE	71	500	200	1	0	4	0	1	1	6312	0
P-FCARTRG	71	100	100	2	0	4	0	1	1	0310	0
B-IXRESIN	71	1800	200	1	0	4	0	1	1	6312	0
B-CONCLIQ	71	640	200	1	0	4	0	1	1	6312	0
B-FSLUDGE	71	500	200	1	0	4	0	1	1	6312	0
P-COTRASH	71	8000	200	1	0	4	0	1	1	6312	0
P-NCTRASH	51	600	100	0	0	1	0	1	2	3010	0
B-COTRASH	71	8000	200	1	0	4	0	1	1	6312	0
B-NCTRASH	51	600	100	0	0	1	0	1	2	3010	0
F-COTRASH	72	4000	200	0	0	4	0	1	1	6311	0
F-NCTRASH	52	600	100	0	0	1	0	1	2	3020	0
I-COTRASH	63	2000	200	0	0	4	0	1	1	5311	0
I+COTRASH	73	8000	200	3	0	4	0	1	1	7322	0
N-SSTRASH	62	1000	200	0	0	4	0	1	1	5311	0
N+SSTRASH	72	4000	200	2	0	4	0	1	1	7322	0
N-LOTRASH	62	2000	200	0	0	4	0	1	1	5311	0
N+LOTRASH	72	8000	200	3	0	4	0	1	1	7322	0
F-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
I-LQSCNVL	63	452	200	0	0	4	0	1	1	5311	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I-ABSLIQD	63	10000	200	0	0	4	0	1	1	5311	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I-BIOWAST	63	1500	200	0	0	4	0	1	1	5311	0
I+BIOWAST	73	100	192	2	0	1	1	0	1	0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1	0000	0
N-LOWASTE	31	100	100	3	3	1	1	1	1	0000	0
L-NFRCOMP	51	100	100	0	0	1	0	1	2	0000	0
L-DECONRS	71	1800	200	0	0	4	0	1	1	6312	0
N-ISOPROD	51	100	200	1	0	4	1	1	1	0310	0
N-HIGHACT	52	100	100	0	0	1	0	1	3	0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1	0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2	0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1	0000	0

Appendix I

The following branch technical position on site closure and stabilization is reproduced in its entirety.

UNITED STATES NUCLEAR REGULATORY COMMISSION

BRANCH POSITION - LOW-LEVEL WASTE BURIAL GROUND SITE CLOSURE AND STABILIZATION

Low-Level Waste Branch

Background

Recent events have caused the staff to reassess the terms and conditions of licenses that have been issued under 10 CFR Parts 30, 40, and 70 of NRC's regulations for disposal of materials at low-level waste burial grounds. Licenses do not specifically address measures required to close and stabilize sites when operations cease.

In the past, decommissioning of all types of nuclear facilities was addressed only in general terms, if at all. In recent years, decommissioning of fuel cycle facilities, and particularly stabilization of uranium mill tailings, has been receiving increased regulatory attention. Most licenses for fuel cycle facilities specifically address decommissioning. A Colorado State University report entitled, "Evaluation of Long-Term Stability of Uranium Mill Tailing Disposal Alternatives," was prepared in April 1978. The effectiveness and stability of various engineering designs for the tailings caps, embankments, liners, and water diversion structures were assessed against failure modes such as wind erosion, floods, and settlement. Work such as this, coupled with extensive experience in working out specific methods of uranium mill tailings management, contributes to both a conceptual and technical base for formulating performance objectives for site closure and stabilization for shallow land burial of packaged low-level waste since the activities and engineering are similar in many respects.

The Office of Standards Development, NRC, has a major effort underway to develop criteria and standards for decommissioning of all types of fuel cycle facilities. A comprehensive technical information base is being developed by Battelle's Pacific Northwest Laboratory. Reports on each type of fuel cycle facility are being prepared. A report on decommissioning of low-level waste burial grounds is scheduled to be completed later this spring. Although the report of this work is not completed, information on alternative methodologies, procedures, and costs required for site closure and stabilization has been developed.

The NRC has underway the development of a specific regulatory program for management of LLW. On October 25, 1978, NRC noticed, in the Federal Register,

its intent to develop a proposed new 10 CFR Part 61 for LLW and invited advice, recommendations, and comments on the scope of the environmental impact statement for the new part. Site decommissioning is intended to be an integral part of the new regulations, currently scheduled to be published as a proposed rule in late 1980.

Specific events at the Sheffield, Illinois site have, however, necessitated development of an interim Branch Position before these regulatory framework efforts and technical base specific for burial grounds are completed. Towards this end, the NRC staff has developed interim performance objectives for LLW burial ground site closure and stabilization based on information available at this time.

Site closure and stabilization plans developed to meet the objectives outlined below are intended to prepare the site for transfer to a custodial government agency. The custodial agency or agencies will be needed until the site can be released for unrestricted use (usually a few hundred years). The site operator's responsibility and authority for possession of buried wastes continues until the Commission finds that the plan established for preparation of the site for transfer to another person has been satisfactorily completed in a manner to reasonably assure protection of the public health and safety and takes action to terminate responsibility and authority under their license.

Position

The staff recognizes that the site closure and stabilization program required at a site will vary depending on site or region specific parameters, such as geology, hydrology, and climate as well as arrangements that may have been concluded between the licensee and site owner. The operating history of the burial ground, site performance as shown by maintenance and monitoring programs, site inventories, and anticipated future use of the site will also be important factors. The overall objective is to leave the site in a condition such that the need for active ongoing maintenance is eliminated and only passive surveillance and monitoring are required at the point when the license is terminated.

Low-level waste burial ground licensees shall develop a site closure and stabilization plan that addressess, as a minimum, the following performance objectives.

1. Bury all waste in accordance with the requirements of the license.

2. Dismantle and decontaminate as required and dispose of all structures, equipment, and materials that are not to be transferred to the custodial agency.

3. Document the arrangements and the status of the arrangements for orderly transfer of site control and for long-term care by the government custodian. Also document the agreement, if any, of state or federal government participation in, or accomplishment of, any performance objective. Specific funding arrangements to assure the availability of funds to complete the site closure and stabilization plan must be made.

4. Direct gamma radiation from buried wastes should be essentially background.

5. Demonstrate that the rate of release of radionuclides through air and ground and surface water pathways are at or below acceptable levels. Acceptable levels for water are those set forth in 10 CFR Part 20, Appendix B, at the site boundry and EPA drinking water limits at the nearest water supply. Acceptable levels for air are a small fraction of those in 10 CFR Part 20, Appendix B. The EPA environmental standard for disposal of low-level wastes should be used when available.

6. Render the site suitable for surface activities during custodial care. Planned custodial care may be limited to activities such as vegetation control, minor maintenance, and environmental monitoring. However, use of the site surface for activities such as parking lots may be planned. Final conditions at the site must be acceptable to the custodial agency and compatable with its plans for the site.

7. Demonstrate that all trench bottom elevations are above water table levels taking into account the complete history of seasonal fluctuations.

8. Eliminate the potential for erosion or loss of site or trench integrity due to factors such as ground water, surface water, wind, subsidence, and frost action. For example, an overall site surface water management system must be established for humid sites to drain rainwater and snowmelt away from the burial trenches. All slopes must be sufficiently gentle to prevent slumping or gullying. The surface must be stabilized with established short-rooted grass, rock, riprap, or other measures. Trench caps must be stabilized so that erosion, settling, or slumping of caps does not occur.

9. Demonstrate that trench markers are in place, stable, and keyed to benchmarks. Identifying information must be clearly and permanently marked.

10. Compile and transfer to the custodial agency complete records of site maintenance and stabilization activities, trench elevation and locations (in USGS coordinates), trench inventories, and monitoring data for use during custodial care for unexpected corrective measures and data interpretation.

11. Establish a buffer zone surrounding the site sufficient to provide space to stabilize slopes, incorporate surface water management features, assure that future excavations on adjoining areas would not compromise trench or site integrity, and provide working space for unexpected mitigating measures in the future. The buffer zone must also be transferred to the custodial agency. The width of the buffer zone will be determined on a site-specific basis. The buffer zone may generally be less than 300 feet.

12. Provide a secure passive site security system (e.g., a fence) that requires minimum maintenance.

13. Stabilize the site in a manner to minimize environmental monitoring requirements for the long-term custodial phase and develop a monitoring program based on the stabilization plan for implementation by the custodial agency.

14. Investigate the causes of any statistical increases in environmental samples which have occurred during operation and stabilization. In particular, any evidence of unusual or unexpected rates or levels of radionuclide migration in or with the ground water must be analyzed and corrective measures implemented.

15. Eliminate the need for active water management measures, such as sump or trench pumping and treatment of the water to assure that wastes are not leached by standing water in the trenches. Passive systems are preferred. Engineered methods of intercepting contaminated ground water or diverting ground water should also be passive.

16. Evaluate present and zoned activities on adjoining areas to determine their impact on the long-term performance of the site and take reasonable action to minimize the effects. Staff recognizes that these actions would normally be limited to areas under control of the licensee.

Implementation

All objectives will be considered and satisfied to the extent practicable during the review of requests for burial ground operating license termination. Existing licenses will be amended to add conditions requiring submittal of site closure and stabilization plans and explicit requirements for satisfactory completion of the plan before the license can be terminated and the material buried at the site transferred to custodial government care. New applicants will be required to submit preliminary site closure and stabilization plans as part of the initial application.

Appendix J

REGIONAL CASE STUDIES

This appendix presents the results of four regional case studies. Each regional case study consists of the calculation of impact measures for a geographic region of the conterminous United States resulting from the disposal of low-level radioactive waste (LLW) generated and disposed within that region for a period of 20 years. The regional case studies are meant to help provide an illustration of the unmitigated impacts of LLW disposal on a regional basis following the application of the performance objectives and technical criteria for LLW disposal established in this environmental impact statement.

In this appendix, the conterminous U.S. has been divided into four regions with boundaries based upon those for the U.S. NRC Regions, shown in Figure J.1. These waste generating regions will be referred to in this appendix as the northeast (Region 1), southeast (Region II), midwest (Region III), and western regions (Regions IV and V). Each of these regions are projected to generate up to one million m^3 of LLW between the years 1980 and 2000 (see Appendix D).

Within each region a hypothetical disposal facility is assumed to be located at a site which is consistent with: (a) the basic disposal facility siting considerations discussed in Chapters 4 and 5 and Appendix E, and (b) the generic environmental characteristics within that geographical region. These regional sites are described in Section 1. A description of the disposal facilities assumed to be situated at each of these sites are presented in Section 2. The design, operation, and closure of these hypothetical disposal facilities are consistent with the performance objectives and the technical criteria outlined in this environmental impact statement. Finally, the various quantifiable impact measures associated with the management and disposal of LLW generated within that region at each of these regional disposal facilities are outlined and compared in Section 3.

1. REGIONAL SITE DESCRIPTIONS

This section provides a brief description of the hypothetical sites utilized for the regional case studies. These hypothetical sites are meant to be consistent with the basic siting considerations presented in Chapters 4 and 5, Appendix E, and the generic environmental characteristics within the region in which the site is assumed to be located. The regional site descriptions are meant to be typical of the environmental characteristics of the regions and have been developed from a number of sources. The regional site descriptions are intended to describe reasonable sites--i.e., sites that could be licensed--but are not intended to represent the "best" site that could be located within a region. The site descriptions should not be interpreted as representing any existing disposal facility or specific location within the regions. Neither should they be interpreted as NRC advocacy of any region or any specific location or site within a region.

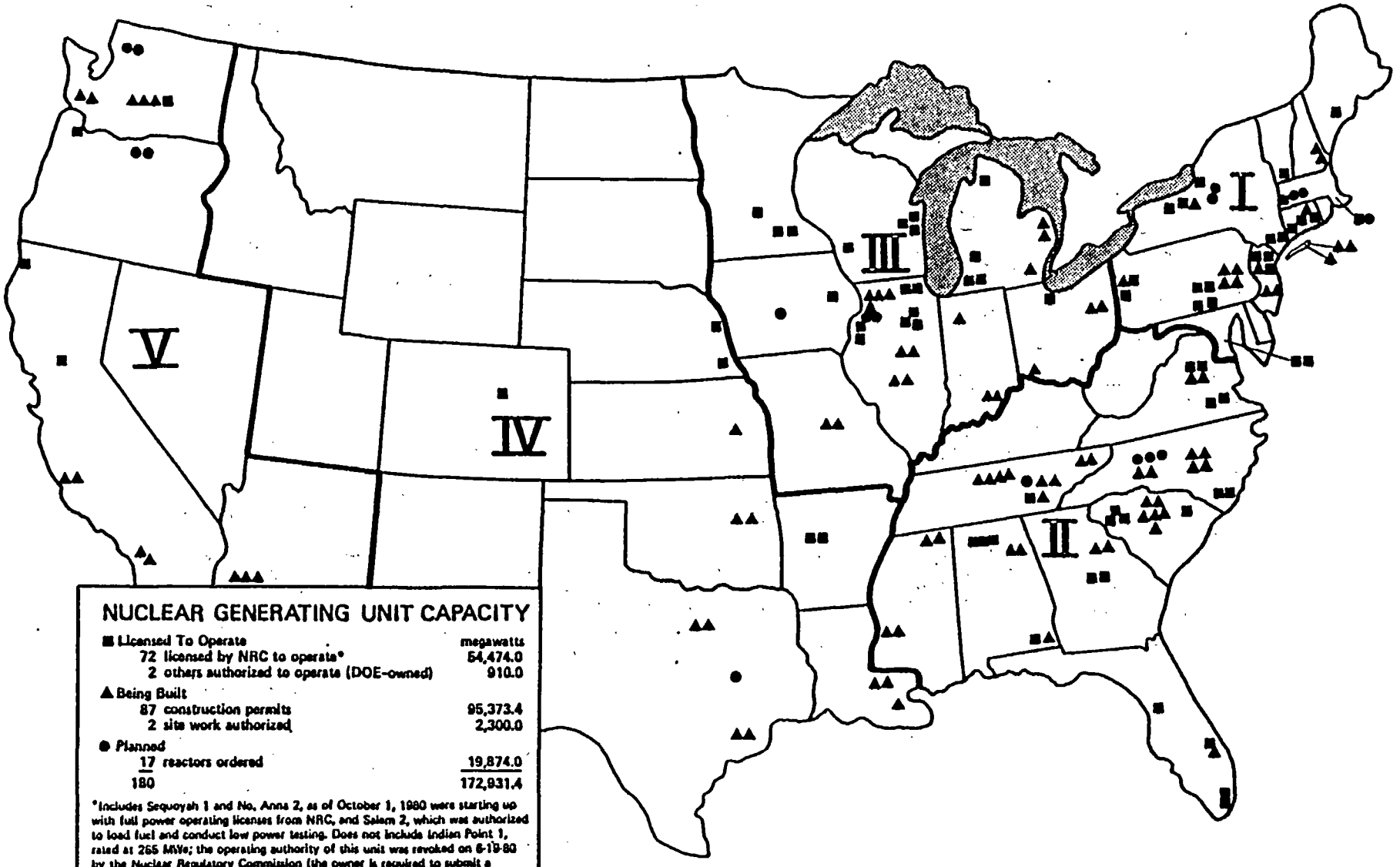

Figure J.1 U.S. NRC Regions

1.1 Northeastern Site

The northeastern site is assumed to be located within the Appalachian Upland portion of the Appalachian Plateau physiographic province. A general topographic map of the site is presented in Figure J.2.

The area has been reworked by erosional and depositional forces associated with glacial and postglacial activities. The disposal facility site is on an upland area, having an average elevation of about 555 m (1,820 ft) above mean sea level (msl), and slopes to the south at a rate of about 3%. The drainage from the site flows into the headwaters of Point Creek.

1.1.1 Geology

Throughout most of the Appalachian Upland, the bedrock is underlain by unconsolidated deposits of glacial origin. The thickness of these units is generally greater in the lowlands and valleys, gradually thinning out over the upland regions. The material properties of the deposits are highly variable.

The site is underlain by approximately 9 to 23 m (30 to 75 ft) of compact glacial till frequently referred to as hardpan. Thin and discontinuous interbedded layers of sand and gravel are observed locally in the area. Coarser-grained sediments are principally found in valleys and lowlands, and are associated with stream channels.

Underlying the glacial mantle are flat lying rocks of upper Devonian Age belonging to the Schaffer Group. These rocks consist of marine, black, and gray shales and siltstones, with some thin sandstone layers. The regional dip of the strata is to the south-southwest at a rate of about 2%. A west-northwest/east-southeast geologic profile of the site area is shown on Figure J-3.

The northeast site falls within one of the more tectonically stable regions of the northeast. The site location has been estimated to have a peak horizontal ground acceleration of 0.04 g, with a recurrence interval of more than 500 years. Based on available data, no capable faults are known to underlie the site or lie within 5 miles of the site.

1.1.2 Soils

The site area is covered by silty loams with an underlying brittle, dense fragipan. The predominant soil types belong to the Brickton, Warren, Chitta and Highland series. The parent material consists of acidic, low lime content, dense glacial till.

The site has slopes ranging from nearly level to moderately rolling grades, and the runoff potentials are correspondingly variable. The soils are deep and generally poorly drained. Permeabilities for the uppermost foot of soils are moderate, ranging from 15 to 50 mm per hour (0.6 to 2 inches per hour). However, the dense silty fragipan subsoil is of considerable thickness and is highly impervious, affording low permeabilities ranging between less than 1.5 to 5 mm (0.06 and 0.2 inches) per hour. The soil is strongly acidic, especially

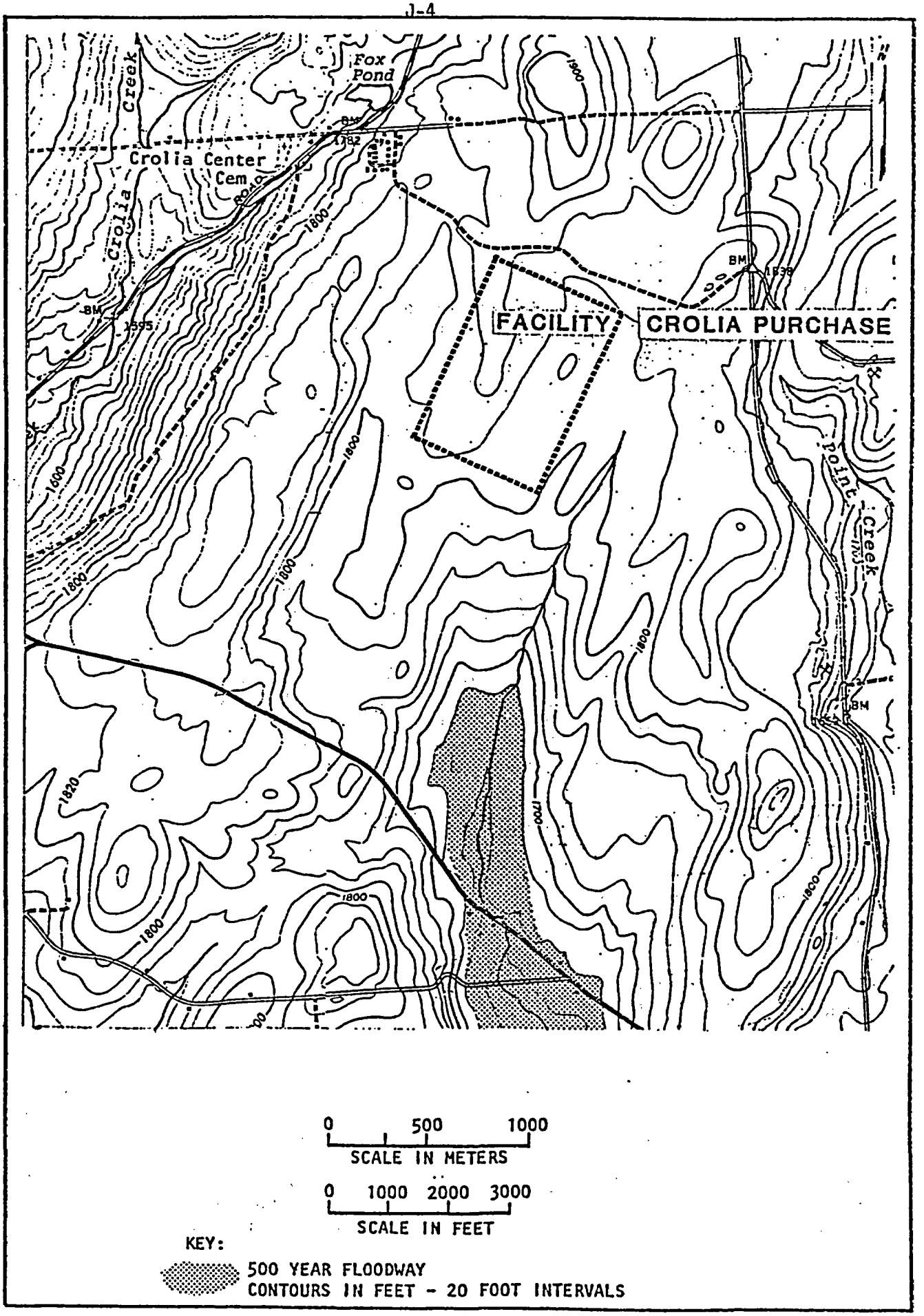

Figure J.2 Northeast Site

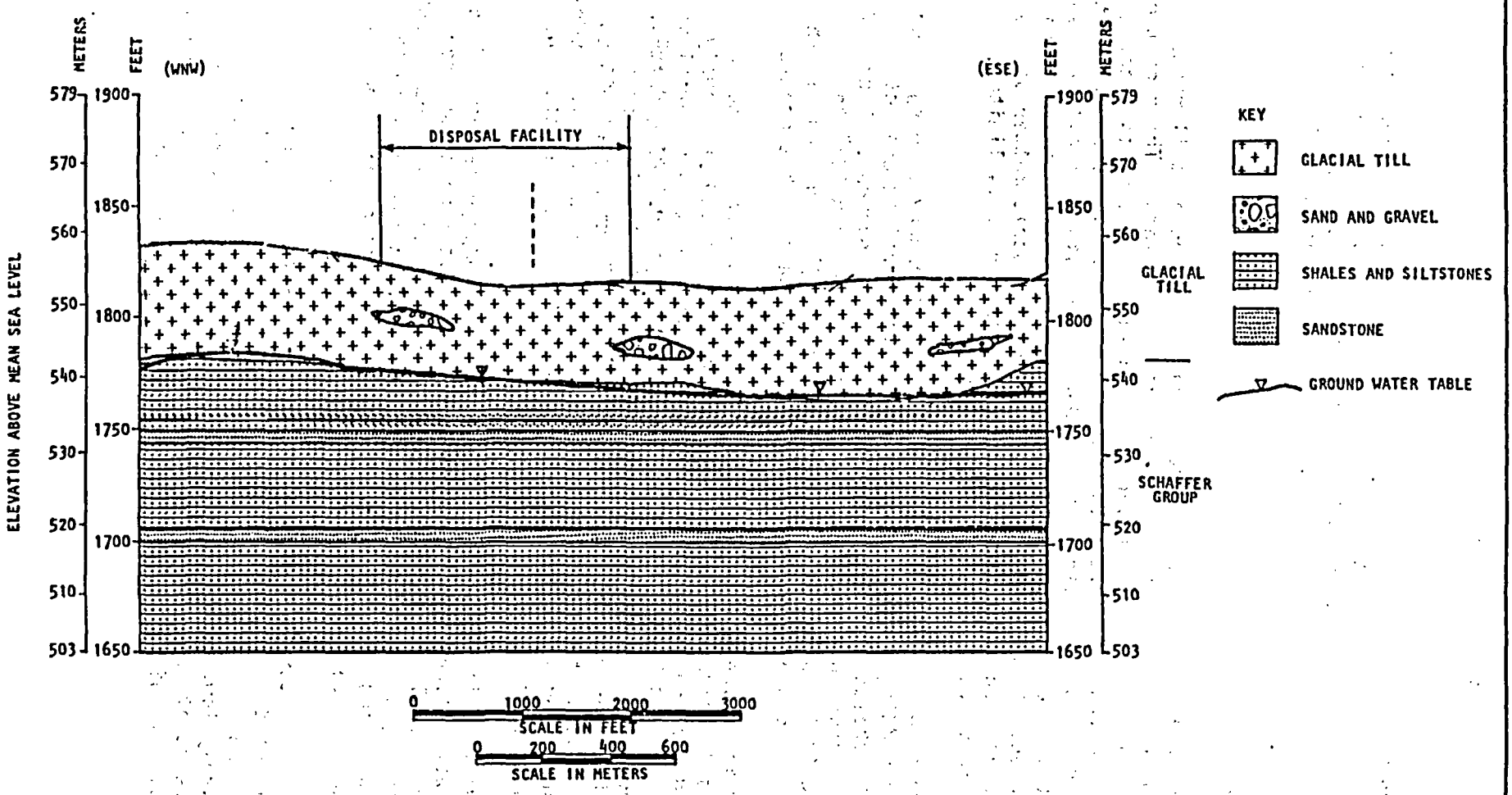

Figure J.3 Geologic Profile of the Northeast Site

in the topsoil layer. The plentiful root material in the upper layers contribute to the relatively high organic matter composition. In general, available nitrogen is high, with a moderate phosphorus and potassium content. The low lime content of the glacial till might indicate a correspondingly low calcium content.

1.1.3 Ground Water

The ground water generally occurs where the bedrock and glacial till meet. The depth to ground water at the site averages about 12 meters. The amount of ground water available in the local upland area in which the site is located is largely limited to that which reaches the zone of saturation from precipitation falling upgradient of the site. This recharge quantity is small because of the low permeability of the till, and the heavily vegetated nature of the land surface which acts to hold water in the surficial organic matter affording greater loss via evapotranspiration. Recharge in these areas is limited, ranging from 5 to 50 mm (0.2 to 2.0 inches) per year.

Ground water occurrence in the bedrock is limited to secondary openings along fracture zones and bedding planes. Generally, the fine-grained character associated with the shales and siltstones inhibits water movement. Rocks of this type typically have an upper permeability of about 4.72×10^{-7} to 4.72×10^{-5} cm/sec (0.01 to 1.0 gallons/day/ft^2 (gpd/ft^2)). Movement in the intergranular pore spaces of the sandstone layers will be somewhat greater.

Ground water flow is to the south, following the local topography, and enters the unconsolidated deposits at erosional interfaces. As stated previously, till is not a good water-bearing unit. The permeability of this material is on the order of 4.72×10^{-8} to 4.72×10^{-9} cm/sec (0.001 to 0.0001 gpd/ft^2). here coarse-grained deposits are encountered, the permeability increases considerably, with values ranging from 4.72×10^{-2} to 4.72 cm/sec (1,000 to 10,000 gpd/ft^2). Most of the recharge entering at the site follows the hydraulic gradient to the south and is discharged as base flow into the headwaters of Point Creek which is about 1,000 m (3,000 ft) away.

Ground-water usage in this rural setting is very low. Pumpage is limited to widely scattered wells serving as domestic supplies to local homes and farmsteads. Most of these rural supplies are obtained from bedrock wells, 30 to 61 m (100 to 200 ft) in depth, although some of the water comes from seepage from the overlying deposits around the well casings. The average yields range between 23 to 30 liters per minute (6 to 10 gpm).

The quality of ground water in the unconsolidated deposits and upper shale units is generally good. Occasional samples collected in the upper shales were found to be high in total dissolved solids and hardness; however, average values are relatively low. Water in the unconsolidated deposits tends to reflect the influence of the underlying bedrock. In general, water from the deep gravel deposits is high in iron, and water from shallow gravel deposits is very hard.

1.1.4 Surface Water

The site is located in the once glaciated region of the Brokill Mountains. The rolling terrain is typical of the region, the result of glacial scour and fill. The drainage basin in which the site is located covers 7.36 km^2, with a coarse drainage density of 0.5 (dimensionless). Total stream length above the site is 2,286 m (7,500 ft).

The site vicinity is generally sloping to the south with total vegetative cover. The surface soils and vegetation allow for considerable retention of precipitation; only 20 to 30 percent of precipitation becomes surface runoff. A strong correlation exists between stream discharge and precipitation in the basin. Mean annual discharge at the outlet of the basin is 0.99 m^3/s (35 cfs), but a wide variation in flow occurs throughout the year. Analysis of the unit hydrograph indicates that while peak discharge in the stream occurs within 30 minutes of rainfall commencement, recession of the flow takes up to 30 hours. This variation is likely due to the base flow sustained by and fair weather runoff derived from ground water.

Saturation of the lower basin area occurs during high intensity precipitation events, causing return flow. The maximum discharge of a 500 year flow is estimated to be on the order of 368 m^3/s (13,000 cfs). The floodway of such a flow is delineated on Figure J-2. As can be seen, the site is located well above the floodway.

Development of the site will tend to reduce the infiltration area of the basin, reduce the time to peak discharge and increase the flood stage of the stream. Facility operations such as placement of impervious cover materials and clearing of vegetation are expected to increase the runoff by approximately 60% by the time the facility is closed. This increased runoff, however, will not result in increased potential for site flooding.

1.1.5 Meteorology

The climate in the area of the northeastern site is classified as humid continental, characterized by wide variations in seasonal precipitation and temperature. Moisture sources for precipitation are obtained from the southerly flow of Gulf air during the summer, cyclones that originate in the Great Lakes, and Atlantic Coast systems. Precipitation is uniformly distributed over the year with the greatest average monthly amounts occuring during April through September in the form of thunder showers. The average annual precipitation is approximately 1,034 mm (41 in).

The area is characterized by distinct seasonal temperature variations. Winters are predominantly cold with maximum temperatures ranging from 0 to 20°C (32 to 68°F), and nightime minimums of from -9 to -7°C (15 to 20°F). The temperatures are generally mild during June through August and maximum temperatures average from 24 to 26°C (75-79°F). The mean annual temperature for the area is 8°C (46.0°F).

The prevailing wind direction is southerly from May through November and westerly during the winter and early spring. The average wind speeds during these periods are 15.6 and 17.8 km/hr (8.4 and 9.6 knots), respectively. The average annual windspeed near the site is 16.6 km/hr (10.3 mph), and occurs from the west-southwest direction. Thunderstorms occur on an average of about 30 days per year and are more vigorous during the warm season. Tornados are not common but may occur between late May and late August. Freezing rain storms generally occur on one or more occasions during the winter but are of short duration.

Since the area is characterized by frequent storm passages, particularly from late fall to early spring, relatively low frequencies of nocturnal solar radiation occur. Northwest winds blowing over the western slopes of the nearby mountains during winter also enhance the instability of the area climate. Inversions based below 152 m (500 ft) above the surface may be expected to occur 20 to 30 percent of the time in any season. As a result, mixing heights and wind speeds have less variations

1.1.6 Terrestrial Ecology

The site is located within the Appalachian Highland Division of the Hemlock-White Pine-Northern Hardwoods Region. The region is characterized by pronounced alternating presence of decidious, coniferous, and mixed forest communities. Approximately half of the county in which the site is located is currently used for agriculture, with much of the remaining area covered by secondary forest growth. Public use areas within a 40 km (25 mi) radius of the site include the Crolia Wildlife Management Area located 2.7 km (1.7 mi) north, the Crown Lake State Park located 9.7 km (6 mi) south, the Frog Pond State Park located 29 km (18 mi) east, and the Severn Fish Hatchery located 6.4 km (4 mi) northwest.

The disposal facility site itself is entirely forested. The dominant species are sugar maple, American beech, yellow birch, hemlock and white pine. The immediate vicinity of facility is also forested to a great extent, continuous with the woodlands found onsite.

No state or federally declared rare or endangered species are known to occur onsite. A variety of mammal species are found onsite. The most abundant are small mammals such as the white footed mouse, short-tailed shrew, woodland jumping mice, and meadow mole. Common medium sized mammals are woodchuck, opossum, and gray squirrel. White-tailed deer are also abundant in this area.

Most mammals utilizing the site, with the exception of woodchucks, are not burrowing species. These mammals dig tunnels which average 1.2 to 1.5 meters (4 to 5 ft) deep, and 7.6 to 9.2 meters (25 to 30 ft) long. Home ranges of the common mammals vary depending upon the availability of food.

A moderate number of reptiles have been observed or are expected to occur within the deciduous woodlands. Reptiles found include the eastern garter

snake and snapping turtle, the latter being essentially restricted to areas immediately adjacent to water. Other reptiles observed include the spotted salamander, the wood frog, and the American toad.

1.1.7 Aquatic Ecology

The aquatic environment near the site is limited to Point Creek (2 mi from the site to the east) and its tributary, Boyle Creek (1 mi from the site to the south). Point Creek leads into the Sprite River at a point 37 km (23 mi) downstream, which then drains into the Wilder River, 27 km (17 mi) further south. Both Point Creek and Boyle Creek are considered Class C waters, best suited for recreational fishing. Point Creek and its tributaries are shallow, rocky bottom streams. The major primary producers of these waters consist of several genera of diatoms, green and blue-green algae. The most common phytoplankton are Tubellaria, Fragillaria, Asterionella, and Cyclotella. The flow of these streams somewhat limits the abundance of macroflora. Forty seven fish species are known to occur within the county in the Wilder River watershed.

Most of these species are expected in Point and Boyle Creeks. Point and Boyle Creeks are also stocked with rainbow trout, and tiger muskellunge.

1.1.8 Land Use

The site, which is forested, is located in a rural land area. The general region in which the site is located is comprised mostly of forested land and active or inactive farmland. There are no farm dwellings or other residences located onsite. The site is not suited for any unique uses, but the soils are considered to be suitable for farming. There is no significant mineral resource development within 10 km (6 mi) of the facility. County plans for the site, which is not in a visually sensitive area, and surrounding land (2 to 7 km) include reforestation and compatible uses.

There are no known mineral resources of economical consequences within the vicinity of the site. Recovery operations in the area are limited to a small bedrock quarry located one mile to the north, and a sand and gravel quarry, located one mile to the east. No oil and gas reserves of economically recoverable quantities are known to exist in the area.

1.1.9 Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is equal to 136. The average cation exchange capacity of the subsurface media is about 12 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 65 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 50 years. The horizontal saturated zone travel times from the edge (of the vertical projection into the saturated zone) of the disposal cell closest to the discharge locations are as follows: to the restricted area fence, 150 years (30 meters); to the closest drinking water well 2,450 years (500 meters); and to the nearest surface water discharge location, 4,950 years (1,000 meters).

1.2 Southeastern Site

The southeastern site is assumed to be located within the Liptone Upland segment of the Atlantic Coastal Plain physiographic province. For the purposes of this appendix, the southeastern site description is assumed to be consistent with the reference facility described in Appendix E.

1.3 Midwestern Site

Falling within the Central physiographic province, the midwestern site rests at an average elevation of about 247 m (810 ft) above mean sea level. The general topography of the site, which is shown in Figure J.4, is that of a well dissected plain which is virtually encircled by various branches of the West Fork of Finley Creek. The regional topographic surface undergoes only small changes in relief.

1.3.1 Geology

A considerable thickness (approximately 35 m or 115 ft) of unconsolidated deposits underlies the site. Most of this is composed of a rather impermeable glacial till consisting predominantly of pebbly and sandy clay and silt, and gumbotil. Gumbotil is a clay-rich till produced as a result of thorough chemical decomposition. Portions of the glacial drift may contain sand and gravel pockets of limited areal extent.

Southeast of the site is an area underlain by buried channel deposits reflective of an ancient stream channel. This channel consists of stream alluvium that filled the valley prior to or between glacial periods. The buried channel in the site area represents the upper reaches of a tributary to what is presently called the Washoe Channel. Evidence of this system is the increased depth to bedrock by about 23 m (75 ft).

The bedrock consists of approximately 30.5 m (100 ft) of Mississippian age rocks belonging to the Dette and Adams Series. The uppermost formation of the Dette series, the Pile shale, which generally acts as an aquiclude to the underlying Karesh and Becker formations, is absent from the site area. The Karesh limestone is thin and discontinuous over the Becker. Both formations are chiefly dense, crystalline, lithographic or tightly cemented fragmental limestones and dolomites with very low porosities. The basal 3 m (10 ft) of the Becker consists of cherty sandstone.

Underlying the Dette series are the dense, cherty dolomites and limestones of the Adams series. These rocks are exposed at the buried channel/bedrock contact point. These two series make up what is known as the Mississippian Aquifer. They are underlain by approximately 400 feet of siltstones and shales of Devonian age that serve as a good aquiclude to the underlying Devonian Aquifer. Stratigraphic sequences and the location of the ground-water table are illustrated in the geologic profile on Figure J-5.

The midwestern site is located within the tectonically stable interior of the North American continent. The closest area of major seismic risk covers the

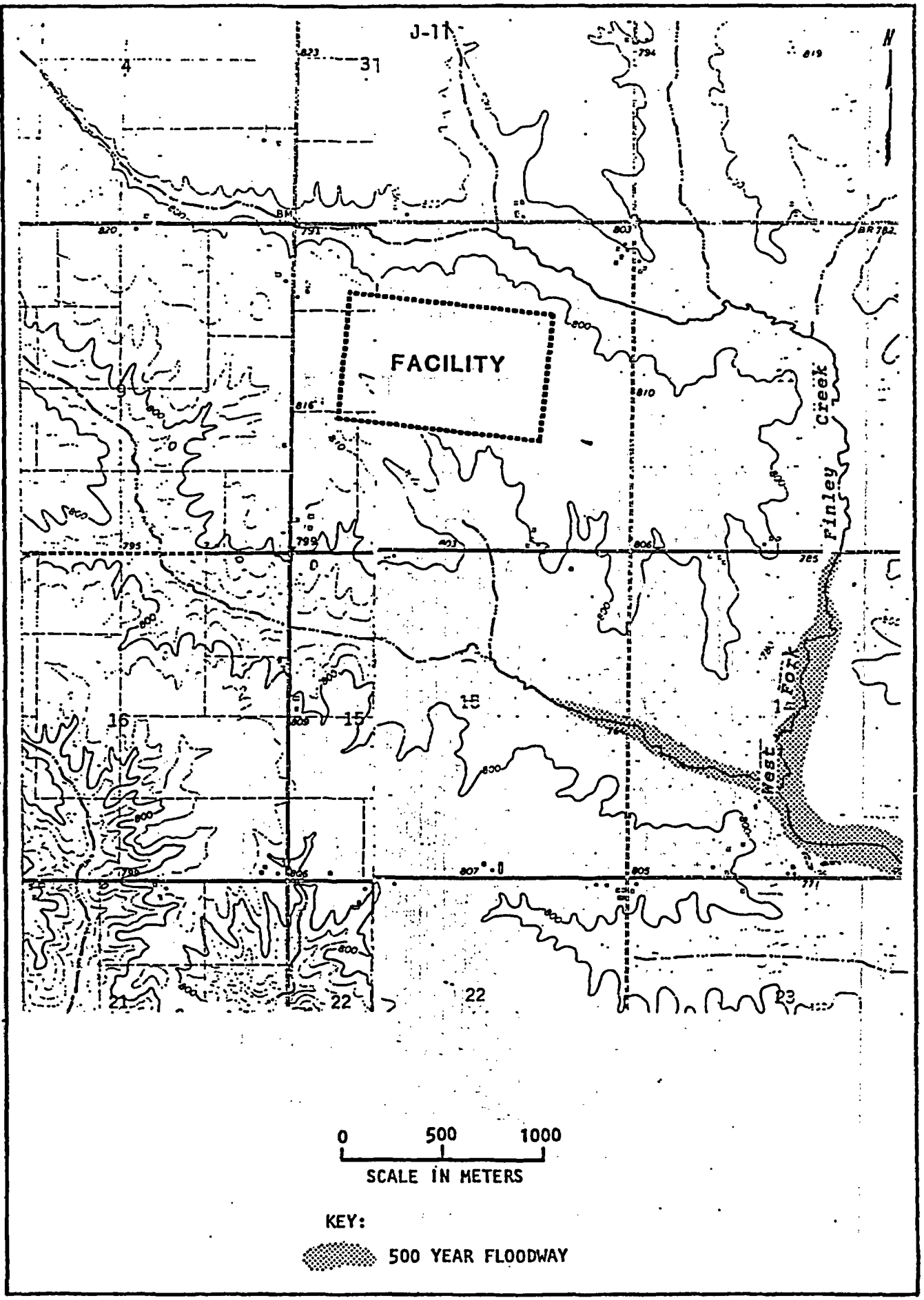

Figure J.4 Midwest Site

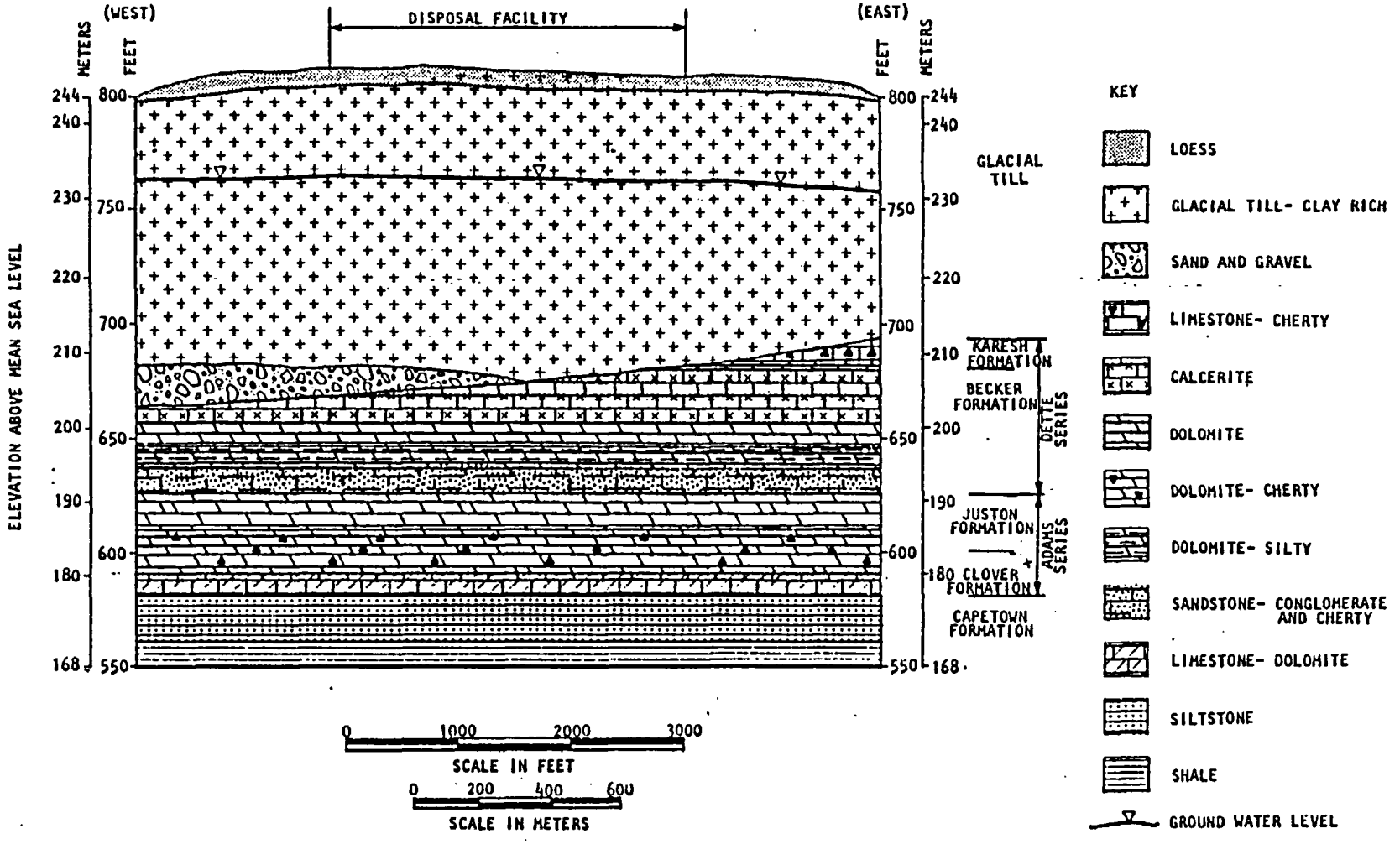

Figure J.5 Geologic Profile of the Midwest Site

eastern section of the adjoining state to the north. The site area has a probable peak horizontal ground acceleration of less than 0.04 g, with a recurrence interval of more than 500 years. Within historical record, no evidence was found to indicate the occurrence of a capable fault within the site area.

1.3.2 Soils

The entire area in which the site is located is covered by about 3 to 3.7 m (10 to 12 ft) of Wisconsin loess, which is the parent material of the site soils. The predominant soil types are silty clay loams belonging to the Wancho, Houlik and Lyle series.

These soils are generally moderately-slow to moderately-well drained and have permeabilities ranging between 5 and 50 m/hr (0.2 to 2.0 in/hr). The soil is generally highly acidic in the topsoil layer and slightly acidic to neutral in the substratum. Organic matter content is consistently high throughout the series. Available nitrogen and phosphorus are low to medium, and the soil content of potassium and calcium is very low.

1.3.3 Ground Water

Ground water of appreciable amounts occur chiefly in the sand and gravel deposits associated with the glacial drift and buried channel systems. These "drift aquifers" are notably limited in areal extent, although they sometimes serve as sources for farmsteads and livestock drinking water. Water quality from the drift aquifers is generally good, being low in dissolved solids and mineral constituents; however, nitrates in excessive amounts are common, especially in those deposits close to heavily fertilized ground surfaces.

Thicknesses of about 15 m (50 ft) or more of sand and gravel have been associated with some of the larger buried valley systems. As the channel in the site proximity is more representative of the upper limits of a tributary to such a valley, it is likely to have lesser quantities of permeable sediments. Water from these deposits is more highly mineralized than in the drift aquifers. Permeabilities on the order of 0.048 to 0.48 cm/sec (1,000 to 10,000 gpd/ft^2) can be expected depending upon how well sorted the sand and gravel deposits are within these aquifers.

Water in these Mississippian rocks is generally confined to secondary openings, and movement is considered to be very slow. Specific capacities are estimated to be less than 1.0 gallon per minute per foot of drawdown. Based upon the dense, impervious nature of the rock, a permeability of 2.4x10^{-5} cm/sec (0.5 gal/day/ft^2) can be assumed. With little exception, water from the Mississippian aquifer in the site area offers good to fair quality water.

The depth to the seasonally high ground-water table under the site is expected to be about 12 m (38 ft) from the ground surface. Local ground-water movement in the drift aquifer will be governed by the topography, draining toward and being discharged into the various branches of the West Fork of Finley Creek. Ground water from the surficial aquifer, and also from the shallow bedrock

aquifer, can be expected to discharge to the buried alluvial deposits. The regional ground-water flow in the Mississippian aquifer is to the south-southeast as controlled by the nearest major stream, the Deer River.

Ground water usage in the area is limited to consumption as needed by local homes and farmsteads for domestic, irrigation and livestock supplies. It is estimated that the majority of wells tap Mississipian aquifers and to a lesser degree, the drift aquifers. Yields of less than 76 lpm (20 gpm) are the rule for this area. The only municipal supply in proximity to the site belongs to the town of Mica, located about 5.6 km (3.5 mi) to the southeast. Four of the nine municipal wells tap the Lower Mississippian Aquifer. The remaining wells utilize the Lower Ordovician Aquifer.

1.3.4 Surface Water

The site is located on a section of the Great Plains that is undergoing dissection as a result of recent climatic change. Approximately 90% of the streams in the drainage area are intermittent, flowing only 6 to 8 months of the year. The drainage density of the basin is 0.64, indicating a coarse drainage texture which is typical of this region. Flow rates from the site average between 0.74 to 0.99 m^3/s (26 and 35 cfs) for the year.

Since the site is of limited areal extent, the correlation between precipitation and stream discharge is very close. Peak discharge rates are related to precipitation events of high intensity. Between 60 and 80 percent of the precipitation in the drainage basin is discharged as surface runoff. Unit hydrograph analysis of the site area indicates that peak flow usually develops between 6 and 7 hours after precipitation begins. Base flow and return flow play important roles in the basin drainage; the extent is determined by the intensity and duration of the precipitation event.

As expected, the highest stream discharge rates are associated with rain storms of limited duration but with high intensity (ranging between 102 and 152 mm/hr). The 500-year flow floodway is delineated in Figure J.4.

During the development of the site the discharge rate is expected to increase as the area is cleared of vegetation and impervious material is placed over the disposal cells. While the site development will decrease the time to peak discharge and increase the peak flood stage, there will be no significant risk of flooding at the site due to the elevation differences between the area and the site outflow. While overland flow of considerable velocity may be expected during site development, prudent drainage engineering will be able to divert flow, reduce velocities and limit erosion of the site.

1.3.5 Meteorology

The area has a humid continental climate, with a total annual local precipitation of 777 mm (30.5 in). Approximately two-thirds of the annual precipitation occurs during the months of April through September. The source of this precipitation is the warm moist southerly air from the Gulf of Mexico. The normal mean snowfall for the site area is approximately 686 mm (27 in).

The average annual temperature in the site vicinity is approximately 11°C (51.0°F). July is the hottest month, having an average daily maximum of 31°C (87°F) and an average daily minimum of 18°C (64°F). During January, the coldest month, the daily temperature range is approximately -0.6°C (31°F) to -11°C (12°F).

The prevailing wind direction at the site is southerly at an average speed of 17 km/hr (9.0 knots). During the months November through March, a northwesterly wind component develops in response to the Canadian cold air outbreaks. Wind speeds during these months average 22 km/hr (12.1 knots).

Severe weather events such as thunderstorms and tornadoes occur during midspring to late summer. Statewide occurrences of tornadoes average about 10 for any given 8 year period. From the period 1920 to 1960, there have been approximately 75 occurrences within 2° latitude/longitude square inclusive of the site.

Since the site has a pronounced continental type of climate, it has inversion frequencies closely related to the diurnal cycle. In general, inversions occur 20 to 30% of the time during spring and summer, while during the fall and winter months, inversions may be expected about 30 to 45% of the time. The higher frequency during the fall and winter is probably a reflection of the relatively low number of storms in the fall and maximum length of stable nocturnal period in winter. The opposite is true for the summer months. As a result, seasonal annual morning and afternoon mixing heights vary by small amounts.

1.3.6 Terrestrial Ecology

The natural vegetation within the vicinity of the site is a mixture of oak-hickory forest and bluestem prairie. The forest community occurs primarily along valley slopes and upland ridges. Big bluestem is the dominant grassland plant where the prairie remains. However, most of this area is cropland. Two terrestrially environmentally sensitive areas, Deer River Access and Chatham Timbers, are located 18 km (11 mi) to the southwest and 38 km (24 mi) to the south, respectively. Green Lake, which is a prime recreational fishing area, is located 21 km (13 mi) southeast.

The two major land uses of the county in which the site is located are pastureland (24 percent) and row crops (65 percent), with corn and soybeans representing the dominant crops. Approximately 35 and 12 percent of the county, respectively, are planted in these crops. Most of the naturally occurring prairie has been lost in the county. Existing grasslands, dominated by introduced species, are interspersed in 60 to 80 ha (150 to 200 acre) blocks throughout the county.

Almost 60 percent of the land area adjacent to the site is planted in corn. Four small woodlots, about 4 ha (10 a) total, are found in the near vicinity of the site--either adjacent to residences or farm buildings, or along creek boundaries. White oak, red oak, and shagbark hickory dominate these woodlands. Small blocks of grassy areas occur along stream banks, roadsides and other

areas. Common introduced grasses include bluegrass and smooth brome. Similar ground cover types are found within an 8 km radius of the site, with slightly more oak-hickory forests occurring along the tributaries of Deer River.

No federally declared endangered or threatened species have been observed on or near the site. The most common mammals found onsite and within a five mile radius are those for which corn is a predominant food source, and can live in proximity to man. The most abundant species include the racoon, striped skunk, eastern cotton-tail, opossum and fox squirrel. Several burrowing mammals are also found in the area, primarily in fields not actively cultivated; these include the badger, plains pocket gopher and thirteen-lined ground squirrel. The badger and pocket gopher dig tunnels in search of food that can be 1.2 to 1.5 m (4 to 5 ft) in depth and up to one hundred meters long.

Most of the mammals that utilize the site have small home ranges, e.g.: thirteen-lined ground squirrel - 0.8 to 1.21 ha (2 to 3 acres); eastern cotton-tail - 3 to 8 ha (7 to 20 acres); and opossum - 6 to 16 ha (15 to 40 acres). The raccoon, with a maximum range of 3.2 km (2 mi), and an average of 1.6 km (1 mi), has the largest home range of those species expected in this area.

Corn very often is a major winter food source for many upland game birds, including birds found in the area. The ring-necked pheasant, and bobwhite quail are the species most commonly hunted. Black ducks, mallards and pintails are also numerous in the area, and feed heavily on corn.

Numerous resident bird species are also found onsite and in the surrounding cornfields. The most common species found, and which feed extensively on corn, include the redwing, cardinal, meadowlark, purple grackle, and common crow. Resident birds of prey include the red-tailed hawk and great-horned owl. Transient species include the coopers hawk, broad-winged hawk, and red-shouldered hawk. As a result of ongoing agricultural activities, the reptile and amphibian population of the area is limited. An occasional eastern plains garter snake, bullsnake, or black rat snake may be found.

1.3.7 Aquatic Ecology

With the exception of the northwestern border, the site is surrounded on all sides by the West Fork of Finley Creek, and other unnamed intermittent tributaries. Finley Creek feeds into the Deer River approximately 51 km (32 mi) downstream. There are no federally declared wild or scenic rivers within five miles of the site.

The west fork of Finley Creek and its tributaries are Class B warm waters. Primary uses of the creek are for wildlife, fish, aquatic and semiaquatic life, and secondary contact water uses. Although the soils along the stream banks are moderately to highly erodable, the vegetated banks limit the amount of sediments that enter the streams. No federally declared endangered or threatened fish or snails are expected in these streams.

1.3.8 Land Use

The site is located on agricultural land used extensively (85%) for cultivation of crops, mostly corn. Five houses are located within 5 km of the site. The site vicinity contains 4 towns--Mica, Grendle, Reed and Lyme--but most of the land is not developed intensively. Hayer Park (10 acres) is located 4.8 km from the site. There are no other community facilities, historic places, or other visually sensitive land uses within a 8 km radius. Two state-owned lands, Lake Darling and Deer River Access, are located within 24 km of the site.

The chief source of economically important resources in the state lies in the substantial coal resources associated with Pennsylvanian age rocks. No such deposits occur under the site as the initial bedrock encountered is of Mississipian age. There is a potential for some natural gas deposits. However, the Ordivician source rocks are thin, making recovery unconsequential and uneconomical.

1.3.9 Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is 93. The average cation exchange capacity of the subsurface media is about 12 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 85 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 30 years. The horizontal saturated zone travel times from the edge (of the vertical projection onto the saturated zone) of the disposal cell closest to the discharge locations to the restricted area fence, 90 years (30 meters); to the closest drinking water well, 2,070 years (1,250 meters); and to the nearest surface water discharge location, 3,770 years (2,500 meters).

1.4 Southwestern Site

The southwestern site is assumed to be located within the Northern High Plains subdivision of the Great Plains physiographic province. The regional topography shows sharply contrasting flat plains and rolling to rugged erosional breaks (see Figure J.6). The plains are about 17,872 km^2 (6,900 mi^2) in areal extent and show a gradual eastward slope on the order of 0.2%. The site has an estimated average elevation of 1,219 m (4,000 ft) above mean sea level. As is characteristic of the area, the site is flat. Drainage is to the southeast and southwest to various intermittent branches of Hotsprings Creek.

1.4.1 Geology

Below the surface cover of loam and clay-loam soil are Pliocene age deposits of the Bixler formation. These sediments were eroded from the ancient Rocky Mountains and transported by streams to this area. Because of their origin of deposition, their character varies both vertically and horizontally. As a general rule, however, the sand and gravels are in the basal portion of the formation.

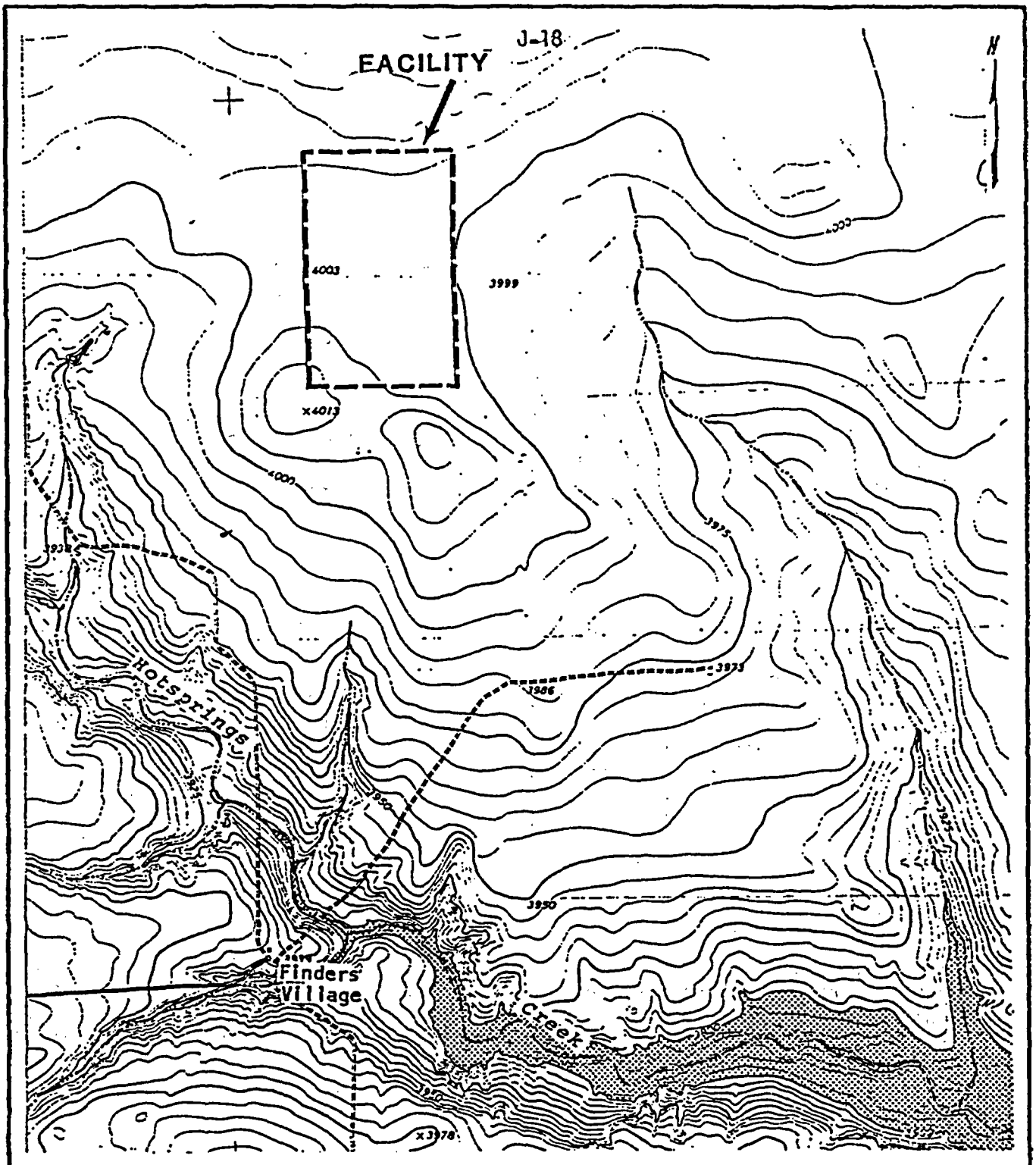

Figure J.6 Southwest Site

The Bixler Formation is about 91 m (300 ft) thick in the site area. The upper 12 to 15 m (40 to 50 ft) is composed of caliche, a calciumrich, carbonate-impermeable sandy clay which acts in a similar manner as a hardpan. Effects of the semiarid climate have cracked the upper 0.9 to 1.5 m (3 to 5 ft) of the caliche. Underlying the caliche is approximately 15 m (50 ft) of dense, brown clay. Thin, discontinuous streaks of sand are also associated with the clays. The balance of the Bixler is principally composed of sand and gravel, extending down to the eroded surface of the Triassic rocks.

The Triassic shales and sandstone belonging to the Maxwell group are estimated to be about 152 m (500 ft) thick in the site area. The first material encountered under the permeable Bixler strata is a red clay, indicative of the weathered shale surface. A schematic representation of the site geology is shown in the geologic profile in Figure J.7.

The site falls within an area designated as having a peak horizontal ground acceleration of less than 0.04 g with a recurrence interval of more than 500 years. No evidence was found to indicate the occurrence of capable faults under or near the site.

1.4.2 Soils

The predominant soil types underlying the site are loams and clay loams belonging to the Starble, Nester, Wixman and Jeeper series. They were formed from moderately fine-textured, calcareous, windblown sediments derived mostly from alluvial outwash from the Rocky Mountains.

Because rainfall is low, and there are long, dry periods, soil development has been slow. The soils are seldom wet below the root zone, and, as a result, many of the soils have a horizon of powdery lime accumulation. Leaching has not yet removed free lime from the upper layers of the calcareous Starble and Wixman soils. Soils belonging to the Nester and Jeeper series tend to be more neutral.

Calcium contents are high in all the soils. Generally, the prairie type of vegetation contributes large amounts of organic matter to the soil. The soils are rather deep (up to 2.5 m) and well-drained, having nearly level to gentle slopes. Runoff is generally slow and permeability values range between less than 1.5 to 50 mm/hr (0.06 to 2.0 in/hr).

1.4.3 Ground Water

The Bixler formation is an unconfined aquifer with very limited consumptive use. The water occurs under water table conditions, and the differences in the thickness of the water saturated material are closely related to the thickness of the Bixler formation. The saturated thickness under the site is only abut 7.6 m (25 ft) as the water table lies some 84 m (275 ft) below ground surface. Available data indicates that the Bixler is the local source for recharge to the Triassic rocks where they are in contact.

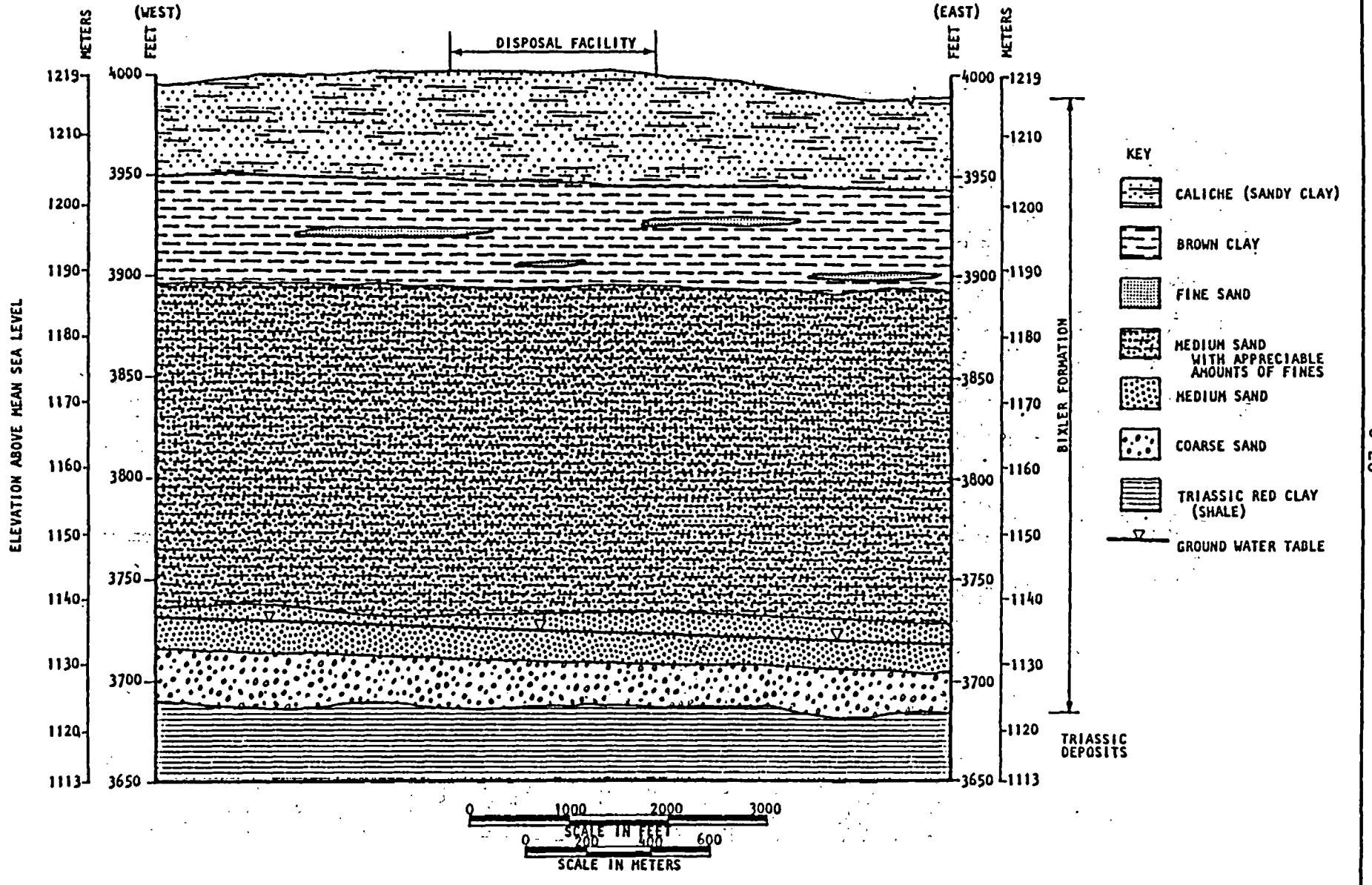

Figure J.7 Geologic Profile of the Southwest Site

The source of water (recharge) to the Bixler, and thence to the Triassic rocks, is precipitation on its more permeable surfaces. The amount of precipitation that enters the ground water is a very small percentage of the total precipitation falling at the surface. It has been estimated that the quantity of precipitation annually reaching the ground water is negligible. For the purposes of this environmental impact statement, however, it is assumed that the annual percolation is 1 mm. Due to the rather impervious nature of the onsite surficial materials, most of the precipitation will be lost by evaporation or drain to Hotsprings Creek as runoff. Part of this runoff will percolate downward through the coarser stream deposits and enter the ground water regime. This probably constitutes the major source of recharge within the area of the site. Some infiltration may work its way through the fractured portions of the caliche and slowly downward to the water table, but this is of limited quantity.

Under natural hydraulic gradient conditions, the water table slopes to the east, generally parallel to the surface slope which is about 0.2%. The average permeability of the Bixler-Triassic aquifer in this area is estimated to be 4.7×10^{-3} to 9.4×10^{-3} cm/sec (100 to 200 gal/day/ft^2).

Ground water within the site vicinity is used almost exclusively as a supply for livestock with a few domestic wells serving ranches. The wells are generally powered by windmills and generate yields not likely to be greater than 7.6 to 11.4 liters/min (2-3 gpm). The nearest irrigation well is located about 13 km (8 mi) from the site.

1.4.4 Surface Water

Elevations on the site range between 1,169 and 1,223 m (3,835 and 4,013 ft) above mean sea level. Total stream length above the site is over 90 km (295,680 ft). With the limited precipitation in the region, streams flow intermittently throughout the year. A wide variation in discharge occurs at the site. Since no base flow is known to occur in the area, precipitation accounts for all of the stream discharge. Short duration, high intensity thunderstorms account for the peak discharges from the site.

While the area of the basin receives considerable intense rain (greater than 50 m/hr), most peak flow is dissipated before discharge at the outlet. Peak discharge occurs when the rain event is within 32 km (20 mi) of the outlet. Analysis of unit hydrograph of the site area and flow data indicate that high discharge rates of up to 28.2 m^3/sec (1,100 cfs) may be expected to occur at least once a year. The 500 year flood has been determined to be about 736 m^3/sec (26,000 cfs) and the floodway is delineated on Figure J-6. As shown, the site is well above the floodway.

1.4.5 Meteorology

The climate of this site is considered semiarid, which is characterized by low humidity, wide temperature and precipitation variations, and frequent windstorms. The average annual precipitation for the site area is approximately

485 mm (19 inches). Departures from the norm can be great with extreme yearly totals ranging from 243 to 1,010 mm (9.56 to 39.75 in). Nearly three-quarters of the total annual precipitation occurs during the growing season from April through September, primarily in the form of thundershowers.

The average annual temperature for the area is about 14°C (57°F). Maximum temperatures occur in the mid-summer months of June, July, and August. Rapid and wide variations are common, especially during the winter months when cold fronts from the Rocky Mountains and Plains States sweep across the plains. Temperature drops up to 16°C (60°F) occurring within a 12-hour period may be associated with these fronts. The highest recorded temperature in the region was 42°C (108°F) and the lowest was -27°C (-16°F).

The prevailing winds from March through October are southerly at 25 km/hr (13.6 knots), and southwesterly at 21 km (11.4 knots) during the winter months. The annual mean speed for all directional components is 24 km (13 knots) and southerly. These winds contribute to the evaporation rate associated with the region. The strongest winds generally occur in March and April and are associated with thunderstorm activity. The strongest winds recorded (134 km/hr in 1949) were associated with a tornado; however these climatic events are rare.

1.4.6 Terrestrial Ecology

The site is located in the High Plains area, also known as the Tinson Province. This area is a relatively level high plateau, and is better drained than most other regions in the state. The shorter growing season (179-225 days) and lower annual average temperature (12° to 13°C) found in this region, compared to other parts of the state, play an important role in the types of plants and animals found here.

The area has been characterized (within a 40 km radius of the site) as Grama Buffalo Grasslands. The most abundant native plant species in this short grass/mixed grass prairie are buffalo grass, and blue grama. Total ground cover is relatively dense, and tends to increase under grazing. The preponderance of grass species results in large quantities of organic materials in the form of living and dead grass roots within the first ten to twelve centimeters of soil (some roots of blue grama and buffalo grass extend to 0.9 m however). The vegetative cover of the site is typical of the region. Although various species of trees, including oaks, elms and hackberries are often found along stream floodplains and steep-walled canyons, these are not found along Hotsprings Creek, an intermittent stream, or its feeder streams, which surround the western, eastern, and southern portions of the site. Federally declared endangered species have not been observed within the site.

The mammalian fauna of this general area includes at least 50 to 60 species, two of which are restricted to this area of the state: the swift fox and plains pocket mouse. During the hot daylight hours, a large number of mammals of this semiarid region live in burrows which they either dig themselves, or which they share or overtake from other species. The larger species which create their own underground burrows include the badger, plains pocket gopher, and swift fox. Only the former two species were observed within 1 km of the

site. The fox uses its burrow, which averages 3.7 m (12 ft) in length and 81 cm (32 inches) in depth, as a den. Many other species also dig their own burrows, or use those of others, to escape the heat and predators, to search for food (insects, seeds or other burrowing mammals) or to use as dens. However, these burrows are shallow.

Other nonburrowing mammals characteristic of this area and which have been observed onsite include the coyote, pronghorn antelope, bobcat, jack rabbit, and eastern cottontail. While six species of bats are known to inhabit the county, none were observed to nest at the site. The most common game species found on the site are rabbit, quail, dove and pheasant.

The mixed grass prairie found onsite and in the general area does afford suitable habitat to numerous resident bird species. The most common small birds include the Western meadowlark, dickcissel, bobolink, savanna sparrow, and prairie chicken. The most numerous resident birds of prey include the golden eagle, horned owl and burrowing owl.

Several species of lizards and snakes also inhabit the site. The more common ones include the northern earless lizard, prairie lizard, great plains skunk, prairie rattlesnake, western diamondback rattlesnake, and bullsnake. Only the last two species have been observed within the site boundaries. As with many mammals of this region, these reptiles extensively utilize underground burrows. Most of the snakes use rodent burrows both for cover and in search of food. The great plains toad and plains and western spadefoot toads dig their own underground tunnels, which can range from several centimeters to a meter in depth.

1.4.7 Aquatic Ecology

The aquatic environment of the site is limited to Hotsprings Creek and its two feeder streams, all intermittent, which surround the site to the east, west, and south. This creek remains intermittent until approximately nine miles prior to its confluence with the Montreel River approximately 136 km (85 mi) downstream. The only other tributaries to Hotsprings Creek occur within an 8 km (5 mi) radius of the site. After rainstorms when water does flow in this stream, aquatic biota is limited to algae, insects (which use the water to breed), and potential fish species such as minnows and sunfish. These fish survive the dry seasons by gathering in small pools of water that may remain throughout the year, and are then dispersed throughout the stream with the flowing waters.

1.4.8 Land Use

The site is located near the administrative borders of a national grassland administered by the USDA, on open grassland. The site itself was privately owned before purchase by the state. There are no residences onsite or within the close vicinity (1 mi) of the site.

The site region is a plain containing numerous parcels of federal grassland, distributed throughout this portion of the state and into neighboring states.

Portions of the site are used at times for grazing cattle. The national grassland is the overriding factor influencing land use in the area, and this is not expected to change significantly in the foreseeable future.

The only known mineral resource occurring in the site area is caliche. This calcium carbonate cement is associated with sand and gravel deposits of the Bixler formation, and may be suitable for use as aggregate. However, these deposits are widespread throughout the entire region and do not represent unique resources.

Whereas numerous producing oil and gas wells have been drilled in the adjoining county to the east of the site, no historical production has occurred within the county. Prospect wells drilled within proximity to the site have not indicated the presence of oil or gas reserves of recoverable quantity.

1.4.9 Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following: The precipitation-evaporation (PE) index of the vicinity is 21. The average cation exchange capacity of the subsurface media is about 5 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 65 percent. The vertical travel time (and distance) from the bottom of the trenches to the saturated zone is 275 years. The horizontal saturated zone travel times (and distances) from the edge (of the vertical projection onto the saturated zone) of the disposal cell closest to the discharge locations are the following: to the restricted area fence, 5 years (30 meters); to the closest drinking water well, 300 years (3,000 meters); and to the nearest surface water discharge location, 600 years (6,000 meters).

2. SUMMARY OF REGIONAL ENVIRONMENTAL PARAMETERS

This section presents a summary of the regional environmental parameters and characteristics presented in this appendix and used in this EIS to calculate radiological and economic impacts from LLW management and disposal.

The assumed population distribution in the vicinity of each of the four regional sites at the year 2000 (postulated year of end of facility operations) is presented in Table J.1.

Water balance calculations for determining the amount of precipitation reaching the saturated zones of the regional sites (i.e., the amount of percolation) are presented in Tables J.2 and J.3. As shown in Table J.3, the water balance calculations for the southwestern regional site indicate that there is no calculable percolation reaching the saturated zone. However, for purposes of determining bounding impacts from waste disposed at this site, it is assumed that the percolation coefficient equals 1 mm at the southwestern site.

Based upon this information, information presented in this appendix, Sections 1.1 through 1.4, and information presented in Appendix E, environmental parameters specific to the four regional disposal sites may be calculated. A list of the region-dependent parameters is included in Table J.4, together with the parameters

Table J.1 Population Distributions for Regional Case Studies

Distance From Facility	Northeast	Southeast	Midwest	Southwest
0-5 miles	3,440	2,024	3,070	59
5-10 miles	20,513	8,115	4,998	180
10-20 miles	73,636	36,000	27,890	3,529
20-30 miles	121,559	124,995	104,181	9,062
30-40 miles	556,639	203,435	121,893	4,888
40-50 miles	1,012,788	104,933	359,146	27,158

Table J.2 Water Balance Analysis Data and Assumptions

Legend: All units in (mm of water) except for C which is dimensionless.

S_M = Maximum Soil Moisture Storage
P = Precipitation
C = Surface Runoff Coefficient
R = Surface Runoff
I = Infiltration
PET = Potential Evapotranspiration
I-PET = Difference Between (I) and (PET)
CNS = Cumulative Sum of Negative (I-PET)
S = Soil Moisture Storage
dS = Change in Soil Moisture Storage
AET = Actual Evapotranspiration
PERC = Percolation into Ground Water System

Assumptions:

P = Data from Representative Location (Ref. 24)
PET = Data from Representative Location (Ref. 24)
C = Estimated for Each Region Based on Typical Soil Descriptions of Region.
S_M = For Humid Sites Assumed 100 mm and for Arid Site Assumed 50 mm.

Calculations: Follow in Table J-3.

Table J.3 Detailed Water Balance Calculations

	J	F	M	A	M	J	J	A	S	O	N	D
NORTHEAST REGION: S_M: 100 mm												
P	71	65	73	72	92	110	114	110	92	86	78	71
C	.20	.20	.20	.20	.15	.15	.15	.15	.15	.18	.20	.20
R	14	13	15	14	14	16	17	16	14	15	16	14
I	57	52	58	58	78	94	97	94	78	71	62	57
PET	0	0	0	28	77	111	129	110	75	38	6	0
I-PET	57	52	58	30	1	-17	-32	-16	3	33	56	57
CNS						-17	-49	-65				
S	214	266	324	100	100	84	60	51	54	87	100	157
dS	57	52	58	0	0	-14	-24	-9	3	33	13	57
AET	0	0	0	28	78	108	121	103	75	38	6	0
PERC	0	0	0	30	1	0	0	0	0	0	43	0
SOUTHEAST REGION: S_M: 100 mm												
P	80	100	96	84	82	102	149	147	103	64	77	81
C	.14	.14	.14	.14	.14	.12	.12	.12	.12	.12	.14	.14
R	11	14	13	12	11	12	18	18	12	8	11	11
I	69	86	83	72	71	90	131	129	91	56	66	70
PET	13	15	37	65	115	158	172	157	114	64	29	13
I-PET	56	71	46	7	-44	-68	-41	-28	-23	-8	37	57
CNS					-44	-112	-153	-181	-204	-212		
S	100	100	100	100	64	32	21	16	12	11	48	100
dS	0	0	0	0	-36	-32	-11	-5	-4	-1	37	52
AET	13	15	37	65	113	147	162	151	10	63	29	13
PERC	56	71	46	7	0	0	0	0	0	0	0	0
MIDWEST REGION: S_M: 100 mm												
P	21	23	36	73	108	108	94	91	101	64	33	25
C	.15	.15	.15	.15	.13	.10	.10	.10	.10	.13	.15	.15
R	3	3	5	11	14	11	9	9	10	8	5	4
I	18	20	31	62	94	97	85	82	91	56	28	21
PET	0	0	6	43	88	127	147	131	86	44	7	0
I-PET	18	20	25	19	6	-30	-62	-49	5	12	21	21
CNS						-30	-92	-141				
S	101	121	10	100	100	74	39	24	29	41	62	83
dS	18	20	0	0	0	-26	-35	-15	5	12	21	21
AET	0	0	6	43	88	123	120	97	86	44	7	0
PERC	0	0	25	19	6	0	0	0	0	0	0	0

Table J.3 (continued)

	J	F	M	A	M	J	J	A	S	O	N	D
SOUTHWEST REGION: S_M: 50 mm												
P	6	10	20	48	71	79	64	72	37	45	19	14
C	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
R	1	1	2	5	7	8	6	7	4	4	2	1
I	5	9	18	43	64	71	59	65	33	41	17	13
PET	1	4	21	47	86	129	154	136	95	49	15	0
I-PET	4	5	-3	-4	-4	-58	-95	-71	-62	-8	2	13
CNS			-3	-7	-29	29	-182	-253	-315	-323		
S	20	25	23	20	14	8	3	1	1	1	3	16
dS	23	9	-2	-3	-6	-6	-5	-2	0	0	1	18
AET	1	4	20	46	70	76	67	67	95	41	15	13
PERC	0	0	0	0	0	0	0	0	0	0	0	0

Table J.4 Region Index Dependent Parameters

Symbol	Scenario	Environmental Property
TPO	Accident	Air-to-air transfer factor FSC
	Construction	Soil-to-air transfer factor FSA
	Agriculture	Soil-to-air transfer factor
QFC	Groundwater	Dilution factor TTM
	Groundwater	Water travel time TPC
	Groundwater	Peclet number
RGF	Groundwater	Factor rg
RET	Groundwater	Retardation coefficients
PRC	Groundwater	Infiltrating percolation
POP	Exposed Waste	Air-to-air and surface water transfer factors.
DIST	Transportation	One-way travel distance
STPS	Transportation	Number of stops per trip
CASK	Transportation	Cask days per round-trip

symbols used in the computer codes developed by Dames & Moore of White Plains, NY for this EIS. Values determined for each of these parameters for each of the four regional sites are provided in Table J.5.

Use of a specific set of property values to calculate impacts is determined by the value of the regional index, IR (See Appendix G). The transfer factors are used to calculate the site selection factors (f_c) for the accident, intruder-construction, intruder-agriculture, and exposed waste scenarios are described in Sections 3.3, 3.6, and 3.7 of Appendix G. The parameters for the groundwater scenarios are used to calculate the waste form and package factors (f_w) and the site selection factors (f_c) for these scenarios as also described in Section 3.5 of Appendix G. The transportation parameters are used to calculate radiological and economic impacts of waste transport to the regional disposal sites as described in Section 4 of Appendix G. Additional information regarding the use of the parameters in the computer codes is provided in Appendix H.

Table J.5 Environmental Parameters for Regional Locations

Parameter	Symbol	Northeast	Southeast	Midwest	Southwest
Accident Scenario					
Fire	TPO(1)	1.83E-10	1.83E-10	1.83E-10	1.83E-10
Single-Container	TPO(2)	2.61E-12	3.32E-12	2.55E-12	1.79E-12
Intruder Scenarios					
Construction	FSC	9.18E-12	2.01E-11	2.51E-11	2.64E-10
Agriculture	FSA	2.96E-11	3.18E-11	3.28E-11	8.06E-11
Exposed Waste Scenario					
Intruder-Air	POP(1)	1.01E-09	3.50E-10	3.86E-10	2.66E-11
Erosion-Air	POP(2)	1.51E-09	5.25E-10	5.79E-10	3.99E-11
Surface Water	POP(3)	1.12E-07	1.12E-07	1.12E-07	1.12E-07
Groundwater Scenario					
Travel Times - years					
Between Sectors	DTTM	400	64	120	8
Individual Well*	TTM(1)	200, 350	42, 66	130, 175	283, 280
Population Well	TTM(2)	2500	400	2100	580
Population Surface	TTM(3)	5000	800	3800	880
Peclet Numbers					
Between Sectors	DTPC	800	1600	800	800
Individual Well*	TPC(1)	400, 700	1300, 1900	400, 700	1300, 1600
Population Well	TPC(2)	10000	10000	12500	30000
Population Surface	TPC(3)	20000	20000	25000	60000
Dilution Factors - m^3					
Individual Well	QFC(1)	7700	7700	7700	7700
Population Well	QFC(2)	2.0E+5	2.0E+5	2.0E+5	2.0E+5
Population Surface	QFC(3)	4.5E+6	4.5E+6	4.5E+6	4.5E+6
Goemetric Reduction					
Individual Well	RGF(1)	1	1	1	1
Population Well	RGF(2)	1	1	1	1
Population Surface	RGF(3)	1	1	1	1
Percolation - mm					
Regular Cover		74	180	50	1
Thick Cover		38	30	25	1
Retardation Coefficient Set Used	NRET	4	3	3	2
Transportation					
Oneway Distance (mi)	DIST	300	400	600	1000
Stops Along the Way	STPS	1	1	2	3
Cask Turnaround (days)	CASK	2	3	5	8

*The first values listed are for the intruder well, the second are for the boundary well.

Appendix K

FINANCIAL ASSURANCES FOR CLOSURE, POSTCLOSURE, AND ACTIVE INSTITUTIONAL CONTROL FOR AN LLW DISPOSAL FACILITY

1. OVERVIEW

The Commission staff has evaluated the need for financial requirements for a license applicant interested in siting and operating a low-level waste site. Based on their analysis, the staff has recommended that an applicant for a license meet certain financial standards so that financial responsibility for closure, postclosure, and active institutional control is provided by the applicant, and not by the taxpayers. The recommended financial requirements are in two parts: short-term financial assurances to cover the costs of closure and postclosure care, and long-term financial arrangements to cover the costs of active institutional control, or long-term care for a period not to exceed one hundred years. Since these are two separate concepts, the subjects of short-term and long-term financial requirements are dealt with separately in two sections of this appendix.

1.1 Need for Financial Protection Requirements

Financial assurance requirements for low-level waste disposal facilities are needed to help ensure the long-term protection of the public health and safety and the environment. A review by the staff of the operating experiences at both hazardous waste and LLW disposal sites reveals that sites of both types did not adequately plan for closure and long-term care activities. With respect to the LLW sites, however, state and federal governments recognized the need to care for the sites over the long term. The state and federal governments required the LLW sites to be located on federal or state government-owned land and funds were collected for long-term care activities. In most cases, however, the funds collected for long-term care activities (e.g., the Maxey Flats, Kentucky site) were not adequate and there was essentially no financial planning for contingencies that might occur, (e.g., the need to pump trenches and treat trench leachate). In addition, until recently little planning or financial assurance was provided for funding the final closure and stabilization of the existing sites. This has led to a situation where financial responsibility for the continued assurance of protection of the public health and safety at several of the existing closed sites already has or could become a responsibility of the state or federal government. Early proper financial planning to assure the availability of adequate financial resources for closure, contingencies, postclosure care, and institutional control could have prevented this from happening.

As discussed later in the review of the operating histories of low-level waste disposal sites, the necessary closure and long-term care activities have in some cases not been undertaken, or have had to be conducted by the state government, because of the lack of planning for and lack of financial assurances for such activities. The possibility that a licensee will be unable to

assume financial responsibility for closure, postclosure, and long-term care activities at a site is increased as a result of the period when these activities begin, relative to when revenues are received. Closure, postclosure, and active institutional control costs are generally incurred after the site operator is no longer receiving revenues from waste generators. Thus, proper planning during the operating phase when revenues can be accrued is essential Based on these considerations, there is a strong need for regulatory requirements to ensure that: (1) the licensee has sufficient financial resources to provide for final closure and postclosure care of the site; and (2) the licensee provides financial assurance for the active institutional control period after the site is closed and stabilized. The staff believes that these closure and active institutional control costs should be identified early and should be provided for as part of the necessary costs of operating a site. Financial assurance mechanisms to provide for these costs should be established during the active operating period of the site, when revenues are still being received by the licensee, and he has access to financial resources. An applicant seeking a license for the disposal of low-level waste must estimate the costs of closure in order to provide for adequate financial assurances based on these estimates. Therefore, the amount of financial responsibility required of licensees will be consistent with the degree of risk associated with the closure and long-term care of the site. (Estimates of the costs of various potential expenses of closure and postclosure care of a site are presented in Appendix Q of the EIS.)

Meeting such a technical requirement for closure and active institutional care will involve a cost to the licensee. However, proper closure should help to prevent other costs, such as remedial costs, administrative costs to the regulatory agency, and environmental costs. For example, failure to provide for adequate financial assurances for closure could result in a situation where it is necessary for the responsible regulatory agency or the site owner to provide for final closure and stabilization at taxpayer expense. Any corrective actions would also need to be taken by the agency as well as the longer-term institutional control activities. Environmental costs that could be incurred if a licensee was unable to conduct final closure and stabilization could include increased potential for contamination of soil, air, and surface and ground waters. Adequate funds must be provided during operations to cover the costs for closure and for long-term care activities.

The need for stringent closure and long-term care financial regulations for low-level waste site licensees at the federal level has been voiced by a number of sources, including:

- The NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds provided a forum where NRC staff and state officials expressed their concern regarding the need for adequate closure and long-term care financing regulations for LLW sites. The majority of state officials felt that funds were not being collected at a sufficient rate to adequately provide for closure and long-term care of the sites.

- In 1976, the GAO issued a report to Congress recommending that the federal government should establish criteria for long-term care and adequate funding of radioactive waste sites.

- The National Conference of Radiation Control Program Directors has established Task Forces on Waste Management and Bonding. In their report, the Conference's Bonding Task Force developed general guidelines relating to bonding, and to perpetual care funds for the commercial waste burial grounds. The Task Force concluded that a review system should be instituted at both the state and the federal levels.

- Public comments on the preliminary draft (dated November 5, 1979) of 10 CFR 61 have expressed the view that the Commission should develop adequate closure and postclosure care financial regulations for low-level waste sites. (See Section 6 of this appendix for a detailed description of these comments.)

- The Commission has also sponsored regional workshops in Boston, Chicago, Denver, and Atlanta for the public and for representatives from industry, environmental groups, waste shippers and generators, and public interest groups, to review and comment on the preliminary draft financial assurance regulations in 10 CFR 61. Comments from these officials, as well as from other members of the public, strongly supported the need for financial assurance regulations, but also expressed the opinion that the Commission staff should modify the financial regulations in draft Part 61 with regard to (a) the types of costs to be recovered from LLW users through a long-term care fund, and (b) the parties responsible for paying for these costs.

1.2 Other Closure and Long-Term Care Funding Requirements

The Commission staff reviewed a variety of regulations in their analysis of funding requirements for a low-level waste disposal site (see Section 5 for a full listing of the financial assurance regulatory provisions reviewed by the staff.) These include:

- Discussions with staff at the U.S. Environmental Protection Agency's Office of Solid Waste, who are working on financial requirements pertinent to RCRA and the "Superfund" Act (P.L. 96-510).

- Discussions with staff at the U.S. Department of Interior's Office of Surface Mining who were involved with the financial regulations for surface coal mine operations.

- Discussions with staff at the U.S. Federal Maritime Commission who administer the financial regulations pertaining to water pollution.

- Commission final Generic Environmental Impact Statement and regulations pertaining to long-term care requirements for uranium milling operations under NRC license.

- o Review of existing state regulations for long-term care funds.

Based on this review, the staff has been able to develop recommendations for financial regulations for closure and long-term care that build upon existing regulatory developments in this area.

1.3 Overview of Closure and Long-Term Care Financial Requirements

The recommended financial regulations for 10 CFR 61 have the purpose of assuring financing of disposal site closure and postclosure activities and also any long-term care that is necessary at the site. The two concepts of requiring short-term financial assurances for site closure and postclosure activities, and financial requirements for long-term care or institutional control are treated as separate topics in this discussion. In order to see how these two financial requirements fit into the overall activities at a disposal site, Table K.1 depicts the relationship of the proposed financial requirements to the life cycle of a near-surface disposal facility.

As used in this discussion, a short-term financial assurance refers to an arrangement intended to ensure that the disposal site operator is financially capable at all times for undertaking all required and necessary closure and postclosure activities. For a typical near-surface disposal facility, these closure costs are estimated by the staff to be between $1.0 to $3.0 million dollars, in 1980 figures. (See Appendix Q of the EIS for a fuller analysis of closure costs.) Currently, many states already require hazardous waste site operators to provide various types of financial assurances for closure. In their review of various financial assurances, the staff examined the following mechanisms: sureties, letters of credit, escrow arrangements, trust funds, certificates of deposit, cash deposits, deposits of securities, secured interests, and self-insurance. The discussion in Section 3 of this appendix presents the staff's assessment of different types of short-term financial assurance mechanisms by various criteria, and then recommends certain types of mechanisms.

Long-term care funding at a near-surface disposal site refers to the financing of any necessary maintenance, monitoring, and surveillance that may be required during the 100-year period of active institutional control after the disposal facility licensee's site closure and postclosure responsibilities have been fulfilled and the license is transferred to the site owner. The 100-year custodial period is the upper bound that the Commission considers feasible for active institutional control to be exercised. The landowner or custodial agency during this active institutional control period would physically control access to the site. Activities carried out during the active control period also include, but are not limited to, carrying out an environmental monitoring program at the site, periodic site surveillance, minor custodial care, and other requirements as determined by the Commission. The active institutional control costs include all necessary maintenance, surveillance, and monitoring costs deemed necessary at the site.

The staff currently lacks the authority to require the licensee to provide funds for long-term care (see Section 4). Therefore, until such time as the

Table K.1 Life Cycle Financial Assurances for a Disposal Facility

Time in Years	Activity	Form of Financial Assurance
1-2 years	Site Selection and Characterization	Licensee responsible for costs incurred
1-2 years	Licensing Activities	Licensee responsible for costs incurred including licensee fee
		Site closure plan including cost estimates for closure is submitted as part of licensee application
		Lease arrangement with long-term care arrangements for financial responsibility between licensee and state submitted to NRC for review for adequacy
		Licensee obtains adequate short-term sureties to provide for closure
20-40 years	License Issued; Site is in Active Operation; Waste Received	Short-term sureties in place for closure: NRC periodically reviews and requires updating to account for changes in inflation, site conditions, etc.
		NRC periodically reviews revisions to lease arrangements to ensure that arrangements for financial responsibilities for long-term care are adequate
1-2 years	Site Closure and Stabilization	Costs covered from short-term sureties, if necessary; otherwise, licensee performs activities
		Lease arrangement between site owner and operator for long-term care is still in effect
5-15 years	Observation and Maintenance	Licensee still responsible for all further costs during this period, with short-term financial assurances still in place.
100 years	License Transferred to Site Owner "Active Institutional Control Period"	Terms and conditions of lease are met, and either state or licensee provides funds to pay for all required and necessary activities of this period.

Commission receives this authority, the staff has recommended that the licensee submit a binding arrangement (such as a lease) between the licensee and the landowner (the state or federal government), which delineates financial responsibility during the 100-year institutional control period. (See Section 4 for a more detailed discussion of the various alternatives for active institutional control financial requirements.)

Further sections of this appendix will deal with the following subjects: Relation of Life-Cycle Activities at an LLW Site to Proposed Financial Requirements (Section 2), Short-Term Assurances for Closure and Postclosure (Section 3), Long-Term Funding Requirements (Section 4), Other Governmental Financial Requirements for Closure and Long-Term Care (Section 5), Public Comments Pertaining to Financial Requirements (Section 6), Background Reference Materials (Section 7), and a Bibliography (Section 8).

1.4 Staff Recommendations for Financial Requirements

Based on the analyses for operators of a disposal site, the staff developed the following technical criteria:

- Each disposal facility applicant must provide evidence of financial responsibility for all operational and predictable site closure costs, and evidence of suitable arrangements for long-term care costs for up to 100 years.

- The licensee has the responsibility for determining that all of the site-specific activities and resultant costs of closure and postclosure observation and maintenance are accounted for in the stabilization and closure plan. On reviewing the site application, the Commission would then determine that all necessary costs had been included in the plan.

- Prior to startup of operation, the licensee must obtain a short-term financial assurance mechanism found acceptable to the Commission that is sufficient at all times to cover all costs of closure and postclosure care.

- The cost estimates for closure and active institutional control at a disposal site used in arriving at the amount of financial responsibility should be flexible and provide for annual reviews to account for advances in state-of-the-art technologies, work already completed at the site, and changes in inflation.

- With regard to developing regulations for long-term care, the staff is aware of the need to develop specific regulations that establish a long-term care fund to ensure that there are adequate funds for up to 100 years of active institutional control, including surveillance, monitoring, and required maintenance. Currently however, the Commission lacks statutory authority to require long-term financial assurances (see Section 4 for a more extended discussion). The Commission has

recognized the need to receive legislative authority from Congress that would allow the Commission to explicitly require that a fund to provide for long-term care be established. However, until such time as the NRC is given this authority, the staff recommends that the staff carefully review a binding arrangement (such as lease agreement) between the license applicant and the site's landowner. This lease arrangement submitted to the Commission for review must demonstrate that one or the other (or both) of the parties to the lease is responsible for all necessary maintenance, monitoring, and surveillance for up to a 100-year period following closure at the site.

- o Financial responsibility for cleanup of unanticipated long-term activities that are acts of God and that are not explicitly provided for in the lease, would be borne between the appropriate governmental agencies, and by the site owner. The staff feels it is the responsibility of the applicant, the regulatory authority, the land owner, and all other parties to the proceeding to review the lease at the time of the licensing hearing to ensure that the proposed lease arrangement provides for all of the possible site specific expenses that pertain to required and predictable activities at that particular site. In developing financial assurances for closure and for long-term care of disposal sites, the staff's recommendations are predicated on the assumption that no contingencies will occur at the site and necessitate remedial actions. Both short-term and long-term financial assurances provide for adjustments in the event of any required and predictable changes in site conditions, inflation, or technology. However, they do not provide for major contingencies that are an act of God.

Therefore, the Commission staff recommends that the proposed regulations include the following:

1. During the operating life of the disposal facility financial assurances will be required of the licensee to provide full coverage of the costs of closure, decommissioning, and decontamination of the site. The amount of funds to be insured by such arrangements will be based on licensee-submitted cost estimates that are approved by the NRC staff during the time of license review. The licensees' cost estimates shall take into account the total costs that would be incurred if an independent contractor performed the work. The terms of the financial assurance mechanism must be open-ended, and must be reviewed annually. Mechanisms for closure found acceptable by the staff include: (1) surety bonds, (2) cash deposits, (3) certificates of deposit (CDs), (4) deposits of government securities, (5) letters or lines of credit, (6) trust funds, (7) escrow accounts, and (8) combinations of the above, or such other types of arrangements as may be approved by the Commission. However, the staff finds that self-insurance, financial tests, and secured assets by an operator are not an appropriate financial assurance mechanism.

2. Prior to the issuance of a license, the terms and conditions of the lease (or other binding arrangements) between the licensee and the site's landowner will be examined by the NRC staff to ensure that provision has been made between the two parties so that sufficient funds are available to cover the cost of long-term surveillance, monitoring, maintenance, and all required and predictable site-specific activities for the active institutional control period.

2. OVERVIEW OF LIFE CYCLE ACTIVITIES AND FINANCIAL ASSURANCES AT A DISPOSAL FACILITY

The development of financial requirements for 10 CFR Part 61 is based on a scenario of the operating cycle of a low-level waste site that follows the sequences generally represented in Table K.1 of Section 1. It should be noted that although the appendix describes a generic burial ground, the precise actions that occur during the life-cycle of a disposal facility may be site specific. This section of the appendix characterizes the nature and extent of activities required during the life cycle of the disposal facility in order to provide a basis for the analysis of both short- and long-term funding issues. In order to trace the flow of costs, and the responsibility for these costs to the respective parties at a disposal facility, the following section will present the staff's scenario of activities occurring during the life cycle of a licensed low-level waste site.

Appendix Q of this EIS also provides a more detailed description of the typical life cycle costs at a disposal facility. In developing their scenario of the events, activities, and costs of a disposal facility, the Commission staff is aware of the limitations of forecasting possible scenarios and resultant costs, such as inflation for long periods into the future. Nevertheless, they feel that the financial regulations should still attempt to cover some of those future costs that can be reasonably predicted, so that the present generation of users of the site receiving the benefits of the site are financially responsible for them, and the public's health and safety is still protected.

Under the requirements of NEPA, the Commission is charged as a federal agency with the responsibility of conducting their activities so as to help the nation fulfill the responsibilities of each generation as trustee of the environment for succeeding generations. The intent of these financial regulations is to satisfy this goal by ensuring that the present generation of users of the site be responsible for the majority of cradle-to-grave costs of a disposal facility. The staff believes that the financial requirements for site closure and for the long-term care will lessen the probability that succeeding generations of taxpayers will have to be responsible for the costs of today's commercial applications of nuclear power or use of radiation and radioisotopes.

2.1 Site Selection and Characterization

During this period (estimated to last approximately 2 years) the applicant selects a region of interest, and then narrows down the possible sites to a

proposed site. The applicant is responsible for all costs and will probably capitalize them, and pass them on at a later date to customers as a future business expense. The applicant's choice of sites during this period is also based on the performance objective of minimizing the need for long-term care at the disposal site.

2.2 Preoperational Phase

The applicant begins to develop data and makes overall plans for the facility. The applicant also starts to develop a preliminary site closure plan, based on the information about the geology, hydrology, and other characteristics of the site. A site utilization plan is prepared by the applicant that outlines how the applicant plans to use the site for disposal. The applicant must also have preliminary estimates of the expected cost for (1) closure (including personnel needs and materials and equipment needs), and (2) active institutional controls, including surveillance and monitoring by the site's custodial agency. As in the site selection activities, these expenses are probably capitalized by the applicant, and passed on at a later date to customers as a normal expense of doing business.

The license application provides financial proof that the applicant possesses sufficient financial resources to cover construction and operating expenses. At this time, the applicant also provides assurances that he or she will have sufficient funds to carry out closure of the disposal site. These financial assurances are based on costs estimated in an approved plan for site closure and stabilization.

In the license application, the site operator should also provide a copy of a binding arrangement (such as a lease) between the applicant and the site owner for Commission review and approval for adequacy to ensure that sufficient funds will be available to cover the costs for up to 100 years of long-term surveillance, monitoring, and custody. Either the licensee or the state must demonstrate in a lease or other binding arrangement that they have assumed financial responsibilities for up to 100 years of responsibilities after the site has been closed and the license transferred to the site owner.

2.3 Operational Phase

When a license is granted the licensee can begin work on the construction of the site. The construction and associated regulatory costs of inspection are all borne by the applicant and are again, probably passed on at a later stage to the customers during the operational phase.

During the operational phase, that lasts from 20-40 years, waste is received and the licensee or landowner (depending on the lease conditions) is responsible to ensure that procedures are in effect to ensure that recovery is being made for the closure and active institutional control costs. (These closure and active institutional control costs are based on estimates submitted by the applicant to the Commission during the initial license application.) Future funds for the "short-term" decommissioning activities are guaranteed by financial assurance mechanisms such as sureties, CDs, letters of credit, cash

deposits, trust funds, or combinations of these mechanisms. Again, the regulatory goal during this operational stage is to ensure that the activities are conducted so as to minimize the need to conduct long-term and extensive maintenance after the site is closed, and also to develop requirements for long-term care to ensure that adequate long-term care funds are available.

During this phase of active operation, when wastes are being received for burial, some trenches are closed and stabilized. Records are kept of all repair work done to fences, trench caps, and site grounds due to erosion or subsidence. These records will later be used by authorities to determine future maintenance activities and their associated costs. During this period, if it is found that a particular site has special problems that require more closure or postclosure activities than was orginally planned for, then the Commission may authorize increases in the amounts required for collection of closure and long-term care funds. These increased costs for closure and long-term care to the operating company would be passed on to the users in the same manner as any other cost of doing business. During this period, if the licensee were to go bankrupt, the funds for closure would be protected. The short-term financial assurance mechanisms approved by the Commission would provide full coverage for the necessary closure funds.

2.4 Site Closure Phase

When the site is filled to capacity, it is closed. Approximately one year before anticipated closure, the licensee must submit a final site-closure and stabilization plan to the Commission for review and approval. When the plan has been approved its requirements must be met by the licensee for such activities as decontamination and dismantlement, final site contouring, and preparation for long-term care. The activities and expenses for these activities should be minimal, since the licensee has already worked continually during the operational phase to prepare the site for closure. Specific site problems would also be taken care of at this time.

At this phase in the life cycle of the site, no revenues are being received from users, since no wastes are being taken in and the site is either at or near capacity. The licensee will probably have collected a surcharge from the site users to cover costs and will also have a short-term financial assurance in effect. For long-term care he will have made financial arrangements with the site landowner (i.e., federal or state government). Since the licensee would have no revenues coming in, it is important that at the time of licensing all parties do a careful job of forecasting all closure activities, and also recognizing the impacts of inflation in calculating these figures.

2.5 Postclosure Observation and Maintenance Period

This stage occurs after the terms and conditions of the closure plan have been met. The licensee is still held responsible for the site during this period when the monitoring and maintenance programs continue and these activities are, in a sense a continuation of the closure and stabilization activities. This period of the site's life cycle would last approximately five to fifteen

years, and during this period, it is anticipated that the licensee's activities and costs at the site would gradually taper off to the point where little or no maintenance would be necessary. Essentially, this period would be one of monitoring, which would enable the Commission staff to fully satisfy itself that all of the terms and conditions of the license had been fully met by the operator, and that the licensee was still under regulatory authority to correct any problems that might develop at this time due to subsidence. Again, the licensee would presumably be paying for these expenses from the fund that was collected earlier from a surcharge on the site's customers. If the licensee were to default at this time, the appropriate short-term financial assurance mechanism would cover these expenses. It is also important for the licensee to carefully calculate and provide for a thorough analysis of all costs that can be quantified for this period, and to include them into the fund. If significant unexpected expenses do develop during this period, then, as in the previous period, the government or the governmental body responsible for owning the land site would probably eventually be liable for these expenses.

2.6 Long-Term Care (Institutional Control Period)

After the postclosure observation period ends and conditions at the site have stabilized and all closure responsibilities by the licensee have been met, then the licensee is relieved of this responsibility and the license is transferred to the site owner. The new licensee is then responsible for maintenance, monitoring, and surveillance at the site. During this period, which should last approximately 100 years, funds for long-term care will be transferred to the new licensee and they are responsible to disperse the long-term care funds to take care of monitoring, inspection, and necessary maintenance costs at the site. (The collected long-term care funds were received from either the site owner or the site operator, depending on what arrangement was made in the lease.) Minor maintenance activities during the 100-year long-term care period are envisioned to consist of repair of fencing, upkeep of the site, such as revegetation, mowing the lawn where necessary, and any repair of trench caps, due to subsidence or other conditions. At the end of this period, in the unlikely event that any of the funds collected for long-term care remain, they then would be returned to the contributing party (i.e., the original licensee).

3. SHORT-TERM FINANCIAL ASSURANCE MECHANISMS FOR CLOSURE AND POSTCLOSURE OBSERVATION AND MAINTENANCE

3.1 Introduction

This section addresses short-term financing mechanisms that provide a means of guaranteeing the financing of closure, stabilization, and all other required closure and postclosure observation and maintenance activities at a low-level waste site. This short-term financial mechanism for closure activities is separate and distinct from "long-term" care financial arrangements that cover the active institutional control period, and are discussed in Section 4 of this appendix.

The staff recommends that operators of an LLW disposal facility obtain a short-term financial assurance mechanism that is in effect throughout the operating period of the site. The financial assurance must also be sufficient to cover all anticipated costs of closure, including decommissioning and decontamination of the above ground buildings, equipment, and facilities, as well as stabilization of the disposal site. The amount of funds to be provided are to be based on Commission-approved cost estimates in a Commission-approved plan for closure. Such a short-term financial assurance would provide sufficient financial capacity during the entire operating period to cover all costs of closure, and the financial assurances would remain in place until all necessary closure and postclosure care activities had been conducted.

The staff is sensitive to comments given to the Commission indicating a strong need to require disposal operators to possess financial assurances for closure (see Sections 1, 6, and 7 of this appendix). The staff believes that the closure activities at a low-level waste site must be conducted in a prompt manner in order to ensure that the public's health and safety is protected. The requirement for a financial assurance for closure can be viewed as a type of financial guarantee to ensure that in the event of operator default, there are funds available for closure.

This section of Appendix K will present the types of short-term financial mechanisms examined and found acceptable by the staff. The advantages and disadvantages of each mechanism are briefly discussed, and a staff position on acceptable financial assurances is presented. Because the primary function of this section is to present a broad evaluation of various financial assurance mechanisms, the section is written in general language. A regulatory guide will be issued by the staff at a later date and will provide more specific guidance on the format and content of the various financial assurances.

3.2 Eligibility

The short-term financial assurance requirements recommended by the staff for the draft regulation should be met by all private sector licensees. However, this financial requirement would not have to be met if the applicant is a government entity and has the taxing authority to raise revenues. However, the staff feels that certain public entities, such as public authorities that lack taxing authority, may have a degree of financial risk associated with their operations necessitating that they meet the proposed financial assurance requirements. Therefore, for these types of public authorities that lack taxing authority, the staff recommends that they be required to fulfill all of the terms and conditions for short-term financial requirements.

3.3 Closure Activities and Expenses

In order to provide some background to this discussion, a review of the pertinent closure and stabilization activities and costs at a disposal facility is necessary. Appendix E provides a detailed discussion of the life cycle activities at a reference LLW site and Section 2 of this appendix presents the proposed life cycle activities in a schematic fashion for a typical disposal

facility. It should also be emphasized that the precise activities that will take place during the closure and stabilization phase at a disposal facility will be site-specific. The closure activities will mainly consist of dirt-moving operations, such as trench cap reworking, in order to prepare for long-term care. As indicated in Appendix Q, costs associated with final closure for a reference site are estimated to be in the range of $1.0 million to $3.0 million (1980 dollars).

Closure of a low-level waste site includes the final operational activities carried out at a disposal facility after completion of active waste receipt and disposal operations to:

1. Dismantle site structures;

2. Decontaminate site surfaces and remaining structures;

3. Conduct final closure and stabilization of the site (facility) and emplaced waste; and

4. Carry out any other activities to prepare the site for postoperational care and transfer to the eventual site owner.

The Commission staff assumes that the site closure and stabilization program required at a site will vary depending on specific site geology, hydrology, and climate conditions, as well as any arrangements that may have been concluded between the licensee and site owner. The operating history of the burial ground, as shown by records of maintenance, monitoring programs, site inventories, and anticipated future use of the site, will also be important factors in determining if revisions to the financial assurance are necessary, to be certain that these closure activities are properly carried out. The primary objective of closure and postclosure care activities is to leave the site in a condition such that the need for active, ongoing maintenance is eliminated after license termination, and only passive care is required.

The licensee must develop site closure and stabilization plans and ensure that the site is prepared for transfer to a custodial government agency. After the active period of operation of the site, the site operator's responsibility and authority for possession of buried wastes at the site continues until the Commission finds that the site is ready for transfer to the custodial agency. The remainder of this section will review the various types of financial assurance mechanisms and delineate those assurances deemed adequate by the staff.

3.4 Short-Term Financial Assurance Mechanisms for Closure and Postclosure

Short-term financial assurance mechanisms refer to arrangements intended to ensure that the licensee is financially responsible for undertaking all required closure and stabilization activities at a low-level waste disposal site. As used here, the concept of financial assurances (short- or long-term) does not include any requirements for third party liability coverage for damage to

people or property resulting from operation of the facilities. Rather, the staff is establishing various financial assurance criteria which will ensure that the sites are properly closed, stabilized and monitored for up to 100 years.

There are a wide variety of short-term financial assurance mechanisms to assure that proper closure occurs that could be investigated; however, the short-term financial assurance mechanisms considered by the Commission staff for the purposes of this regulation include:

1. surety bonds, obtained from a surety company
2. escrow arrangements between the bank, the government, and the licensee
3. trust funds arranged between the government, a financial institution, and the licensee
4. certificates of deposit to a state or federal agency
5. cash deposits to a state or federal agency
6. deposits of securities to a state or federal agency
7. pledges of securities and liens against properties of the licensee
8. letters of credit from a financial institution
9. self insurance by the LLW operator
10. financial tests of the LLW operator's assets.

These types of financial assurances are presently being used, or provision has been made for their use by state and federal government agencies, for the chemical waste, uranium milling, low-level waste, and surface coal mining industries. The staff did not explicitly review a financial assurance consisting of a sinking fund for closure based on surcharges collected from waste generators, since at this time, the Commission lacks the statutory authority to impose a surcharge or other tax on waste generators. However, this financial assurance mechanism has been traditionally employed at low-level waste sites, and states having authority to permit this may wish to consider a sinking fund in combination with some other form of short-term financial assurance mentioned above.

3.4.1 General Criteria for Financial Assurances for Closure and Postclosure

The staff's development of these technical criteria for financial assurances for closure was based on recognition of the importance of balancing the need to require sufficiently stringent assurances with the economic consequences of such an alternative. For example, in the staff development of criteria that

the financial assurance mechanism must be fully funded prior to startup of operations, the staff also considered the less stringent approach of allowing the funds to build up over the life of the site. The staff was aware that this second approach would have been a lesser financial burden to the operators, since it would not require them to set aside a large sum of capital. (The EPA staff's development of RCRA regulations also noted that the fully-funded approach placed a tax burden on the operator, because current tax laws do not allow this fund to be considered a deductible expense, since no expense occurs in a tax sense, until the funds are used for closure.) Nevertheless, the staff also realized that allowing a closure fund to build up over the life of the site could well result in having an inadequate fund available in the event of premature closure of the site, with the result being that the taxpayers would then be financially responsible. In weighing these two equity alternatives, the staff concluded that the fully-funded approach to closure offered the most reasonable assurances that the license be fully responsible for the costs of closure.

- Regardless of the financial assurance used, the licensee's cost estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the stabilization and closure activities.

- The financial assurance mechanism must be full funded prior to the start of operation, to provide full assurance regardless of whether closure occurs as was originally planned, or else occurs prematurely.

- The face value of the short-term financial assurances must be at least equal to the cost estimates submitted by the licensee in the approved plan for site closure and stabilization.

- In order to avoid unnecessary duplication and expense, the Commission may accept financial assurances that have been consolidated with financial arrangements established to meet requirements of other federal or state agencies and/or local governing bodies for these decommissioning, decontamination, reclamation, and closure activities, provided that such arrangements are considered adequate by the staff to satisfy these requirements, and that the portion of the financial assurance that covers the closure of the site is clearly identified and committed for use in accomplishing these activities.

- The licensee's financial assurances should be reviewed annually by the Commission to assure that sufficient funds are available for completion of the closure plan. At that time, the amount of coverage is also required to be adjusted to recognize inflation, changes in engineering plans, previous activities already performed, and any other conditions affecting closure costs.

- Regardless of what portion of closure is phased through the life of the operation, or if it takes place at the end of operation, an

appropriate portion of coverage has to be retained until final compliance with the closure plan is determined. This will yield an assurance that is at least sufficient at all times to cover the costs of closure of the site prior to the next license renewal.

- The term of the financial assurance mechanism must also be open-ended (i.e., not cancellable), unless the licensee can demonstrate that another arrangement would provide an equivalent level of assurance. This assurance could be provided with a financial assurance that is written for a specified period of time (e.g., five years) and will be automatically renewed, unless the party administering the financial assurance notifies the beneficiary (the Commission or the state or regulatory agency) and the principal (the licensee) at some reasonable time (e.g., 90 days) prior to the renewal date of their intention not to renew. In such a situation the financial assurance still exists, and the licensee would be required to submit a replacement assurance within a brief period of time to allow at least 60 days for the regulatory agency to collect.

- The Commission will allow the licensee to terminate the financial assurance mechanism after a finding that all licensee conditions have been met.

- Proof of forfeiture must not be necessary to collect the financial assurance for closure, so that in the event the licensee could not provide an acceptable replacement surety within the required time, the surety will be collected automatically prior to its expiration. The conditions described above would have to be clearly stated on any financial assurance instrument that is not open-ended, and must be agreed to by all parties.

With respect to Commission-licensed facilities, the implementation of this requirement to provide financial assurances to cover costs associated with closure activities could occur in several ways. The Commission could directly administer the financial arrangements, or a state could administer them. The staff believes state administration would be appropriate where an existing state agency already handles the financial assurance arrangements for hazardous sites or for mining activities. All of the states have the authority to impose financial requirements as an exercise of their general police power to protect the public health and safety. This would be true whether or not the state is an Agreement State under the provisions of the Atomic Energy Act of 1954, as amended.

3.5 Criteria for Evaluating Financial Assurance for Closure and Postclosure

Financial assurance mechanisms to cover costs associated with closure were evaluated by the staff on a specific set of criteria. The primary factor considered by the staff in evaluating the various mechanisms was the degree of assurance provided by each method to ensure that funds were available for closure costs at the disposal site. Other criteria the staff considered include:

- o Degree of security (or level of difficulty) in obtaining funds in case of default.
- o Amount of regulatory staff administrative time and expense required to implement and monitor the financial assurance.
- o Amount of staff effort required to evaluate assets of the licensee.
- o Cost of financial assurance mechanism

A description of the various financial assurances considered by the staff in their review follows.

3.6 Financial Assurance Alternatives for Closure

3.6.1 Surety Bonds

A surety bond provides a cosigner on an obligation. The surety bonding relationship is essentially a three party relationship in which the surety company, for a fee, promises to the obligee (the NRC) that the principal (the licensee) will perform specified activities (in this case, all closure and decommissioning activities). If, as a result of this obligation, the surety company incurs a loss, it can sue the contractor to recover its loss. The surety company takes on a possible liability for a profit. Like insurance, a premium is paid to the surety company by the insured or bonded entity (such as the disposal site operator). However, a surety company does not expect the principal to default, and if default does occur, then the surety has the right to receive reimbursement from the principal for the obligations met. If a bonded operator were to default on his obligation to carry out closure activities, then the bonding company must provide the remainder of the guaranteed funds to the holder of the bond (the regulatory or other suitable government agency) to have the work done. On the other hand, upon successful completion of closure activities by the operator, the bonding arrangement can be terminated and the bonding company is then released from its obligation.

When surety companies provide coverage for closure by issuing a bond to the applicant, they check the financial strength of the applicant. They will likely require a licensee to provide some form of collateral in order to write performance bonds. The amounts required of the operator will vary, depending on the business history and credit rating of the applicant. Generally, the types of collateral required by a surety company include letters of credit, corporate stocks, and certificates of deposit. The applicant then has to maintain a commitment of collateral value sufficient to cover a certain percentage of the face value of the surety bonds.

The cost of a surety bond is dependent on the type of required activities covered by the bond, but fees on premiums generally range from between 1.0 and 1.5 percent of the face value of the bond. The surety company also needs to have sufficient assets to provide for possible default.

Surety companies have the option of filing with the U.S. Treasury, which sets limits on the face values of bonds. This limit of a surety bond is generally 10% of the surety's capital surplus. Since filing with the Treasury represents a form of certification, the Commission staff recommends that surety bonds only be accepted from companies listed in the Department of Treasury circular #570, entitled "Surety Companies Acceptable on Federal Bonds" (published annually) and only for an amount that is within the company's single policy limitation as identified.

Surety companies are generally regulated by state laws that are designed to ensure that the surety company is solvent and has assets of a certain minimum amount. Additionally, state regulation of sureties involves assessment of financial management practices, including examination of whether the sureties are diversified in their lines of credit.

All bonds specify the terms and conditions of their guarantee, including terms of default. Generally, contract bonds contain provisions that state what constitutes a default. Some events used are: inadequate performance, such as abandonment of work or bankruptcy proceeding. If an owner defaults and has not completed the required and necessary decommissioning activities, then a claim can be made by the NRC. If a default occurs, then the surety will first examine its defenses against liability before making payment to the obligee, the NRC. If it is determined that a default has occurred and that no defenses exist, then the surety company is responsible for bringing the permitted work to completion.

According to a draft study done by the International Research and Technology Corporation (IRT) in 1980 for the EPA, defaults on surety bonds occasionally wind up in court. Therefore, surety bonds may be more of a problem to collect than certificates of deposit, which would not become involved in such litigation. However, the Commission staff investigation has shown that collection records on these forfeitures in the coal industry has been satisfactory.

Several commenters on the NRC uranium milling regulations and EPA solid waste regulations expressed doubt that the surety industry would provide bonds to the hazardous waste industry with open-ended terms. The Surety Association, a trade association that recommends bonding rates to members, has, in the past, told the NRC they doubted there would be any market in the U.S. for such corporate surety bonds with open-ended terms. However, a brief review of other hazardous waste facilities indicates that there is some market demand for this type of insurance. The Federal Surface Mining Act of 1977 requires mining companies to obtain a performance bond certifying that the mining activities will be conducted subject to license requirements. The reclamation operations are done as an ongoing operation of the site, rather than waiting until all of the land is strip mined. Performance bonds of strip mining have been written for time spans paralleling the 30-year periods anticipated for bonds of some typical facilities. The Environmental Protection Agency has also proposed the use of surety bonds for coverage of closure of hazardous waste sites in their proposed RCRA regulations. It is possible that the

Department of Interior and the EPA regulations for sureties may stimulate a demand for this type of surety mechanism.

If one assumes that the surety bond would be obtained in the site's first year of operation and continue for five to fifteen years after the active operating lifetime, the licensee would be responsible for the cost of the bond for a total of 25-35 years. In some cases, the bond may have to continue for longer than five years after the end of operation. However, once operations cease and the site is closed, and the license transfered to the site owner, the licensee would terminate the bond.

The major advantages of the surety bonding mechanism are:

- Staff administrative effort associated with a bond, exclusive of the effort related to forfeitures, would be minimal. A document sent to the federal or state regulatory agency from the surety company and filed with the license application assuring that the surety was properly certified by the appropriate agency licensing sureties, would be all the effort necessary to implement this bonding mechanism. Amendments to the amount of the bond would also involve minimal correspondence with the surety company. Bonding companies thoroughly screen the credit record of the companies they bond, so the agency does not have to conduct a financial analysis of the operator's operations.

- A rider to an existing bond, or the purchase of a new bond, would be sufficient to adjust the amount of the bond to account for inflation or required changes in closure activities.

The major disadvantages of this bonding mechanism are:

- Obtaining funds from the surety upon default may be more difficult than under some other alternatives, such as trustee funds or cash deposits.

- The cost of obtaining a surety bond is higher than some of the other surety mechanisms.

- There is some doubt that surety companies are willing to provide sureties for waste disposal businesses for a 20 to 30-year time period. In informal conversations with surety officials, the staff found that officials were not certain of the extent to which surety companies are willing to become involved in this type of coverage.

3.6.2 Cash Deposits

A cash deposit is another method of assuring closure, whereby an amount at least equal to the estimated cost of closure is deposited into a special

account that could be held by a government agency. Use of the funds in this account would be restricted to covering the costs of closure and postclosure. If the operator were to default, then the state or federal government could withdraw the funds from the special account and arrange for the necessary closure work to be completed by either themselves, by the site owner, or by an independent contractor.

Some advantages of this method are:

- o There is no difficulty in obtaining funds in case of default by the site's owner, since the special deposit fund could be set up so that it was controlled by the government agency.
- o There is no problem in asset evaluation.

Some disadvantages of this method are:

- o If the funds are deposited into a special account with the U.S. government, then no interest can be paid on these funds. Therefore, there is a lack of productive assets, and additional funds would have to be paid into the fund to account for losses in inflation.
- o Management of the funds by the government would require periodic review and evaluation by the staff to ensure that the funds were adequate to reflect changes in inflation, engineering plans, activities performed, and other site-specific conditions affecting costs.

3.6.3 Escrow Funds

An escrow fund is another method of assuring funds for closure. Under such an arrangement, cash or marketable securities in an amount equal to or greater than the estimated costs of closure are deposited into a special account held by a financial institution. An escrow serves as a receptacle for the deposit of goods or property until the licensee completes closure activities. The institution holding the funds is the depository, and an escrow agreement sets out the terms and conditions by which the materials can pass to either party. Depositors, however, are not trustees. An escrow that functioned as an assurance for closure and postclosure costs would involve a binding agreement with terms and conditions that would specify that upon failure to meet prescribed closure activities, the fixed amount necessary for all closure activities held in escrow would pass to the appropriate state or federal government. Conversely, upon a finding that closure had been satisfactorily conducted, the escrow arrangement would be terminated and the amount in it returned to the licensees; or the escrow could be set up such that the escrow funds could be returned to the grantor or licensee as closure costs are completed by the licensees.

Generally, administrative fees are charged for the management of an escrow account and will vary depending on the degree of activities, not on the amount of funds. Banks may set a flat fee for a certain number of transactions; other banks will set their fees for managing an escrow account on the basis of each investment or transaction. One of the big differences between a trust

and an escrow fund occurs because a bank managing an escrow generally will perform only those activities specified in the agreement. Generally, the escrow fee is less than the fee for trusts. Use of an escrow fund would require that the amount established in an escrow fund would be sufficient at all times to pay a fixed amount for closure in the event of licensee default. As with all other financial assurances, the types of investment made would have to be examined on a periodic basis by the NRC staff to ensure that the funds in the escrow account keep pace with inflation. In the unlikely event that any excess amounts were earned, they would be returned to the licensees. Use of the funds in this account would be restricted to covering the cost of site decommissioning and closure. If the operator were to default, then the state or federal government could withdraw the funds from the special account and use the funds to conduct closure activities.

Some of the advantages of this method include:

- o There is minimal difficulty in obtaining funds in case of default by the operator since the special deposit account is controlled by an escrow agreement between the government agency and the licensee that clearly stipulates the terms and conditions for the use of funds.
- o The staff does not need to manage the funds; they are managed by professional staff.
- o No problem of asset valuation exists in this alternative.
- o The funds can be invested in long-term securities, thus protecting their value from erosive inflation.

Some disadvantages of this method are:

- o Fees for managing an escrow account are based on the amount of activity in the account, not on the amount of principal or income. Therefore, if frequent adjustments are made to the amount in the escrow, to account for inflation or changes in site conditions, then there may be more costs to the operator.
- o In the past, escrow accounts were short term in nature, and problems may arise with a commercial escrow agent managing a fund for 20 or more years.
- o Like certain types of trusts, escrow accounts must pay taxes on their income at the full federal tax rate.

3.6.4 Trust Funds

A trust fund is a well-established mechanism for holding property and applying it, or income from it, to a particular purpose. The concept of a trust fund to provide for closure of a disposal facility is not new. In 1980, a trust fund to provide for closure costs was proposed by Chem-Nuclear, Inc., for their LLW disposal facility in Barnwell, South Carolina. The RCRA financial requirements being developed by EPA for operators of hazardous waste sites

have also recognized the trust mechanism as an acceptable type of financial assurance mechanism for closure.

A trust is an arrangement whereby one party holds and may even manage funds or property for the benefit of another. In this case the beneficiary of the trust fund would be the state or federal government. The trustee of the closure trust would be a bank or some financial institution. The terms of the trust would define the investment responsibilities of a trust. The trustee has possession of the property or funds placed in trust by the party who created the trust (in this case, the state or federal government). The trustee is said to have the legal interest in the funds, since he has control over it, can sue to protect it, and is responsible for its preservation. The beneficiary cannot use the trust funds, but is entitled to those benefits (such as income) derived from the trust, and intended for him under the terms of the trust. The trustees are under a fiduciary duty to comply with the terms of the trust and, unless the trust provides otherwise, are liable for breaches of this duty.

Like other financial assurances, the necessary amount in the trust fund is determined at the time of the license review, and the trust must include the full costs of closure at all times. The trustee is then required to turn over a fixed amount in the event of licensee default. A trust fund's revenues could be used, if the NRC determines that it is necessary. Once this determination has been made, the NRC could (1) arrange for closure activities and bill the costs to the trust; (2) do the closure itself, and then apply for reimbursement from the trust, or (3) require that the trustee undertake all of the approved closure activities, and then pay for them out of the trust funds.

The Internal Revenue Service has developed a series of rulings to control the use of trusts since they are popular mechanisms for tax avoidance. The closure trust fund is functionally equivalent to simply placing certain money in savings accounts and then accumulating the interest from it for a period of years. In that situation, a draft study done by IRT for the EPA found that the owner of the account is taxable on the income from the account. A closure fund would be established in a lump sum by the licensee at the outset of site operation, and would consequently be returned to him, plus its appreciated value at the end of site life, assuming that the closure activities were in compliance with the site closure plan.

As part of the license application, a site operator must estimate closure costs in an approved site closure and plan. If the licensee defaults at the site before closure can be properly conducted, then the government, as trustee, could require that the money in the trust fund be used to meet the requirements of the site closure plan for the site. If closure activities were properly conducted, then the trust fund could be set up in such a way as to include reimbursement for closure costs as they are incurred, rather than waiting until all closure activities were finished.

A trust fund can contain more than just cash. Property such as securities or government notes can be placed in trusts. However, if cash substitutes are allowed within the framework of trusts, then the function and obligation of the trustee must be redefined, and they may possibly charge more for their

services. If other types of assets were allowed, the trust would have to agree to pay the NRC a stipulated cash amount.

Although, the NRC is responsible for determining if the funds in the trust are adequate, the staff also realizes that it is not difficult to make the trustee responsible for merely maintaining the funds at a certain value. However, giving the trustee the power to demand a supplementation of funds from the owner/operator is more difficult. One possibility would be to have the trust commit the licensee to provide a sum sufficient to close the site instead of stipulating a flat dollar amount, and then bind the licensee to provide more, if necessary, at the request of the trustee. The NRC staff could determine that the fund or assets were inadequate over time, and require the owner/operator to add assets to the trust, leaving the trustee with only the administrative responsibilities for the trust, or the regulations could be revised to allow for periodic adjustments in the cost estimates and the trust, in order to reflect changes at a site or in the technical requirements of the regulations.

If assets other than cash are deposited in the trust fund, it may be necessary for the trustee to buy and sell securities with the approval of the NRC staff, or to take other steps to manage the assets in order to maximize their value. However, unless specified in the terms of the trust, a trustee usually must invest under a reasonably prudent investor standard, as defined by statute or case law of the jurisdiction where the trust is located. The trustee has a fiduciary obligation to honor the terms of the trust, and this standard of fiduciary duty is so strict that most trustees will only accept carefully defined responsibilities.

In addition to cash, trusts may also hold securities, stocks, bonds, certificates of deposit, savings accounts, real property, or commercial buildings. According to one report that consulted with bank officers, the type of assets that trusts were asked to hold were not of as much concern as the quality of the particular asset. The bank officers' concern lay in the degree of uncertainty of the risk they were assuming. The report also found that the prospect of holding assets in trust for 30 years or longer did not concern the trust officers of the banks interviewed. In fact, trust officers pointed out that because of the duration of the site life, and consequently the trusts, trust accounts would be preferable to escrow accounts that traditionally are used for, though not limited to, short-term agreements.

The NRC could consider any individual for the position of trustee in addition to financial institutions, who can succeed in obtaining insurance for the position. This type of insurance is currently available and is commonly obtained by banks and by other financial institutions.

Trustee fees may be relatively constant, but are normally defined as a percentage of income or principal, with the result being that it cannot be known with certainty if the income from the trust is not certain. Trustee fees can range from between 1% and 2% annually of the amount to be managed in the trust, and may also vary according to the degree of management responsibilities given to the trustees.

The burden of a trust fund to the licensee may be quite high because of income taxes. If a trust is a conventional private trust, then payments to the trust are not tax deductible, and the taxes on income from the trust are paid by the trust at the tax rate applicable to trust income. The resulting cost to the licensee could be significant. To the extent that closure costs are a significant fraction of the total costs of operating a site, the cost of taxes to the licensee will increase the economic impacts of closure.

In conclusion, the staff finds the trust fund to be an adequate financial assurance mechanism. However, care must be taken to ensure that the licensee put up an amount sufficient to cover closure over a given period and make annual payments to this fund to cover inflation and any changes to the site. However, the high cost of this financial assurance mechanism, relative to other alternatives, necessitates a close analysis by all parties involved.

Some of the advantages of this method are:

- o A trust arrangement can give a careful delineation of the responsibility of all parties to the trust.
- o The trust fund can accept noncash securities such as stocks, bonds, CDs, or savings accounts.
- o Trustees with financial experience can invest the funds in a manner to keep pace with inflation.

Some of the disadvantages of this method are:

- o If noncash assets are placed in a trust fund, then the trust fund will require more care and review by the trustees and the regulatory authority.
- o If the trustees are responsible for maintaining the fund at a certain amount, it may be difficult to set up an arrangement whereby they have the authority to call for additional money from the licensees.
- o If noncash assets are placed in the trust, then the trustee may manage their sale and purchase and some risks are taken. However, the trustee must be committed to yielding a specified dollar amount.
- o Depending on how the trust is set up, taxable income from the trust may have a tax imposed on it by the IRS that the grantor (the site operator) must pay.

3.6.5 Certificates of Deposit (CD)

Another possible mechanism for assuring closure activities is through the use of certificates of deposit (CDs). Generally, certificates of deposit may be issued by any bank. Cash or securities are deposited by the site owner with the bank, and a certificate of deposit is issued, made payable to a government agency. Only the government agency could cash the certificate. The CD is then cashed if the operator is unable to complete decommissioning activities.

Again, the amount of this surety is adjusted over time to reflect inflation. At the end of operation, if the operator satisfactorily closes the site, then the government agency would return the CD to the operator.

Some advantages of this method are:

- o There is minimal difficulty in obtaining funds in case of default by the operator, since the certificate is held by the government agency.
- o The fee for purchasing the certificate of deposit is small.

Some disadvantages of this method are:

- o More effort is needed to adjust the amount of the fund than is required under some other alternatives. (A new certificate of deposit must be purchased.)
- o Certificates of deposit result in a significant amount of corporate funds being unavailable for the business.

3.6.6 Deposits of Securities

Using this scenario, the licensee would be responsible for depositing securities to the appropriate government agency with a face value equal or greater to the highest cost of closure at the site. Theoretically, the securities referred to here could be of several different kinds, including long-term U.S. bonds; municipal bonds; or corporate securities.

Some of the advantages of this method include:

- o There is little difficulty in obtaining the funds if the operator defaults, as the government agency already has access to the necessary funds.
- o The operator incurs no additional expenses (such as an annual premium for a surety bond) beyond the face value of the securities and any required transfer fees.

Some disadvantages associated with this method are:

- o Unless a trust administrator is used, the responsible government agency must play a more active role under this method than under most other alternatives. It must hold the funds, distribute dividends from the securities to the operator, determine security values, and exchange securities for other securities as the operator desires or as the market demand changes.
- o The values of the securities will fluctuate as the market demand changes, thus causing additional administrative time to be spent to ensure that the proper amount is maintained in the fund to keep pace with inflation.

- Some administrative time is required of the staff for adjusting the amount in the account. This involves contacts with the operator for additional securities, and fund administration time.

3.6.7 Pledges of Securities and Liens Against Properties of the Licensee (Secured Assets)

These types of secured interest are interests in personal property or fixtures of the operator that gives the holder of the interest the right to possess the assets to ensure payment of an obligation. These financial assurance mechanisms are similar to self-insurance except that the licensee pledges certain assets which could be used by the Commission to perform closure and postclosure activities in the event of licensee default. A secured interest gives the government agency the right, in the event of default by an operator, to take possession of the assets and sell them in satisfaction of the claim. In most cases where a secured interest has been properly created, the holder of the interests has first claim or priority over these assets, if the operator goes bankrupt. The secured assets may be repossessed by the secured interest holder, and proceeds from the sale of the assets are not required to be shared with other creditors in bankruptcy proceedings. Pledges of securities would require the Commission to possess collateral and have the staff make periodic assessments that the value of the securities was sufficient to meet closure activities. Furthermore, the status of a securities pledge in the event of financial failure of the pledger is uncertain and can differ substantially with variations in state law.

Liens against land and real property would also require the Commission staff to undertake periodic assessments to ascertain that changes in inflation, depreciation policies, etc., had not reduced the ability of the liens on the land and real property to pay for closure of the site. Additionally, liens would require the Commission to first foreclose and then sell the property before funds would be available for closure activities at the site. An EPA review of this financial assurance mechanism has also found that liens also suffer from an uncertain status in the event of financial failure of the owner.

Some of the advantages of this method are:

- Few additional expenses are incurred by the operator. The only costs involved would be those legal costs associated with preparation of documents.

- There is no loss of productive use of corporate assets. The collateral that is used as the secured interest remains with the operator.

Disadvantages of this method are:

- A significant amount of adminstrative staff time is necessary. Staff effort is necessary to establish a security interest by completing all the necessary paperwork and renewing the collateral to ensure that their value is sufficient to pay for closure costs.

- When it becomes necessary to adjust the amount of the fund, additional assets must be added to or withdrawn from the agreement. Again, staff time is necessary to reevaluate the value of the operator's assets.

- Significant problems can occur if the government finds it necessary to obtain funds for closure in the event of licensee default. Other creditors may also place liens on the company's assets, and the legal process may considerably delay recovery of the assets, as well as resulting in significant staff time and expense.

3.6.8 Letters of Credit

Irrevocable letters of credit are another short-term financial assurance alternative to ensure that sufficient funds are available for closure and postclosure expenses at a disposal site. Traditionally, letters of credit have been primarily used in international trade. In using this method, the operator would apply to a bank for the issuance of a letter of credit that commits the bank to pay the beneficiary (the state or federal government) if the letter of credit comes due. A letter of credit consists of a bank's document written on behalf of the party (licensee) that would give the governmental agency the right to draw funds from the issuing bank upon the presentation of papers in accordance with the letters of credit. The cost of a letter of credit is based on the face value of the amount, the amount of time required for coverage, and the risk to the bank. Banks issuing standby letters of credit charge fees on between .5 to 2% of the face amount of the letter of credit.

Guidelines for a letter of credit are found in regulations issued by the Department of Treasury, Comptroller of the Currency (12 CFR §7.7016). A national bank can issue letters of credit permissible under the Uniform Commercial Code on behalf of its customers. Guidelines stipulate that letters of credit should meet the following conditions met:

1. Letters of credit should conspicuously state that it is a letter of credit.

2. The bank's undertaking should contain a specified expiration date, or be for a definite term.

3. The bank's undertaking should be limited in amount.

4. The bank's obligation to pay should arise only upon the presentation of a draft or other documents as specified in the letter of credit, and the bank must not be called upon to determine questions of fact or law at issue between the account party and the beneficiary.

5. The bank's customers should have an unqualified obligation to reimburse the bank for payments made under the letter of credit.

Originally, letters of credit were "documentary"; they were used to finance a shipment of goods and require the beneficiary of the letter to present documents, such as invoices, before obtaining payment under a letter of credit. For the purposes of this regulation, the staff considers this type of letter of credit is not an appropriate mechanism for assuring closure at a disposal site. Rather a "clean" letter of credit, which doesn't require shipping or invoice documents before drafts on letters are paid, would be the most appropriate form of letter of credit for disposal facility licensees. The guarantee or standby letter of credit is a clean letter of credit that is written to financially protect the beneficiary from failure on the part of the account party to meet the terms of a contract between them. This type of credit is then irrevocable for the life of the credit.

An acceptable letter of credit for the purposes of this regulation would specify the NRC as the party who may draw upon the fund in the amount of the most recent closure care estimate required to be made in the site closure and stabilization requirements. The letter should also specify that the NRC can draw upon the funds behind the credit, following the finding of a violation of the closure/postclosure care requirements. Letters of credit can also be created to reflect the regulation's requirement for periodical adjustments to reflect changes in inflation.

Open-ended letters of credit are traditionally not written. However, staff research indicates that the same level of assurance provided by an open-ended surety mechanism can be obtained with an automatically renewed, irrevocable letter of credit. A letter of credit with such a clause provides that the credit is for a definite period with a renewable term. If the letter is not extended by the bank, then the NRC is empowered to draw against the credit. If the letter of credit were written for a specified period of time (e.g., one year), it would have to state that the bank agreed to automatically renew the letter of credit upon expiration unless the bank notified the beneficiary (the regulatory agency) and the principal (the licensee) some reasonable period of time (e.g., 90 days) prior to the renewal date of their intention not to renew. In such a situation the requirement still exists and the licensee would be required to submit another financial assurance in order to allow at least 60 days for the regulatory agency to collect.

The staff finds that a necessary condition of this financial assurance is that proof of forfeiture must not be necessary to collect. The conditions described above would have to be clearly stated on any letter of credit that is not open-ended, and must be agreed to by all parties. Such an arrangement demands efficient procedures for collection.

In order for an operator to obtain a letter of credit, he must apply to banks or financial institutions that will issue one. The operator would often be required to give the bank some type of security interest in his property. In the alternative, he may need to supply capital to the bank to ensure that he will not default.

Fees for issuing a letter of credit are generally lower than those for trusts or bonds. Guarantee letters of credit have fees ranging up to 2% of the face value of the amount.

Some of the advantages of this method include:

- o This method requires only a minimal amount of time, on the part of the government agency, to administer. The letter of credit could be filed with the license.
- o There is no problem of having to evaluate assets for the government agency; this activity is performed by the bank. NRC simply receives the letter of credit for the amount required.
- o The administrative fees for this type of financial assurance are generally less than for trusts or bonds.

Disadvantages of this method include:

- o More administrative time would be necessary to adjust the amount of the letter of credit. This would require the issuance of a new letter of credit from the bank.
- o A direct cost is involved to the operator for obtaining the letter of credit.

3.6.9 Self Insurance by the LLW Site Operator

As used in this analysis, self insurance means an arrangement whereby the operator agrees to perform the closure and postclosure activities, and finance the activities out of his own resources, such as cash working capital. In effect, it is an alternative involving no additional assurance other than the licensee's legal obligation to perform closure activities, which are required as a condition of the license. The legal obligation pursuant to the license exists regardless of any separate contract or lease, whereby the operator agrees to perform closure.

The primary problem of using self insurance occurs when the licensee may not have sufficient funds to meet his responsibilities, at a time when no revenues are arriving from the operation.

One advantage of this alternative is:

- o There is no cost to the licensee.

Some disadvantages of this method are:

- o In case of default, the government agency would have to obtain a legal judgment based on its contract with the licensee and then would have to execute its judgment if the operator has assets out of which the judgment can be satisfied. The staff believes such a regulatory approach is not acceptable.

3.6.10 Financial Tests

Financial tests are another variation of self-insurance, which require the licensee to develop a set of criteria showing that he has sufficient unencumbered assets to provide for closure. These assets are not pledged or retained for closure. Rather, financial tests would enable the Commission to monitor the financial health of the licensee's operations. In the event of deteriorating financial conditions of the licensee, he would then be required to establish another form of financial assurance.

There are a variety of financial tests which could be used by the regulatory staff to ascertain that the licensee has sufficient financial health: net working capital, net worth, a review of the total liability to net worth ratio, the current or quick ratio, and the age of the firm. A brief description of these different types of financial tests follows.

Net Working Capital

Net working capital is the difference between current assets and current liabilities. Provision of sufficient net working capital would enable the regulatory agency to determine that the licensee has sufficient unencumbered assets available for closure. Net working capital would have to be greater than the potential closure expenses because of the quickness with which the net working capital can decline. One study reported by IR&T of 32 failed firms during the period of 1964 to 1970, found that net working capital for the average firm declined 33 percent between the fourth and third years prior to failure and disappeared entirely between the third and second years to failure. This information suggests that if this financial test were used, there would be a need for net working capital in excess of the actual closure costs.

Net Worth

Net worth is the difference between the total assets and total liabilities, and is equivalent to the equity of the owner. Net worth would have to be equal to or greater than the potential closure expenses.

Total Liability to Net Worth Ratio

This test would serve to exclude firms which are large enough to meet a net worth test but so highly leveraged as to present potential insolvency problems. (A highly leveraged firm has a relatively high fraction of its capital structure in the form of debt.)

Current or Quick Ratio

The current or quick ratio is the ratio of current assets to current liabilities. The quick ratio is the ratio of cash, current receivables, and marketable securities to current liabilities. This financial test differs from the current ratio chiefly by the exclusion of inventory. A firm with a large net working capital could still have serious financial problems if its current or quick ratios were relatively small.

Age of the Firm

The age of the firm is another financial test that could be used to predict the likelihood of insolvency of firms. For example, one study referenced in the IR&T report mentioned that in 1978, 53% of all business failures were firms which had been in existence five years of less.

One advantage of this alternative is:

- Financial tests are an advantageous form of financial assurance for the operator, since they require no use of assets.

Some disadvantages of this alternative are:

- Financial tests provide no protection that funds will be available for closure and postclosure care. Rather, financial tests serve as a stop-gap measure by which the regulatory agency determines if the operator's business is sufficiently strong to pay for closure activities. If the operator's operations are failing, then the regulatory agency would require the licensee to obtain another form of financial assurance. However, if a firm were in this position, then it probably would not be in sufficient financial health to obtain other adequate financial assurance mechanisms. For example, surety companies would probably not be interested in covering a company who could not meet the financial tests required by a federal agency. In such a case, the licensee would have to use a trust fund, deposit of securities, or some other form of financial assurance, which he may not be able to afford if in such a precarious financial position.

- The use of financial tests also imposes a tremendous administrative burden on the licensing staff. As a result, the regulatory process may be lengthened as the staff is forced to evaluate various financial tests of the companies' financial stability. In conclusion, the staff feels that financial tests fail to provide a sufficiently stringent degree of protection, and therefo[illegible] they cannot recommend the use of this financial assurance mecha[illegible] for closure.

3.6.11 No Financial Assurance Requirements for Closure and Postclosure Care

Another regulatory alternative for short-term care would be for the regulatory agency to not establish any funding requirement on waste licensees for financial responsibility for closure and postclosure care. With such a scenario, the custodial care regulatory agency or the site owner would be responsible for all costs incurred during closure and postclosure. The staff did not consider this alternative for long-term care, since some forms of financial assurance for closure and postclosure care are already being implemented at existing LLW disposal sites. The Commission staff has also received comments on the need to establish financial responsibility for short-term closure and postclosure care activities for low-level waste sites. Based on these findings, the staff has determined that a regulatory approach of not requiring short-term financial assurances for closure of a site is not acceptable.

3.6.12 Other Short-Term Financial Assurances

3.6.12.1 Surcharge on Waste Generators and Collection of Funds Into a Sinking Fund

Requiring a licensee to impose a surcharge on a cubic foot or meter basis on the users of the site to recover closure expenses is a mechanism that is currently in use in several states with LLW disposal sites. The Natural Resources Defense Council has also previously requested the NRC to require a surcharge on a capacity basis to be imposed on users of disposal facilities. The staff recognizes the merit of such an approach from an equity basis. The use of a surcharge deposited into a sinking fund has been used as a collection method by several states to ensure that sufficent funds are available for closure. The burden of financial responsibility for closure is borne by the waste generators who use the waste disposal service. Nevertheless, there are several reasons why the staff cannot recommend this mechanism's use.

First, a sinking fund builds up funds gradually as revenues are received, and over the life of the site there is a high probability that there will not be sufficient funds at its inception to account for the full costs of closure. Such a mechanism would not guarantee that the full costs of closure were available at all times to account for closure. (This problem could be alleviated by simultaneously requiring another form of financial assurance on the remaining balance of closure funds.) A second reason why this financial assurance mechanism is not acceptable is because the Commission currently lacks the statutory authority to require licensees to impose a surcharge or a fee per unit volume of waste. Establishment of an earmarked fund would also require Congressional authorization. In 1978, the NRC staff responded to a petition for rulemaking by the Natural Resources Defense Council that called for the NRC to establish a special fund based upon a cubic foot charge. In their response to the petition, the staff noted that a federally mandated fee per unit volume of waste that is not a product of the landlord/tenant contract (i.e., a lease) would be, in essence, a tax that requires legislative enactment. Based on landlord/tenant (state or federal government/site operator) contracts authorized by state law, the states containing commercial burial sites have collected disposal fees from the site operator on a capacity basis. However, for the reasons stated above, a financial assurance requirement consisting of a surcharge as a means of collection cannot be imposed at the federal level.

Since the NRC currently lacks the authority to require the operator to establish a surcharge on waste generators, the staff has not conducted an analysis of using a sinking fund based on a surcharge. However, the use of a sinking fund based on a surcharge on a capacity basis may be an appropriate way of building up funds for closure if a guarantee on the balance of closure funds is implemented to ensure that, at all times, there are sufficient funds to pay for closure. (For those Agreement States that may wish to consider the imposition of such a financial assurance system, the staff has calculated estimates of these surcharges using the Decost Computer Program and these estimates are available upon request.)

3.6.12.2 Closure Pool

Another possible variation for assuring adequate financial funds for closure involves the development of a pool of closure assurance funds. This approach was included in the Battelle Study on Decommissioning. Disposal facility operators (and possibly, operators of other fuel cycle facilities) would make payments to such a fund. An independent "Closure Assurance Agency" would be chartered to retain and invest the funds and perhaps oversee activities and disperse payments to those conducting the activities. The pooling of closure funds into such a centralized agency could help to ensure closure performance even if a particular facility operator defaults. The agency would act in a fiduciary capacity for the public. Payments and interest received by the stewardshop entity would be exempt from federal income tax because the entity is a creation of the U.S. or a state government and is an exempt scientific entity.

The pool would be obligated to pay for closure of a site if the operator defaulted on performance of required closure activities. However, setting the appropriate premiums would be difficult, since the pool administrator would have to estimate the likelihood of nonperformance or partial performance, and then calculate the magnitude of the fund required to complete the closure activities. Such an assurance would have to be established by the federal government and would require Congressional action. Therefore, since the Commission currently lacks the statutory authority to create such a financial assurance mechanism, such a short-term financial approach is not discussed further.

3.7 Conclusions and Staff Recommendations

There are a number of financial assurances to provide adequate public protection to ensure that funds for closure exist in the event that the LLW site operator defaults. The alternatives that the staff finds acceptable on a generic basis for an LLW disposal facility licensee are: surety bonds, trust funds, escrow arrangements, cash deposits, certificates of deposit, deposits of government securities, and irrevocable letters of credit. These alternatives were all found to be acceptable by the staff because without incurring a significant administrative burden, they can be structured in such a way that there is a high degree of assurance that funds are available to ensure a proper closure. Although the administrative burdens associated with the various mechanisms the staff has approved do vary to a certain extent, this variance is not expected to be significant. Approving a range of satisfactory alternatives allows the operator flexibility in selecting the mechanism that best suits his needs. In addition, this range allows the use of a combination of financial assurance mechanisms.

While the other financial assurance mechanisms discussed earlier may be acceptable in certain cases, with the exception of self insurance, the staff finds that they are not acceptable on a generic basis. Plans for alternative financial assurances not discussed here would have to be evaluated on a case-by-case basis.

Therefore, with regard to short-term financial assurances for closure and postclosure, the staff developed the following criteria for operators of a disposal facility:

- Each applicant must demonstrate adequate financial resources to cover the estimated costs of conducting all licensed activities over the planned life of the project including ensuring that sufficient funds will be available to carry out final site closure, postclosure care, and stabilization activities.

- Prior to startup of operations, the licensee must obtain a short-term financial assurance mechanism found acceptable to the Commission that is sufficient at all times to cover all costs of closure and postclosure care, and must be based on a Commission-approved plan for closure and stabilization.

- The short-term mechanism must be in effect throughout the operating period of the site.

- The licensee's costs estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the decommissioning and closure activities.

- The face value of the short-term financial assurance must be at least equal at all times to the cost estimates submitted by the licensee in the approved Plan for Site Closure and Stabilization.

- The financial assurance mechanism must be full funded prior to the start of operation, to provide full assurance regardless of whether closure occurs as was originally planned, or else occurs prematurely.

- The licensee's cost estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the decommissioning and closure activities.

- The licensee may use one or more of the mechanisms allowed in the regulation to meet these requirements.

- The financial assurance mechanism must be open-ended and cannot be cancellable.

- Proof of forfeiture must not be necessary in order to collect the financial assurance mechanism. If the licensee cannot provide an acceptable financial assurance substitute within the required period, then the mechanism will be automatically collected prior to its expiration.

- The Commission will allow the licensee to terminate the financial assurance mechanism after a finding that all license conditions have been met.

- The licensee must annually adjust the amount of funds provided by the financial assurance mechanism to account for changes in inflation, site conditions, and technology.

- Flexibility be allowed regarding the specific financial assurance mechanism used, stating that:

  - cash deposits
  - trust funds
  - surety bonds
  - escrows
  - certificates of deposit
  - deposits of government securities, and
  - irrevocable letters of credit

  or combinations of these financial assurances would be acceptable on a generic basis, and that that other financial assurance mechanisms would be evaluated on a case-by-case basis for acceptability.

- Factors should be stipulated that must be considered in setting up the financial assurance, including:

  - inflation;

  - term of the mechanism (i.e., the term of the assurance must be open-ended and remain in effect until the regulatory agency releases it on satisfactory completion of closure);

  - an adjustment provision that requires a periodic review of adequacy of the financial assurance mechanism. The face amount should be adjusted to recognize any increases or decreases resulting from inflation, changes in engineering plans, activities performed, and any other conditions affecting costs. This will yield an assurance sufficient at all times to cover the costs of closure and postclosure.

Based on these findings, the staff has determined that an LLW disposal licensee provide financial assurances for closure and postclosure care. The costs developed for a typical facility described in Appendix E of the EIS includes the costs for a financial assurance for closure as part of the base case costs.

As was mentioned earlier, the NRC lacks the authority to require the licensee to establish a surcharge on waste generators to pay for the costs of closure (and postclosure) activities. Some states, however, may have this authority, and they may want to implement this funding mechanism. Section 4 of this appendix provides a brief description of aspects a state might wish to consider in establishing a sinking fund based on a surcharge for either a closure or long-term care fund.

4. LONG-TERM CARE (ACTIVE INSTITUTIONAL CONTROL) FUNDING REQUIREMENTS

4.1 Introduction

The staff recommends that a low-level waste license applicant should provide the NRC with a binding arrangement (such as a lease between himself and the state), which specifies that adequate funds for up to 100 years of long-term care of the closed site will be provided by either the applicant or by the governmental body owning the land. The staff considers this approach necessary in order to ensure that these activities will be performed promptly and in a manner that will protect the public health and safety. Such activities would be site-specific, and include monitoring, surveillance, and any necessary maintenance. The lease must also take into account the cost of inflation over that period. The Commission would also periodically review this lease to ensure that the terms and conditions are kept current to reflect changes in inflation and specific site conditions. Examples of specific lease forms that the staff finds acceptable will be presented in a forthcoming regulatory guide issued by the Commission.

The Commission currently lacks the statutory authority to require the licensee to develop a long-term care fund. (See the discussion of SECY-78-613 in Section 8 of this appendix for a fuller analysis of this issue.) The staff is cognizant that establishing a regulation that required a licensee to establish a long-term care fund would be a stronger regulatory approach than the more indirect method of reviewing a lease or binding arrangement that delineates financial responsibility for this period. However, until such time as the Commission receives this statutory authority, the Commission staff considers that requiring the licensee to submit a binding arrangement or lease for review by the Commission is the most appropriate regulatory approach, based on current authority. Such a lease arrangement is currently used at all six sites to delineate the roles and responsibilities between the landlord (state or federal government) and the tenant (the operating company) with regard to the long-term care of the site.

4.2 Need for Requiring Financial Assurances for Long-Term Care

A review of the history of commercial low-level nuclear waste sites in this country (see Section 6 of this appendix) indicates that there has been continuing concern by the public and by regulatory authorities over long-term financial responsibility for low-level waste disposal sites. In addition to questions over the equity issues of who pays for long-term care, the government and the public are concerned that funds be readily available in order to ensure that the public's health and safety are continually protected. The controversy over long-term care at the Sheffield, Illinois low-level waste disposal site that ensued between the licensee and the state of Illinois is a contemporary illustration of the dilemma that exists in this area. Another event that has highlighted this controversy concerning the adequacy of long-term care funds occurred at the closing of the reprocessing plant at West Valley, New York. The GAO report to Congress on this site found that the "perpetual" care fund was inadequate to cover the long-term associated costs

of the site. The GAO report also found that the recommendations raised larger policy issues "concerning whether or not, and to what extent, the federal government should provide financial assistance to the nuclear industry by taking over the cost of managing activities in the back end of the fuel cycle."

Based on these and other considerations, the Commission staff has been careful to include requirements for financial guarantees for long-term care in the proposed low-level waste regulations, in order to ensure that the public health and safety is protected.

Existing state financial requirements for care of a disposal site after the license is transferred have frequently been referred to as "perpetual care arrangements." They are based on the same concept as scholarships, research endowment funds, or perpetual care funds for cemeteries. Funds are invested and a return is earned on this principal. When the amount of interest earned is adjusted by the annual inflation rate, then the net rate of return is determined. This net return is then used to pay for various activities, such as research, scholarships, maintenance at a cemetery, or conversely, surveillance, monitoring, and maintenance at a low-level waste disposal site. If the net rate earned on the principal is larger than inflation, then the principal is left intact, and the principal can be invested again and again (in "perpetuity") to fund these various activities through the return earned on the invested principal. However, if the interest rate earned on the principal is less than the inflation rate, or large, extraordinary expenses develop that were not originally planned for, then the principal must be used if the activities are to be paid for. In that case, the principal is eventually reduced to zero, and the "perpetual" care fund is of short duration.

4.3 Shortcomings of Existing Financial Mechanisms for the Recovery of Long-Term Care Funds

The actual experience with "perpetual" care funds at low-level waste disposal sites (henceforth referred to as long-term care or institutional control funds) has not been good. A staff review of the existing low-level sites (see Section 6) found that the majority of state officials indicated that the "perpetual" care funds were inadequate to cover the costs of long-term care activities. This shortcoming of long-term care funds at disposal sites occurred because of several factors. First of all, conservative investment policies, traditionally adhered to by state-investing agencies, mandated that the funds be invested in low-risk investments that traditionally do not earn high rates of return. Frequently, returns on these less risky investments have not kept up with inflation. (In one case, the collected funds for long-term care were never even invested or put in an earmarked fund, thereby guaranteeing that no funds would be available for long-term care.) Second, the continued high inflation rates in the last decade have resulted in a devaluation of the funds. Additionally, state authorities in charge at the time the funds were set up, and who were responsible for establishing the amount and surcharge required to collect the long-term care fund, were frequently unaware of the magnitude of the types of remedial activities required for long-term care at the low-level waste disposal sites, with the result being that not enough

funds were collected to take care of water-management problems. Because of these shortcomings, the long-term care funds have been inadequate to meet the necessary long-term care activities at low-level waste sites.

In specifying the types of costs to be considered in the establishment of a long-term care binding arrangement, the Commission staff has patterned their suggested requirements after portions of recommendations made on this topic by the 1976 Task Force Report on Bonding and Perpetual Care of Licensed Nuclear Activities (see Section 9 of this appendix). The report recommended that a perpetual care trust fund for long-term care be legally established, which drew interest adequate to pay the costs of monitoring and maintaining the closed site. The perpetual care trust fund was to be earmarked and be limited to monitoring, maintenance, and other perpetual care activities at the radioactive waste burial site.

The staff does not recommend the use of a "perpetual" care financial arrangement for LLW disposal sites. Rather, they believe there should be a limited financial responsibility for long-term care for a period of up to 100 years of active institutional control. To the extent that the licensee and the licensing authority have correctly estimated the types of activities necessary during this period, along with their resultant costs (adjusted for inflation), then the long-term care funding mechanism should be adequate to properly handle the known and predictable expenses of this 100-year period. Beyond the period of 100 years, no expenses have been calculated for inclusion into the determination of active institutional control responsibility.

4.4 The Active Insitutional Control Period

The first 100 years of a low-level waste disposal site that occur after the site is closed and the license is transferred to the site owner is known as the active institutional control period. Activities carried out during this period include surveillance to physically control access to the site, environmental monitoring, and minor maintenance. During this period, the staff envisions there will be no major maintenance necessary at the site if it has been properly sited, designed, operated, and closed.

4.5 Types of Funding Arrangements for Active Institutional Control

There are a variety of long-term financial assurances that have been used by regulatory authorities to provide for long-term care (including surveillance, maintenance, monitoring, and all required and predictable activities) at a low-level waste disposal site. For example, several of the states currently require their licensees to collect a specified surcharge from their waste generators who use the site. The funds collected from these long-term care surcharges are then deposited into an earmarked state treasury account, or sinking fund, where they are invested to keep pace with inflation. If such a sinking fund were used, in order for the Commission to assure itself that there was protection to assure that funds for long-term care were available, a sinking fund would have to be combined with a performance bond on the unpaid balance. For example, suppose the Commission determined that $10 million in

1980 dollars were necessary for long-term care. During the first year of operation, the licensee might collect $.5 million from surcharges which he would then deposit into a sinking earmarked fund. During that year, they would then be required to post a bond for $9.5 million. In the second year of operation, assume that $10 million is deposited into the sinking fund. Then the licensee would have to have a performance bond of $9.0 million, and so on. Such a long-term care fund could be set up in two ways. First, a fund could be established on a "perpetual" basis where the funds earned each year from the invested principal are used to pay for long-term care costs. As long as the interest on the invested principal earned more than the inflation rate, there would be sufficient funds for postclosure care. The Uranium Mill Tailings regulations issued by the NRC in 1980 made provision for the development of a perpetual care fund for long-term perpetual care at decommissioned tailings sites. In the Generic Environmental Impact Statement on Uranium Milling, developed in conjunction with these regulations, NRC staff determined that funds should be provided by each mill operator to cover the costs of long-term monitoring. A one-time charge adjusted by changes in the Consumer Price Index (to be equivalent to $250,000 in 1978 dollars per site) is to be levied on mill operators before the termination of a license. The charge is to be paid to the federal government unless the state in which a mill is located chooses to take custody of the site. If the long-term monitoring charge is paid to the federal government, it would then be deposited in the General Treasury fund of the United States, as opposed to a special earmarked fund that might be established.

A second way that a long-term care fund could be set up is by the development of a fund for a finite period of care, such as a 100-year period. The funds would not be available in perpetuity, but rather for only a specified time. The principal amount (as well as return on this principal investment) of funds would be drawn on over the 100-year period to pay for all necessary long-term care, so that only a small amount of the principal and interest is left at the end of the 100-year period.

Another type of financial assurance for long-term care that has been proposed by some parties is the development of a federally administered perpetual care program to which all disposal facility operators would be required to contribute. Using this scenario, the federal government would be responsible for administering a radioactive "Superfund," that is similar to the fund being developed by the federal government based on P.L. 96-510. Proponents of this funding mechanism argue that, since burial sites serve national and not state needs, the citizens of individual states should not be required to bear the cost of major contingency actions for long-term care activities at these sites. The 1977 NRC Task Force Report on Review of the Federal/State Programs for Regulations of Commercial Low-Level Radioactive Waste Burial Grounds came to a similar conclusion. This report states "it appears desirable and equitable for the federal government to assume responsibility for long-term care of the sites, since the states generally do not have the resources to assure adequate care under a variety of contingencies," and also since the sites serve regional needs. However, this type of pooled risk long-term care mechanism would require enabling legislation from Congress, since the NRC currently lacks the authority to establish any type of postclosure care fund, let alone a shared risk process.

As has been demonstrated, a variety of long-term financial assurance mechanisms exist to provide for funding active institutional control activities such as surveillance, monitoring, and any necessary maintenance at a disposal site. However, because of a lack of enabling authority, the Commission staff can only require licensees to be party to a lease or other binding arrangement with the site's landlord in order to establish that full financial responsibility for long-term care care has been delineated between the two parties. The Commission staff is proposing this regulatory approach for long-term care at LLW sites until such time as the Commission has enabling legislation.

4.6 Types of Active Institutional Control Costs

What types of long-term care costs for the 100-year active institutional care period for a low-level waste site should be included in the lease arrangement? A variety of studies have been performed that have analyzed types and estimates of costs for long-term care at a low-level waste site. Appendix Q of the EIS provides a discussion of these studies and cost estimates that were developed. A discussion of inflation and interest rates is also provided, and recommendations for these variables are made in that appendix for the purposes of this regulation. The staff considers that responsibility for the following types of costs should be delineated in the lease or binding arrangement between the license applicant and the landowner of the low-level waste disposal site: surveillance; monitoring; and all required and necessary maintenance activities that the Commission deems necessary to protect the public's health and safety and the environment. Table K.2 is excerpted from Appendix Q of the EIS and presents a range of costs in 1980 for 100 years of long-term care activities for a range of different scenarios at a reference low-level waste facility.

Table K.2 Range of Long-Term Care Costs for 100 Years of Active Institutional Control at a Low-Level Waste Disposal Site (1980 Dollars)

Scenario	0-10 years	11-25 years	26-100 years	Total cost, 100 years
Low	$150,000/yr.	$63,000/yr.	$51,000/yr.	$6,270,000
Medium	$302,000/yr.	$150,000/yr.	$88,000/yr.	$11,870,000
High	$440,000/yr.	$302,000/yr.	$150,000/yr.	$20,180,000

4.6.1 Contingency Costs

The concern for ensuring that responsibility for unanticipated contingency costs is delineated during the long-term care period is especially great for disposal sites because of the long time period during which administrative controls may need to be maintained after the license is terminated. (As used

in this discussion, the term "contingency" cost refers to those types of unanticipated long-term care costs that were not included in the original delineation of costs at the site.) However, it is extremely difficult for forecasters to project the frequency and severity of contingencies that might occur during this long of a time period, as well as estimating the costs necessary for the resultant remedial actions at such a site. At this time, the staff has not made a projection of these contingencies. Nevertheless, the staff believes that it may be appropriate to prepare a site-specific assessment based on information developed during the site's operating period, and if the results suggest that certain occurrences have a reasonable certainty of occurring, then the financial responsibility for their resultant costs should be included in the specifications of the binding arrangement or lease for that particular site.

With regard to this issue of who should bear the financial burden of long-term care contingency costs, the Battelle Northwest Laboratories (BNWL) study on Decommissioning a Low-Level Waste Burial Site (See Section 9 of this appendix) concluded, "in practice, it seems likely that the financial burden of unanticipated contingencies after burial ground closure will fall on the state and/or federal government." The study continues by pointing out that since some parties may argue that, since the buried waste originated from throughout the country, the burden for these types of long-term contingency costs may logically fall on the federal government. If this conclusion is followed, the report then argued that one possible solution might be for the federal government to formally assume an insurer's role for unanticipated contingencies and collect premiums as a surcharge.

The authors of the BNWL study also noted that "There is a possibility that the former site operator can be required to assume the burden for contingencies after closure. However, none of the existing license agreements appear to provide for this. In the absence of a contractual agreement, the operator who has relinquished the site could only be forced to assume the burden of contingencies if negligent burial practices can be shown. Even this possible solution may not be available if a cause of the action is initiated after the statute of limitations has expired. The odds are also high that the company may no longer be in business over such a long-term period."

Based on the previous experience gained from existing low-level waste disposal sites, the Commission staff believes that new sites can be licensed that will continue to adequately protect the health and safety of the public when closed. However, the staff also recognizes that in spite of the experience gained by the low-level waste disposal industry, shippers, packagers, and state and federal regulatory agencies, the history of closed low-level waste disposal facilities is insufficient to allow the staff to fully assess the possible long-term contingencies over a 100-year period. Uncertainty does exist about the types of activities and the costs that would be required over a long time period after a low-level waste site is closed and the license is terminated.

The staff considers that some of the uncertainty over financial responsibility for long-term care at an LLW site can be reduced at the time of licensing, when (a) the applicant demonstrates that the proposed site can be sited,

designed, constructed, operated, and closed such that the need for long-term active maintenance is eliminated and (b) the licensee assesses what types of events might occur and what their impacts on a waste disposal site would be (e.g., long-term drought cycles, or long-term excessive moisture cycles). These considerations of possible contingency activities would have to be done on a site-specific basis during the licensing process. The Commission staff recognizes that it is unreasonable to expect the present generation of users of a site to pay for a worst-case scenario of long-term care expenses at that site, when the chance that such an event would occur is minimal. The Commission staff is unaware of any other regulated industry that must provide total costs for such activities that are remote, occur after the license is terminated, and are not easily subject to calculation of risk. Nevertheless, the Commission staff has concluded, based on the comments it has received on the draft, and also from the experience of other agencies in the area of long-term care funds, that it is appropriate that the lease be site-specific with regard to provision for possible long-term care costs.

Several participants at the LLW workshops also pointed out that if the risk of having remedial situations develop in a decommissioned low-level waste site were nonexistent, there would then be no need to have a long-term care inspection and monitoring program at the site. (In their development of the proposed regulations, the NRC staff has recommended that a monitoring and surveillance program be conducted after the site is closed.) As stated earlier, these long-term care activities can be minimized by requiring the licensee to site, design, operate, and close the site in such a manner so as to eliminate the need for active maintenance activities after the site is decommissioned. However, the staff feels that even the presence of such a performance objective in the regulation does not relinquish the Commission from their regulatory responsibilities to ensure that care is taken of the site after the license is terminated. The Commission staff feels that part of this long-term care responsibility should include a monitoring program to determine if unanticipated circumstances occur at the site that would require remedial action. Unexpected remedial costs do not refer to ordinary cost overruns that occurred during long-term care activities.

What will be the financial impact on waste generators at a low-level waste site requiring a long-term care fund? As was mentioned earlier, although the Commission does not have the authority to (a) require that a surcharge or other fee be required of waste generators in order to collect for either closure or for long-term care or (b) to actually require the LLW operator to establish a long-term care fund, nevertheless, the financial burden of long-term care traditionally has been placed on the users of the site. The proposed regulations only require that a binding lease between the licensee and the landowner be established in order to ensure that adequate funding be available for long-term care. The mechanics of collection are left up to the licensee and to the landowner. However, for the purposes of illustration, if the current state government practices of imposing surcharges on a capacity basis for long-term care on waste generators are followed by the licensee, then an estimated surcharge can be calculated. Charges for a long-term care surcharge can be computed based on assumptions made about the return on capital, the rate of inflation, the annual costs of surveillance, monitoring and maintenance,

and the annual and total capacity of the site. The Commission staff has developed a computer program that will use the above figures to calculate the total amount and surcharge necessary to develop a long-term care fund, as well as the required surcharge on a cubic-foot basis. Entitled DECOST, (NUREG-0514), the program is flexible and can calculate costs under varying economic and planning conditions, and present results in either constant or inflated dollars.

4.7 Impact of Proposed Financial Assurance Requirements

The staff has determined that it is necessary to provide financial assurances for up to 100 years of active institutional control in order to protect the public's health and safety. The alternative of not requiring such a financial assurance for long-term care could result in a situation where the federal government and the taxpayers of the state where the site is located would be financially responsible for the long-term care costs of surveillance, monitoring, maintenance, and any remedial action at a site in the event of licensee default. Such a situation would result in an adverse impact to the taxpayers of the region and alleviate the users of such a site from bearing financial responsibility for long-term care. The staff has, therefore, recommended that the license applicant provide evidence of financial assurances for long-term care at the low-level waste site.

4.7.1 Conclusions

The Commission staff has found it necessary to require financial assurances for up to 100 years of active institutional control in order to protect the public's health and safety and the environment. The costs to be considered in the development of such a long-term care fund include surveillance, maintenance, monitoring, inflation, and all other activities deemed necessary by the staff.

Currently, the Commission staff lacks the regulatory authority to require that a license applicant develop a long-term care fund that would provide financial responsibility for up to 100 years. However, until such enabling legislation is received by the Commission, the staff feels that the methods discussed above will give the Commission staff the ability to determine that financial responsibility for 100 years of long-term care at an LLW site is met. Such a regulatory review would be done by examining the terms and conditions of a lease or other binding arrangement that would be provided by the applicant. The lease would have to ensure that either the site owner or the applicant is responsible for all of the previously mentioned long-term care costs. The Commission would also periodically review the binding arrangement to ensure that the lease was updated to account for changes in inflation and for changes in required maintenance activities. Thus, the costs for 100 years of institutional control have been incorporated into the costs for the reference facility, and corresponding alternatives have also been analyzed. The actual costs of long-term care, however, will vary depending upon the level of activities required under varying disposal facility conditions. In recognition of the

need for establishing financial responsibility for long-term care, state authorities at each of the existing LLW sites have made provision for accruing these funds. Therefore, the reference facility described in Appendix E includes the costs for long-term care. The staff assumes that these funds for active institutional control would be obtained through a surcharge based on waste received at the facility. These monies obtained from the surcharge would then be placed into an interest bearing account.

5. OTHER GOVERNMENT REQUIREMENTS FOR CLOSURE AND LONG-TERM CARE FUNDS

A variety of state and federal agencies have developed closure and long-term care for financial requirements for operators of hazardous (both chemical and radioactive) operations. State experiences with financial requirements for disposal sites have shown that these financial requirements for closure and long-term care have not been adequate to fully pay for closure and long-term care of the site. Some of the reasons for this lack of complete financial assurances for closure and long-term care costs include the following: failure to consider inflation; failure to include changes in technology and standards; failure to include recognition of changes in site conditions; and failure to develop an earmarked, separate fund for the collection of these fees. This appendix provides a brief review of governmental experiences with financial requirements for closure and long term care costs for hazardous waste sites. The scope of the EIS serves to indicate that there is a strong need for the federal government to develop requirements for financial regulation in 10 CFR 61 to ensure that the costs of closure and long-term care activities are met in order to protect the public's health and safety.

5.1 Illinois

The Sheffield disposal site is regulated by both the state and federal governments. The site was originally opened in 1967 and received a license from the AEC. The NRC currently regulates the possession of byproduct, source, and special nuclear material at the site. The Illinois Department of Public Health owns the 20 acres used for burial and regulates possession of naturally occurring and accelerator-produced materials at the site. Financial requirements for perpetual care that exist are found in a lease agreement between the site operator (now U.S. Ecology, Inc., formerly Nuclear Engineering Company (NECO)) and the state. The original terms of the lease called for the operator to pay 5 cents annually to the state for each cubic foot of radioactive waste. At the time the original lease was executed (1966), the state did not have an earmarked or state fund for these collected monies. Funds collected for perpetual care and maintenance prior to October 1976 were deposited into the general treasury of the state and are not now available for closure and post-closure activities. In 1978, the lease was amended so that U.S. Ecology had to pay a perpetual care and maintenance fee to the state in the amount of 10 cents per cubic foot of all radioactive waste disposed of at the Sheffield site. The state of Illinois also enacted legislation to develop an earmarked fund for these fees. The Illinois General Assembly recognized that sites used for the disposal of radioactive waste would represent a continuing and perpetual responsibility in the interest of the health, safety, and general welfare.

Fees collected after September 1976 for long-term care were deposited in the state treasury and set apart in a special fund known as the Radioactive Waste Site Perpetual Care Fund. Monies from the invested funds were to be used by the Director of the Department of Public Health (now the Department of Nuclear Safety) to monitor and maintain the site. However, as of July 1, 1981, there was only approximately $40,000 in the fund.

The Sheffield site was closed in the spring of 1978, when NECO filled the last licensed burial trench. NECO withdrew their NRC license application for renewal in December 1978. In March 1979, NECO notified the state of Illinois and the NRC that they were unilaterally terminating their state and NRC licenses. NRC took action to require NECO to continue their responsibilities and obligations under their NRC license. The state of Illinois also brought suit to order NECO back to the site on the grounds that a public health hazard existed at the site due to their abandonment and existing site conditions. A state court injunction was obtained, ordering NECO back to the site. An agreement was reached between NECO and the NRC requiring NECO to act as licensee until the termination of their NRC license was settled before the Atomic Safety Licensing Board.

At the present time, final closure of the site and the conditions for termination of their NRC license are being litigated before the Atomic Safety Licensing Board. The state court case is also continuing in an attempt to settle the closure requirements before the state license and lease is terminated with NECO. Additionally, the state of Illinois has brought a suit to rescind the deed by which the state had become owner of the site.

The Illinois long-term care fund illustrates the problems that develop when the collected funds are not turned over to an earmarked fund, but placed in the general fund. The fund is currently inadequate to pay for any long-term care of the site.

5.2 Nevada

The Beatty, Nevada site was opened in 1962 and is operated by U.S. Ecology (formerly NECO). The site was originally licensed by the AEC, but is currently licensed by the state. The land where the site is located was originally owned by the state and subsequently leased to U.S. Ecology. In an NRC Task Force Study in 1976 (NUREG-0217), the state government has indicated to NRC staff that their earlier provisions for perpetual care funds for the site were inadequate, and state government officials also questioned whether the state had sufficient financial or technical resources if a major problem occurred at the site. Recently, however, the state has taken measures to ensure that a larger amount of funds will be available for closure and postclosure care activities. In 1977, the state of Nevada enacted Senate Bill No. 38, which revised the radiation protection regulation, as well as calling for the development of a long-term care fund for the LLW disposal site. The Act revised Section 5, Chapter 374 of the state of Nevada, 1961, and created a Radioactive Materials Disposal Fund in the state treasury. Fees are deposited in the Radioactive Materials Disposal Fund and are invested until the amount remaining in the fund is sufficient to carry out long-term care activities.

The State Board of Finance is authorized to invest any amount of money in the Radioactive Materials Disposal Fund in excess of $5,000 in short-term obligations. Upon the advice of the Director that it is necessary or advisable to convert all or a part of the obligations into cash, the State Board of Finance is to effect the conversion to the extent necessary, and the monies are to be redeposited in the Radioactive Materials Disposal Fund.

Monies in the Radioactive Materials Disposal Fund can be used for any expenses necessarily incurred by the Director of the Department of Human Resources in carrying out the provisions of the act. This would include administrative and regulatory expenses in amounts authorized by the legislature and the costs of providing protection resulting from the termination of any lease or agreement that is necessary in the interest of public health and welfare.

The lease has recently been updated. The revised lease agreement provides for a surcharge of $0.25 per cubic foot of radioactive waste buried (up from $.07 per cubic foot in 1976). The revenues derived from the burial fees are maintained in an escrow fund and are dedicated to perpetual care and maintenance of the site as well as contingencies.

The amounts established for the disposal or burial of low-level radioactive waste or chemical and toxic waste* under this lease remain fixed for a period of ten years commencing on the effective date of the lease. At the expiration of each ten-year period, both the lessor and the lessee must conduct a joint technical study to reevaluate the then existing conditions.

According to the lease, the primary purpose of the cubic foot charge on low-level radioactive, chemical, and toxic waste disposed of or buried at the site is to provide funds for satisfactory surveillance in conjunction with the implementation of proper safeguards for the public health and safety upon expiration of the lease term or extension thereof and of final closure. Again, the lease stipulates that the primary purpose for the assessment of the burial rate is to ensure the adequate growth of a perpetual care and maintenance fund.

As was mentioned earlier, the experience of the Beatty site with regard to the development of an adequate postclosure care fund illustrates the necessity of periodically reviewing the fund to ensure that the fees are keeping pace with inflation and changes in the site conditions.

5.3 South Carolina

The Barnwell, South Carolina LLW disposal site was licensed in 1971 by the state of South Carolina. The NRC is currently responsible for the licensing and regulation of special nuclear material. The state of South Carolina and Chem-Nuclear Systems, Inc., the operator of the Barnwell, South Carolina site,

*A hazardous disposal site is colocated and physically adjacent to the radioactive site.

entered into a revised lease in April of 1976 to delineate the responsibilities of the state as lessor, and of Chem-Nuclear as the lessee. The lease agreement for the site requires that Chem-Nuclear undertake all surveillance and maintenance for the protection of the public health and safety so long as it occupies the site. However, if the lessee (Chem-Nuclear) defaults or fails to comply with the terms of its license or for any reason withdraws from the premises, then the lessor would be required to assume surveillance and maintenance obligations and pay the surveillance and maintenance costs. Under the terms of the revised lease, Chem-Nuclear agreed to pay to the lessor, at quarterly intervals, the sum of $.16 for each cubic foot of radioactive waste buried at the site during the preceding quarter. The sum was to be increased every three years on the anniversary date of the lease in accordance with the following formula:

> "In accordance with the Consumer Price Index for all items for the 'south' region as published by the Department of Labor in the Current Labor Statistics-Monthly Labor Review utilizing the March 1976 index as the base."

The escrow fund set up by the parties pursuant to an agreement dated April 21, 1971, for perpetual care of the waste buried at the site continues to be maintained, and any payments made pursuant to that paragraph were added to the fund. Interest earned upon the fund accrues to the fund.

In October 1979, the lease agreement and the license at the site was amended. These new lease conditions stipulated that:

> "The Lessee understands that the storage and burial of radioactive waste require perpetual surveillance and maintenance, and so long as it occupies the Site, the Lessee will undertake all surveillance and maintenance as required by all applicable laws, regulations, and licensing requirements for the protection of the public health and safety. The Lessee further understands that if for any reason at any time it should default, or fail to comply with the terms of its license or for any reason withdrew from the premises, the Lessor would be required to assume surveillance and maintenance obligations and pay the surveillance and maintenance costs. The Lessee, therefore, covenants and agrees to pay to the Lessor, at quarterly intervals, the sum of 55 cents for each cubic foot of radioactive waste buried at the site during the period from September 1, 1979 through April 5, 1980. Payments shall be made at quarterly intervals at the rate of 75 cents per cubic foot of radioactive waste buried at the Site during the period from April 6, 1980 through April 5, 1981, and at the rate of one ($1.00) dollar per cubic foot from April 6, 1981 through April 5, 1982.
>
> ...The parties expressly agree that the escrow fund for perpetual care of the waste buried at the Site established by the parties pursuant to an agreement dated April 21, 1971, and continued pursuant to the lease dated April 6, 1976, shall continue to be maintained and the payments made

pursuant hereto shall be added to such fund. Interest earned upon said fund for perpetual care shall accrue to the fund."

By the end of 1980, Chem-Nuclear had collected $1.7 million for closure and $2.4 million for extended care.

Both the state and NRC licenses were amended to require that the license is to continue in effect, and the responsibility and authority for possession of buried radioactive material continues until a finding that the plan established for preparation of the Barnwell site for transfer to another person (e.g., the state or another operator) has been satisfactorily implemented in a manner to reasonably assure protection of the public health and safety, and the department or NRC takes action to terminate responsibility and authority under this license. All requirements for environmental monitoring, site inspection and maintenance, and site security continue whether wastes are being buried or not.

The lease also requires that the site closure and stabilization of the licensee's facility is to be accomplished in accordance with the U.S. NRC Low-Level Waste Branch Position entitled, "Low-Level Waste Burial Ground Site Closure and Stabilization," Revision 1, dated May 1979.

On May 31, 1980 a preliminary plan for preparation of the site for transfer to another person was submitted for review in compliance with state and NRC license conditions. The plan includes a demonstration that funds are being set aside or that other measures taken are adequate to finance the site closure plan. The license conditions required the plan to include preliminary estimates of costs, environmental impacts, data needs, personnel needs, material and equipment needs, planned documentation and quality assurance, and a detailed plan for trench locations and elevations, expected capacities, planned surface contours, and buffer zones.

In May 1980, the company also submitted a draft trust fund arrangement to the South Carolina state government to handle the collection of closure expenses as part of their preliminary site stabilization and closure plan for the Barnwell site. The terms of the draft, which are currently being negotiated with the state, call for the company to transfer the surcharges collected to a trust fund as it is collected. At the present time, a surcharge of $.78/cubic foot is being collected by Chem-Nuclear to pay for closure costs.

5.4 Kentucky

The Maxey Flats LLW site began operation in 1963 under a license issued by the Commonwealth of Kentucky. The burial ground and adjacent area is owned by Kentucky and was leased to NECO (now U.S. Ecology), the site operator.

In 1976, the Kentucky General Assembly passed an act that imposed an excise tax of $0.10 per pound on all radioactive waste materials delivered in the state for processing, packaging, storage, disposal, or burial. As will be

shown later, this change in a surcharge from a cubic foot to a poundage basis drastically reduced the revenues from the waste generators with the result being that the amount in the long-term care funds was inadequate.

In addition to imposing a $0.10 per pound excise tax on all nuclear waste buried in the Commonwealth, the 1976 General Assembly also abolished the Kentucky Science and Technology Commission and transferred responsibility for perpetual care and maintenance of nuclear burial sites to the Executive Department of Finance and Administration. The General Assembly also requested the Legislative Research Commission to appoint a special advisory committee to study the effects of nuclear waste disposal in Kentucky. In its finding and recommendation, the Committee recommended that the 1978 General Assembly amend the nuclear tax to allow for the imposition of a tax based on the relative hazard of the waste material. The Committee made a statement that monies from the nuclear waste tax should be placed in a special escrow account for perpetual care and maintenance rather than in the general fund as was currently the case. The Committee also recommended that a separate perpetual care and maintenance fee should be continued at no less than $0.10 per cubic foot in current 1977 dollars, which was only a slight increase over the current rate of $0.07 per cubic foot. In July 1976 the perpetual care fund contained about $180,000.

In a meeting held July 15, 1976 with NRC staff, Kentucky state officials indicated that funding arrangements for closure had not been adequate. The state government officials estimated that about $100,000 and $150,000 would be needed annually for maintenance to care for the site when it was decommissioned.

After the $.10 per pound surcharge became law on June 19, 1976, the quantity of nuclear waste disposed of at Maxey Flats declined by 95 percent. After the tax was instituted, NECO (now U.S. Ecology) stated that it could not continue to operate the Maxey Flats disposal site under the imposition of the $0.10 per pound tax as currently interpreted by the Department of Revenue.

During the second half of 1976 and 1977, the Maxey Flats site was virtually unused, due to the imposition by the Kentucky legislature of the ten cents per pound excise tax on waste received at the site. Waste generators shipped their materials to other LLW sites who had less expensive long-term care funds. During calendar years 1976 and 1977, 501,609 ft^3 of waste was buried at the site; however, during the period of June 30, 1976 to December 31, 1977, after the tax went into effect, only 29,833 ft^3 of that waste was buried. The site was closed on December 27, 1977 by order of the Kentucky Department of Human Resources until the completion of a water management program, and the completion of further studies to determine the long-term use and safety of the site. In 1978, the Commonwealth of Kentucky under the Department for Human Resources terminated the materials license at the site (License No. 16-NFS-1), issued to NECO, and issued a new license to the Kentucky Department of Natural Resources and Environmental Protection. In May 1978, an arrangement was also signed where Kentucky bought out NECO's remaining lease hold interest in this facility. (The land where the site is located belongs to the state.) Following selection of the site by the state, NECO provided the capital for purchase of

the land that was subsequently deeded to the state. The state, in turn, leased the site to NECO for 25 years with an option to renew for an additional 25 years. Currently, the Kentucky Department of Natural Resources and Environmental Protection continues to be the licensee at the Maxey Flats site; however, no wastes are being received at the site at this time. The Maxey Flats long-term care fund contains inadequate funds to pay for postclosure care maintenance and water care activities. A review of the history of the site illustrates the necessity of developing an adequate postclosure care fund that accurately keeps pace with inflation. The experience at Maxey Flat also illustrates how a surcharge being used to collect funds for long-term care can also be used as a punitive tool to reduce capacity at the site. The result will be a situation where the waste generators will go elsewhere, thus reducing the waste received at the site and also the resultant funds for long-term care.

5.5 Washington

In 1965, the receipt, possession, and disposal of source, byproduct, and special nuclear materials at the Hanford, Washington site was licensed by the Atomic Energy Commission. California Nuclear was originally the developer of the site. On December 31, 1966, the state of Washington became an Agreement State and assumed regulatory responsibility for the disposal of all radioactive materials, except special nuclear materials, that continued to be regulated by the AEC. The land on which the Hanford site is located was leased by the federal government to the state of Washington, which in turn, leased it to the site operator. In March 1968, NECO (formerly California Nuclear, the original site developer and now U.S. Ecology) became the licensee.

In 1967, the state of Washington and Nuclear Engineering Company (NECO) amended their Perpetual Care Agreement for the Hanford site, requiring the development of a perpetual care fund. The state determined that the Perpetual Care Agreement should be modified to provide for annual deposits by the state into a perpetual maintenance fund in the same amount as was received by the state from its sublessees (NECO). The fund established by these annual deposits as required by the 1967 Perpetual Care Agreement was to be known as the Perpetual Maintenance Fund, and was to be used exclusively for defraying the costs of perpetual surveillance and maintenance of the site to the extent required by the terms of any applicable laws, regulations, or licensing for the protection of the public health and safety.

Funds in the Perpetual Maintenance Fund are invested by the State Finance Committee in the same manner as other state monies, and any interest accruing as a result of investment would accrue to the Perpetual Maintenance Fund. As of December 1980, approximately $126,000 in escrow funds have been collected for long-term care. Since 1980, these funds have been collected on the basis of a 25¢/cubic foot surcharge. Again, the experience with collecting long-term care funds at this site illustrates the problems that arise when a collection fee is developed that does not accurately reflect changes in inflation and site conditions.

5.6 Kansas

The state of Kansas passed an act in 1979 that authorized establishing fees for monitoring hazardous waste storage sites, paying extraordinary costs and monitoring after the site is shut down, paying the costs of repairing a site and repairing environmental damage caused by a site, or costs of studies, etc., that would be required if early closure is needed (KSA 65-3402, KSA 65-3406, 65-3406a, 65-3406b, 65-3406bc, and 65-3420). The law speaks to all types of hazardous wastes, not just radioactive wastes.

The fees are collected for the purposes of monitoring such sites and facilities both during and after operation. These fees are to be sufficient to reimburse the state for the cost of performing these monitoring responsibilities. In setting fees, the government may exempt those fees that would be payable on recycling processes that recover substantial amounts of either energy or materials from hazardous wastes. The government is to remit any monies collected from such fees to the state treasury.

The funds from the perpetual care trust fund are limited to the following three uses: payment of extraordinary costs and monitoring a site after the responsibility of owner and operating interests has terminated; payment of costs of repairing a site; and costs of repairing environmental damage caused by a site as a result of a postclosure occurrence not anticipated in the plan of operation that poses a substantial hazard to public health and safety or the environment. If an expenditure made under this paragraph would not have been necessary had the person responsible for the operation or long-term care of the site complied with the requirements of the approved plan of operation, a cause of action in favor of the fund shall be accrued to the state of Kansas against such persons. The department shall take such action as is appropriate to enforce this cause of action by recovering any amount so expended. The net proceeds of any such recovery shall be paid into the perpetual care trust fund.

The required fee is not to exceed twenty-five cents (25¢) per cubic foot of hazardous waste or material for each licensee or permittee who (1) operates a hazardous waste storage area under a license issued under the authority of K.S.A. 48-1607 or (2) operates a land disposal site for solid wastes. Each licensee must remit to the state an amount not to exceed twenty-five thousand dollars ($25,000) along with its initial application for a permit, license, or initial renewal as an advance payment of the fees. This advance payment constitutes a credit against any fee that may then be issued.

5.7 New Mexico

The New Mexico radiation protection regulations have a dedicated continued-care fund provision for postclosure care that requires contributions from both uranium mill and radioactive waste disposal licensees.

Uranium mill licensees must contribute $.10 per pound of yellowcake. The requirement of a mill license holder to make deposits to the continued-care

fund terminates for each mill after the cumulative continued-care fund deposit for that mill has reached $1 million. The state requirements for a continued-care fund are based on different assumptions than the recently promulgated NRC uranium milling requirements. However, NRC staff discussions with the New Mexico state government officials indicated that the state officials considered that even their own funds were inadequate for ensuring that the uranium milling industry in the state would be responsible for paying for the full costs of postclosure care. A study prepared by Winston Harrington for Resources for the Future also indicated that the state's continued-care fund requirements may not be sufficient for long-term care.

Although at this time there are no radioactive waste disposal operators in the state, the state also has financial requirements for continued care that would have to be met by radioactive waste disposal operators in the state, if such an operation were ever to be conducted in New Mexico. The regulations require that continued-care fund deposits from a radioactive waste disposal license holder are to be made at a rate determined by the Division Director and approved by the Environmental Improvement Board as adequate to cover environmental monitoring and all maintenance and emergency measures, including decommissioning of the site, if applicable. (These deposits are not required of uranium mill licensees.)

Section 74-3-7 of the New Mexico Radiation Protection Act describes the management of this continued-care fund. An earmarked fund called the Radiation Protection Continued-Care Fund is to be created in the state treasury. The collected funds are turned over monthly to the New Mexico Bureau of Taxation and Revenue. Cash balances in the Continued Care Fund are invested by the state treasurer, along with other state funds under his jurisdiction.

Discussions with New Mexico state government officials indicated that funds collected were invested in a variety of accounts. Interest rates earned on the invested funds ranged from 10.5% in December 1979 to 12% earned in May 1980. As of November 18, 1980, the fund contained approximately $3,640,470.

5.8 New York

Nuclear Fuel services, Inc. (NFS) and the New York State Energy Research Development Authority (NYSERDA) are co-licensees at the West Valley site under an NRC provisional facility license, CSF-1. In this arrangement, NFS has operational responsibility for the activities ongoing at the site. NYSERDA's responsibility include site ownership, and the long-term care of the site. Under the terms of the license, NFS has a continuing responsibility for the safety of the site. The license covers conditions for protecting the health and safety of the public and employees associated with the reprocessing of nuclear fuel and storage of the separated wastes.

In 1962, Nuclear Fuel Services, Inc. (NFS), submitted a proposal to the U.S. Atomic Energy Commission to establish a commercial nuclear fuel processing facility at West Valley, New York. In addition to this facility, a low-level waste burial ground was also sited there. In May 1963, after a review of the

application, the AEC issued a permit authorizing construction of the NFS plant that was to include a receiving and storage facility to store fuel prior to reprocessing, underground storage tanks for liquid high-level radioactive wastes from the reprocessing operations, and two burial grounds for shallow burial of solid radioactive wastes. (The low-level burial ground was to be regulated by the state and the other burial ground (principally for the use of hulls) was to be regulated by the AEC as part of the facility license.)

NFS, in its proposal, indicated its willingness to maintain and provide storage and maintenance for some finite period of time, thereafter turning over the tanks and wastes to a government agency. NFS also indicated that they were willing to collect and turn over to the state or federal government a charge calculated to provide the estimated full costs for perpetual storage at the point of closure. The funding arrangement contemplated only the eventual transfer of the waste to new tanks, in perpetuity, and did not consider facility decommissioning during the early part of the license term. (In fact, the ultimate reprocessing contract prices permitted NFS to charge under the Base Load Agreement and to its commercial customers included a per kilo charge for perpetual care of the wastes.) The state of New York, through the New York Atomic Research and Development Authority, (NYARDA) provided assurance (as Amendment No. 1 to the application for license) to the federal government that the state would be responsible for the wastes in perpetuity.

However, in order to confirm the costs of perpetual care, the NYARDA requested a study to develop an estimate of the fund that should be set up for perpetual care of radioactive wastes. The results of the study found that a perpetual care fund of $4 million would be sufficient for perpetual care of each filled storage tank, including maintenance, insurance, contingencies, and tank replacement at the end of expected tank life. The October 1962 study also stated that the size of the fund should be adjusted to reflect the actual construction costs of the facility which was not completed until 1966. The fund was to be obtained through annual payments by NFS to NYARDA under the provision of the Waste Storage Agreement. This was one of several agreements negotiated among the parties that provided for postclosure care. Negotiations among NFS, the AEC, and NYARDA led to several contracts and agreements, the main points of which are:

- The amounts paid to NFS by AEC were to include all charges for storage, disposal, and perpetual maintenance of waste at the site.
- At the time the NFS-AEC contract was executed, NFS also entered into several agreements with NYARDA that had the following implications for postclosure care responsibilities:
  - Lease. NFS was granted a lease for the site, with rental payments to be made to the state of New York. NFS would construct, own, and operate the reprocessing facilities. The lease would expire on December 31, 1980, and if the lease was not renewed, New York would then assume ownership of all of the facilities, subject to NFS compliance with other contractual obligations.

Waste Storage Agreement. Under the terms of this agreement, which was made a part of the lease, NFS was to manage and operate facilities for the storage of high-level nuclear wastes. NFS would be responsible for each tank of high-level liquid waste as it was being filled, and then would turn the tank over to NYARDA for perpetual care. A perpetual care fund was established with the intent of enabling New York to replace the waste tanks every 50 years and to maintain the site. The fund would total $4.0 to $5.1 million by 1980. If NFS wished to recover substances of value from the wastes, NFS could delay transfer of the wastes to NYARDA.

By December 31, 1981, the New York State Energy Research and Development Authority held as a perpetual care fund of $4.5 million for the replacement and maintenance of the high-level waste storage facilities. These monies may be paid to the U.S. Government at a future date for disposal of solidified wastes at a federal repository. In addition, approximately $180,000 was paid NYSERDA by NFS through December 31, 1980 for the low-level waste burial area. These fees, like NFS rental payments have been acounted for as General Authority revenue.

The NFS burial ground was voluntarily closed in 1975 by NFS, due to liquids with low levels of radioactivity seeping out of the soil cap of completed trenches. The state has not allowed operations to resume at the site pending further results of USGS and EPA studies. In April 1976, NFS wrote to the Authority announcing their intention of exercising its right under the Waste Storage Agreement to surrender the responsibility for all wastes at the site to the NYSERDA. Subsequently, New York State informed NFS that the terms and conditions had not been met; and therefore, NFS could not relinquish responsibility for the site. Currently, the lease is in the early stages of legal dispute between the state and NFS; NFS is currently maintaining the site until the final disposition of the land is settled.

5.9 Oregon

Oregon requires an owner or operator to obtain a cash bond in the name of the State to cover closure and postclosure costs. Before the state will issue a permit to an owner or operator, the owner or operator must deed to the state all portions of his disposal site in or upon which hazardous waste will be disposed. (Environmentally Hazardous Wastes, Oregon Solid Waste Control Section 459.600.)

5.10 Texas

The state of Texas has also recently proposed legislation that would require financial guarantees of low-level waste site operators. The legislation, which is expected to be introduced into the Texas legislature in 1981, provides for proposed regulations that require each applicant for a license to demonstrate to a state that he is financially qualified to conduct the licensed

activity, including, but not limited to, any required decontamination, decommissioning, reclamation, and disposal. An applicant may be required to provide financial security acceptable to the agency to assure performance of its obligations under this act. (Security here means (1) cash deposits, (2) surety bonds, (3) certificates of deposits, (4) deposits of government securities, (5) irrevocable letters of credit, or (6) other security acceptable to the Radiation Control Agency.)

The draft also established a Radiation and Perpetual Care Fund in the state treasury. The monies from this fund are to be used for any of the following: decommissioning, stabilization, reclamation, maintenance, surveillance, control, storage, or disposal of radioactive material acquired by the agency (the Texas Department of Health). If any licensed activities are found to require maintenance, surveillance, or other care on a continuing or perpetual basis after termination of the licensed activity, the agency may require the licensee to pay annually to the agency for deposit in the Radiation and Perpetual Care Fund, an amount to be determined by the agency.

Each year the agency is to review a licensee's payment to the Radiation and Perpetual Care Fund to determine if the payment schedule is adequate.

5.11 Michigan

Michigan has a model state hazardous waste law, Michigan Act 64, which contains several provisions providing for a state-administered trust fund and, when necessary, assumption of responsibility and liability for the site by the state.

> Sec. 41. (1) An owner or operator of a hazardous waste disposal facility shall file as a part of the application for a licensee to operate, a surety bond or other suitable instrument, or establish a secured trust fund to cover the cost of closing, monitoring, and long-term maintenance of the disposal facility after its capacity is reached or operations have otherwise terminated. The bond, instrument, or fund shall be based upon a reasonable estimate of the cost required to adequately close, monitor, and maintain the site for a period of 15 years or less, as approved by the director...
>
> (2) Following the expiration of the time stipulated in subsection (1), a determination of responsibility of the owner or operator of a disposal facility shall be accomplished by a process established by the rules of the director. If the director determines that the site does not have a foreseeable alternative use, the owner of the site may transfer ownership of the site to the state and the state shall assume the responsibility for the long-term care of the site. After the site is transferred to the state, all claims for injuries occurring after the transfer to persons, property, or the environment brought against the waste generator or the disposal facility owner or operator become the liability of the state.... If a determination is made that the site is suitable for further use, the director shall make the necessary authorization on the restrictive covenant as required in Section 39.

> Sec. 42. There is created in the state treasury a disposal facility trust fund. Each owner or operator of a disposal facility shall periodically pay to the department a surcharge fee as determined by rule of the department.... The department shall promulgate rules establishing the method of payment from the disposal facility trust fund for payment of all costs of long-term care of a disposal facility occurring after the responsibility of the owners has been terminated as provided in Section 41.

5.12 Wisconsin

The owner or operator of a hazardous waste facility is responsible for long-term care of his site for either twenty or thirty years after closure (using trust funds, surety bonds, or escrow accounts required by law.) "After that the state assumes responsibility. The State Waste Management Fund is used to pay for costs of long-term care of a site occurring after the owner's or operator's responsibility has ended. The Waste Management Fund is supported by fees collected from facility owners or operators." (1977 Wisconsin Hazardous Waste Management Act (Assembly Bill 1024).)

5.13 New Jersey

"Private firms cannot be relied upon to provide perpetual management and financial responsibility for closed facilities. There are no assurances private firms will remain viable in perpetuity, nor is it likely an insurer will insure against risks forever. Even if one was willing to do so, insurance companies, too, can fail. However, local communities cannot be asked to accept the risk of having a hazardous waste facility operating in their midst unless they are guaranteed protection should potential for harm become actual harm. Since only government has likelihood of perpetual existence, government must at some point take over responsibility for closed facilities.

One way of doing this is to have the state take ownership of the site after closure--or perhaps 20 years after closure, after the operator's RCRA-mandated responsibility has expired. The state would then become responsible for monitoring and for compensating any damaged parties for subsequent pollution. To prevent this from being a form of subsidy to the facility operator, there should be a requirement that the operator leave with the state an escrow fund built up from revenues during the facility's operating life. (Report of the New Jersey Hazardous Waste Advisory Commission to Governor Brendan Byrne, January 1980, p. 47.)

5.14 U.S. Nuclear Regulatory Commission Uranium Milling Regulations

In 1980, the NRC published regulations and an EIS on the Uranium Milling Industry that require financial standards to be met by NRC licensees in the area of uranium mill decommissioning and tailings management. The Commission staff analyzed the financial assurance requirements for decommissioning and long-term care from two different concepts: one, of a short-term or decommissioning surety fund, and two, of long-term care.

Long-term funding refers to the financing of any ongoing care and monitoring that may be required at a mill tailings site after termination of the mill operator's decommissioning responsibilities and license.

The staff concluded that tailings should be disposed of so that no ongoing active care of a disposal site shall be needed after the site is decommissioned. However, the staff also concluded that it would "be prudent to continue monitoring and exercising land use controls at most disposal sites. Such controls, for as long as they could be provided, would constitute an added measure of protection to that provided by physical containment barriers. The purpose of this monitoring activity would be to confirm that the site was not disrupted by natural erosion or by human or animal activities. The nature of the situation of these sites would, therefore, be a passive one. No active maintenance would be required, and costs at individual sites are, therefore, expected to be relatively small, on the order to about $2,500.00 per year in 1978 dollars.

In establishing requirements for funding to cover the costs of long-term monitoring of the mill tailings sites, the staff made a basic assumption with respect to the nature and extent of the effort required for site control. In their development of long-term care costs, the staff assumed that no active care or remedial actions such as irrigation, revegetation, hauling of fill to the site, regrading, seeding, or the like are expected to be needed. There was also no consideration of replacement of fencing that may be left at the site or maintenance of any onsite facilities or equipment. There was also to be no sampling or airborne environmental measurements at the sites. Some ground-water monitoring might be performed by inspectors using portable ground-water sampling equipment. Therefore, the staff concluded that the only cost item would be the time and effort of government inspectors who will visit the sites, their time in travel, making inspections, and preparing for and following up on inspections.

The regulations also require short-term financial assurances of licensees. The purpose of short-term financial sureties is to provide assurances that the mill operator will be around, or that a sufficient sum of the mill operator's money will be around to perform tailings site reclamation. The staff concluded that a number of surety mechanisms were adequate to protect the public against mill operator default prior to performance of reclamation. The alternatives that the staff found acceptable on a generic basis were: surety bonds; cash deposits; certificates of deposit; deposits of government securities; and irrevocable letters of credit. The staff considered that this range of alternatives would allow the mill operator a measure of flexibility in selecting a mechanism that best suits their needs.

5.15 U.S. Environmental Protection Agency Regulations

The Environmental Protection Agency has recently proposed financial requirements for long-term care funds for owners and operators of hazardous waste management facilities. The revised financial regulations for 40 CFR Parts 254 and 265 require assurances that funds will be available when needed for properly

closing a hazardous waste facility and for maintaining and monitoring it after closure. (The revised proposal also included a new requirement for liability insurance for facilities in certain states. The coverage is for injuries to people and property that result from the operation of hazardous waste management facilities.)

Owners or operators of treatment, storage, or disposal facilities must establish financial assurance for the closure of their facilities. The owners or operators of disposal facilities must also establish financial assurances for up to 30 years of postclosure care. The owner or operator can establish financial assurances through a trust fund, a letter of credit, a surety bond, or by combinations of these methods. Under the revised regulation, the owner or operator of each hazardous waste facility must prepare a closure plan for the facility. The owner or operator must also prepare a cost estimate for closure of the facility at the point in the facility's operating life when the extent and manner of its operation would result in the greatest closure costs. He must also adjust the estimate of inflation annually and prepare a new estimate when a change in the closure plan affects the cost of closure; inflation must also be taken into account. The applicant can build up the closure trust fund over the expected life of the site, or 20 years, whichever period is shorter. The revised proposed requirements for the trust fund include provisions for adjusting the annual payments in response to inflation, changes in the closure cost estimate, and changes in the value of securities in the trust fund. The EPA staff evaluates the estimates to ensure that the amounts and types of securities in the fund are adequate.

Originally, the general standard required an owner or operator to make a cash deposit equal to the cost estimate for closure, multiplied by the appropriate present value factor, in a closure trust fund as a condition of receiving a permit. The present value factor accounted for growth of the fund over the operating life at a 2 percent per annum real interest rate (interest minus inflation). Based on comments received, EPA decided that a 2 percent real interest rate was too high, so provisions in the revised proposal were based on a zero real interest rate to adequately account for the effects of long-term inflation and trustee fees. Based on long-term data, the EPA said that they felt that over an extended period, the purchasing power of the deposited funds is likely to be static, i.e., the nominal interest realized will be cancelled out by inflation and by trustee fees.

The original proposal did not allow reimbursement of the owner or operator for closure expenses from the trust fund, until closure was completed to the satisfaction of the EPA. This was later amended, since the staff considered this to be too much of a hardship for the operators. Now, if the staff approves, the trust funds can be used to pay for certain costs of decommissioning.

Subpart G of the EPA regulations requires that an operator of a facility prepare a plan for 30 years of postclosure care. The owner and operator must prepare and keep current a cost estimate for 30 years of postclosure care of the facility. At the end of 30 years of postclosure care, any funds remaining in the trust would be returned to the owner or operator.

The proposed regulations stipulate that facilities owned or operated by states or the federal government are exempt from the financial requirements of the EPA.

Another major development in the area of financial management of existing hazardous waste sites was the passage of the "Superfund" bill by Congress in December 1980 (P.L. 96-510). The act sets up a postclosure liability fund of $1.6 billion to clean up abandoned waste sites and hazardous substance releases. The bill also sets up a $200 million fund to take care of present hazardous waste facilities after they are closed. The liability fund assumes all liability for claims made against a site permitted under the Solid Waste Disposal Act for a period of 5 years after the site is shut down by the site owners provided the site meets criteria spelled out in the "Superfund" bill.

The fund is supplemented by a surcharge of $2.13 per dry weight ton of hazardous waste disposed of at facilities. However, the bill also requests the Secretary of the Treasury to conduct a study looking into an optional system of private insurance for postclosure financial responsibility for hazardous waste disposal facilities.

5.16 Department of Interior; Office of Surface Mining

The Office of Surface Mining of the Department of Interior has issued regulations requiring bonding for coal mining operators. The regulations provide that a permitee be required to file a performance bond prior to issuance of a permit for surface coal mining and reclamation operations. The regulations require the applicant to estimate the cost of reclamation, but it is likely that the bond amount set by the regulatory authority may be different, since they have responsibility over determining that the final bond amount is adequate.

Bond amounts must be based on the estimated cost to the regulatory authority and not the operator. By setting the bond in this manner, if the operator forfeits, then the regulatory authority required to do the work will have sufficient funds.

5.17 Conclusions

Based on a review of state and federal financial requirements for closure, postclosure, and long-term care at LLW disposal sites and for other types of hazardous disposal sites, the staff finds that there is a precedent for establishing financial assurances at low-level waste disposal sites in order to protect the public health and safety and the environment and also to ensure that those parties who benefit from the disposal services pay for them.

6. PUBLIC COMMENTS ON PRELIMINARY DRAFT OF 10 CFR 61 CONCERNING FINANCIAL REQUIREMENTS FOR AN LLW SITE

6.1 Workshop Comments on the Draft Regulation

In 1980, the NRC held four workshops in Atlanta (April 21-22), Chicago (July 17-18), Denver (July 14-15), and Boston (November 6-7) that provided

state officials, industry representatives, waste generators, the public, and public interest groups with an opportunity to comment on the draft of Part 61. Both the Chicago and Denver workshops had extensive discussions about the financial assurances proposed in the draft LLW regulations.

The workshop discussion on financial requirements ranged from confusion over the NRC's goals in this area to strong recommendations for more stringent regulations. The workshop participants at the meetings concluded that the draft regulations needed more stringent requirements imposed on the licensee with regard to both closure and long-term financial assurances. Workshop participants from state governments, in particular, expressed the view that more stringent, financial guarantees would help to relieve some of the public's resistance towards siting a low-level waste site in their respective jurisdictions.

In their discussions, workshop participants strongly recommended that the long-term care fund should include explicit provisions for unexpected and contingency expenses to protect their constituents from future financial burdens.

- For example, one workshop participant stated that:

  "I think that some errors are going to occur, and that any type of fund that is set up, that is based on the premise that funds need only cover some routine monitoring, and siting is going to be so good at this time because of these new rules that are under development, I think is very naive..."

Staff Comment

The staff agrees with the concept underlying this statement which recognizes that the licensee be responsible for more than just long-term care monitoring at a facility. The proposed regulations require the licensee to be a party to a binding arrangement that ensures that sufficient funds will be available to cover the costs of monitoring and any required maintenance during the institutional control period (emphases added). The site-specific conditions would be evaluated by the staff in order to determine what costs of required maintenance are necessary.

- Another participant echoed this belief that the long-term performance objective of the proposed regulation minimizing the need for long-term care was insufficient to adequately protect taxpayers.

  "I think you know, government makes mistakes, and I think we're going to make mistakes with current siting issues, notwithstanding the fact that the impact statements are written and other documents are produced. I think we're going to find that there are errors in the future, and to decide that there is never going to be a need for continued care, that just a little bit of routine monitoring is going to take care of these things because of the superior decisions to be made now with the new ruling is very naive."

Staff Comment

Provision is made in the long-term care binding arrangement to accommodate more than just monitoring expenses at a site. The proposed regulations require that the binding arrangement provide for any required maintenance during the institutional control period.

- Members of the workshops also felt that not enough costs were being included in the financial requirements. In particular, Denver workshop participants from western state governments who were already familiar with the uranium mill tailings financial criteria currently being developed by the Commission, expressed scepticism about the adequacy of the draft LLW financial regulations. They felt that the LLW provision for long-term care funds had not gone far enough in protecting taxpayers from possible future expense for long-term care.

Staff Comment

As has been mentioned earlier, the staff lacks authority to require that a license establish funds for perpetual long-term care at a low-level waste site. However, the proposed regulations in Section 61.63 establishes a flexible binding arrangement for long-term care, which will enable the Commission to ensure that financial responsibility is provided for any required maintenance at the site.

- At the Denver workshop, one participant pointed out that certain naturally occurring phenomena might mandate possible active post-closure maintenance; wind erosion in arid areas and water damage to trenches in humid areas. The workshop included a technical session where one of the industry speakers spoke of the need to include unexpected expenses in the perpetual care and maintenance fund. One industry spokesman stated:

  > "Let me offer a suggestion as to how to maybe do that. You've got to back up one step where we've talked about--we said, 'i.e., that financial assurance arrangements to provide for long-term surveillance should include adequate funding to pay for,' and at this point insert the words 'all unexpected remedial work.'"

Staff Comment

The long-term care funding required in Section 61.63 includes a provision requiring the licensee to provide an assurance for any maintenance which would include remedial work at the site.

- The spokesman added that,

  "I know in the PC&M (SIC-perpetual care and maintenance) negotiations we've had with all the States that we've operated in, we had incorporated into, that a certain amount of repair work, but we don't expect that the State will ever have to do that; but we said let's be reasonable. Let's put some money in there every year for that, and let's put in a block of dollars to say one time we're going to have a big expense, and we put those dollars in there. Because that's really what we're talking about. If one site has a major problem to solve and the money is not there, they've got to go some place to get it; and the industry should have provided those funds in some way."

Staff Comment

The binding arrangement required in Section 61.63 provides for any required maintenance at the site, and this would have included any necessary repair work for the site.

- On July 14, 1980, another delegate to the Denver workshop was critical of the draft financial regulations, and suggested that the perpetual care fund needed to incorporate more unexpected costs. The participant stated,

  ".... The fund is based on the idea that the Federal government isn't going to make any mistakes, so there isn't going to be any continued care. We think people are going to make mistakes, and that there may be some need for continued care in the future...." (p. 194 of the July 14, 1980 transcripts)

Staff Comment

See previous comments.

- Another participant at the Colorado workshop also stressed the importance of including more than just monitoring in the postclosure care fund:

  "...their concept is rather narrow in that they envision just the need for routine monitoring and, I think that based on a premise that they're not going to make mistakes. But anyone who looks at the history of uranium mill tailings, and who looks at the kind of mistakes that have been made in the past ... should easily draw the conclusion, I think, that some errors are going to occur...."

Staff Comment

See previous comment.

- Participants also discussed the wisdom of depositing the long-term care fund into the General Treasury. Some participants favored the use of an earmarked fund in the state or federal government to protect the funds. Another issue raised for extended discussion at the workshops was the possibility of pooling financial assurance funds into a national contingency fund, in order to spread the risk of unexpected cost.

Staff Comment

At this time the Commission lacks the authority to require that a long-term care fund be established.

In addition to the discussions mentioned above, the following specific recommendations were made by the workshops:

6.1.1.1 Chicago Workshop

The group expressed doubt concerning surety arrangements for decommissioning, decontamination, closure, and stabilization. The group approved of the requirement that the surety mechanism be reviewed "from time to time, at the time of the license renewal or more frequently, if necessary." Furthermore, the group believed that financial assurance arrangements should be limited to cash or equivalent. The Nuclear Regulatory Commission should reexamine the appropriateness of a letter or a line of credit as a generally acceptable surety arrangement.

Staff Comment

The staff has concluded that there are a variety of financial assurance mechanisms that offer degrees of security equivalent to cash deposits. A review of the appropriateness of using a letter of credit as a financial assurance has convinced the staff that such a financial guarantee offers adequate financial assurances for recovery in the event of licensee default. Therefore, the staff has decided to retain letters of credit as a financial assurance option for the proposed regulations.

6.1.1.2 Denver Workshop

The workshop participants concluded that the financial assurance requirements should clearly prohibit the option of industry self-insurance. Any financial assurance arrangement should provide for unexpected mistakes and costs. Using the abandoned uranium mill tailings problem as an example, it was pointed out that to assume comparable mistakes will not be made in the future is naive and that financial assurance arrangements to provide for long-term surveillance should include adequate funding to pay for unexpected remedial work. Recognizing the financial difficulties in providing a large enough fund both to take care

of unexpected costs and to last over some indefinite period, it was suggested that a portion of the financial assurance funds from all low-level waste facilities be pooled into one national contingency fund. The rationale is that the odds are against all sites experiencing unexpected and costly remedial programs, thereby freeing up some of the funds in their financial arrangements to help pay the costs of those sites that do run into unpredictable contingencies beyond the control of the operator, the state, or the federal government. This would also avoid taxation problems that the facility operators would experience by holding this money themselves.

In addition to pooling the financial assurance funds of the facility operators, it was also suggested as an alternative, that a federal tax be levied, either on the front-end user of the product whose production resulted in LLW (e.g., electricity production) or on the back-end waste disposer. This tax would be exclusively earmarked for deposit in the LLW national contingency fund, recognizing that LLW disposal and perpetual care is a national responsibility.

There was a general consensus that a standard, specified method of calculating costs was inappropriate, because such costs would be site-specific. A list of criteria needed to be considered in calculating costs could be provided, but how these criteria would be calculated in determining costs would depend on the specific site.

Staff Comment

Several issues were raised in the Denver workshop conclusions, namely.

- o Regulations should prohibit self-insurance.

  The staff agrees and Section 81.51(g) states that "self-insurance, or any arrangement which essentially constitutes pledging the assets of the licensee will not satisfy the surety requirement for private sector applicants since this provides no additional assurance other than that which already exists through license requirements."

- o Long-term financial assurance arrangements should include adequate funding to pay for unexpected remedial work.

  The staff agrees and the long-term care financial assurance mechanism proposed in 61.63 states that responsibility for all necessary maintenance costs are to be provided for.

- o Calls for a national contingency fund.

  The Commission currently lacks the authority to establish such a shared pool, and hence, the staff cannot propose such a mechanism in the regulations.

- Recommends levying a federal tax on producers of LLW in order to have all users pay for LLW disposal and perpetual care.

  The staff agrees with the equity decision that those parties benefiting from an LLW site should be responsible for the costs of such an LLW site. However, the Commission lacks the authority to require that a surcharge be levied on waste users. Therefore, the staff has not been able to incorporate such a cost-recovery mechanism into the proposed regulations. However, certain Agreement States with such taxing authority who have an LLW site located within their jurisdiction may wish to consider levying such a surcharge for closure and/or long-term care costs.

- A standard, specified method of calculating costs is inappropriate because such costs are site specific.

  The staff agrees, and has tailored the proposed regulations so that the financial provisions for both the short- and long-term case provisions will be on a site-specific basis.

6.1.1.3 Altanta Workshop

Generally, the financial assurance section is adequate. However, a specific problem may exist with open-ended financial assurance requirements. Calculating costs is a site-specific problem. The goal of Part 61.28, setting up a fund for postoperational costs, is difficult but very necessary.

6.1.1.4 Boston Workshop

The group emphasized the need for setting adequately high disposal fees so that the perpetual care fund would be large enough to cover the costs of anticipated and unanticipated postoperational needs. The group noted that several states are now saddled with large postoperational expenses that cannot be covered by the low disposal fees charged during its operation.

The group also briefly discussed financing. In view of the present high rate of inflation, the group expressed concern that the value of the perpetual care fund would decrease over time. One suggestion made by a participant was that every ten or twenty years before license termination, the government should recalculate the value of the fund so that if its value had decreased over time, corrective action could be taken.

Staff Comment

Currently, the Commission lacks the authority to establish a fund for long-term care of an LLW site, so they cannot set standards for how such a fund would be adjusted to account for inflation, charges in site conditions, etc. However, for those Agreement States wishing to set up a long-term fund, the staff agrees with the Boston recommendations that if such a fund were to be established by a regulatory agency, that there should be consideration of annual inflation adjustments.

6.2 Written Comments on the Preliminary Draft Regulation

After the Commission circulated their preliminary draft (November 1979) of the LLW regulation, they received a variety of written comments concerning the financial requirements found in 10 CFR Part 61.

As of July 30, 1980, the following comments had been received specifically addressing the financial requirement of the proposed regulations.

1. Walt Rodgers, Nuclear Safety Associates, "Some of the proposed requirements for funding could well lead to prohibitively high front-end costs. The basis for the assumption of 1% real interest should be documented."

Staff Comment

The staff has removed the perpetual care fund provision for long-term care from the proposed regulations, and therefore, there is no reference to a 1% real interest rate.

2. Chem-Nuclear Systems, Inc. examined the preliminary regulation and remarked, "The requirement of subsection 10 CFR Part 61.28(a) lacks specificity and therefore will be difficult, if not impossible, to review and administer." Chem-Nuclear also suggested that the Commission revise the requlations to require specific performance criteria, or that the requirements be eliminated altogether. Chem-Nuclear also felt that the requirements of also lack specificity in the language.

Staff Comments

The staff agrees that more specificity is needed in the language, and the regulations have been amended to include more detailed requirements.

3. The California Energy Resources Conservation and Development Commission generally approved of the draft regulation on the long-term care fund. They stated that requiring the licensee to provide "financial surety, covering all costs to safely terminate the facility and to monitor the facility after shutdown is appropriate and necessary. They also said, "the authors of the regulation were astute to require that the licensee estimate termination costs under the assumption that operations would be performed by an independent contractor (61.28(b))." The California Commission suggested that the wording of the section be changed to make its intent somewhat clearer.

Staff Comments

The staff agrees with this comment and has amended the proposed language to make the intent more clear.

7. BACKGROUND REFERENCE MATERIALS

The following section presents summaries of studies and reports dealing with the financial aspects of closure and long-term care at hazardous facilities. The materials provided were used by the staff in the development of the financial requirements.

1. In December of 1979, the NRC published the draft of a report entitled "ASSURING THE AVAILABILITY OF FUNDS FOR DECOMMISSIONING NUCLEAR FACILITIES" (NUREG-0584, Revision 1).

   The report stated that the NRC had undertaken a comprehensive reevaluation of its policy regarding the decommissioning of nuclear facilities. Until regulations on uranium mills were recently proposed, NRC regulations had been generally silent with regard to decommissioning nonreactor facilities, although decommissioning of these facilities had been generally addressed in their licenses.

   The NRC staff developed five criteria to evaluate the relative effectiveness of the alternative financial assurance mechanisms being considered: The first criterion used is the actual degree of assurance provided by the alternative. The second is the cost of providing the assurance, in both direct dollar costs and indirect administrative costs. The third criterion is the equity of the alternative. The fourth is the degree to which the alternative is responsive to changes in inflation and interest rates, to changes in estimated or actual operating life, and to changes in technology that decrease or increase ultimate decommissioning costs. Fifth is the ability of the alternative to handle effectively differing ownership and jurisdictional arrangements existing in the particular industry. The NRC staff found that there were six basic alternatives for assuring the availability of funds for decommissioning costs; prepayment of decommissioning costs; a funded reserve over the estimated life of the plant, an unfunded reserve, or funding at decommissioning; surety bonds, decommissioning insurance, and funding from general tax revenues. (Note: as used here, surety bonds are defined to include bank letters and lines of credit.)

   The report also examined the Federal Income Tax considerations of the various funding arrangements. Under Internal Revenue Service regulations, decommissioning expenses for other nuclear facilities and licensees would not be deductible from income until actually incurred. A blind trust could be established with the principle from such a trust invested in tax-free securities, such that both contributions to principal and interest would not be subject to federal tax. The report emphasized that in this regard, nonreactor licensees have the same range of accounting options as do utilities. Funded and unfunded reserves can be structured so as to take advantage of accelerated depreciation, through normalization or flow-through accounting methods, by net-after-tax funding, or by any of the other methods that are used by utilities.

The report concluded that the deposit at the start-up method for the collection of postclosure costs, provided the greatest assurance that funds would be available; and that deposits of postclosure funds at the period of decommissioning provided the least assurance that sufficient closure funds are available. In their conclusions and recommendations, the study found that the most secure method for development of a postclosure care fund appeared to be the deposit at start-up method. The development of a sinking fund or an escrow account was also found to be acceptable in these cases with little likelihood of premature shutdown. The report also noted that, unlike reactors, smaller facilities have the option of surety bonding and concluded that it may be acceptable if the bond is not able to be terminated by the surety company.

2. On November 1978, the Commission released a SECY paper (SECY 78-613) that examined whether the Commission should require financial regulations for its low-level waste management program. The request for a financial regulation for perpetual care had been made by the Natural Resources Defense Council in a petition for rulemaking for low-level waste management. One of the alternative methods to provide long-term funding that was recommended by the petitioner was the establishment of a regulation requiring a special fund based upon a cubic-foot charge. However, as the Commission's Notice of Denial of Petition for Rulemaking noted, legal problems existed that prevented the Commission from establishing a long-term care fund through fees based on the volume of materials. Although fees for use of property can be established between the landlord and the tenant as is currently the case, to order a fee-per-unit volume of waste by Commission regulation and to establish an earmarked fund would require Congressional authorization. A federally mandated fee-per-unit volume of waste that is not a product of the landlord/tenant contract would in essence be a tax-requiring legislative enactment. (See Federal Power Commission vs. New England Power Co., 415 U.S. 345 [1974]; National Cable Television Association, Inc., vs. United States 415 U.S. 336 [1974].) The establishement of a special fund based upon such a tax would also require special legislation.

3. In December 1979, the NRC released "Decost-Computer Routine for Decommissioning Cost and Funding Analysis" (NUREG-0514). The study developed a computer routine for the analysis of decommissioning costs and funding mechanisms. The DECOST model calculates the costs of and evaluates the payments for decommissioning nuclear facilities, including postclosure costs under varying economic and planning conditions. As used in this study, decontamination and decommissioning are defined as the "removal of the radioactively contaminated and activated materials from the site to appropriate disposal sites or the containment of the materials away from the general public." The DECOST study used seven possible methods for funding the decommissioning of the facilities: (1) use of a constant-fee sinking fund; (2) use of an escalating-fee sinking fund; (3) use of a deposit

to cover the costs at the expected end of life; (4) use of a deposit to cover the decommissioning costs at the time of the deposit; (5) use of the previous method, but with net earnings returned to the utility; (6) use of straight-line, negative salvage value depreciation of the facility; and (7) use of adjusted straight-line negative salvage value depreciation of the facility.

The DECOST program package can be run to allow planning to reduce the costs and financial risks of all types of nuclear facilities, and to allow wide ranging study of the various options available when planning for decommissioning of nuclear facilities.

4. In 1977, Science Applications, Inc., published a report entitled "The Financial Alternatives for Stabilization, Reclamation, and Long-Term Monitoring, and Maintenance of Uranium Mill Tailings Piles." Alternative financing approaches were evaluated for assuring short-term tailings stabilization and reclamation, and long-term monitoring and maintenance. Short-term financing assurances considered included surety bonds, cash deposits, certificate of deposits, deposits of securities, secured interests in an operator's assets, letters of credit, and self-insurance. The most favorable short-term financing alternatives were determined by a rating system that evaluated administrative time; operator expense; loss of productive use of corporate assets; flexibility of surety value; ease of collection in case of default; and problems encountered in asset valuation.

   For long-term financing alternatives, three methods were considered: uranium product taxation, surety bonds and other performance guarantees, and mill operator generated funds. Only specific approaches within the last categories were considered acceptable. These alternatives were: an earmarked annuity managed by the regulatory body; purchased investment securities managed by the operator during the active milling period; and a lump sum final payment secured by surety bonding.

5. The Western Interstate Nuclear Board Committee on Mining and Milling of Nuclear Fuels also issued policy recommendations related to the financing of stabilization and perpetual surveillance and maintenance of uranium mill tailings.

   The objective of the April 1977 study was to determine appropriate methods of financial responsibility for stabilization and perpetual maintenance of uranium mill tailings as a means of reducing potential radiation exposure. Long-term financial responsibility was needed in the event of noncompliance or insolvency by a licensed uranium mill operator, and the subsequent assumption of responsibilities for remedial actions and monitoring by government agencies.

   Among their recommendations, the Committee found that long-term financial requirements for maintenance and surveillance of the

stabilized pile by the responsible agency should be assured through the accumulation of an annuity by a separate tax or fee per ton of ore processed. The Committee also recommended that provision be made in licensing agreements for transferring ownership of final disposal sites, with all mineral rights, to the government agency responsible for maintaining the stabilized tailings pile. A price adjustment index was also recommended for adjusting the taxes, fees, or bonds, in order to maintain the purchasing power parity of the financial requirements identified in the above recommendations.

6. During June 1974, the Task Force on "Bonding and Perpetual Care of Licensing Nuclear Activities" was established by the Executive Committee of the National Conference of Radiation Control Program Directors in joint sponsorship with the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). The specific charge of the Task Force was to examine in detail the requirements for establishing bonding and perpetual care programs for all types of licensed nuclear activities, and to report the findings of the task force as guidelines to assist states in program development.

   The study examined the status of bonding programs related to licensed nuclear activities (excluding waste burial licensees) and found that only one state, New York, had instituted such a program. During 1975, both North Carolina and Arkansas assessed bonding legislation. The reports examined four major areas: (1) the determination of the licensed activities that may require consideration for bonding and or perpetual care; (2) to identify the legislative authority necessary to establish bonding and perpetual care programs; (3) to develop monetary ranges of performance bonds and perpetual care trust funds; and (4) to identify specific administrative areas to be considered by the state in developing, implementing, and maintaining bonding and perpetual care programs.

   As a prerequisite for certain licensees to possess radioactive materials, the Task Force concluded that a financial responsibility review system should be instituted at both the state and federal level. They also found that other alternatives to bonds and perpetual care trust funds have been considered and were, at that time, generally not viable.

   The Task Force report included the recommendation of the 1974 National Conference on Radiation Control, which was that a perpetual care trust fund be legally established that would draw interest adequate to pay the costs of monitoring and maintaining the decommissioned site. The perpetual care trust funds would be identified and their use limited to the monitoring, maintenance, and other perpetual care at the radioactive waste burial site. Items to be considered in determining the perpetual care trust funds are:

   - surveillance, including salaries, travel expenses, instrument maintenance, overhead, and well drilling.

- o maintenance of site, including labor, salaries, overhead, special equipment (evaporators, etc.), fence repair, and erosion control.

- o contingency fund, including protective actions to prevent unacceptable release of waste material from the site, including land acquisition and blocking procedures.

Another recommendation was that performance bonds should be posted by the burial site operator payable to the state agency having the responsibility for closing and maintaining the site in the event of default or other inability of the operator to meet the requirements of the regulatory authority or contract. The report suggested that the performance bond should be adequate to cover the following costs: (a) the decommissioning of the site so as to require minimum maintenance; (b) the payment of funds due the perpetual care trust fund at the time of default; (c) the maintenance and monitoring of the site for at least one year to permit possible site reactivation, if so desired.

7. In 1976, the South Carolina State Department of Health and Environmental Control commissioned a study by Clemson University to examine the state's funding arrangements for meeting the state's obligations for maintenance, surveillance, and contingency costs associated with the Barnwell site. The state required Chem-Nuclear Systems, Inc., as a condition of their license, to pay $.08 per cubic foot of radioactive material buried at the Barnwell site. The fee was passed directly on to Chem-Nuclear System's clients. No study was done to arrive at the decision to set the charge at $.08 per cubic foot. The researchers were asked by the state to determine what should be the charge per cubic foot of radioactive materials to assure that the sinking fund would, in perpetuity, adequately finance all routine and contingency costs associated with managing the Barnwell site, so as to pose no threat to man or his environment, and also to determine what funding arrangements are needed to protect the state of South Carolina in the event the licensee ceases operations before the expected decommissioning date. The four specified objectives of the study were: (1) to estimate the annual costs of routine maintenance and surveillance at the Barnwell site, including salary and labor costs, travel expense, instrument maintenance and depreciation, sampling and laboratory costs, and costs of erosion control practices; (2) to establish procedures for estimating contingency costs associated with emergency conditions that may threaten the health and safety of the surrounding population; (3) to estimate the per-cubic-foot contribution to the sinking fund needed to establish a fund sufficient to meet all routine and continuous costs in perpetuity; and (4) to examine alternatives for protecting the taxpayers of the state from being required to assume custodial costs for the Barnwell site, as a result of failure of the licensee to fulfill its obligations.

In their conclusions and recommendations, the authors of the Clemson study found that the costs of meeting the state's possible future responsibilities toward the Barnwell site should be borne out of interest earned on the sinking fund, and that the principal should be protected intact. They found that the charge of $.08 per cubic foot was inadequate to create a sinking fund of sufficient size to yield returns that would cover even routine responsibilities of the state relative to the site. With the existing rate, the study found that the state would be required to fund about one-half of the cost of meeting their routine obligations toward the Barnwell site out of general tax revenues. Major unexpected problems would create even more of a burden to the state's general tax revenues.

The study used the long-run real return on U.S. Government bonds as the basis for estimating an appropriate rate of interest for use in this analysis. This was done by estimating the long-run real return by examining yields on high-quality municipal bonds from 1900 to 1912 and on U.S. Government bonds from 1913-1973. The study then corrected these yields for increases in the wholesale price index. In the most recent period from 1969, the mean real rate of return was found to be 1.64 percent per annum. The study used two percent as the real rate of return in their calculations.

Based on their analysis, the study recommended that a declining-term performance bond represented the best approach for protecting the state against a default by the licensee.

The study offered three final recommendations: (1) the fee levied on each cubic foot of radiological waste material buried at the Barnwell site should be increased from $.08 to $.14 as soon as possible; (2) the licensee should be required to post a declining-term performance bond to protect the state against default by the licensee, with that bond equal to $1.6 million in 1975, and declining by no more than $90,000 in any year; and (3) that the licensee be declared in default, and the performance bond forfeited, should it cease operations at the Barnwell site for any reason prior to June 30, 1995.

8. The Kentucky Legislative Research Commission also released a study by the Research Triangle Institute that did a financial analysis of perpetual care and maintenance for the Maxey Flats disposal site. The study estimated those costs (i.e., site maintenance, surveillance and monitoring, and water treatment) associated with a perpetual care and maintenance site for a variety of different scenarios. The study found that contributions to a perpetual care and maintenance fund sufficient to raise the fund to a level necessary to care for the Maxey Flats site in perpetuity, must be between $.010 and $.020 per cubic foot and be indexed to the rate of cost inflation. The study found that the initial contribution rate was dependent upon assumptions about annual costs in 1977 dollars, the rate of inflation, and the disposition of funds from a tax based on radiotoxicity of the buried waste that was being proposed by NECO, the site operator.

9. In January 1978, Winston Harrington of Resources for the Future, published a report entitled "Continued Care of Uranium Mill Sites: Some Economic Considerations." The report analyzed the financial adequacy of the New Mexico State Environmental Protection Agency's perpetual care funds for uranium mills. The purpose of the fund was to provide for the maintenance in perpetuity of the mill sites after decommissioning. The state was authorized to require each mill to contribute up to 10 cents per pound of yellowcake (U_3O_8), until a total of $1,000,000 was deposited by that mill. The author argued that even this maximum amount of $1,000,000 proposed by the state was inadequate to generate an income stream that would support an adequate maintenance program at the sites. The author assumed that the continued care fund would have to be sufficient to meet the following expenses at the mill site:

   - Fencing is assumed to be around the tailings pile, which will have to be replaced when it wears out. Repairs will also have to be done.
   - Monitoring of the site is necessary on at least an annual basis. Repairs will have to be made if the structural integrity of the pile has been compromised by erosion or animals.
   - Ground-water quality must be monitored.
   - If case of a natural disaster, repairs may be necessary.
   - Unanticipated problems must be considered. Revegetation is not included.

   The author developed two criteria that he assumed a perpetual care fund must satisfy:

   - Based on currently available information on costs and interest and inflation rates, the fund should generate an income stream sufficient to meet all maintenance costs, (i.e., fencing, monitoring and repair, emergencies, and unanticipated problems); and
   - The terms of the continued care contribution should be readily alterable as new information becomes available. Thus, the perpetual care contribution from a mill operating ten years from now should reflect ten additional years' data for inflation and maintenance costs.

10. In September of 1980, the Texas Advisory Committee on Nuclear Energy on Low-level Nuclear Waste Disposal prepared a report on low-level waste management that dealt with the economic considerations of decommissioning and postclosure care for a low-level waste site. The report recommended that the disposal fees for an LLW site should

include an assessment to accumulate an extended-care fund. The Department of Health would be responsible for annually reviewing the cubic foot assessment for the extended-care fund. The funds collected for extended care are to be deposited with and managed by the Department of Health with the purpose of assuring proper decommissioning when the site is closed and assuring long-term maintenance and surveillance of the site. The report indicates that provisions for the extended-care fund ultimately should be incorporated into a constitutional amendment to assure long-term protection of the fund.

11. The NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds (NUREG-0217) also examined the long-term care of disposal sites.

Officials from the states indicated that under present leases, low-level waste burial ground operators could abandon sites at any time without a continuing financial obligation for long-term care and maintenance.

In all states except Illinois where disposal fees are paid into the general state funds, a specific fund has been established for perpetual care of sites. The money is paid to the state by the operator and is based on per-cubic foot burial charges, which range from 5¢/ft^3 to 16¢/ft^3.

With the possible exception of the South Carolina site, neither the state members nor the Task Force members believed that funds were being accrued at a rate sufficient to adequately care for the sites.

The report also mentioned that the Task Force Report on Radiation Control Program Directors recommended that annual interest from perpetual care trust funds for low-level waste sites should total between $50,000 and $250,000 depending on ground characteristics. Such an amount would be sufficient to pay for the annual long-term costs of monitoring, minor maintenance, and surveillance.

Initially, the funds were established to provide money from interest for perpetual care of the sites. They were not considered as resources for corrective action, since major problems in site operations were not expected.

However, with recent operational problems at several sites, the report noted that site operators have reevaluated use of the funds and found that it was evident that present funds were insufficient for major corrective actions.

Furthermore, such use of the funds would deplete the principal, leaving little money for long-term care. All states indicated that they would need federal financial and technical assistance if major deficiencies in site performance are found at the burial sites.

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Appendix L

(Reserved for final EIS)

Appendix M

POTENTIAL LONG-TERM IMPACTS OTHER THAN GROUND WATER MIGRATION AND INADVERTENT INTRUSION

This appendix addresses potential long-term radiological impacts associated with near-surface disposal of radioactive waste other than those directly associated with ground-water migration and potential inadvertent human intrusion. These latter impacts are extensively addressed in Chapters 4 and 5 of this environmental impact statement. These impacts may be divided into three areas:

- o Gaseous releases from decomposing wastes.
- o Plant and animal intrusion.
- o Erosion.

Potential ways to mitigate such impacts are also addressed.

1. GASEOUS RELEASES FROM DECOMPOSING WASTES

Much of the waste currently being disposed in shallow land burial facilities consists of organic material such as wood, paper, or animal carcasses. As such buried organic material decomposes over time, gaseous decomposition products such as CO_2 or CH_4 (methane) are formed which can be transported upward, through the trench caps, and into the atmosphere. Such decomposition gases can contain tritium (H-3, or T), C-14, or other radioisotopes contained in the disposed waste.

As stated by EPA in connection with decomposition gases generated at sanitary landfills (Ref. 1):

> A major product of landfill waste decomposition processes is a gaseous mixture consisting largely of methane (55 percent) and carbon dioxide (45 percent), with trace amounts of elemental nitrogen, hydrogen and oxygen, and varying trace constituents such as ammonia, carbon monoxide, ethylene and water vapor. The extent of gas production depends primarily on landfill age, percent and type of waste organic materials, cover material permeability and thickness, landfill temperature variation, waste density and moisture content. Once generated, methane can migrate radially by diffusion and convective flow processes through the gas permeable waste and the adjacent and overlying soil. Under certain conditions, the methane can collect in explosive concentrations (5 to 15 percent in the presence of air) in conduits or buildings adjacent to the landfill. The presence of methane can also result in damage to a variety of plant species due to reduced oxygen concentrations in the plant root zone. Carbon dioxide will dissolve in ground water forming carbonic acid, therefore mineralizing and contaminating it. A common methodology utilized to predict the potential extent of methane migration is to assume that ten feet of horizontal methane migration may occur for each foot of landfill depth. The resulting value is only a very general estimate, since site specific subsurface conditions such as an impermeable cover and porous substrata can result in methane migration on the order of hundreds of feet.

The presence of tritium and carbon-14 tagged decomposition products at shallow land burial facilities was first observed by Matuszek, et al. (Refs. 2, 3). Samples of gases collected from trench sumps at the Maxey Flats, Kentucky, and West Valley, New York disposal facilities have been shown to contain elevated quantities of tritiated gaseous compounds, primarily CH_3T (methane) and HTO, but also HT and other tritiated hydrocarbons. Such C-14 tagged hydrocarbons as $^{14}CO_2$ and $^{14}CH_3$ have also been identified as well as Kr-85 and Rn-222.

Table M.1 is a summary of radionuclide concentrations and gas composition in samples of trench sump gas at the West Valley facility. Also shown are the results of the analysis of a single sample of soil gas over a fractured area in the cap over trench no. 3. This sample was obtained through collection of gas accumulated underneath a plastic tarpaulin placed over the fractured area. The most abundant radioactive species in the trench gas was tritium as CH_3T, which constituted 22-68% of the sump gases (Ref. 2). Lu and Matuszek also developed an empirical method to estimate the bulk permeability of disposal trench covers to estimate rates of gas production and gas release. This was determined by measuring the pressure differential between trench gas and the atmosphere, and correlating the measured pressure differentials measured in the field with those calculated through a Darcy-Flow Model, GASFLO. Using this method, the annual volume of gas released to the environment (which can vary depending upon seasonal climatic changes) was estimated. This gas volume was then multiplied by the measured gas concentrations in disposal trench sumps and annual radionuclide release rates determined. Lu and Matuszek calculated that the amount of TCH_3 released to the environment could be estimated to be approximately 1 to 8 curies per year from various West Valley disposal trenches (Refs. 3, 4).

Gas samples taken from trench sump monitoring wells are an indication of the nature of the gaseous source term, but may not indicate the magnitude of the gaseous emanation through a disposal trench cover. The actual concentration of radionuclides emanating from a disposal trench cover are of more significance to potential offsite exposures to the public. For example, the data from the West Valley disposal facility indicates that the concentration of tritium emanating from a trench (in pCi/cc of air) may be a factor of 1000 less than tritium concentrations measured from a trench sump well. Similarly, the concentration of C-14 emanating from a disposal trench may be a factor of 10 to 140 less.

Since the acquisition of the West Valley, New York data, experimental measurements of tritium and C-14 concentrations in gases emanating from disposal trenches have been made at the Maxey Flats, Kentucky (Ref. 5) and Beatty, Nevada (Ref. 6) disposal facilities. These measurements provide a comparison of gas concentrations in trench wells and trench covers at both a humid and an arid disposal facility. Measurements of Rn-222 fluxes (in pCi/m^2-sec) emanating from disposal trench covers have also been made at the Maxey Flats and Beatty facilities.

Samples were collected at these facilities from trench sump wells in addition to soil gas samples. As the Beatty facility is located in an arid environment, the sump wells are all dry. In addition, samples were obtained at the Beatty facility from dry observation wells located between some of the disposal

Table M.1 Radionuclide Concentrations and Gas Composition in Trench Gas and Soil Gas Samples at West Valley, New York.

Concentration (pCi/cc)	Well 2-1A	Well 3-1	Well 5-1A	Well 5-3A	Trench 3 soil gas
HT	1.30 ± 0.12	8.2 ± 0.5	0.53 ± 0.08		<.0013
^{85}Kr	3.7 ± 1.4	3.9 ± 0.6	40 ± 2		0.0027 ± 0.0003
$^{14}CH_4$	5.5 ± 0.9	2.0 ± 0.2	6.4 ± 0.9	96 ± 12	0.7 ± 0.1
CH_3	130 ± 0.2	250 ± 30	480 ± 50	1580 ± 160	0.110 ± 0.111
$^{14}CH(HC)$	1.1 ± 0.4	0.4 ± 0.2	<0.16		
$^{3}H(HC)$	2.5 ± 0.8	29 ± 3	47 ± 5		
^{14}CO	0.06 ± 0.03		0.19 ± 0.03		
$^{14}CO_2$	2.2 ± 1.0	0.9 ± 0.4	7.4 ± 1.5	4.8 ± 0.3	0.0067 ± 0.0008
^{14}C (total)	6.7 ± 1.5	15 ± 0.9	26 ± 7		
^{222}Rn	2.56 ± 1.10	83 ± 3	0.94 ± 0.03	35.5 ± 1.1	0.117 ± 0.005
Gas Composition (%)					
N_2	62.0	67.0	63.6	25.8	79.1
O_2	0.22	0.70	3.5	0.12	19.7
CO_2	10.35	2.82	10.3	4.52	0.22
CH_4	26.7	28.7	21.8	68.3	<0.02
Ar	0.73	0.76	0.69	0.37	9.93
H_2	<0.03	<0.3	<0.4	0.84	<0.02

trenches. Sump samples at both facilities were obtained by pumping air from the sumps which was then either compressed into air cylinders or collected (relatively uncompressed) into 15-liter air sample collection bags. To determine concentrations of radionuclides in soil gas, accumulation canisters constructed of 55-gallon steel drums were used. The drums were sealed to the soil through use of water-emulsified polymer sealant and draped with thermal aluminized space blankets. Similar to the sump samples, air withdrawn from the soil gas accumulation canisters was collected into compressed air cylinders and uncompressed sample bags.

The results of these experimental measurements are shown in Tables M.2 through M.5. The results of the gas composition analyses for the two facilities are

Table M.2 Composition of Trench and Soil Gas at the Maxey Flats Disposal Facility

Location	N_2 (% Volume)	O_2 (% Volume)	CO_2 (PPM)	CH_4 (PPM)	Trace H_2O (mg/l)
Background					
North Fence	77	22	98	2	0.95
South Fence	77	22	168	2	2.11
Trench Gas					
TR-7 Sump	77	22	148	2	1.48
TR-11S Sump	77	22	470	114	2.60
TR-18 Sump	78	20	12000	6720	2.56
TR-26 Sump	77	22	29	2	2.22
TR-35 Sump	77	22	186	8	1.38
Soil Gas					
TR-11S	77	22	255	1	1.04
TR-18	77	21	2580	12	1.33
TR-20	78	22	881	1.4	1.47
TR-26	77	22	819	2	2.12
TR-35	77	22	1410	4	2.83
Natural Dry Atmospheric Air	78.1	20.9	315	1.2	--

Table M.3 Composition of Trench and Soil Gas at the Beatty Disposal Facility

	N_2 (% Volume)	O_2 (% Volume)	CO_2 (PPM)	CH_4 (PPM)	Trace H_2O (mg/liter)
Background	78	22	300	10	1.95
Observation Well R-1	78	20	1860	7.7	2.81
Observation Well R-2	78	17	8100	19	2.74
Observation Well R-3	74	15	1270	41	2.55
Observation Well R-6	78	22	600	7	N.A.
Sump Well TR-14	76	21	530	16	2.88
Sump Well TR-16	64	17	2200	9.80	3.59
Canister TR-2	73	21	300	5.1	1.77
Canister TR-3	77	22	300	7.1	2.11
Canister TR-4	76	21	300	6.5	2.08
Canister TR-5	73	21	300	6.5	2.02
Canister TR-14	79	21	300	6.5	2.02
Canister TR-16	78	22	300	7.3	2.58

Table M.4 Tritium and Carbon-14 Activity in Trench and Soil Gas (pCi/cc) at the Maxey Flats Disposal Facility

	Gaseous Tritium	HTO Tritium	Gaseous C-14
Background			
North Fence	4.18±0.18 (E-2)	2.48±0.11 (E-3)	0±0.45 (E-4)
South Fence	1.28±0.06 (E-2)	8.33±0.45 (E-3)	0±0.45 (E-4)
Trench Gas			
TR-7 Sump	1.29±0.07 (E-2)	6.31±0.34 (E-3)	0±0.45 (E-4)
TR-11S Sump	1.58±0.11 (E-2)	1.48±0.08 (E-2)	4.95±3.15 (E-5)
TR-18 Sump	1.12±0.07 (E-1)	2.25±0.22 (E-2)	7.88±0.33 (E-2)
TR-26 Sump	1.61±0.09 (E-2)	2.25±0.11 (E-3)	0±0.45 (E-4)
Soil Gas			
TR-11S	2.84±0.09 (E-3)	8.67±0.47 (E-4)	0±0.45 (E-4)
TR-18	9.01±0.90 (E-4)	6.42±0.34 (E-4)	4.50±3.15 (E-5)
TR-20	1.13±0.05 (E-2)	2.59±0.11 (E-3)	0±0.45 (E-1)
TR-26	5.81±0.36 (E-3)	4.95±0.23 (E-4)	0±0.45 (E-4)
TR-35	9.50±0.45 (E-3)	1.80±0.09 (E-3)	0±0.45 (E-4)

Table M.5 Tritium and C-14 Activity Measurements at the Beatty, Nevada Disposal Facility

	Gaseous Tritium (pCi/cc)	HTO Vapor (pCi/cc)	C-14 (pCi/cc)
Background	<1.35 (E-4)	5.52 (E-2)	<9.01 (E-5)
Trench Gas			
Observation Well R-1	2.68 (E-1)	8.22 (E-2)	5.90 (E-2)
Observation Well R-2	5.68 (E-3)	3.08 (E-2)	3.60 (E-2)
Observation Well R-3	4.73 (E-2)	2.93 (E-2)	3.04 (E-2)
Observation Well R-6	2.11 (E-1)	--	1.46 (E-3)
Sump Well TR-14	9.86 (E-2)	5.52 (E+0)	2.59 (E-2)
Sump Well TR-16	9.82 (E-1)	9.35 (E-2)	8.56 (E-3)
Soil Gas			
Canister TR-2	<1.35 (E-4)	5.18 (E-2)	<9.01 (E-5)
Canister TR-3	1.99 (E-1)	1.90 (E-2)	2.21 (E-4)
Canister TR-4	1.17 (E-1)	7.55 (E-2)	1.35 (E-4)
Canister TR-5	7.75 (E-2)	1.27 (E-2)	5.27 (E-3)
Canister TR-14	1.53 (E-1)	3.72 (E-2)	5.41 (E-4)
Canister TR-16	1.98 (E-1)	1.62 (E-2)	8.11 (E-4)

shown in Tables M.2 and M.3. Tritiated water vapor, gaseous tritium (all tritiated gas compounds except water vapor), and gaseous C-14 results for the Maxey Flats and Beatty facilities are shown in Tables M.4 and M.5, respectively.

The data is limited and there are a number of environmental and sampling variables which may not totally have been taken into consideration, such as the extent to which the sampling process itself changes the conditions to be measured. However, methane generation at the Beatty facility appears to be generally significantly less than that at West Valley or Maxey Flats. Measured concentrations of gaseous tritium and HTO vapor in the trench sumps at Maxey Flats appear to be elevated. However, concentrations of these radionuclides measured emanating from trench covers are significantly less--e.g., on the order of background concentrations at this disposal facility or less. Except for one sump measurement (trench-18), C-14 measurements at the trench sumps are consistent with C-14 concentrations measured in soil gas.

At the Beatty facility, elevated concentrations of C-14 are observed at the observation wells and the dry sumps; however, reduced C-14 concentrations are observed in soil gas. Also of interest is the observation that similar

concentrations of C-14 are observed in the observation wells as in the trench sumps, which may mean that lateral diffusion of C-14 is taking place beneath the facility. A similar situation is observed for gaseous tritium and HTO vapor. For gaseous tritium, similar concentrations of gaseous tritium is observed at the observation wells, sump wells, and accumulation canisters. Except for one abnormally large measurement at sump well TR-14, all measured concentrations of tritium as HTO vapor lie within a relatively small range--i.e., from 1.27 to 9.35 E-2 μCi/cc. It may also be observed that while C-14 concentrations in the soil gas at the Beatty facility are about the same as those concentrations measured at Maxey Flats, gaseous tritium and HTO vapor soil gas concentrations are generally higher at Beatty than at Maxey Flats. This may be caused by the higher evapotranspiration at the Beatty facility, in addition to trench covers having higher permeability.

It is of interest to compare the concentrations of tritium and C-14 measured in soil gas to maximum permissible concentrations (mpc) for release to unrestricted areas listed in Table II of 10 CFR Part 20. For submersion doses, which would be the case here, the mpc for tritium is 4×10^{-5} μCi/ml while the mpc for C-14 is 1×10^{-6} μCi/ml (for CO_2). Taking the maximum H-3 and C-14 concentrations observed at the Beatty facility--i.e., 0.2 μCi/cc gaseous tritium and 5.27×10^{-3} μCi/cc C-14--the maximum observed concentrations are a factor of 200 below mpc for H-3 and a factor of 5300 below mpc for C-14. Concentrations in unrestricted areas would be much less due to atmospheric dispersion.

Radon-222 fluxes measured at the Maxey Flats facility ranged from negligible levels to 0.095 pCi/m^2-sec. These levels, however, were determined in the month of December, when generally wet conditions existed at the facility. Radon-222 flux measurements at the Beatty facility ranged from background (approximately 0.48 pCi/m^2-sec) to about 0.9 pCi/m^2-sec. By contrast, typical Rn-222 flux measurements from a bare uranium milling tailings pile are estimated at about 281 pCi/m^2-sec (Ref. 7). The proposed radon flux limit for reclaimed tailings is 2 pCi/m^2-sec. Table M.6 presents a list of typical radon flux measurements for various parts of the country (Ref. 7).

There are two concerns due to the observed generation of waste decomposition gases within disposal trenches: (1) offsite exposures due to release of radioactive gases, and (2) onsite nonradiological safety to operating crews.

In the former case, potential offsite releases and exposures to individuals would not appear to be significant. Although the existing data is limited, the emanation rates that have been measured at near-surface disposal facilities are small, and would indicate that potential offsite exposures would not be significant. That is, potential exposures would be expected to be orders of magnitude less than limits established in 10 CFR 20 and much less than limits established in 40 CFR 190 for effluents from operation of a nuclear fuel cycle facility. However, additional field investigation should be performed to verify this and to investigate the extent that differences in site design, operation, site climate, seasonal variation, measurement techniques, etc. have upon the emanation rates. For example, the observed differences in tritium emanation rates between the Beatty facility and the Maxey Flats facility may be due to the lesser permeability of the cover material at the Maxey Flats facility. As

Table M.6 Radon-222 Flux Measurements in the Contiguous United States

Location	Average Reported Radon Flux pCi/m^2-sec
Illinois	
Champaign County (472)*	1.4
Argonne (8)	0.56
Massachusetts	
Lincoln (10)	1.34
New Mexico	
Socorro (10)	0.90
Socorro (6)	1.01
Socorro (164)	0.64
Nevada	
Yucca Flats	0.47
Texas	
Varied Locations (9)	0.27

*Number in parentheses indicates number of separate measurements.

mentioned earlier, the soil was generally saturated when the measurements were taken, which would impede upward gas flow. Other site specific conditions--such as the greatly increased evapotranspiration at the Beatty facility compared with the Maxey Flats facility--may also have an impact.

It is expected that the performance objectives established in Chapter 5 to reduce or eliminate the requirement for active long-term maintenance activities following disposal facility closure will also act to significantly reduce radionuclide emanation rates from trench covers--particularly from disposal facilities located in humid environments.

Decomposition of organic waste and generation of gases are complex processes accelerated by moist, saturated conditions and retarded by dry, unsaturated conditions. The former is illustrated by the conditions at Maxey Flats and West Valley facilities, where waste decomposition has led to increased infiltration and saturated conditions, further accelerating decomposition. The latter situation is illustrated by the Beatty, Nevada facility, which has no water management problems and a greatly reduced rate of waste decomposition. Emanation of the generated gases through the trench cap is a variable depending upon such factors as trench cap thickness and composition. In general, emanation rates would be reduced by thicker covers composed of lower permeable materials.

Key variables, of course, are the composition of the waste material itself, as well as the disposal practices at a particular site. Compressible, easily degradable organic waste material can lead to water management problems at humid sites as well as increased generation of gaseous decomposition products. It, therefore, can be deduced that essentially the same improvements in waste form and disposal facility design and operating practices that would eliminate the need for active long-term maintenance activities following site closure would also act to greatly reduce the rate of decomposition of the waste material. Such a reduction in the decomposition rate of the disposed waste would not only reduce the instanteous rate of gaseous decomposition products, but would also allow time for decay of the tritium (half life of about 12.3 years), which is the most significant radionuclide in terms of total curies. Thus, total integrated releases over time would be smaller.

In summary, the emanation rates actually measured from LLW disposal sites are very small, and would be expected to result in offsite doses which are expected to be considerably less than, for example, the 25 mrem/year whole body criteria proposed for protection of ground water at the facility boundary. Even under less than ideal conditions--that is, for example, at Maxey Flats where decomposing waste has produced a bathtub situation--decomposition gases have not resulted in significant releases. Furthermore, such generation rates would be expected to fall off over time. This is the experience seen by EPA for methane generation at nonradioactive solid waste disposal sites.

The principal long-term impact of a potential waste decomposition problem is probably not the gas emanation per se, but a potential problem with long-term active site maintenance, and has already been addressed as a performance objective. It should also be noted that the recent establishment of a de minimis or exempt level for tritium and C-14 contained in liquid scintillation fluid and biological waste would probably reduce the potential for active long-term site maintenance as well as reduce the generation of gaseous decomposition products at LLW sites (Ref. 8).

The second area of concern is of a relatively shorter-term nature--i.e., a potential nonradiological safety hazard at the disposal facility from generation of methane gas. Methane explosions have been observed at or nearby sanitary landfills (Ref. 9). This potential concern, however, can be mitigated or eliminated at low-level waste disposal facility by, for example, reducing the decomposition rate of the waste material. This has already been shown to be important for minimizing the need for active long-term maintenance. In addition,

methane gas generation and migration in sumps and observation wells may be readily monitored through currently available techniques. If monitoring shows methane gas generation to be a problem, the technology for construction of engineered control systems has already been developed for sanitary landfills and chemical and hazardous waste disposal facilities, where methane generation would be expected to be a much greater problem due to the nature of the disposal technology utilized and the typically higher organic content of the disposed waste material. Application of a given methane gas control technology would be applied if necessary on a site-specific basis as part of licensing an individual facility.

2. POTENTIAL FOR PLANT AND ANIMAL INTRUSION

Another potential source of long-term environmental releases is through potential intrusion of burrowing animals and deep-rooted plants into disposed waste. As discussed in Appendix F, a number of isolated cases of plant and animal intrusion into disposed waste have been documented (principally at government facilities). However, the existing information indicates that the past instances of plant and animal intrusion have not resulted in a significant public health and safety problem. Nonetheless, methods by which the potential impacts of plant and animal intrusion may be minimized are of interest to this environmental impact statement.

There appear to be three principal pathways in which potential intrusion of deep-rooted plants and burrowing animals can impact humans:

- Plant and animal intrusion can create pathways in a disposal trench cover for increased percolation of rainwater into the disposal trench, thus potentially increasing ground-water migration.

- Radionuclides may be brought to the surface where they may be dispersed by wind and water.

- Contamination on or within plants and animals may be potentially eaten by humans.

The first pathway is believed to probably be the most significant as it can potentially affect a larger population than the other two pathways. The effects of increased percolation of rainwater into disposal trench covers due to intrusion has already been included in the groundwater impacts calculation in Chapter 5. That is, for the cases in the case study that improved disposal trench covers are implemented, the maximum effectiveness of the improved covers is assumed only for a period of 100 years (active institutional control period) following facility license termination. During this time period, the site owner would maintain the facility and control access to it. Site maintenance activities would include surveillance for and control of potential presence of deep-rooted plants and burrowing animals. Following 100 years, some degradation in effectiveness of the disposal cell covers is assumed to occur due to the potential for inadvertent human intrusion, and the potential presence of deep-rooted plants and burrowing animals.

The other two pathways are believed to be less significant and would be bounded by the individual and population impacts calculated for potential human intrusion.

A consideration is that potential impacts of plant and animal intrusion into disposed wastes are highly site-specific and are, furthermore, difficult to calculate. Some of the factors which greatly influence potential impacts include:

- o The climate of the disposal site.
- o The varieties of plants and animals indigenous to the disposal site.
- o The characteristics of the disposal operations.
- o The characteristics of the disposed wastes (e.g., higher potential impacts would be expected from wastes having higher radionuclide contents, and/or wastes with higher potential for leaching or dispersion).

This indicates that the best approach may be to address ways to minimize plant and animal intrusion on a case-by-case basis as part of licensing individual disposal facilities. It is useful, however, to consider on a generic basis ways in which this may be accomplished.

It appears that many of the potential methods which can be used to minimize plant and animal intrusion or to reduce the impacts of such potential intrusion are similar or identical to those which are useful against potential human intrusion. For example, the potential for (and resulting impacts from) plant and animal intrusion can be minimized by:

- o Institutional controls;
- o Waste form and packaging; and
- o Facility design and operating practices.

As discussed earlier, the site owner would be expected as part of institutional control to maintain control over the closed facility, and would carry out monitoring and surveillance activities as well as minor maintenance of site grounds. These activities would include control of undesirable vegetation and burrowing animals. Such activities, of course, would be a long-term expense to the facility owner, and it is desirable to minimize these long-term expenses.

The gain from improved waste forms and waste packages is straightforward. Improving waste form and packaging reduces the potential for leaching of the radionuclides out of the waste and subsequent migration or uptake by plant roots. In addition, the waste would be less likely to be in a form which could be brought to the surface by burrowing animals and dispersed.

Some facility design and operating practices which would tend to generally reduce the potential for plant and animal intrusion include the following:

- o Increasing the thickness of earthen fill between the top of the disposed waste and the facility surface.

- Placing higher activity material at greater depths (layering the higher activity waste).
- Filling the interstitial spaces between the disposed waste containers with cement grout.
- Use of barriers to intrusion (bio-barriers).

The first three items are straightforward. The burrowing depths of most animals, except some insects, typically are not more than one or two meters. Increasing the cover thickness (e.g., from one to two meters to three to four meters) would therefore place the waste below the burrowing depths of most burrowing animals. Layering the higher activity waste streams essentially eliminates the potential for intrusion into these waste streams. Contact, if it occurs, would be only with the lower activity waste streams. Grouting the disposed waste packages impedes intrusion into the disposal cells, reduces the potential for waste dispersion, and reduces the potential for increased ground-water migration.

Barriers against intrusion may also be used. One barrier which has been used with success against intrusion by burrowing animals is emplacement of a hard surface such as rip-rap, cobbles, or asphalt over the top of disposal trenches. The hard surface greatly discourages or eliminates burrowing mammals and has the added benefit of controlling potential wind and water erosion. Coatings of cobbles over filled disposal trenches are currently being routinely used at the Hanford Reservation, both at the disposal areas operated by DOE and the commercial disposal facility located within the reservation.

Over the past several years, work on development of biological barriers effective against deep rooted plants and burrowing insects in addition to burrowing mammals has been performed by Cline, et al., and this work is discussed in some detail in Appendix F. This work has included use of asphalt and cobble layers, as well as use of root toxins placed at sufficient depth below the surface to kill deep-rooted plants but allow shallow-rooted plants to grow. It is possible that herbicides could be used which would be nontoxic to the plant but would inhibit root growth.

To summarize Appendix F, the use of cobbles, asphalt, or other hardened layers would appear to be straightforward in application against intrusion by burrowing mammals. Additional work is required, however, to develop effective biological barriers against intrusion by plant roots, particularly in humid environments. In any case, construction of elaborate biological barriers could prove to be an expensive hinderance as long as trench subsidence was in evidence at a disposal facility. Subsidence would tend to crack rigid surfaces such as asphalt layers or concrete, thus reducing or eliminating their effectiveness. Repairs or restabilization activities would also tend to be more difficult and more expensive.

3. EROSION

Another source of potential environmental releases is through the effects of wind and water erosion. Through these mechanisms, the covers over disposal

trenches may be removed over time, eventually exposing the disposed wastes which then could be potentially dispersed into the environment through airborne or waterborne pathways. In addition, a significant erosion problem would reduce the ability to predict disposal facility impacts over time.

It is recognized that minimizing the effects of erosion is of significant importance when siting, designing and operating a disposal facility. The effects of erosion are site-specific and would be analyzed as part of individual licensing actions for a particular disposal facility. For some facilities--for example those located in an arid region having high winds--wind erosion may be of most significance. For facilities located in humid environments, gully or sheet erosion due to the action of water may be of most significance. Gully erosion would affect less of the disposed waste, but could occur over a shorter time frame. Sheet erosion would eventually effect a larger area, and hence a larger amount of the disposed waste, but would take longer to occur.

It is believed that the effects of erosion at a disposal facility can be minimized through proper siting, design, and operation to the point that it needn't be considered a problem. Practical measures which can be readily taken to minimize or eliminate this potential problem include the following examples:

- o Avoid areas characterized by rapid erosion, such as floodplains, areas of high topographic relief, and so forth.
- o Stabilize the site against erosion through application of a soil cover such as grass or a layer of rip-rap.
- o If drainage channels are used at the facility, minimize gully erosion through appropriate engineering such as lining with rip-rap.

Still, it is difficult to predict the effectiveness of measures intended to minimize erosion over the long term, and it is instructive to obtain an upper-bound estimate of the level of potential exposures that could occur if through some reason the waste did become exposed through erosion. To do this, an estimate must be made of the length of time that it takes for the cover over the waste to be removed through weathering activities. As stated above, gully erosion could be a fairly rapid process. However, its effects would tend to be localized and if it were to occur, then it would probably occur during the 100-year institutional control period. During this time period, the disposal site would be under the surveillance and control of a governmental agency and steps could be taken to correct the problem. Sheet erosion, however, would appear to be a less perceptible, long-term potential problem.

3.1 Water Erosion

A short but illustrative discussion of soil-water erosion rates is provided by Healy and Rodgers in Reference 10. As observed by the authors, erosion rates can vary widely depending upon such site-specific factors as rainfall, soil type, ground slope, soil cover, and human activities. To calculate the potential erosion rate, use may be made of the universal soils loss equation (USLE). This equation has been used (or a derivative has been used) for a number of

years to estimate erosion rates from plowed agricultural fields. A derivative of the semi-emperical equation has also been used to determine erosion rates during highway and other forms of construction activities. As stated above, the equation is actually intended for use in determining erosion from plowed agricultural fields. The length of time over which the erosion rate is calculated is short and the conditions under which the equation is used (e.g., plowed fields) are those in which sheet erosion would be accentuated. Considerable care must be taken when applying the equation to a disposal facility. Still, the equation is useful as a basis of discussion of the variation in erosion rates and the types of factors which influence erosion rate.

A simplified derivative of the universal soil loss equation is as follows (Ref. 11):

$A = R \times K \times LS \times VM$, where

A = The computed soil loss in tons/acre per year. This quantity may be converted to cubic meters using selected conversion factors.

B = The rainfall intensity factor, which is a measure of the erosion force of rainfall.

K = The soil erodibility factor, which is highly regional.

The next two parameters are of importance as they may be varied to control and minimize erosion:

LS = The topographic factor--e.g., the effect of length and steepness of slopes on the soil loss per unit area.

VM = The erosion control factor, which is a function of all erosion control measures such as vegetation, mechanical manipulation of the surface, chemical treatments, etc. For bare slopes, VM=1.

In general, a maximum rate of erosion is apparently reached in areas having precipitation on the order of 25 cm/yr (10 in/yr), with decreased rates in more humid as well as in more arid climates. The number and severity of rain storms is also an important factor. To determine the effect of rainfall, a rainfall erosion-index (or rainfall intensity factor) has been developed, which is a function of the total kinetic energy of a rainstorm as well as its maximum intensity over a 30-minute period. Iso-erodent maps are available giving regional values of this index and in the eastern states, this factor can vary from about 50 to about 600.

The soil erodibility factor accounts for the differences in erosion potential among different soils. This factor can vary widely--e.g., from 0.69 for a Dunkirk silt loam to 0.03 for an Albin gravelly loam (Ref. 10).

Of course, the gradient of the ground slope as well as the steepness of the ground slope are also important factors. Complicated formulas can be used to

determine the topographic factor for multiple slope lengths and gradients. One such formula is illustrated in Reference 11. In general, however, the factor is larger with larger gradients. Healy and Rodgers gives an example of this in Reference 10. "For a length of 60 m (200 ft.), the soil loss ratio varies from about 0.3 at a 2% gradient to about 6 at a slope of 20%."

The last factor--the erosion control (soil cover) factor--greatly influences the calculated erosion rate. For agricultural purposes, determining this factor can be complicated. It may, for example, be influenced by such factors as crop management techniques, growth stages of crops during periods of heavy rainfall, and so forth. However, as stated in Reference 10, "with established meadows of grass, alfalfa or clover, the soil loss rates are 0.4 to 2% of that from fallow land."

For purposes of waste management, this implies that a good soil cover over a disposal facility such as a thick vegetative carpet or a layer of rip-rap can reduce potential erosion rates from a given site (all other factors such as rainfall, soil erodibility, and topography being equal) by 2 or 3 orders of magnitude.

The combined effect of the different possible rainfall, soil erodibility, topography and soil cover factors can result in wide differences in erosion rates. For example, Table M.7, obtained from Reference 10, provides an illustration of different erosion and runoff rates for a number of widely scattered soil types, rainfall, crops, and so forth. The erosion rate of clean tillage can exceed that associated with dense soil covers by 2 to nearly 3 orders of magnitude.

Human activities such as construction of houses or roads can result in greater erosion rates with respect to agricultural activities while erosion rates associated with natural weathering activities are generally in a lower range. Table M.8, obtained from Reference 10, illustrates this. As can be seen, erosion rates from construction activities can be quite high. However, such erosion rates would only be temporary and after construction had ceased, erosion rates would quickly fall to much lower levels--perhaps to levels below those associated with preconstruction. Erosion rates for clean tilled farming activities can also be high (e.g., on the range of 10-60 tons per acre per year). However, it is again unlikely that such erosion rates would occur over long time periods. Continued erosion rates of that magnitude would result in a rapid loss in productivity of the farmland.

Natural erosion rates are an estimate based upon consideration of the volume of deposits in closed systems.

Given the above discussion it would appear that while the potential for water erosion is an important consideration for radioactive waste disposal, it is a site-specific phenomenon and can best be regulated as part of licensing actions for a specific disposal facility. However, it is useful on a generic basis to determine the range of potential exposures that could occur over the long term at the reference facility. To do this, an estimate must be made of the length of time that it would take for the disposal cell covers to be removed. One

Table M.7 Annual Soil and Water Losses per Acre from Five Widely Separated Types of Land Under Conditions of Clean Tillage and Dense Cover of Vegetation*

Soil, Location and Years of Measurements	Average Annual Precipitation	Slope	Clean-Tilled Crop		Dense Cover-Thick-Growing Crop		Approximate Number of Years to Remove 18 cm of Soil	
			Annual Soil Loss	Annual Water Runoff**	Annual Soil Loss	Annual Water Runoff**	Clean Tillage	Dense Cover
	(cm)	(%)	(tons)	(%)	(tons)	(%)		
Shelby silt loam, Bethany, MO, 1931-35.	88	8.0	68.78	28.31	0.29	9.30	16	3,900
Kirvin fine sandy loam, Tyler, TX, 1931-36.	104	8.75	27.95	20.92	0.124	1.15	49	11,100
Vernon fine sandy loam, Guthrie, OK, 1930-35.	84	7.7	24.29	14.22	0.032	1.23	50	38,200
Marshall silt loam, Clarinda, IA, 1933-35.	68	9.0	18.82	8.64	0.06	0.97	48	15,200
Cecil Clay loam, Statesville, NC, 1931-35.	115	10.0	22.58	10.21	0.012	0.33	51	95,800

*Measurements at the soil and water conservation experiment stations of the Soil Conservation Service.

**Of total precipitation.

Table M.8 Erosion Rates Under Varying Conditions

Soil or Rock Description	Use	Erosion Rate
		(tons/acre per year)
Igneous rock	Geologic past	0.08
Appalacian Mountains	Geologic past	0.7
Midcontinent farmland	Typical farming (other than clean tilled)	0.5-6
	Clean tilled	10-60
Urban or suburban	During construction	70-200

reference, (Ref. 12) in considering this question, postulated a range of one to six tons of soil lost per year. Reference 10 also assumed a range of one to six tons a year, and based on a bulk density for soil of 1.5 gm/cm^3, postulated a time period of from 2,000 to 13,000 years to remove 2 meters of soil cover over disposed waste.

Similarly, for purposes of this environmental impact statement, a time of 2,000 years is assumed to be required to uncover 2 meters of soil, or about 1,000 years per meter of cover over the disposed waste. This essentially assumes a soil loss of 6 tons per acre per year from the disposal trench. A continual (over 2,000 years) soil loss rate of this magnitude from the disposal facility is extremely unlikely. It ignores ground cover and other surface engineering measures that would be incorporated into the disposal facility design. The loss rate is at an upper range associated with typical farming activities. Such farming activities are unlikely to occur and if they do occur, it would be unlikely that a continual soil loss rate of 6 tons per year would be tolerated by a farmer. Such rates would probably reduce the productivity of the soils to unacceptable levels long before the 2 meters of soil thickness is lost.

In any case, after a time period equal to 1,000 years per meter of cover thickness, the trench covers are hypothetically assumed to be eroded away and the scenario is initiated. As a further conservatism, no credit for waste form is assumed for the erosion scenario. Neither is credit taken for barriers against erosion such as a rock cover or more elaborate measures such as disposing of the waste in walled trenches. The contaminated exposed soil/waste mixture is assumed to be carried by the water into the surface body water located one kilometer from the disposal facility. The natural mobilization rate calculated

for the reference facility (about 0.75 tons/acre/year) is used. The reduction in the activity due to deposition along the route is neglected and the soil/waste mixture is assumed to all dissolve in the surface water, where the water is used by an individual for consumption, crop irrigation, and so forth. The total exposures received by all significant pathways may be then calculated. Additional detail regarding the calculational procedure is provided in Appendix G.

Table M.9 presents the results of the calculations for each of the cases considered in the analysis carried out in Chapter 5 for ground-water migration. As discussed in Appendix G, the calculated exposures will vary depending upon such factors as the waste spectrum (e.g., the radionuclide concentrations), the disposal efficiency, the amount of land area exposed, the disposal cell cover thickness, and the density of the waste. Another factor is the placement of the waste to limit exposures to intruders--e.g., the amount of waste that must be layered to meet intruder exposure limitation requirements. In any case, all exposures seem to lie within a relatively small range. For example, exposures to all organs except thyroid range from about 0.05 mrem/yr to about 0.7 mrem/year. Exposures to the thyroid range from about 0.1 to 1 mrem/year. These calculated exposures are less (in some cases significantly less) than the 4 mrem/year limit for drinking water promulgated by the Environmental Protection Agency in 40 CFR 190. Given the conservatism of the calculational procedure, and the hypothetical nature of the institution's mechanisms (e.g., the facility would be sited and designed so that erosion would not be a problem), it is believed that actual waterborne erosional impacts would be much less.

It is also of interest to compare these calculated exposures to those corresponding to a "no action" case in regard to intruder exposures. In Chapter 4, "a base case" is considered in which no consideration is given to intruder exposures. Two waste streams included in this base case analysis--L-DECONRS and N-SOURCES--were excluded from cases 1 through 10 on Table M.9 due to the transuranic content of these streams. In addition, no consideration is given in the "no action case" to disposing of higher activity waste streams by methods, such as layering, that provide a barrier against intrusion. The corresponding waterborne erosion impacts are shown below in Table M.10 for waste spectrum 1. As can be seen, the calculated results for the base (no action) case are significantly higher (two orders of magnitude) for all organs except thyroid. In general, layering of the higher activity waste streams results in thyroid exposures of 10 less than the base case.

3.2 Wind Erosion

The mechanism for mobilization of particulates from soil by wind depends upon such factors as wind speed, soil properties, and the nature of the soil surface. Wind action results in three basic modes of particle motion: surface creep (particulates above approximately 500 μm in size), saltation (particles between approximately 100 μm and 500 μm in size), and airborne suspension (particles less than about 100 μm in size). Under surface creep, particles are rolled along the surface by the push of strong winds and by exchange of momentum after impact with smaller particles in saltation. Saltation consists of individual particles jumping and lurching within a few centimeters of the ground. Particles borne by airborne suspension may be carried through the atmosphere for long

Table M.9 Waterborne Radiological Impacts Assuming Erosion of the Facility Designs Considered in Chapter 5 Case Study

	Organ						
Case	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(millirems/yr to an individual)							
1	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
2	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
3	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
1A	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
4A	5.36E-2	4.63E-1	7.59E-2	1.19E-1	9.15E-2	4.25E-2	7.26E-2
4B	5.36E-2	4.63E-1	7.59E-2	1.19E-1	9.15E-2	4.25E-2	7.26E-2
4C	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
4D	4.74E-2	4.15E-1	6.34E-2	1.14E-1	7.62E-2	3.78E-2	6.53E-2
4E	4.74E-2	4.15E-1	6.34E-2	1.14E-1	7.62E-2	3.78E-2	6.53E-2
5	5.23E-2	4.56E-1	9.06E-2	8.79E-1	6.11E-2	2.37E-2	1.17E-1
6	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
7A	6.42E-2	4.93E-1	7.81E-2	9.73E-2	9.73E-2	5.33E-2	8.13E-2
7B	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
7C	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
7D	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
8	7.49E-2	6.35E-1	1.28E-1	9.82E-1	9.37E-2	4.02E-2	1.68E-1
9	4.69E-2	4.29E-1	8.52E-2	8.74E-1	5.57E-2	1.82E-2	1.11E-1
10A	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
10B	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
10C	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1
12A	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
12B	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
12C	9.74E-2	7.75E-1	1.61E-1	9.98E-1	1.31E-1	6.03E-2	1.94E-1
12D	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1
12E	9.74E-2	7.75E-1	1.61E-1	9.98E-1	1.31E-1	6.03E-2	1.94E-1
12F	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1

Table M.10 Waterborne Erosion Impacts for the Base Case

Organ Exposures (millirem/yr)						
Body	Bone	Liver	Thyroid	Kidney	Lung	GI
3.203	171.2	17.36	1.036	14.50	0.424	10.17

periods and to great distances from their original location. The mechanism by which fine particles are lifted off the ground is different from that of saltation. Samples of soil composed only of fine dust particles may be extremely resistant to wind erosion, but in mixtures with coarser grains these particles move readily. Thus, suspension of fine dust in air may be primarily the results of movement of grains in saltation (Ref. 7).

Calculational procedures are available to estimate the soil loss (in gm/m^2-sec) from an exposed area. Such calculations depend upon such factors as soil erodibility, soil-ridge roughness, climate, and the presence of a cover which would preclude or greatly reduce wind erosion. As in the case of water erosion, such covers could include application of a vegetative cover or a layer of gravel, rocks, or rip-rap. At the reference disposal facility, the soil loss for bare soil is calculated to be 4.1 E-7 g/m^2-sec. Assuming a soil density of 1.6 gm/cm^3 and a trench cover thickness of 2 meters, this implies that the wind erosion rate of a bare cover would be about 0.001 cm/yr. This would imply that it would take 250,000 years for the waste to become exposed. A longer period of time would be necessary to expose the waste if stabilizing soil covers such as a layer of rocks are applied.

However, for the purposes of bounding potential exposures due to water erosion, it was previously assumed that wastes would be exposed at a time period equal to 1,000 years per meter of cover. Given this assumption, a bounding estimate of the impacts of wind erosion at the reference disposal facility can be estimated. Similarly to the water erosion case, the equations for calculating total volume of soil/waste mixture assumed to be mobilized after a long time period (2,000 years for the reference case) are described in Appendix G.

Conservatively assuming no credit for waste form, the total population exposures within 50 miles of the facility are calculated for each of the case study cases in Chapter 5 and presented in Table M.11. The population is again assumed to be three times the size of the population within the vicinity of the facility while the facility is operating. As can be seen, such exposures are very small and are an order of magnitude or so below those exposures calculated during the hypothetical operation of a regional incinerator (1870 man-millirem/yr).

The exposures calculated and presented in Table M.11 can again be compared with those corresponding to the base (no action) case considered in Chapter 4. For random disposal, a thin cover, and waste spectrum 1, these exposures are calculated to be as shown in the following Table M.12.

Table M.11 Airborne Radiological Impacts Assuming Erosion of the Facility Designs Considered in Chapter 5 Case Study

	Organ						
Case	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(man-millirem/yr)							
1	4.19	80.13	55.32	5.38	21.21	76.43	0.21
2	4.19	80.13	55.32	5.38	21.21	76.43	0.21
3	4.19	80.13	55.32	5.38	21.21	76.43	0.21
1A	4.19	80.13	55.32	5.38	21.21	76.43	0.21
4A	4.19	80.01	55.24	5.37	21.18	76.31	0.21
4B	4.19	80.01	55.24	5.37	21.18	76.31	0.21
4C	3.48	69.52	46.05	5.36	16.14	74.39	0.19
4D	3.48	69.46	46.01	5.35	16.13	74.33	0.19
4E	3.48	69.46	46.01	5.35	16.13	74.33	0.19
5	4.23	84.87	55.02	58.67	18.02	84.85	0.24
6	3.48	69.46	46.01	5.36	16.14	74.39	0.19
7A	3.11	59.29	40.19	3.17	15.21	70.66	0.23
7B	7.31	137.6	95.00	64.53	36.03	111.9	0.38
7C	7.31	137.6	95.00	64.53	36.03	111.9	0.38
7D	6.11	119.8	79.40	64.51	27.50	108.6	0.35
8	6.09	119.8	79.50	64.58	27.51	108.8	0.32
9	4.22	84.81	55.01	58.66	18.01	84.84	0.22
10A	3.48	69.52	46.05	5.36	16.14	74.39	0.19
10B	6.11	119.8	79.40	64.51	27.50	108.6	0.35
10C	6.10	119.5	79.22	64.36	27.43	108.4	0.35

Table M.12 Airborne Erosion Impacts for the Base Case

Organ Exposures (man-millirems/yr)

Body	Bone	Liver	Thyroid	Kidney	Lung	GI
2.61E+3	5.48E+4	3.60E+4	65.80	1.18E+4	4.15E+4	54.28

The base case (no action) exposures are again seen to be one or more orders of magnitude higher.

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Appendix N

ANALYSIS OF EXISTING RECOMMENDATIONS, REGULATIONS AND GUIDES

INTRODUCTION

This appendix reviews a number of proposed and promulgated NRC and EPA regulations and guidance which may be applicable to LLW disposal. Recommendations by the National Council on Radiation Protection and Measurements (NCRP), International Commission on Radiation Protection (ICRP), and the Federal Radiation Council (FRC) are also briefly reviewed. The regulations, recommendations, and guidance documents reviewed include those for radiation protection, surface contamination, ground-water protection, and disposal of solid and chemically hazardous waste.

1. NUCLEAR REGULATORY COMMISSION REGULATIONS

1.1 10 CFR 20: Standards for Protection Against Radiation

The NRC regulation, 10 CFR 20, provides standards for control of and limitations for release of radioactive materials to the environment from operations of NRC-licensed facilities, as well as limitations on allowable radiation doses to radiation workers and the public. The regulation was originally promulgated in the late 1950s, and has been subsequently revised a number of times. Although originally 10 CFR 20 was based on the recommendations of the NCRP and ICRP, subsequent guidance has been provided by the FRC. The FRC has been incorporated into the Environmental Protection Agency (EPA). NRC is currently considering a wholesale restructuring and modernization of the regulations. A Federal Register notice requesting public input on the potential areas of change was issued by NRC in March 1980 (Ref. 1).

The principal limits for exposure of radiation workers (exposure to individuals in restricted areas) are as follows:

	Rems per Calendar Quarter	
1.	Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1-1/4
2.	Hands and forearms; feet and ankles	18-3/4
3.	Skin of whole body	7-1/2

However, an individual in a restricted area may receive a whole body dose up to and including 3 rems, provided that the whole body dose, when added to the accumulated occupational whole body dose, does not exceed 5 x (N - 18) rems. As used here, N equals the individual's age in years at his last birthday, and "whole body dose" is deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye. More restrictive

requirements--that is, a factor of 10 lower--are in effect for individuals (minors) less than 18 years of age. The regulation also provides limits on airborne concentrations of radioactive materials in restricted areas.

Section 20.105 concerns permissible levels of radiation in unrestricted areas (0.5 rem/year to the whole body of any individual). In addition, paragraph 20.105(b) places limits on allowable hourly and weekly exposure rates to individuals in unrestricted areas. These are:

- 2 mrem in any one hour; or
- 100 mrem in any 7 consecutive days.

In addition, the regulation provides a table of maximum permissible concentrations (MPC) of radionuclides in air and water from releases to unrestricted areas. These MPC values are contained in Appendix B, Table II of the regulation and were calculated based upon a maximum potential dose to the whole body of an individual of 500 mrem/year. Limits for other organs include 500 mrem/yr to blood-forming organs, 3000 mrem/yr to bone surfaces, and 1500 mrem/yr to other organs except thyroid. For thyroid, a limit of 3000 mrem/yr was used except for exposures from radioiodine, for which a limit of 1500 mrem/yr to a child's thyroid was used.

Fairly recently, NRC published a proposed rule regarding amending its regulations to incorporate the existing requirement for certain uranium fuel cycle licensees to comply with the EPA regulation 40 CFR Part 190: "Environmental Radiation Protection Standards for Nuclear Power Operators." This rule requires that most uranium fuel cycle facilities be operated so that release of radioactive materials and resulting radiation doses to the public be below limits set in 40 CFR Part 190. (These limits are discussed in Appendix N, Section 2.2.) The proposed rule also requires licensees to submit reports to NRC when those standards have been or may be exceeded (Ref. 2).

Of importance for the standards for exposure to workers and to individuals in unrestricted areas is a further requirement that all potential exposures must not exceed the standards, but should also be maintained to levels "as low as reasonably achievable" (ALARA). This standard is applied in individual licensing actions to assess the licensee's operations. In the application of the standard, costs and other social considerations are taken into account.

Sections 20.106 and 20.301-20.305 of Part 20 contain requirements on radioactive waste disposal, where, as used in these paragraphs the term "disposal" may mean:

- transfer to another authorized licensee (20.301);
- disposal by a manner not otherwise authorized (20.302);
- release into sanitary sewerage systems (20.303);

- release in effluents to unrestricted areas (20.106 and 20.301); and
- treatment or disposal by incineration (20.305).

In a recent modification to Part 20, NRC amended the requirements in Sections 20.301, 20.303, and 20.305, and added a new Section 20.306, to permit licensees greater leeway in disposal of some wastes (Ref. 4). In the rule, licensees are allowed to dispose of liquid scintillation media and animal carcass waste having concentrations of tritium or ^{14}C not in excess of 0.05 microcuries per gram without regard to its radioactivity. That is, such wastes may be disposed by such means as discharge into ordinary refuse channels (e.g., into a sanitary landfill) or, depending upon the chemical hazard of the waste, by disposal into a hazardous waste facility. In addition, the allowable annual quantities of tritium and ^{14}C disposed into the sanitary sewerage system was raised to five curies for tritium and one curie for ^{14}C.

Licensing of disposal of LLW into licensed burial facilities is currently accomplished through Section 20.302, as well as portions of Parts 30, 40, and 70. The regulations in Section 20.302, which provide only general guidance of an administrative nature, are quoted below:

> "20.302 Method for obtaining approval of proposed disposal procedures.
>
> "(a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.
>
> "(b) The Commission will not approve any application for a license to receive licensed material from other persons for disposal on land not owned by the federal government or by a state government.
>
> "(c) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal."

Finally, 10 CFR 20 contains a number of other criteria and requirements related to radiation protection. These include requirements on surveys, personnel monitoring, and posting; requirements for records, reports, and notification; and requirements on receipt and shipment of packages containing radioactive material.

1.2 10 CFR 50, Appendix I: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low as is Reasonably Achievable" for Radioactive Material In Light-Water-Cooled Nuclear Power Reactor Effluents

This appendix provides an operator of a nuclear power plant with guidance regarding demonstration that the impacts of radioactive liquid and airborne effluents have been reduced to levels as low as is reasonably achievable (ALARA). Design objectives and limiting conditions of operation which correspond to the guidelines in the appendix are considered a conclusive demonstration that the ALARA requirement has been achieved. Information regarding the development of Appendix I can be found in Docket file RM-50-2 and in the final environmental statement on the rulemaking action (Ref. 5).

The design objectives and limiting conditions of operation for a reactor must be such that reasonable assurance is provided that the liquid and airborne effluents from the plant will not cause the annual dose or dose commitment to any person in an unrestricted area to exceed certain criteria. These criteria are:

- Liquid effluent: 3 mrem to the total body or 10 mrem to any organ; and
- Airborne effluent: 5 mrem to the total body or 15 mrem to the skin from effluent existing as a gas (for example, Kr-85); 15 mrem to any organ from radioactive iodine; or 15 mrem to any organ from particulate activity.

In addition to the criteria listed above, an applicant or operator shall "include in the radwaste system all items of reasonably demonstrated technology that, when added to the system sequentially and in order of diminishing cost-benefit return, can for a favorable cost-benefit ratio effect reduction in dose to the population reasonably expected to be within 50 miles of the reactor." As an interim measure, the values $1,000 per total body man-rem and $1,000 per man-thyroid-rem were proposed as values to use in the cost-benefit analysis.

1.3 10 CFR 100.11: Determination of Exclusion Area, Low Population Zone, and Population Center Distance

Dose limits are used in 10 CFR 100.11 for determination of reactor exclusion areas and low population zones. These limitations are 25 rem to the whole body or 300 rem to the thyroid from iodine exposure, assuming a major accident which results in release of appreciable quantities of fission products. As noted in 10 CFR 100, the whole body dose of 25 rems corresponds numerically to the maximum dose recommended by the National Council on Radiation Protection and Measurements (NCRP) for a once-in-a-lifetime accidental or emergency dose to radiation workers. The dose guides are intended as an aid in evaluating a proposed power reactor site with respect to potential reactor accidents of exceedingly low probability of occurrence, and low risk of public exposure to radiation. The dose limits set forth in 10 CFR 100.11 are not meant to imply

that the numbers constitute acceptable limits for emergency doses to the public under accident conditions.

2. ENVIRONMENTAL PROTECTION AGENCY (EPA) RADIATION PROTECTION CRITERIA, STANDARDS, AND GUIDELINES

Since Reorganization Plan Number Three of 1970, the Environmental Protection Agency (EPA) has been responsible for providing federal radiation protection guidance and establishing generally applicable environmental standards. In so doing, EPA has taken over the functions of the Federal Radiation Council. Of special interest to NRC's development of radioactive waste management and disposal regulations is EPA's development of overall criteria and standards for waste disposal. In 1978, EPA issued a proposed set of general "umbrella" criteria applicable to all radioactive waste. These general criteria, discussed below, have not been finalized. EPA also intends to issue a set of numerical environmental standards for specific waste types over the next few years. As outlined in the Final Interagency Review Group Report to the President, EPA planned to develop the following specific standards (Ref. 5):

High-level waste (1979)

Transuranic waste - stable form (1979)

Interim guidance - active uranium mills (1979)

Inactive uranium mill tailings (1979)

Airborne pollutants associated with uranium mill tailings (1980)

Residual activity - decommissioning (1981)

Transuranic waste - other forms (1982)

Low-level waste - shallow land burial (1983)

Low-level waste - sea disposal container standard (1983)

Active uranium mill standard (1985)

Specific schedules for certain of these standards have been published in the Calendar of Federal Regulations published in the Federal Register. The April 27, 1981 issuance (46 FR 23692) does not list a specific schedule for the LLW standard. Based on discussion with EPA staff, however, the standard for LLW disposal by shallow land burial is scheduled to be published in draft in 1982 and in final in 1983 and the schedule will be published in the October Federal Register Calendar. The HLW standard has been drafted and is scheduled for publication shortly. Also of interest is EPA's interim standards for cleanup of inactive uranium mills and tailings. These standards, discussed below, were published in April 1980 and January 1981.

Other standards and guidance on radioactive materials issued by EPA and of interest to NRC's development of long-term performance objectives are:

- o 40 CFR 190: Environmental Radiation Protection Standards for Nuclear Power Operations; and
- o Proposed Federal Radiation Protection Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the Environment.

These standards and guides are also discussed below.

2.1 Proposed Recommendations for Federal Radiation Guidance: Criteria for Radioactive Waste

Proposed guidance for federal agencies regarding management or regulation of radioactive waste material were issued by the EPA in November 1978 (Ref. 7). Comments were requested from the public to be used in the formulation of the final criteria and recommendations to the President for approval. Final criteria are not planned by EPA.

The intent of the criteria was to establish the basic principles to be applied by federal agencies for the formulation of policies, plans, programs, and decisions involving the management and disposal of radioactive waste. The proposed guidelines issued by EPA included the following:

1. Radioactive materials should be considered radioactive wastes requiring control for environmental and public health protection if they have no designated product or resource value and: (a) are human-produced by nuclear fission or activation, fabricated from naturally occurring radioactive materials into discrete sources or, as a result of regulatory activities, are prohibited from uncontrolled discharge into the environment; or (b) contain diffuse naturally occurring radioactive materials that, if disposed into the biosphere, would increase exposure to humans above that which would occur due to the preexisting natural state of the area.

2. The fundamental goal for controlling any type of radioactive waste should be complete isolation over its hazardous lifetime. Controls which are based on institutional functions should not be relied upon for longer than 100 years to provide such isolation; radioactive wastes with a hazardous lifetime longer than 100 years should be controlled by as many engineered and natural barriers as are necessary.

3. Radiation protection requirements for radioactive wastes should be based primarily on an assessment of risk to individuals and populations; such assessments should be based on predetermined models and should examine at least the following factors:

   - o The amount and concentration of radioactive waste in a location and its physical, chemical, and radiological properties;

- The projected effectiveness of alternative methods of control;
- The potential adverse health effects on individuals and populations for a reasonable range of future population sizes and distributions, and of uses of land, air, water, and mineral resources for 10,000 years or any shorter period of hazardous persistence;
- Estimates of environmental effects using general parameters or of health effects based on generalized assumptions for as long as the wastes pose a hazard to humans, when such estimates could influence the choice of a control option;
- The probabilities of releases of radioactive materials to the general environment due to failures of natural or engineered barriers, loss of institutional controls, or intrusion; and
- The uncertainties in the risk assessments and models used for determining them.

4. Any risks due to radioactive waste management or disposal activities should be deemed unacceptable unless it has been justified that the further reduction in risk that could be achieved by more complete isolation is impracticable on the basis of technical and social considerations; in addition, risks associated with any given method of control should be considered unacceptable if:
   - Risks to a future generation are greater than those acceptable to the current generation;
   - Probable events could result in adverse consequences greater than those of a comparable nature generally accepted by society; or
   - The probabilities of highly adverse consequences are more than a small fraction of the probabilities of high consequence events associated with productive technologies which are accepted by society.
5. Locations for radioactive waste disposal should be chosen as to avoid adverse environmental and human impacts and, wherever practicable, to enhance isolation over time.
6. Certain additional procedures and techniques should also be applied to waste disposal systems which otherwise satisfy these criteria if use of these additional procedures and techniques provides a net improvement in environmental and public health protection. Among these are:
   - Procedures or techniques designed to enhance the retrievability of the waste; and

- o Passive methods of communicating to future people the potential hazards which could result from an accidental or intentional disturbance of disposed radioactive wastes.

2.2 40 CFR 190: Environmental Radiation Protection Standards for Nuclear Power Operations

This regulation provides environmental radiation dose standards for operations which are part of the uranium nuclear fuel cycle. Specifically excluded from this regulation are uranium mining operations, operations at waste disposal sites, transportation of radioactive material in support of these operations, and the reuse of recovered nonuranium special nuclear and byproduct materials from the cycle. Background information on the rationale for the standard can be found in the environmental statement on the rule (Ref. 8).

The standards state that operations in the nuclear fuel cycle shall be such to provide reasonable assurance that:

"(a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as a result of exposures to planned discharges of radioactive materials, radon and its daughters expected, to the general environment from uranium fuel cycle operations and to radiation from these operations.

(b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of ^{85}Kr, 5 millicuries of ^{129}I, and 0.5 millicuries combined ^{239}Pu and other alpha-emitting transuranic radionuclides with half-lives greater than one year."

The effective date of standard (a) above was December 1, 1979, except for doses arising from uranium milling operations (effective on December 1, 1980). The effective date of standard (b) above was December 1, 1979, except for ^{85}Kr and ^{129}I (effective on January 1, 1980).

2.3 Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the Environment

This guidance, proposed by the EPA in November 1977, provides radiation protection guidance to federal agencies for persons potentially exposed to transuranics in the environment as a result of existing or possible future planned contamination (Ref. 9). The proposed guidelines state that the recommendations should be used only for guidance on possible remedial actions in incidences of presently existing or possible future contamination from transuranic elements. The guidelines further state that the guidance should not be used by federal agencies as limits for planned releases of transuranic elements into the general environment.

The following is the text of the proposed numerical recommendations: "The annual alpha radiation dose rate to members of the critical segment of the exposed population as the result of exposure to transuranium elements in the general environment should not exceed either:

1. 1 millirad per year to the pulmonary lung; or

2. 3 millirad per year to the bone."

In the guideline, the "critical segment of the exposed population" means that group of persons within the exposed population receiving the highest radiation dose to the lung or bone.

EPA states that the dose limits contained in the guidelines should be applied above those levels currently existing in the environment as a result of fallout from the testing of atomic weapons. EPA believes that the guidelines will achieve adequate health protection for the small fraction of the total population at greatest risk from exposure of transuranic elements. EPA further states that the guidelines will therefore provide much greater protection to the vast majority of the population at lesser risk. As stated in the proposed guidance, "the risk at the proposed guidance level is estimated to be less than one chance in a million per year and less than 10 chances per hundred thousand in a lifetime that an individual would develop a cancer from continuous exposure at the stated dose rates."

2.4 40 CFR 192: Standards for Cleanup of Inactive Uranium Processing Sites

According to the requirements of Public Law 95-604 (The Uranium Mill Tailings Radiation Control Act of 1978, or UMTRCA), EPA must establish environmental standards for the cleanup of open lands and buildings contaminated with residual radioactive materials (mainly tailings) from inactive uranium processing sites. In accordance with the standards, the Department of Energy (DOE) must conduct remedial actions (also required by UMTRCA) for designated inactive uranium processing sites.

Based on this legislative mandate, the EPA issued on April 22, 1980 a set of interim cleanup standards for inactive uranium processing sites (Ref. 10). The issuance of the immediately effective interim standards will allow DOE to begin remedial actions on the inactive sites. On the same day, EPA also issued a Federal Register notice in which the interim standards were proposed as a rule (Ref. 11). Comments from the public were requested on the proposed standards. More recently, in January 1981, EPA published proposed disposal standards for the inactive sites. A draft environmental impact statement was prepared and was issued along with the proposed rule (Refs. 12, 13).

The proposed cleanup standards are identical with the interim standards and require that remedial actions lower the average concentration of radium-226 in contaminated soil below 5 pCi/gm. In the rule, the 5 pCi/gm standard is to be measured at (1) any 5 cm thickness of soils or other materials on open land within 1 foot of the surface, or (2) any 15 cm thickness below 1 foot. Limits are also proposed on the radon decay product concentration and gamma radiation

in occupied or occupiable buildings affected by tailings. The limits are the following:

- The average annual indoor radon decay product concentration, including background, shall not exceed 0.015 working levels (WL).
- Indoor gamma radiation, above background, shall not exceed 0.02 milliroentgen per hour.

A working level (WL) is a measure of the concentration of radioactivity in the air rather than how much radiation exposure a person receives. The concept of a WL grew out of a functional need to measure airborne radioactivity concentrations in mining operations and is defined by EPA as "any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts" (Ref. 10). One working level month (WLM) means the exposure to one WL for 170 hours, which is the number of working hours in a month based on a 40-hour working week.

Although EPA does not set a yearly allowable dose rate in the interim and proposed cleanup standards, EPA does observe as part of supplementary information to the standards that 0.02 mrad of gamma exposure per hour corresponds to 130 mrad/year to the average person. As noted by EPA, this assumes that the person spends 75 percent of his time in a structure where he receives the maximum hourly dose. (Note that 100 percent occupancy would correspond to 175 mrad/year.) EPA also notes that continuous exposure to 1 WL for an average person corresponds to 27 WLM in a year, and that one WLM is roughly equivalent to 0.5 rad to the lung (Ref. 10). This corresponds to roughly 200 mrad/year of alpha exposure to the lung for continuous occupancy of a building at 0.015 WL (about 150 mrad/year at 75 percent occupancy).

3. RECOMMENDATIONS OF THE NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS (NCRP)

The National Council on Radiation Protection and Measurements (NCRP) was originally formed in 1929 as the Advisory Committee on X-Ray and Radium Protection. Since that time, the NCRP has published numerous reports and recommendations on radiation protection and can be considered an authority in this country on radiation protection standards. During this time, the NCRP has worked closely with the International Commission on Radiation Protection (ICRP).

One of the more recent reports issued by NCRP is their Basic Radiation Protection Criteria Report No. 39, which was published on January 15, 1971 (Ref. 14). This report represents a culmination of NCRP review and reevaluation of the basic overall radiation protection criteria which were established by that organization in 1949 and amended in 1957.

NCRP Report No. 39 contains numerical recommendations on permissible levels of radiation dose equivalents received by workers, individuals, and populations.

These numerical recommendations are summarized below. In NCRP-39, recommendations are also made regarding permissible radiation exposures for emergency--including life saving--situations. These include the following:

Maximum Permissible Dose Equivalents for Occupational Exposure

Combined whole body:		
o	Prospective annual limit	5 rems in any one year
o	Retrospective annual limit	10-15 rems in any one year
o	Long-term accumulation	(N - 18) x 5 rems, where N = age in years
Skin		15 rems in any one year
Hands		75 rems in any one year
Forearms		30 rems in any one year
Other organs, tissues and organ systems		15 rems in any one year
Fertile women		0.5 rems in gestation period

Dose Limits for the Public, or Occasionally Exposed Individuals

Individual or occasional	0.5 rems in any one year
Students	0.1 rems in any one year

Population Dose Limits

Genetic	0.17 rems average per year
Somatic	0.17 rems average per year

In establishing the limits for individual members of the public, NCRP notes that experience in many large institutions has indicated that with a worker occupational limit of 5 rems/year, only a very small fraction of the potentially exposed workers would be actually expected to receive a yearly dose equivalent in excess of a tenth of 5 rems. NCRP asserts, therefore, that if an individual member of the public (or an occasionally exposed individual) were to be limited to 500 mrem/year, then the potential dose to an average individual would be expected to be much less--for example, at least a factor of 10 less.

In making this recommendation,* NCRP writes:

> ". . .the incremental radiation received by an individual is at most some four to five times the natural radiation, and is less than twice the existing background in some situations. With an intended limit of 0.5 rem per year for most, if not all, situations, the average incremental dose to population groups from radiation plants and installations would probably easily stay below 0.1 rem per year, comfortably within the limit that consideration of genetic effects sets for the whole populations."

In NCRP-39, NCRP further considers doses to populations. In this report, NCRP recommends that "dose equivalent to the gonads for the population of the United States as a whole from all sources of radiation other than natural radiation, and radiation from the healing arts shall not exceed a yearly average of 0.17 rem (170 mrem) per person." An identical recommendation is made as part of somatic considerations for potential doses to the critical organs (whole body). The recommended 170 mrem to the gonads was basically responsive to the 1956 recommendation of the National Academy of Science Committee on the Biological Effects of Atomic Radiation for an average maximum (per person) of 10 rems total exposure over the first 30 years of life. About half of this exposure was attributed to natural and medical-dental radiation. For manmade sources of radiation, therefore, a total exposure to the gonads of 5 rems over 30 years corresponds to a level of approximately 170 millirem/year.

The recommended limit for gonadal protection was then extended to the whole body as a practical simplification. In extending this limit to whole body (critical organs) considerations, NCRP states that they expect that the average population limit of 170 mrem (along with the dose limit of 500 mrem per year for any critical organ of an individual member of the public) will effectively control the actual population exposures to levels well below the given limit.

A more recent NCRP report, entitled "Review of the Current State of Radiation Protection Philosophy" (NCRP-43), was issued in January 1975 (Ref. 15). This document is essentially a position paper written in response to issues raised in reports published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (Ref. 16) and the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR Committee) (Ref. 17). These reports treated the estimation of risks arising from exposure to ionizing radiation and essentially reached the same numerical results for radiation levels at which observations are available. However, there were differences in philosophy and divergent conclusions regarding the estimation of risk associated with low-level dose rate radiation.

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*This recommendation is consistent with the earlier (1957) recommendation that the maximum dose in the general population be limited to 0.5 rem per year. In making this recommendation, NCRP held that no member of the public should be exposed at levels more than a factor of ten less than the recommended permissible annual occupational dose of 5 rems, as applied to the gonads, blood-forming organs, whole body, head, or trunk.

Based upon its analysis of the two reports and upon review of work available since the publishment of NCRP-39, the Council concluded that no change is required at that time in the conclusions set out in NCRP-39. In so concluding, the Council stated:

> "The NCRP continues to hold the view that risk estimates for radiogenic cancers at low doses and low dose rates derived on the basis of linear (proportional) extrapolation from the rising portions of the dose-incidence curves at high doses and high dose rates, as described and discussed in subsequent sections of this report, cannot be expected to provide realistic estimates of the actual risks from low level, low-LET radiations, and have such a high probability of overestimating the actual risk as to be of only marginal value, if any, for purposes of realistic risk-benefit evaluation.
>
> Such risk estimates by themselves do not consitute justification for urgent action to make numerical radiation protection standards more restrictive than they now are, assuming that the application of such standards adheres to the basic principle of lowest practicable levels of dose."

Also of interest is NCRP's Report No. 45, entitled "Natural Background Radiation in the United States" (November 15, 1975). This report presents a fairly comprehensive picture of the variations in exposures in the United States due to natural background radiation. Included are exposures from cosmic radiation and cosmic ray-produced radiation, direct inhalation and ingestion exposures from radionuclides found in the earth's crust, exposures due to fallout from nuclear weapon test programs, and exposures due to nuclear energy. Of interest is the great variability in natural radiation sources and potential exposures that can be received (Ref. 18).

4. RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP)

The International Commission on Radiological Protection (ICRP) is a body which reviews and analyzes potential health effects of ionizing radiation and publishes international recommendations for protection from ionizing radiation. Established in 1928 by the Second International Congress of Radiology, the ICRP was reorganized into its present structure in 1950. Over the years, the ICRP has issued a number of reports, recommendations, and guidance documents on radiation protection.

A recent and significant set of recommendations regarding basic radiation protection criteria were issued in 1977 as ICRP-26, which was issued based upon a review of new information which had emerged over the previous decade (Ref. 19). In this report, ICRP makes two major changes from previous recommendations as regards to (1) maximum recommended dose limits for individual organs, and (2) maximum limits for exposure to populations. Prior to discussing the recommendations contained in ICRP-26, however, it is instructive to briefly consider the development of the earlier recommendations.

The first recommendations of the ICRP were published in 1928, with additional reports following in 1931, 1934, and 1937. Following the 1950 reorganization, basic recommendations were issued in 1951, 1955, and 1959. The 1959 recommendations were published as ICRP-2 ("Report of Committee II on Permissible Dose for Internal Radiation"), and for 20 years served as a basic guide for the control of intakes of radionuclides into the body (Ref. 20). (The report was eventually superseded in 1979 by ICRP-30, discussed below.) These recommendations were subsequently subject to relatively minor revisions as newer data became available, and one such revision is ICRP-6, published in 1964 (Ref. 21).

In ICRP-6, the recommended maximum radiation level to individual members of the population at large is 0.5 rem per year to the gonads and blood-forming organs. In this report, the population at large is assumed to contain children. The recommended doses to other organs and tissues and to the extremities is one-tenth of the corresponding annual occupational dose. In the report, ICRP also recommends that the total genetic dose to the whole population from all sources in addition to natural background and medical exposures should not exceed 5 rem. The genetic dose to the population is taken as the dose received by each person from conception to the mean age of child bearing (30 years). A level of 5 rems per person over 30 years, therefore, corresponds to an average dose of 170 mrem/year.

ICRP-9, issued in 1965, was based upon a further review of ICRP's recommendations (Ref. 22). Substantive changes in recommended protection criteria for individuals and populations were relatively minor. Amendments to ICRP-9 were later issued in 1969 and 1971 (Ref. 19).

A summary of ICRP's recommended individual dose limits as of 1970 are included below (Ref. 23):

Summary of Dose Limits for Individuals

Organ or Tissue	Maximum Permissible Doses for Adults Exposed in the Course of Their Work	Dose Limits for Members of the Public
Gonads, red bone marrow	5 rems in a year	0.5 rems in a year
Skin, bone, thyroid	30 rems in a year	3 rems in a year*
Hands and forearms, feet and ankles	75 rems in a year	7.5 rems in a year
Other single organs	15 rems in a year	1.5 rems in a year

*1.5 rems in a year to the thyroid of children up to 16 years of age.

In ICRP-26, the Commission recommends a system of dose limitation, based upon the following criteria (Ref. 19):

"(a) No practice shall be adopted unless its introduction produces a positive net benefit;

(b) All exposures shall be kept as low as reasonably achievable, economic and social factors taken into account; and

(c) The dose equivalent shall not exceed the limits recommended for the appropriate circumstances by the Commission."

Based on these criteria, the Commission analyzes and makes recommendations on numerical dose-equivalent limits for workers (including occupational exposure of women of reproductive capacity and of pregnant women), for individual members of the public, and indirectly, exposure of populations.

In ICRP-26, the Commission retains the principal of accounting for the fact that different organs have different susceptabilities to radiation damage. However, rather than providing a list of maximum dose limits for individual organs, ICRP proposes a system whereby different organs would be assigned different weighting factors. Doses to each organ would be multiplied by the appropriate weighting factors and summed to obtain the equivalent whole body dose. The recommended occupational whole body dose limit is 5 rem/year. The recommended whole body dose limit for individual members of the public is 0.5 rem/year. The weighting factors (W_T) for the respective organs are:

gonads	0.25
breast	0.15
red bone marrow	0.12
lung	0.12
thyroid	0.03
bone surface	0.03
remainder	0.30

Thus, if only the breast were exposed, for example, an acceptable annual occupational exposure to the breast of a radiation worker would be 5 rem ÷ 0.15 = 33.3 rems. The Commission also recommends a value of $W_T = 0.06$ for each of the five organs or tissues receiving the highest dose equivalents. The exposure of all other remaining tissues can be neglected.

Similarly, the Commission recommends a total maximum whole body dose to individual members of the public of 0.5 rem/year. This corresponds to a fatal risk of an order of magnitude lower than that for occupational workers, or 10^{-6} to 10^{-5} per year. The weighting factors would again be utilized as discussed above.

ICRP also drops their previous recommended dose limit of 170 mrem to populations, stating that such a recommendation is not really needed to protect populations. The Commission believes that application of the 500 mrem/year dose equivalent whole body dose limit to individual members of the public would be likely to result in an average dose equivalent to the public of greater than an order of magnitude less (i.e., less than 50 mrem/year), provided that the practices exposing the public are few and cause little exposure outside the critical groups. Thus, the Commission believes that protection of an individual member of the public to a level of 0.5 rem/year (whole body), will ensure protection of populations.

Also of interest is the recently published ICRP-30, "Limits for Intakes of Radionuclides by Workers," a document that supersedes ICRP-2 (Ref. 24). In ICRP-30, annual limits for intakes (ALIs) of radionuclides are recommended. (ICRP defines an ALI as "the activity of a radionuclide which taken alone would irradiate a person, represented by Reference Man, to the limit set by the ICRP for each year of occupational exposure.") The system of dose limitation presented by the Commission in ICRP-30 takes account of all body tissues that are irradiated following intake of radioactive material rather than the former practice of only considering critical organs. The system is intended to ensure that the total risk from irradiation of any combination of organs does not exceed the equivalent whole body risk. The ALIs for some radionuclides are greater than others and are smaller than the equivalent ALIs that would be derived from the methodology in ICRP-2. These changes have principally resulted from improved knowledge of sensitivity of organs to radiation damage and of uptake and retention of radionuclides in bodily tissues, as well as the radioactive decay schemes of some radionuclides.

ICRP-30 also considers radiation risks. The recommended dose-equivalent risk for the lens of the eye is reduced from 0.3 Sv per year to 0.15 Sv per year. In addition, the document summarizes the Commission's review of additional epidemiological and radiobiological information available between May 1978 and March 1980. Aside from the recommendation regarding the eye lens, the Commission concludes that no change is called for from the recommendations in ICRP-26 regarding risk factors for stochastic effects or dose-effect relationships for nonstochastic effects basing the ICRP-26 dose-equivalent limits.

ICRP-30 is being issued in several parts, including supplements. Part 1, published in 1979, describes the dosimetric methods used and presents ALIs and metabolic data on twenty-one elements having isotopes that are significant in terms of radiation protection. A supplement to Part 1 contains further data regarding the radionuclides considered. Part 2 of ICRP-30, published in 1980, presents ALIs and metabolic data for an additional 30 elements. Similar data for 44 additional elements will be provided in Part 3.

5. RECOMMENDATIONS OF THE FEDERAL RADIATION COUNCIL (FRC)

The Federal Radiation Council (FRC) was formed in 1959 in the United States as a federal policy making group on health aspects due to exposure to ionizing radiation. In discharging its duties, the FRC has consulted such qualified organizations as the ICRP, NCRP, and National Academy of Science. FRC's basic

recommendations for radiation exposure is contained in their Report No. 1 issued in 1960 (Ref. 25). In these recommendations, FRC essentially adopted the NCRP recommendation that the dose to the whole body of the maximally exposed individual in the population should have a limit of 0.5 rem. In making this recommendation, FRC adopted the terminology of Radiation Protection Guides for exposure.

The FRC also considered population doses and a factor of 3 was recommended to allow for variations in radiation susceptibility of different groups in the general population to radiation effects (for example, the susceptibility of different age groups, sexes, and genetic backgrounds). Thus, FRC recommended an average yearly population exposure limit of 170 mrem (whole body), with a strong caveat that the limit be used with reason and judgment. As stated by the FRC..."it is noted that the use of the average figure, as a substitute for evidence concerning the dose to individuals, is permssible only when there is a probability of appreciable homogeneity concerning the distribution of the dose within the population included in the average." The figure of 170 mrem/year from somatic considerations coincided with the FRC's recommended average dose limit to the gonads of the population of 5 rems over 30 years.

In a later publication (FRC Report #5), FRC applies the recommended 170 mrem/year limit to the "critical segment" of the population receiving the highest dose from a given event resulting in environmental contamination (Ref. 26).

The functions of the FRC were later transferred to the EPA by the Reorganization Plan Number Three of 1970.

6. ENVIRONMENTAL PROTECTION AGENCY SOLID AND HAZARDOUS WASTE MANAGEMENT REGULATIONS

6.1 Management and Disposal of Nonradioactive Solid Waste

Regulations promulgated by the Environmental Protection Agency (EPA) for the disposal of nonradioactive solid waste are found in Subchapter I of Chapter 40 of the Code of Federal Regulations (40 CFR). As defined by EPA, "'solid waste' means any garbage, refuse, or sludge from a waste treatment plant, water supply treatment plant, or an air pollution control facility or other discarded material resulting from industrial commercial mining, and agricultural operations, and from community activities..." Regulations promulgated to date by EPA for the management and disposal of solid waste include:

- o 40 CFR 240 Guidelines for the thermal processing of solid wastes.
- o 40 CFR 241 Guidelines for the land disposal of solid wastes.
- o 40 CFR 243 Guidelines for the storage and collection of residential, commercial, and institutional solid waste.
- o 40 CFR 244 Solid waste management guidelines for beverage containers.
- o 40 CFR 245 Promulgation resource recovery facilities guidelines.

- o 40 CFR 246 Source separation for materials recovery guidelines.
- o 40 CFR 247 Guidelines for precurement of products that contain recycled material.
- o 40 CFR 249 Public participation in solid waste management.
- o 40 CFR 254 Public notice of citizen suits.
- o 40 CFR 255 Identification of regions and agencies for solid waste management.
- o 40 CFR 256 Guidelines for development and implementation of state solid waste management plans.
- o 40 CFR 257 Criteria for classification of solid waste disposal facilities and practices.

Of special interest for the disposal of low-level waste are the regulations 40 CFR 241 (Guidelines for Landfill Disposal of Solid Waste) and 40 CFR 257 (Criteria for Classification of Solid Waste Disposal Facilities). The existing Part 241 regulation was originally promulgated on August 14, 1974 under the authority of the Solid Waste Disposal Act, as amended by the Resource Recovery Act of 1970 (Pub. L. 91-512). However, in March 1979, EPA published a Federal Register notice (44 FR 18138) proposing a new regulation, 40 CFR 241, which would entirely replace the existing regulation (Ref. 27). The revised Part 241 regulation, entitled "Guidelines for the Landfill Disposal of Solid Waste," is intended to give more explicit guidance regarding the location, design, construction, operation, and maintenance of solid waste landfill disposal facilities. Specific design features of a solid waste landfill are discussed for control of such potentially troublesome occurrences as leachate generation, gas generation, and run-off. Site monitoring is also discussed. The guidelines are meant to be a concise identification of recommendations. A more detailed description of the technical and economical aspects of recommended landfill practices can be found in the "Draft EIS on the Proposed Guidelines for the Landfill Disposal of Solid Waste" (March 1979) (Ref. 28).

The proposed guidelines stipulated in 40 CFR 241 are meant to closely interact with the recently promulgated EPA regulation 40 CFR 257, "Criteria for Classification of Solid Waste Disposal Facilities." These criteria were promulgated in September 1979 under the authority of Sections 1008(a)(3) and 4004(a) of the Solid Waste Disposal Act, as amended by the Resource Conservation Recovery Act of 1976 (RCRA) as well as Section 405(d) of the Clean Water Act, as amended (Ref. 29).

The criteria contains minimum criteria for the level of health and environmental protection that must be achieved by a land disposal facility. Those facilities that cannot meet the criteria are to be classified as "open dumps" for the purposes of RCRA. RCRA prohibits the practice of open dumping. The criteria also provides the criteria to be applied in the federal district courts in determining whether or not open dumping had occurred, in addition to

providing guidelines (Section 405 of the Clean Water Act) for the utilization and disposal of waste water treatment plant sludge.

The purpose of the criteria is to determine whether there is "no reasonable probability of adverse effects on health or the environment." This determination would be made on a case-by-case basis, taking into account particular site-specific conditions at a particular facility. (The guidelines, on the other hand, are certified by EPA to represent sound solid waste management practices, but do not necessarily guarantee a site's compliance with the criteria. The guidelines are an informational resource which can assist state officials and site operators in determining the types of site practices which, if performed properly, would provide reasonable assurance that the criteria would be met. EPA notes that the criteria could also be met by employing a new innovative technology which is not discussed in the guidelines.) A guidance manual ("Draft Guidance Manual for the Classification of Solid Waste Disposal Facilities," November 1979). for use by state agencies and disposal site operators in determining compliance with the criteria has been issued by the EPA Office of Solid Waste staff (Ref. 30).

Criteria listed by EPA which if violated would "pose a reasonable probability of adverse effects on health or the environment" include criteria for:

- floodplains;
- endangered species;
- protection of surface water;
- protection of ground water;
- application to food-chain cropland;
- air quality; and
- safety (including control of gases, fires, bird hazard to aircraft and access).

Of particular interest are the criteria for protection of surface water and of ground water.

In the criteria, protection of surface water is carried out under the auspices of Sections 402, 404, and 208 of the Clean Water Act (CWA), as amended. Discharge of pollutants into the waters of the United States must conform to the requirements of the National Pollutant Discharge Elimination System (NPDES; Section 402 of the CWA). Discharge of dredged material or fill material must conform to the requirements of Section 404 of the CWA. Nonpoint source pollution of the waters of the United States must conform to an area-wide or state plan approved by the EPA Administrator (Section 208 of the CWA).

Protection of ground water is primarily based upon application of the National Primary Drinking Water (NPDW) regulation, 40 CFR 141 (see Section N.7). The

criteria states that "a facility or practice shall not contaminate an underground drinking water source beyond the solid waste boundary or beyond an alternative boundary specified in accordance with paragraph b of this section." In this requirement, "contaminate" means to introduce a substance which would either exceed the allowable levels of contaminants listed in the NPDW Standard, or increase the concentration of the substance in the ground water where the existing levels of that substance already exceed the allowable levels. The definition of an underground drinking water source is:

"(i) An aquifer supplying drinking water for human consumption;

(ii) An aquifer in which the ground water contains less than 10,000 mg/1 total dissolved solids; or

(iii) An aquifer designated as such by the (EPA) administrator or a state."

A solid waste boundary means "the outermost perimeter of the solid waste (projected in the horizontal plane) as it would exist at completion of the disposal activity." Finally, Paragraph b establishes means by which a state with a solid waste management plan approved by the EPA administrator may specify an alternative boundary for application of the ground-water criteria other than the solid waste boundary.

The criteria would appear to essentially provide for no releases from a facility when existing contaminant levels exceed the specified limits. This implies that an aquifer that is contaminated either naturally or artificially (by man) could be protected to a greater degree than one that is uncontaminated. The criteria are also unclear as to their applicability when the aquifer in question is not an underground drinking water source. The ground-water criteria are similar to those proposed by EPA in December 1978 for disposal of hazardous wastes. (See discussion below of EPA's hazardous waste regulations.)

The criteria and the use of the criteria by EPA are related to the characteristics of the waste to be disposed. Annually, hundreds of millions of tons of solid and hazardous wastes are produced, not counting mining wastes. There are over 18,500 solid waste disposal sites in the U.S. (Ref. 31). The characteristics of the waste streams are very hard to specify. Much of the waste is in a liquid or in a semisolid form, or is otherwise easily compressible. Much of the contaminant materials are essentially nonbiodegradable. Inorganic toxic elements such as arsenic, cadmium, chromium, lead, mercury, and selenium have essentially infinite half-lives. Previous improper disposal practices have contaminated ground water on a local basis in many parts of the nation and on a regional basis in some heavily populated and industrialized areas, precluding its use as drinking water.

The great volume of the waste material to be disposed has dictated certain practical limitations in alternative methods for disposal of the waste--that is, the key practical disposal method for most of the waste is by some variation of landfill operations. This fact, coupled with the very great difficulty in predicting the impacts of large volumes of diverse, long-lasting difficult-to-characterize waste material, has led to use of "impermeable" liners on the

bottom of the landfills. The aim is essentially "zero release" from these facilities. The facilities would be designed to collect, remove, and treat any leachate produced by infiltrating precipitation prior to discharge to the environment. However, the release of collected and treated leachate would not constitute "zero release" and the system implies a more or less continual maintenance requirement which someone will have to pay for once the site license has been terminated.

EPA is also considering expanding the list of maximum contaminant levels used in the criteria to include those levels published in the National Secondary Drinking Water Regulations (40 CFR 143). A Federal Register notice (44 FR 53465) announcing the proposed amendment to the criteria was issued by EPA in September 1979 (Ref. 37). The proposed amendment would add maximum permissible levels for eleven contaminants, including chloride, color, foaming agents, iron, manganese, odor, pH, sulfate, total dissolved solids, and zinc. These additions are intended to protect ground water from discoloration, odor, and taste-causing contaminants.

6.2 Management and Disposal of Hazardous Waste

The authority of the EPA to promulgate regulations to protect human health and the environment is provided under the authority of the Resource Conservation and Recovery Act of 1976, as amended--an act which significantly amended the earlier Solid Waste Disposal Act.

A sweeping set of procedural, administrative, and technical regulations for the management and disposal of hazardous waste was proposed by EPA as 40 CFR 250 on December 18, 1978 (Ref. 33). Over a thousand comments on the proposed rule from the public were subsequently received by EPA. Since the December 1978 Notice of Proposed Rulemaking, the EPA has completely reorganized the proposed regulation into a number of parts of Title 40 and are promulgating separate parts at different times. A listing of the principal parts of 40 CFR applicable to hazardous waste management are provided below (Ref. 34).

- o 40 CFR 260 Hazardous Waste Management: General.
- o 40 CFR 261 Hazardous Waste Management System: Identification and Listing of Hazardous Waste.
- o 40 CFR 262 Standards for Generators of Hazardous Waste.
- o 40 CFR 263 Standards for Transporters of Hazardous Waste.
- o 40 CFR 264 Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.
- o 40 CFR 265 Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

- o 40 CFR 122 EPA Administered Permit Program: The National Pollutant Discharge Elimination System; the Hazardous Waste Permit Program; and the Underground Injection Control Program.
- o 40 CFR 123 State Program Requirements.
- o 40 CFR 124 Procedures for Decisionmaking.
- o 40 CFR 125 Criteria and Standards for the National Pollutant Discharge Elimination System.

Parts of 40 CFR 260 were originally promulgated on February 26, 1980 (Ref. 35), concurrent with promulgation of Parts 262 and 263. However, certain provisions of Parts 260, 262, and 263 were amended on May 19, 1980 to reflect some additional refinements as well as changes due to the publication of Parts 261, 264, and 265. Parts 261, 264, and 265 were also published on May 19, as well as extensive amendments to Parts 122, 123, 124, and 125 (Ref. 34).

The following is a brief discussion of EPA's requirements for notification of hazardous waste activities, as well as a discussion of each separate part:

Preliminary notification of hazardous waste activity. A notification form (and procedures for filling it out) for persons engaged in hazardous waste activities was issued by EPA and noticed in the Federal Register on February 26, 1980 (45 FR 12746). As required by Section 3010 of RCRA and codified by the notification form, each person who generates or transports hazardous waste, or who owns or operates a facility for the treatment, storage, or disposal of hazardous waste must notify EPA of their activities within 90 days of the publication of the Federal Register notice. Alternatively, notification is to be given to those states having authorized hazardous waste permit programs (see 40 CFR 123). Specific requirements for generators, transporters, and owner/operators of treatment, storage, or disposal facilities are provided in Parts 262 through 265.

Those who fail to comply with the notification requirement may be compelled by EPA to close operations. In addition, owner/operators of treatment, storage, or disposal facilities that do not comply with the notification requirements may become ineligible for interim status as provided in Part 265.

The function of the notification form is to identify all those who are currently engaged in hazardous waste activities. This may entail as many as 400,000 persons, businesses, and federal agencies. Respondees to the notification form will be issued a 12-digit identification number to be used on shipping manifests and other reporting forms required under Parts 262 through 265. This will facilitate EPA's use of a computer-based system for monitoring hazardous waste activities in the country.

40 CFR 260. The intent of 40 CFR 260 is to consolidate in one part several provisions which are generally applicable to Parts 261 through 265. Provisions contained in Part 260 include:

- o Rules concerning the designation and handling of confidential information;
- o Rules concerning grammatical construction;
- o Definitions of key word and phrases;
- o Rules concerning EPA procedures to act on petitions for rulemaking and alternative analytical test methods; and
- o A "road map" to the hazardous waste regulations providing general guidance regarding the most important provisions of the regulations.

40 CFR 261. This regulation (May 19, 1980; 45 FR 33084) identifies the criteria for and characteristics of hazardous wastes as well as provides lists of several wastes which must be managed as hazardous wastes. Certain portions of 40 CFR 261--particularly administrative and procedural portions--are promulgated as final rules. Other portions, including the lists of hazardous wastes, the criteria for listing hazardous waste, and the definitions of solid waste and domestic sewage, are being issued as "interim final" regulations. Public comment on the interim final regulations is encouraged prior to their being issued by EPA as final regulations.

According to the criteria, a waste stream is hazardous if it exhibits certain characteristics, is fatal in low doses to humans or laboratory animals, contributes to illness, or contains certain listed toxic constituents. Characteristics of hazardous wastes include ignitabilty, corrosivity, reactivity, or extraction procedure (EP) toxicity. (According to the EP toxicity procedure, a waste stream is considered hazardous if a prescribed test of the waste produces an extract of chemicals 100 times greater than the maximum levels listed in the National Primary Drinking Water (NPDW) regulation, 40 CFR 141.) The lists of hazardous waste streams currently include 85 waste streams from certain industrial processes as hazardous. More waste streams are scheduled to be listed in the summer and fall of this year. In addition, approximately 400 chemicals are listed which are considered to be hazardous if not disposed properly.

In the Part 261 regulation, EPA doesn't generally classify hazardous waste according to the degree of the hazard. All wastes that fall under the criteria are essentially disposed on an equal basis. Special procedures are required in other parts, however, depending on chemical characteristics such as compatability or physical characteristics such as liquidity.

Certain wastes are specifically excluded from consideration as hazardous wastes. These include domestic sewage, industrial point source waste water discharges, irrigation return flows, material subject to regulation by NRC, household wastes, agricultural wastes, ash from burning fossil fuels, drilling fluids, and materials subject to in situ mining techniques but not removed from the ground. In addition, persons generating less than 1000 kg of hazardous wastes per month are exempt from the promulgated requirements. (This criterion of 1000 kg/month is 10 times greater than the limit in the 1978 proposed rule.)

40 CFR 262. Part 262 provides requirements for generators of hazardous waste. The main portions of the regulation were promulgated on February 26, 1980 (45 FR 12722) and revised as of May 19, 1980 (45 FR 33140) to incorporate certain administrative and technical refinements. The regulation requires that a person determine whether or not he generates a hazardous waste under the requirements of Part 261. If so, and if he stores this hazardous waste onsite for a period greater than 90 days, he is then considered to operate a waste storage facility that must comply with the detailed requirements of Parts 122, 264, and 265. If he stores the hazardous waste for less than 90 days and complies with certain other requirements such as containing and labeling wastes, he is considered to be a waste generator and is subject to other requirements.

The heart of Part 262 is the hazardous waste manifest system. This system is meant to track the generation, transport, and disposal of hazardous waste "from cradle to grave," and therefore greatly reduce such improper waste disposal practices as midnight dumping. Under the regulation, generators are required to identify themselves and to describe the waste (type, weight, and volume) on the manifest, which must accompany the waste shipment to the disposal facility. The disposal facility to which the wastes will be sent must be indicated on the manifest, as well as at least one alternative facility. A certification requirement is also included. Other requirements in the regulation include requirements for packaging, labeling, marking, and placarding in compliance with DOT requirements in 49 CFR Parts 172, 173, 178, and 179.

Also of interest are the recordkeeping and reporting requirements. After receiving and disposing of a waste shipment, an operator of a waste disposal facility must sign the accompanying manifest document and return a copy of it to the waste generator. If the waste generator does not receive the returned manifest document within 35 days after he has shipped the waste, he must locate the waste shipment. Failing to locate the waste shipment, the waste generator must submit an exception report to the EPA.

Other requirements on the waste generator include those for recordkeeping and for annual reporting to the EPA.

40 CFR 263. These regulations, prescribing standards for the transporters of hazardous waste, were originally promulgated on February 26, 1980 (45 FR 12737). Minor administrative amendments were noticed in the Federal Register on May 19, 1980 (45 FR 33150).

Under the regulation, a transporter must not transport hazardous waste material without applying for and receiving an identification number from the EPA. The transporter may not accept a hazardous waste shipment from a generator without it being accompanied by a manifest. The transporter must then ensure that the manifest accompanies the hazardous waste and deliver the manifest to the disposal facility along with the waste shipment. Less restrictive requirements apply to the bulk shipments of waste transported by rail or water. Also included in the regulation are recordkeeping requirements as well as requirements on the transporters to undertake immediate cleanup actions on any waste spills during transport.

40 CFR 264 and 265. Parts 264 and 265 are very closely related and were promulgated by EPA in recognition of the many hundreds of hazardous waste facilities already existing. Both regulations apply to owners and operators of hazardous waste treatment, storage, and disposal facilities. The Part 265 regulations are a less restrictive (abbreviated) set of regulations than the Part 264 regulations which will eventually apply to those owners/operators which qualify for "interim" status under the regulation. To qualify for interim status, an owner/operator must:

1. Have been treating, storing, or disposing of hazardous waste prior to October 21, 1976, or have had a hazardous waste facility under construction before that date;

2. Notify EPA in compliance with requirements promulgated pursuant to Section 3010 of the Solid Waste Disposal Act (see the earlier discussion on notification of hazardous waste activity); and

3. Apply for a permit pursuant to 40 CFR 122.

Assuming that an owner/operator complies with these requirements, he may then operate under Part 265 while EPA evaluates his permit. EPA expects that, due to the sheer number of applicants, several years may elapse prior to their issuing a permit to some owner/operators that have been awarded interim status. When a permit is eventually issued to such a facility, the permit will be issued based on the Part 264 requirements.

New facilities must, of course, comply with the more restrictive Part 264 requirements. As discussed below, the Part 264 regulations currently cover only administrative and procedural matters. Existing facilities which do not qualify for interim status under the above rules must stop operations at the storage/treatment/disposal facility pending issuance of a permit under the Part 264 requirements.

In the proposed regulations issued in October 1978, EPA specified a set of detailed prescriptive technical requirements for operation of a storage, treatment, or disposal facility. However, in the May 19 interim final regulations, EPA has adopted a much more general performance-objective approach. As stated in the May 19 Federal Register notice (Ref. 34, 45 FR 33156), EPA believes that it will take "several years to promulgate detailed national technical standards for some types of facilities (for example, the design requirements for landfills)." Therefore, EPA is promulgating its hazardous waste standards under Parts 264 and 265 in three phases. Phase I corresponds to the regulations issued on May 19. Phase II requirements are expected later this year and will contain more detailed technical requirements. Phase III will involve a further refinement of the Phase I and Phase II standards based upon additional study and operational experience.

The Phase I regulations form a relatively complete set of administrative and procedural interim status standards as well as an abbreviated set of interim status technical standards (Part 265). On the other hand, the general status

regulations (Part 264) cover only administrative and procedural requirements. The main subparts of the two parts include:

Part 264

A. General
B. General Facility Standards
C. Preparedness and Prevention
D. Contingency Plan and Emergency Procedures
E. Manifest System, Recordkeeping, and Reporting

Part 265

A. General
B. General Facility Standards
C. Preparedness and Prevention
D. Contingency Plan and Emergency Procedures
E. Manifest System, Recordkeeping, and Reporting
F. Ground-water Monitoring
G. Closure and Postclosure
H. Financial Requirements
I. Use and Management of Containers
J. Tanks
K. Surface Impoundments
L. Waste Piles
M. Land Treatment
N. Landfills
O. Incinerators
P. Chemical, Physical, and Biological Treatment
Q. Underground Injection

The Phase I (March 19) regulations do not contain any specific standards regarding protection of ground water. These are scheduled by EPA to be promulgated as part of the Phase II regulations. However, the Part 265 regulations do require that all hazardous waste disposal facilities or surface impoundments institute a ground-water monitoring program which includes at least one monitoring well up-gradient and three wells down-gradient of the facility. Other technical requirements include those for control of precipitation or other surface run-on to or run-off from active portions of a disposal facility. Also included are requirements for security, daily inspections by the site owner/operator, and waste liquids, as well as special requirements for ignitable, reactive, or incompatible wastes.

Of special interest are the Phase I regulations for closure, financing, and institutional controls. Under the regulations, every owner/operator of a hazardous waste facility must submit a site closure plan (Part 265, Subpart G). This plan is intended to be resubmitted by the owner/operator and reviewed by the EPA at five-year intervals. Also included as a part of the closure regulations is a requirement that each owner/operator submit an estimate (to be updated annually) of the projected closure costs. There are, however, no requirements for acceptable funding mechanisms to ensure that sufficient capital will be available for closure and postclosure maintenance and monitoring of a disposal facility. As part of the original December 1978 proposed rule, EPA proposed that an owner/operator make a cash deposit for the entire amount of the closure cost estimate into a closure trust fund. Based on comments

received, EPA decided to repropose the financial requirements for Parts 264 and 265 (see 45 FR 33260; May 19, 1980). The new proposed rule would allow greater flexibility in meeting the financial requirement. Other options for funding are considered acceptable (i.e., use of surety bonds, letters of credit, individual company financial worth), and payments may be made over a 20-year period. The proposed rule would also require liability insurance.

Part 265 requires that after closure, the owner/operator maintain a disposal site for 30 years. More than or less than 30 years may also be acceptable depending upon site-specific conditions. After the owner/operator has been relieved of responsibility of the site, it is not clear, however, to whom the title to the site passes.

40 CFR 122, 123, 124, and 125. NRC issues licenses for control of radioactive materials principally under one act--the Atomic Energy Act of 1954. EPA, however, issues permits as part of programs established by a number of acts. These include:

- The Hazardous Waste Management Program under the Resource Conservation and Recovery Act (RCRA);
- The Underground Injection Control (UIC) program under the Safe Drinking Water Act (SDWA);
- The National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act (CWA);
- The state dredge or fill programs under Section 404 of the CWA (commonly termed the "State 404 Programs"); and
- The Prevention of Significant Deterioration (PSD) program under the Clean Air Act (CAA).

The intent, therefore, of the extensive revisions to Parts 122 through 124 (45 FR 33290) is to consolidate the program-permitting requirements for the RCRA and UIC programs with those already established for the NPDES program. Also consolidated are the permit issuance procedures for the PSD permits under the CAA with those permits issued for the RCRA, UIC, and NPDES programs. Newly established are requirements for state programs under the RCRA, UIC, and Section 404 programs.

Summaries of each of the revised EPA regulations are as follows:

- Part 122 ("EPA Administered Permit Programs") establishes definitions and general permitting requirements for RCRA, UIC, and NPDES programs administered by EPA. These requirements include applicability (that is, who must apply for a permit); contents of permit applications; mandatory permit conditions; and procedures for revision, reissuance, or termination of permits. Certain requirements applicable to state programs are also presented.

- Part 123 ("State Program Requirements") establishes requirements and procedures for state programs for the management and control of hazardous material, as well as procedures for EPA approval, revision, and potential withdrawal of a state program. EPA programs which may be transferred to approved state control include the RCRA hazardous waste program, UIC program, NPDES program, and the Section 404 programs for control of discharge or dredged or fill materials into the waters of the United States. Included in the Part 123 requirements are requirements for public participation in the issuance of permits.

- Part 124 ("Procedures for Decisionmaking") establishes EPA procedures for actions on permit applications made as part of the RCRA hazardous waste, UIC, PSD, and NPDES programs. Included are procedures for public participation, consolidated review and issuance of two or more permits to the same facility or for the same activity, and for appealing EPA decisions.

- Part 125 contains criteria and standards for the National Pollutant Discharge Elimination System. On May 19, some minor revisions and technical amendments were promulgated (45 FR 33512) principally to correct certain cross references to Parts 122, 123, and 124. As noted above, these parts were extensively revised under the May 19 promulgated rule.

Consolidated permit application forms were also published on May 19 in the Federal Register (45 FR 33516).

7. 40 CFR 141: NATIONAL PRIMARY DRINKING WATER REGULATION

The National Primary Drinking Water (NPDW) regulation was promulgated by the Environmental Protection Agency (EPA) pursuant to Sections 1412, 1414, 1415, and 1450 of the Public Health Service Act, as amended by the Safe Drinking Water Act (Pub. L. 93-523). The regulations cover allowable chemical (40 FR 59566, Dec. 24, 1975) and radiological (41 FR 28402, July 9, 1976) contamination in a "public water system." A guide book on the regulation has been published, entitled "National Interim Primary Drinking Water Regulations" (Ref. 36).

In the regulation, a public water system is defined as a "system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections or regularly serves 25 individuals daily at least 60 days out of the year." The definition further distinguishes between a "community water system" or a "noncommunity water system," where:

1. A community water system is a "public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents"; and

2. A noncommunity water system is "a public water system that is not a community water system."

In the regulation, maximum nonradioactive contaminant levels are stipulated for certain inorganic chemicals, organic chemicals, turbidity, and microbiological activity.

Requirements for radioactive elements in ground water include the following:

Maximum containment levels for radium-226, radium-228, and gross alpha particles:

- Combined radium-226 and radium-228: 5 pCi/1.
- Gross alpha particle activity (including radium-226 but excluding radon and uranium): 15 pCi/1.

In addition, the regulation states that the concentration of beta particles and photon radioactivity from man-made radionuclides in drinking water should not produce an annual dose equivalent to the total body or to any internal organ greater than 4 millirem/year. If two or more (man-made) radionuclides are present, the sum of the annual dose equivalent to the total body or to any organ shall not exceed 4 millirem/year.

The regulation also contains requirements for water sampling and monitoring, analytical techniques, recordkeeping, and reporting. If the concentrations of the contamination in a public water supply exceed those in the standard, the water supplier is required to notify billing customers. This notification is to take the form of a notice included with the bill as well as publication of the notice in a local newspaper(s). A copy of the notice is to be provided to radio and television stations servicing the area. No enforcement provisions are contained in the regulation in the event that the containment levels are exceeded or if the water supplier fails to carry out the provision in the regulation as regards to monitoring, recordkeeping, reporting, or notification of excessive contamination levels.

The regulation makes no specific mention of alpha-emitting transuranic radionuclides.

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Appendix O

(Reserved for final EIS)

Appendix P

(Reserved for final EIS)

Appendix Q

CALCULATION OF PREOPERATIONAL, OPERATIONAL, CLOSURE AND INSTITUTIONAL CONTROL COSTS

1. INTRODUCTION

This appendix presents a summary of the assumptions and calculational procedures used in this environmental impact statement to determine costs for siting, designing, constructing, operating, and closing a reference radioactive waste disposal facility, as well as costs for 100 years of active institutional control (the terms institutional control and long-term care are used synonymously). The costs are calculated in three segments:

1. Capital Costs, which include costs associated with siting, designing, licensing and initial construction of the facility.

2. Operational Costs, which include costs associated with receipt and disposal of waste, as well as construction of disposal cells.

3. Postoperational Costs, which include costs for (a) facility closure, and (b) institutional control by the site owner.

Included in the calculations are costs associated with acquisition by the licensee of surety bonds, letters of credit, or other financial instruments which are used to provide assurance to the site owner that funding for closure and institutional control will be available. For the purposes of this appendix, it is assumed that the licensee acquires a surety bond sufficient to cover the entire facility closure costs. Funding for closure and institutional control is assumed to be provided by sinking funds into which money is periodically placed after being collected as a surcharge on waste received at the disposal facility.

In this appendix, capital costs are discussed in Section 2.0, operational costs are discussed in Section 3.0, and postoperational costs are discussed in Section 4.0. In each section, a sample calculation is performed using the reference facility described in Appendix E as an example. Following these sections is Section 5.0, which analyzes some financial aspects connected with closure and institutional control. Section 6.0 then summarizes the example calculations performed in the previous three sections and provides an example calculation of a total unit disposal cost ($ per m^3 of waste). (The total unit disposal cost is that charge sufficient to amortize the capital investment, pay all operating expenses, earn a specified rate of return on equity and establish a fund of sufficient size to pay for all site closure and institutional control expenses.) The unit disposal cost is derived by multiplying a set of factors by each of the three cost components (capital, operational and post-operational costs).

2. CAPITAL COSTS

Capital costs include all costs required to site, design, license, and construct a disposal facility; and include direct costs, indirect costs, and an annual fixed capital charge. Direct costs are costs which can be specifically assigned to particular tasks or actions, such as construction of a building or installation of a particular piece of equipment. Indirect costs are calculated as a percentage of the direct costs and are costs incurred during siting, licensing, and construction operations which cannot be specifically allocated to particular tasks or actions. The annual fixed capital charge is a fixed charge that occurs during the operating life of the facility, but is calculated as a percentage of the capital costs. It represents that portion of the total costs which are required during the (20 year) operating life to recover capital and interest expenses and to earn a specified return on a firm's equity.

2.1 Direct Capital Costs

Direct capital costs include the material, labor, overhead and necessary site improvements required to site, license and construct the facility. In this appendix, direct capital costs are assumed to include costs for:

- Site selection;
- Environmental impact studies;
- Administrative support;
- Licenses and permits;
- Site improvements (e.g., roads, fences, lights, etc.);
- Buildings and structures; and
- Engineering and design costs.

In the analysis, the required direct labor costs are assumed to be included as part of construction operations. For the purposes of this environmental impact statement, costs for site selection, environmental impact studies, and licenses and permits are assumed to be constant for all the alternatives considered. Adminstrative and legal costs are also assumed to be constant. The costs for buildings, structures, and other site construction activities, however, are a variable depending upon the alternatives considered.

In this appendix, equipment used to construct disposal cells (e.g., disposal trenches), to dispose of received wastes, and to carry out support activities are not included as part of the capital costs but are included as equipment leasing charges through the operational life of the facility. At an actual disposal facility, some equipment would undoubtedly be purchased--possibly second hand--and some would probably be leased. Assuming that equipment is purchased would require a number of additional assumptions regarding purchase costs, finance charges, insurance, depreciation, equipment operating life before replacement, salvage value, and so forth. As a simplification, therefore, all equipment is assumed to be leased. This assumption is maintained consistently through the alternatives considered in this environmental impact statement for facility design and operation.

For the reference facility presented in Appendix E, the following items are included as direct capital costs, in 1980 dollars:

Capital Outlay		1980 $ (X 1000)
1.	Site selection	$ 500
2.	Environmental impact studies	600
3.	NRC licensing fees	325
4.	Other licenses and permits	250
5.	Land acquisition (200 acres @ $1200/acre)	240
6.	Corporate administration	1,625.25
7.	Construction administration	450.45
8.	Legal fees	1,000
9.	Road construction	200
10.	Initial land preparation (40 acres @ $1145/acre)	45.8
11.	Office and other miscellaneous light equipment	400
12.	Building construction	1,173.25
13.	Utilities and supplies during construction	175
14.	Peripheral systems (fencing, lighting, utilities installation, telephone, etc.)	300
15.	Engineering and design (10% of items 9, 12, and 14)	167.3
		$ 7,452.

The costs for items 1 through 4 above are held constant throughout the alternatives considered in this environmental impact statement. The costs for the other items, however, may vary depending upon the alternatives considered.

Building costs, which include the costs of labor required for construction, may be estimated as follows:

Building	1980$
Administration	$ 235,400
Health physics/security	387,500
Warehouse	126,500
Garage	113,000
Waste activities	302,250
Storage shed	8,600
	$ 1,173,250

Building costs are assumed to vary depending upon the complexity of the activities taking place within the particular building. For example, costs ranged from $108/m^2 ($10/ft^2) for the storage shed to $538/m^2 ($50/ft^2) for the waste activities building, with an average building cost of $388/m^2 ($36/ft^2). A description of the function(s) of each building is provided in Appendix E.

Engineering and design costs are assumed to be 10% of the costs for road and building construction and installation of peripheral systems (fencing, lighting, utilities, monitoring wells, telephone connections, etc.). These costs include the costs associated with consulting, quality control, and inspection fees.

Estimated costs for corporate administration during facility siting, design, licensing, and construction are assumed to persist for 5 years and are broken down in Table Q.1. During initial construction of the facility, which is assumed to last one year, additional manpower is required to oversee site activities, to coordinate contracts, and to arrange for waste shipment customers. All personnel charges are increased from the basic rates by addition of a 10% fringe charge. A 50% overhead is then calculated from the combined base and fringe charges. Also shown in Table 1 are the legal fees during facility siting, licensing, and construction. These are assumed to average approximately $200,000 per year for each of the five years.

2.2 Indirect Capital Costs

Indirect capital costs are expenses of a general nature which apply to the overall project of siting, licensing, designing and constructing the disposal facility, and are calculated as a percentage of the direct capital costs. For the purposes of this environmental impact statement, the indirect costs are estimated as follows:

Item	Percentage of Direct Costs
Interest during construction	33
Contingency	30
Other Costs	10
	73 %

Interest during construction charges include the sum of interest charges for capital expenditures. It covers the net cost of funds utilized to finance the siting, design, and construction of the facility. Interest charges are a function of the amount of expenditures, the time period for which funds are borrowed, and the interest rate. Interest charges are included in the indirect capital costs even if the money used during siting and construction activities is from the company's own funds. (It is a "return" that could have been realized if that money were invested during the operational lifetime of the facility.) For this appendix, the interest on construction was calculated at 6-month intervals assuming a 15% interest rate over a period of five years. In addition, the rate that funds are expended is assumed to increase during the five years prior to facility operation--i.e., $2.4 million is spent during the first two years, an additional $1.5 million is spent over the next two years, and the remainder over the last year.

Contingency costs cover any additional (unplanned for) costs that may arise during siting, licensing, and constructing the disposal facility. An example is the possible need to acquire additional hydrogeologic data regarding the proposed disposal facility. Other costs cover miscellaneous overhead expenses during the preoperational phase such as insurance, sales tax on purchased equipment and material, and so forth.

Table Q.1 Administrative Costs During Siting, Licensing, and Construction

Corporate Personnel (annual for 5 years):		Costs ($x 1000)
1 Project Leader	@ 55 k	55.00
2 Senior Engineers	@ 35 k	70.00
3 Engineers	@ 24 k	48.00
2 Clerical	@ 12 k	24.00
		$ 197.00
	10 % Fringe	+ 19.7
		$ 216.70
	50 % Overhead	+ 108.35
		$ 325.05
Legal Fees (annual for 5 years):		
		$ 200.00
Site Administration (during one year construction period)		
1 Site Manager	@ 40 k	40.00
1 Assistant Site Manager	@ 35 k	35.00
1 Foreman	@ 28 k	28.00
1 Site Radiation Safety Officer	@ 35 k	35.00
1 Contracts Coordinator	@ 24 k	24.00
1 Radiation Safety Technician	@ 15 k	15.00
1 QA and Safety Supervisor	@ 26 k	26.00
1 Customer Service Coordinator	@ 24 k	24.00
1 Waste Shipment Scheduler	@ 16 k	16.00
1 Billing/Accounting Personnel	@ 12 k	12.00
2 Secretarial	@ 9 k	18.00
		$ 273.00
	10 % Fringe	+ 27.3
		$ 300.3
	50 % Overhead	+ 150.15
		$ 450.45

For the example reference disposal facility presented in Appendix E, the total capital investment is the sum of the direct and indirect capital costs, that is:

$$\begin{aligned} \text{Investment} &= 7{,}452{,}050 + 0.73\ (7{,}452{,}050) \\ &= 1.73\ (7{,}452{,}050) \\ &= \$12{,}892{,}000 \end{aligned}$$

2.3 Annual Fixed Capital Charge

The annual charge for the capital represented by the total investment includes such items as interest on borrowed money, return on equity, depreciation, taxes, and insurance. Calculation of annual fixed charges for a real disposal facility can become quite complicated; however, for the purposes of this appendix these charges are assumed to be calculated as a constant fixed percentage (the fixed capital charge rate) of the initial total investment cost, carried out over the 20-year operating life of the facility. The fixed charge rate can also be considered to be the ratio of the total, annual capital charge to the total capital investment.

To estimate the annual fixed charge rate, some typical fixed charge rates associated with nuclear fuel cycle facilities may be examined. One DOE document prepared by Battelle, Pacific Northwest Laboratories (PNL) provides an estimate of the fixed charge rate for a large private company, based upon a number of assumptions regarding the cost of money, federal and state income tax rates, insurance and contingencies, depreciation, and estimated site operating life (Ref. 2). Similar estimates (based on somewhat similar assumptions) may be found in an extensive series of studies by Oak Ridge National Laboratories (ORNL) on the costs and benefits of installation of additional airborne effluent treatment equipment in nuclear fuel cycle facilities. A typical document in this series is reference 3. A summary of the assumptions and fixed charge rates obtained from the DOE and ORNL references, are shown below.

	DOE	ORNL
Plant lifetime (years)	15-20	15
Capital Investment-bonds	25%	30%
Capital Investment-equity	75%	70%
Bond Interest rate	8%	5%
After tax return on equity	12%	16%
Federal Income Tax Rate	48%	50%
State Income Tax Rate	6.5%	3%
Annual Property Taxes and Insurance	7%	3.8%
Weighted Cost of Money	10%	
Investment Credit Rate	7%	N. A.
Fixed Charge Rate	23-25%	24%

In the ORNL document, the 5% bond interest rate was characterized as being probably somewhat low. ORNL also noted that increasing it to 8% would increase the fixed charge rate to about 26%.

For the purposes of this appendix, a fixed charge rate of 25% is assumed. This rate is also consistent with an assumed nuclear facility fixed charge rate in WASH-1538 ("Final Environmental Statement Concerning Proposed Rule-making Action: Numerical Guides For Design Objectives and Limiting Conditions For Operation to Meet the Criterion "as Low as Practicable" For Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents") (Ref. 3).

2.4 Total Capital Costs

Total capital costs are estimated as the product of the total capital investment times the annual fixed change rate (25%) over a period of 20 years, times a profit margin. For the purposes of this appendix, operating a disposal facility is taken to be a high-risk business venture, and a profit margin of 20% is assumed. Therefore,

Total capital costs = Direct Costs X Indirect costs X Annual Fixed Charge X Profit.
= Direct Costs X 1.73 X 0.25 X 20 X 1.20
= 10.38 Direct Costs

For the example reference disposal facility,

Total capital cost = 10.38 ($7,452,050)
= $77,352,300.

3. OPERATIONAL COSTS

The operational costs consist of the labor, equipment, materials and supplies required to conduct waste receipt and disposal activities. Included in these costs are overhead, contingency and profits, as well as the costs of site monitoring. The necessary costs for providing financial guarantees such as security bonds or letters of credit are included under postoperational costs. While they are incurred during operations, they are a function (as based on annual premiums) of the projected postoperational costs. To the extent that estimated postoperational costs change, the resultant costs of financial guarantees will change.

3.1 Direct Operational Costs

Total direct operational costs over the 20-year life of the disposal facility are estimated for the following cost components:

- Operations and maintenance;
- Disposal cell construction;
- Heavy equipment leasing;
- Corporate administrative and legal overhead;
- Payroll;
- Utilities and supplies;
- Environmental monitoring; and
- Regulatory costs.

Operations and maintenance costs include costs associated with routine operation and maintenance (upkeep) of site grounds, office and miscellaneous other light equipment, buildings, site facilities, and other structures such as roads, fences, lighting, etc. These costs are estimated at 10% of the capital outlay for these grounds, buildings, facilities, and other structures per year. (For the reference facility, this would total approximately 10% of $2,313,250 per year, or about $231,325 per year.)

Disposal cell construction takes place continuously during facility operation; therefore, costs for disposal cell construction are included under operational costs rather than capital costs. Construction operations include clearing away existing foliage, excavation of disposal cells, installation of standpipes and French drains, backfilling and compacting with heavy machinery, seeding and mulching, and emplacement of markers and monuments. Costs for disposal cell construction include those associated with equipment use (including fuel and lubrication), labor, and materials. For the reference facility, labor and equipment costs are included as part of costs for payroll, heavy equipment leasing, and consumables.

Estimated disposal cell materials and surveying costs are summarized on Table Q.2. Costs for 150 mm (6" I.D.) polyvinyl chloride (p.v.c.) standpipes (three to a trench) are estimated based upon consideration of reference 5. The cost for gravel placed within the French drain is estimated at $6.50/m^3 ($5/yd^3). Costs for grass seed and mulching materials are estimated based upon Reference 6. Costs for cornermarkers and monuments are estimated from information in reference 5. The cornermarkers and monuments are assumed to be made of polished red granite slabs, at $18.30/ft^2 for a 4" slab. Each disposal trench has four 30" X 4" X 4" cornermarkers and one 30" X 16" X 4" monument. Hourly surveying charges are taken from Reference 6.

Equipment leasing costs are costs required to lease construction and waste handling equipment for use at the site (e.g., cranes, trucks, tractors, fork lifts, etc.) over a 20 year facility operating period. As stated above, operators of an actual facility may own part of the equipment and lease part of the equipment used at the facility. Assuming that the equipment is owned would require developing a number of additional assumptions regarding the fraction of owned equipment, how it was purchased (new, used), the financial arrangements regarding the purchases, and the operating life of the equipment prior to replacement. For this appendix, then, it is more straightforward to assume that all equipment is leased. Leasing costs may be obtained from standard guides for estimating construction costs (Ref. 5). A summary of the equipment requirements assumed for the reference facility is included as Table Q.3.

Corporate administrative costs are estimated at an average of $300,000 per year over the operating life of the facility. In addition, legal fees are estimated at an average of $150,000 per year.

Payroll costs are the largest component of the total expenses incurred during site operations. Payroll costs include personnel directly involved in the disposal operations, as well as site administrative and support personnel.

Table Q.2 Trench Construction Materials and Surveying Costs

A.	Standpipes	
	30 ft. of 6" p.v.c standpipe @ $2.45/ft*	
	3 standpipes per trench = $220.50/trench	
	3 standpipe casings @ $150/standpipe = $450/trench*	
	58 trenches @ $670.50/trench	$38,889
B.	French drain	
	(.6m X .6m X 180m) = 55 m^3/trench = 85 yd^3/trench	
	gravel @ $5/$yd^3$ = $425/trench	
	58 trenches @ $425/trench	$24,650
C.	Seed and mulch	
	1.5 acres per trench	
	materials = $295/acre*	
	58 trenches X 1.5 acres X $295/acre	$25,665
D.	Cornermarkers and monuments	
	granite markers @ $18.30/$ft^2$ for 4" slab**	
	cornerstones = 4 X 30" X 4" = 3.33 ft^2	
	monuments = 30" X 16" X 4" = 3.33 ft^2	
	58 trenches X 6.67 ft^2 X $18.30/$ft^2$	$7,111
E.	Surveyor	
	surveyor @ $60/hr	
	assume 8 hrs/trench	
	58 trenches X 8 X $60/hr	$27,840
	Total:	$124,155
		($2140.60/trench)

*Estimate based upon information obtained from Reference 5.

**Estimate based upon information obtained from Reference 4.

Table Q.3 Equipment Leasing Costs

No.	Equipment	Duration	Rate		Cost
1	Welder/Generator	240 months	@ $1500/mo	=	$ 360,000
1	40 Ton Crane	240 months	@ $4500/mo	=	1,080,000
1	100 Ton Crane	240 months	@ $6400/mo	=	1,536,000
4	Four Wheel Drive Vehicles	240 months	@ $ 800/mo	=	768,000
5	Pickups	240 months	@ $ 750/mo	=	900,000
2	Forklifts	240 months	@ $1000/mo	=	480,000
2	Crawler Tractors	240 months	@ $4200/mo	=	2,016,000
2	Farm Tractors	240 months	@ $ 800/mo	=	384,000
2	Pan Scrapers	240 months	@ $8000/mo	=	3,840,000
6	Miscellaneous Corporate Vehicles	240 months	@ $ 600/mo	=	864,000
					$12,228,000

Source: Reference 5

The assumed payroll costs per job function are listed in Table Q.4. A 10% fringe is added to the base personnel costs; a 50% overhead is then calculated from the combined base and fringe charges.

Environmental monitoring costs involve costs associated with analysis of environmental samples collected as part of the facility environmental monitoring program. The assumed operational environmental monitoring program for the reference facility is shown as Table Q.5. All gamma-isotopic, HTO, and ^{131}I sample analyses are assumed to be performed using offsite services. Costs are estimated based upon: (1) an assumed average cost of $50 per analysis of atmospheric, soil and vegetation, well water, and sump samples (530 analyses per year), and (2) an assumed charge of $200 per year for TLD analysis.

Regulatory costs include costs associated with license renewals, inspection fees, and amendments, and are listed in Table Q.6. Assuming that the disposal license is renewed every 5 years, the licensee would then undergo 3 license renewals over the 20 year operating life of the facility. NRC renewal fees would run approximately $100,000 per renewal. In addition, the licensee is assumed to prepare an environmental assessment of facility operations for each renewal. Each assessment is assumed to include an update of the facility closure plan, including an update of funding assessments. A final site closure plan will be prepared for NRC approval prior to implementation of the plan. An NRC review charge would also be levied on this final plan. Assuming that the licensee expends approximately $100,000 to prepare each of the 3 license renewals as well as the final closure plan, the total administrative costs for license renewal and facility closure would be approximately $800,000 over the operating life of the facility. Also included are NRC inspection fees which are assumed to total approximately $40,000 over 20 years, assuming 2 inspections per year. Finally, fees for license amendments are included, assuming one major amendment and ten minor amendments over the operating life of the facility.

Table Q.4 Reference Disposal Facility Payroll

No.	Job	Annual Salary($)	Extended Total($)
	Senior Staff		
1	Site Manager	40,000	40,000
1	Executive Secretary	12,000	12,000
1	Site Radiation Safety Officer	35,000	35,000
1	Assistant Site Manager	35,000	35,000
1	Foreman	28,000	28,000
1	Operations Manager	26,000	26,000
1	QA & Safety Supervisor	26,000	26,000
1	Office Manager	24,000	24,000
1	Security Chief	25,000	25,000
1	Librarian (Records)	12,000	12,000
1	Customer Service Coordinator	24,000	24,000
1	Contracts Coordinator	24,000	24,000
	Support Staff		
4	Waste Shipment Schedulers	16,000	64,000
2	Billing/Accounting Personnel	12,000	24,000
4	Security Personnel	12,000	48,000
4	Secretarial Personnel	9,000	36,000
	Staff		
3	QA Technicians	14,000	42,000
8	Radiation Safety Technicians	15,000	120,000
8	Heavy Equipment Operators	21,000	168,000
13	Semi-Skilled Laborers (includes mechanics)	15,000	195,000
12	Unskilled Laborers	10,000	120,000
70			$1,128,000

Table Q.5 Reference Facility Operational Enviromental Monitoring Program

Sample Description	No. of Locations	Type	Media	Frequency of Analysis	Type of Analysis
External Gamma	50	Continuous	TLD	Quarterly	Exposure
Atmosphere	3	Continuous	Particulate Filter	Daily	Gross Beta-Gamma
			Particulate Filter	Weekly	Gamma Isotopic
			Charcoal Cartridge	Weekly	I-131
Soil and Vegetation	10	Grab	Soil and Vegetation	Quarterly	Gross Beta-Gamma Gamma Isotopic Gross Alpha HTO
Offsite Wells	5	Grab	H_2O	Semi-Annual	Gamma Isotopic Gross Alpha HTO
Site Boundary Wells	10	Grab	H_2O	Semi-Annual	Gamma Isotopic Gross Alpha HTO
Disposal Area Wells	15	Grab	H_2O	Quarterly	Gamma Isotopic Gross Alpha HTO
Disposal Trench Sumps	As constructed	Grab	H_2O	Monthly	Gamma Isotopic Gross Alpha HTO

Estimated annual costs: $26,700.

Table Q.6 Summary of Regulatory Costs

		Costs (X 1000)
1.	3 Environmental assessments for license renewals (@ $100 k each)	$ 300
2.	3 license renewal fees (@ $100 k each)	$ 300
3.	1 Final site closure plan	$ 100
4.	1 Closure plan review fee	$ 100
5.	Inspection fees (assume 2 per year over 20 years)	$ 40
6.	License Amendments	
	Assume: 1 major amendment	$ 291
	10 minor amendments	$ 7
		$1,138

The cost of consumables (utilities, fuel, supplies, etc.) are estimated at $200,000 per year, which is an estimate based upon consideration of consumable costs estimated by DOE in reference 8.

For the reference disposal facility, total direct operational costs are estimated as follows:

	Operating Costs Over 20 years (X 1000)	
1.	Operations and maintenance (10% of buildings, facilities, and light equipment over 20 years)	4,626.5
2.	Disposal cell materials (58 trenches)	124.2
3.	Heavy equipment	12,228
4.	Payroll:	
	o Base	22,560
	o Fringe	2,256
	o Overhead	12,408
5.	Corporate administration (@ $300 k/yr)	6,000
6.	Legal fees (@ $150 k/yr)	3,000
7.	Environmental monitoring	534
8.	Regulatory costs	1,138
9.	Consumables (utilities, fuel, supplies, etc.) (@ $200 k/yr)	4,000
		$68,875

3.2 Indirect Operational Costs

Indirect operational costs are approximated as a percentage of the total direct operational costs and are assumed to consist of a 30% contingency

allowance. Operational costs prior to profit are therefore calculated as the following.

Costs = 1.3 (Direct costs).

For the reference disposal facility, this comes to:
1.3 x $68.9 million = $89.5 million.

3.3 Total Operational Costs

Again, a profit of 20% is assumed. Total operational costs are estimated as the following:

Total operational costs = (1.2)(1.3)(Direct Costs)
= 1.56 (Direct Costs)

For the reference facility, total capital and operational costs equal the following:

Total Costs = 10.38 (Direct capital costs)
+ 1.56 (Direct operational costs)
= 10.38 (7,452,100) + 1.56 ($68,875,000)
= $184,797,000
= $185./$m^3$
= $5.23/$ft^3$

4. POSTOPERATIONAL COSTS

Postoperational costs are composed of two components: (1) costs for facility closure following the end of the facility 20-year operating life, and (2) costs for institutional control of the facility after closure. In this appendix, costs for closure are assumed to be borne by the licensee. To fund closure activities, the licensee is assumed to set aside a sum of money on an annual basis for investment and accrual. This is represented in this appendix by a surcharge ($ per m^3 of waste) on waste received at the disposal facility. Monies received from this surcharge are assumed to be placed into an interest-bearing investment fund. However, to ensure that funds will be available to implement closure should for some reason the site be closed earlier than scheduled, the projected costs for closure are assumed to be protected by a surety mechanism obtained by the licensee. Funds for institutional control are assumed to be obtained through a surcharge ($ per m^3 of waste) placed upon the waste received at the facility. Monies obtained through the surcharge mechanism are placed in an interest-bearing state operated investment fund.

The remainder of this section is divided into two subsections: Section 4.1 addresses closure and Section 4.2 addresses institutional control. Each subsection develops scenarios regarding the specific level of activities required. That is, two levels of closure activities (and costs) are developed (e.g., high, and low), as well as three levels of institutional control activities (high, medium and low). The possible need for long-term contingency (remedial) actions are also addressed in Section 4.2.

Section 4.0 is then followed by a Section 5.0 which briefly illustrates how closure and institutional control costs may vary depending upon assumptions regarding funding mechanisms (surety bonds, letters of credit, sinking funds) as well as interest and inflation rates.

4.1 Closure

Closure activities involve final decontamination and dismantlement of buildings and other structures, as well as preparation of the disposal facility for institutional control by the site owner. Closure activities are referenced in this section to the reference disposal facility discussed in Appendix E. Closure costs are estimated based upon the following factors:

- Building decontamination and demolition;
- Final grounds preparation;
- Onsite disposal of demolished buildings and other waste material;
- Personnel costs (including fringe and overhead);
- Supplies and utilities;
- Equipment costs; and
- Environmental monitoring costs.

As an illustration in this appendix, two levels of closure costs are estimated: low and high. These two scenarios are discussed below.

4.1.1 Low Scenario

For the low scenario, final closure of the reference facility is assumed to require approximately two years and mainly involves dismantling and decontaminating site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring.

Three of the six buildings on the reference disposal facility--i.e., the administration building, the health physics/security building, and the site warehouse,--are located in the administrative area of the site and should be essentially free of contamination. The administration building and the warehouse--are dismantled and sold for salvage. The health physics/security building is left standing for use by the site owner during the institutional control period. Of the remaining three site buildings, only the waste activities building is expected to have appreciable levels of contamination. This building is decontaminated to the extent practical and demolished, as is the site garage and the site shed. To accommodate the waste produced during dismantlement and decontamination operations, an additional small trench is excavated. The volume of waste produced during these operations is estimated to be relatively small--about 1130 m^3 (40,000 ft^3) (Ref. 6).

For the low scenario, there is assumed to be little effort to recontour the disposal site land. The trench covers are left mounded. The final disposal trenches are filled, capped, graded, and seeded with a grass cover. During this time period, the licensee makes a final survey of the disposal area to determine direct radiation levels. All parts of the disposal area are certified as having radiation levels at essentially background levels.

A summary of the estimated costs are included as Table Q.7. Based upon consideration of the site closure and stabilization plans of an existing disposal facility, building demolition is estimated to cost approximately $300,000, assuming that a private contractor is hired to perform these operations (Ref. 6).

Estimated personnel costs are also shown in Table Q.7, and fringe and overhead are calculated as above. For this appendix, building demolition, waste disposal, and most of the final site preparation is assumed to require approximately a year's effort. However, another year at reduced licensee effort is assumed to be needed for final site surveillance activities prior to license termination.

Supplies and utilities are estimated as 10% of base personnel costs. Environmental monitoring costs are estimated assuming that the operational environmental monitoring program is continued during the closure period. Total closure costs are estimated at about $ 1 million.

4.1.2 High Scenario

In this scenario, a complete site restabilization program is assumed to be carried out at site closure. This program serves to accelerate the compression of wastes and waste containers in the disposal cells. The program is intended to enhance the integrity of the disposal cell covers and therefore reduce the amount of water potentially infiltrating into the disposed waste. The restabilization program involves: (1) stripping off the existing trench caps, (2) use of vibratory compaction to accelerate disposal cell compression, (3) backfilling the resultant compressed (depressed) areas, (4) reconstruction of the trench caps, and (5) revegetation of the trench caps, including fertilizing, seeding, and mulching.

The restabilization program is carried out as an addition to the decontamination, demolition, and final waste disposal activities discussed for the low scenario. Total closure operations are estimated to require approximately 4 years of effort. This results in greatly increased closure costs as shown in Table Q.8--i.e., up to about $3 million. Much of the additional costs are caused by delaying site stabilization activities until closure. If the same compaction and stabilization activities were carried out all through site operations, then overall costs should be reduced.

4.2 Institutional Control Program

For this appendix, institutional control activities are assumed to be carried out by an agency of the state in which the disposal facility is located. Funds for institutional control are provided by a tax exempt sinking fund into which money is placed during site operations from a surcharge placed upon waste received at the facility during the operating life. For this section, estimated funding levels are presented in constant (1980) dollars. The effects of interest and inflation are discussed in the next section.

Table Q.7 Estimated Closure Costs--Low Scenario

I.	Building Demolition		$300,000
II.	Waste Disposal Materials and Survey		
	40,000 ft^3 = 1133 m^3 of waste, need 22,700 m^3 of disposal space, assuming 50% efficiency. Assume one 7m X 47m X 8m trench		
	a) Standpipes 30 Ft of 6" p.v.c. standpipe @ $2.45/ft 2 standpipes per trench = $300/trench well casings @ $150/pipe = $300/trench		$ 547
	b) French drain (.6 m x .6m x 47m) = 17m^3 = 22 yd^3 22 yd^3 @ $5/$yd^3$		$ 2,582
	c) Seed and mulch 0.12 acres @ $295/acre		$ 35
	d) Cornermarkers & monuments 6.67 ft^2 x $18.30/$ft^2$		$ 480
	e) Surveyor Surveys @ $60/hr Assume 8 hrs/trench		$ 480
			$ 1,294
III.	Personnel		
	1st year: 1 Site Manager		40,000
	1 Foreman		28,000
	2 Security		24,000
	1 Radiation safety officer		35,000
	1 Radiation safety technician		14,000
	5 Semiskilled laborer		75,000
	2 Unskilled laborer		20,000
			$236,000
		Fringe	23,600
		Overhead	129,800
			$389,400
	2nd year: 1 Site manager		40,000
	1 Radiation safety technician		14,000
	1 Semiskilled laborer		15,000
			69,000
		Fringe	6,900
		Overhead	37,950
			$113,850

Table Q.7 (continued)

IV.	Consumables		
	(10% of base personnel costs) 2 years:		$ 30,500
V.	Equipment		
	1 4WD vehicle	24 months @ $ 800/mo	19,200
	1 Crawler tractor	6 months @ $4200/mo	25,200
	1 Farm tractor	24 months @ $ 800/mo	19,200
	1 Pan scraper	12 months @ $750/mo	48,000
	1 Pickup	12 months @ $750/mo	9,000
			$120,600
VI.	Environmental Monitoring		
	2 years @ $26,700/yr		$ 53,400
		Total	$1,009,044

For the cost estimates, 3 levels of institutional control are assumed: a high level, a moderate level, and a low level. For each level, costs are broken down into two basic activities:

- o recordkeeping and administrative support; and
- o site surveillance and maintenance (assumed to be contracted by the state agency to individuals or to a private firm)

Recordkeeping and administrative support costs are calculated by estimating the number of man-hours required by the state to administer the institutional control program for the facility. Administrative support costs include personnel salaries, overhead, utilities, etc., and are basically an estimate of the average cost to a government of one year's labor by a government employee. At the Federal level, administrative costs run at about $80,000 to $100,000 per man-year. State costs are generally lower and an approximate figure of $50,000 per man-year is used in this appendix.

The level of effort expended by the state is assumed to be a function of the degree of stability of the facility, and the surveillance, maintenance, and monitoring activities required for the facility. In this appendix, the level of effort is assumed to range from a quarter of a man-year to 3 man-years, depending upon the degree of site stability achieved.

Disposal facility surveillance and maintenance costs are calculated assuming that a company or individuals are contracted by the state for surveillance, maintenance, and environmental monitoring activities. These costs are assumed to include costs for:

Table Q.8 Estimated Closure Costs--High Scenerio

I.	Building Demolition		$ 300,000
II.	Waste Disposal (Survey and Materials)		1,294
III.	Restabilization		
	Total disposal area: 86 acres = 348,000 m^2		
	a) Strip cap (1 m)		
	348,000 m^3 = 455,000 yd^3	@ \$0.75/yd^3*	341,250
	b) Vibratory compaction assume one week per trench	= 58 weeks	
		= 13 months, 2 weeks	
	1 vibratory compactor	@ \$1,950/mo, \$675/wk*	131,100
	3 man crew	@ \$15/hr x 40 hr/wk	
	c) Replace cap (1.15 m)		
	400,200/m^3 = 523,380 yd^3	@ \$0.75/yd^3	392,438
	d) Compact Cap @\$0.55/m^3		220,100
	e) Vegetate @\$500/acre		43,000
			$1,127,888
IV.	Personnel		
	Year 1:		$ 389,400
	Years 2-3:		
	1 Site manager		40,000
	1 Foreman		28,000
	1 Radiation safety officer		35,000
	2 Radiation safety technician		28,000
	3 Semi-skilled laborer		45,000
	3 Unskilled laborer		30,000
			206,000
		Fringe:	20,600
		Overhead:	113,300
			339,900
		x 2 years	679,800
	Year 4:		113,850
			$1,183,050

Table Q.8 (continued)

IV.	Consumables		
	(@ 10% of base personnel costs)		$ 70,200
V.	Equipment		
	1 Crawler tractor	6 mo @ $4200/mo	25,200
	1 Farm tractor	48 mo @ $800/mo	38,400
	1 Pan scraper	6 mo @ $8000/mo	48,000
	1 4WD vehicle	48 mo @ $800/mo	38,400
	1 Pickup	36 mo @ $750/mo	27,000
			$ 177,000
VI	Environmental monitoring		
	4 years @ $26,900/yr		$ 106,800
	air sampler purchase and install		
	10 samplers @ $900/sampler		9,000
	air sampler analyses		
	10 samples x 50 samples/yr x $50/sampler		50,000
	2 years @ $25k/yr		$ 165,800
		Total:	$3,025,232

*Ref. 5.

- o personnel;
- o personnel fringe and overhead;
- o supplies;
- o equipment;
- o environmental monitoring sample analysis; and
- o contractor fees.

As long as the disposal facility is in a stable condition, then the institutional control activities could involve persons whose role would be little more than that of a caretaker. These activities could involve facility inspections, collecting environmental samples for analysis, and minor maintenance (if required) of fences, site grounds, and so forth. These activities would probably require some, but not extensive, knowledge of radiation, radiation safety, and radiation equipment.

However, if modest to extensive subsidence were a recognized problem, or if there was concern that subsidence was a potential problem, then much greater

experience with radiation and contamination control and radioactive waste management would be needed. In these cases, a company experienced in radioactive waste disposal is assumed to be contracted to run the facility. The need to employ the services of such a company and the need to employ the company more-or-less full time at the facility results in considerable additional expenses to the state. Expenses would include personnel payroll and overhead, supplies, equipment and contractor's fees.

In this appendix, four levels of contractor's activities are assumed. A six-man crew is assumed to be associated with a relatively high level of maintenance activities. These activities do not, however, include potential costs for occasional pumping of trench sumps, treating and solidifying any liquid collected, and onsite disposal of solidified waste. A 4-man crew is associated with a more moderate but still significant level of site maintenance. There is projected to be, however, little or no need for trench pumping activities. The 2-man crew is associated with a low level of site maintenance. Such maintenance activities may actually not be required; however, they are conservatively included. As discussed above, the one-man crew is basically a caretaker.

The personnel required for each crew are estimated in Table Q.9. As shown, a 6-man crew is estimated to involve total base personnel salaries of $109,000 annually, while the 4-man crew is estimated to involve total base personnel salaries of $79,000. The 2-man crew involves a base salary of $43,000 and that of the caretaker, $20,000. There is also assumed for each crew a fringe of 10% and an overhead charge of 50%.

Supplies are estimated by assuming that the costs for the supplies needed are a fraction (10%) of the base personnel salaries. The more personnel are required to operate the site, the greater the outlay for supplies and utilities is likely to be.

Equipment costs are geared to the level of effort by onsite personnel, and by the size of the work crew. Assumed equipment use and charges are illustrated in Table Q.10. The 6-man work crew is assumed to require a relatively high level of equipment use while the 4-man crew is assumed to require a relatively moderate level of equipment use. The 2-man crew is assumed to only have very low equipment requirements.

Environmental monitoring costs are estimated by again assuming 3 levels of environmental monitoring needs depending upon the stability of the facility--i.e., a high level, a moderate level, and a low level. A facility which requires a great deal of maintenance would also require a high environmental monitoring effort. This is because there are more activities at the site which might involve handling radioactive material, in addition to an inherent increased level of concern regarding the long term impacts of an unstable site. On the other hand, monitoring costs would be expected to be significantly reduced at a stable site. A summary of the types and frequencies of environmental

Table Q.9 Personnel Requirements for Institutional Control

Level of Effort	Personnel	
High (6-man crew)	1 Site manager	$ 40,000
	1 Health physics technician	14,000
	3 Semi-skilled laborer	45,000
	1 Unskilled laborer	10,000
		$109,000
	Fringe :	10,900
	Overhead:	59,950
		$179,850
Moderate (4-man crew)	1 Site manager	$ 40,000
	1 Health physics technician	14,000
	1 Semi-skilled laborer	15,000
	2 Unskilled laborer	10,000
		$ 79,000
	Fringe :	7,900
	Overhead:	43,450
		$130,350
Low (2-man crew)	1 Foreman	$ 28,000
	1 Semi-skilled laborer	15,000
		$ 43,000
	Fringe :	4,300
	Overhead:	23,650
		$ 70,950
Very Low (1-man)	1 Caretaker	$ 20,000
	Fringe :	2,000
	Overhead:	11,000
		$ 33,000

Table Q.10 Equipment Use During Institutional Control (in months per year)

Equipment	Level of Use		
	High	Moderate	Low
4WD Vehicle	12	0	0
Pickup	12	12	6
Crawler Tractor	6	0	0
Farm Tractor	12	6	3
Estimated Costs	$53,400	$26,400	$6,900

sampling assumed to be undertaken for each level of monitoring activity is presented in Table Q.11, along with the overall estimated costs for sample processing and analysis.

The fee is again assumed to be a fraction of the contractor's total expenses at the facility. In this case, as maintenance activities are assumed to involve a relatively low level of business risks, the fee is assumed to be 10% of the total expenses.

A summary of the costs over 100 years of institutional control (including state administration costs, as well as costs for site personnel, supplies, equipment, monitoring, and the constructor's fee) is presented as Table Q.12. As shown, for each level of institutional control activities, costs for 3 time periods are presented. The time periods considered are 0 to 10 years, 11 to 25 years, and 26 to 100 years. The different time periods are presented due to the expectation that the disposal facility would tend to naturally stabalize over time. This is similar to the approach taken by Battelle-Pacific Northwest Laboratories (PNL) in NUREG/CR-0570 (Ref. 9). However, NRC staff experience has been that initial subsidence at disposal facilities is generally characterized by a 7 to 10 year time frame rather than a zero to 5 year time frame assumed by PNL.

The low level of maintenance costs are in the same range as the PNL projections for minimal long-term care costs at an eastern site over 100 years. (Ref. 9). However the estimated costs may be conservatively high. As long as there is some assurance that the facility is in a stable condition, it may be possible to get by with considerably less expenditures.

Table Q.11 Estimated Long-Term Environmental Monitoring Activities

Sample Description	High		Moderate		Low	
	No. of Loc.	Frequency	No. of Loc.	Frequency	No. of Loc.	Frequency
TLD*	30	quarterly	10	quarterly	0	
Atmospheric	3	daily gross beta-gamma weekly gamma isotopic	1	daily gross beta-gamma weekly gamma isotopic	0	
Soil and Vegetation	10	quarterly	10	semi-annual	10	semi-annual
Offsite Wells	5	semi-annual	2	semi-annual	2	annual
Boundary Wells	10	semi-annual	5	semi-annual	5	annual
Disposal Area Wells	15	quarterly	15	semi-annual	5	semi-annual
Disposal Trench Sumps	58	monthly	58	semi-annual	58	semi-annual
Estimated costs	$19,200		$8,400		$3,100	

*Thermoluminescent dosimeter.

The estimated costs for the high level of maintenance, however, may be too low. For example PNL has suggested a possible 25% contingency for unforseen events (Ref. 9). Unforseen events could include water management problems ranging from periodic withdrawal of water from disposal trenches and solidification, to large scale dewatering activities brought about by an extensive occurrence of the bathtub effect.

Table Q.13 summarizes an estimate of the additional costs that could arise from a relatively moderate scale water accumulation problem at the reference facility. In this case, a total of 25,000 gallons of water is assumed to be pumped from the disposal trenches per year. Leachate withdrawn from disposal trenches is assumed to be solidified in cement (at a volume increase factor of 1.4) and disposed onsite. Costs for leachate solidification are estimated to be

Table Q.12 Estimated Annual Institutional Control Base Costs

Level of Effort	Adm	Contractor Costs ($x 1000 per year)					
		Personnel	Supplies	Equipment	Monitoring	Fee	Total
High							
0-10	150	179.85 (high)	10.9	53.4 (high)	19.2 (high)	26.3	439.65
11-25	100	130.35 (mod)	7.9	26.4 (mod)	19.2 (high)	18.4	302.3
26-100	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
Moderate							
0-10	100	130.35 (mod)	7.9	26.4 (mod)	19.2 (high)	18.4	302.3
11-25	50	70.95 (low)	4.3	6.9	8.4	9.06 (low)	149.6 (mod)
26-100	50	33 (care)	2.0	- (nil)	3.1 (low)	-	88.1
Low							
0-10	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
11-25	25	33 (care)	2.0	- (nil)	3.1 (low)	-	63.1
26-100	12.5	33 (care)	2.0	- (nil)	3.1 (low)	-	50.6

Table Q.13 Small to Moderate Water Accumulation Costs

I.	**Personnel**	
	1 additional semi-skilled laborer @ $15,000/yr	$ 15,000
	Fringe & Overhead	$ 9,750
	Supplies @ 10%	$ 1,500
II.	**Solidification Equipment**	
	Cement solidify into 55 gallon drums @ 25,000 gallons per year, 1:4 VIF $2.50/gal*	$ 62,500
	637 drums @ $20/drum* (Price includes equipment, cement, labor & fuel)	$ 12,740
III.	**Disposal Trench Materials Costs**	
	Continuously operated trench for 10 years (2650 m^3 disp. space) Trench dimensions = 8 m x 47 m x 8 m = 3008 m^3 = 3934 yd^3	
	a) Standpipes	
	30 ft. of 6" p.v.c standpipe @ $7/ft	
	2 standpipes per trench @ $210/pipe	$ 420
	standpipe casings @ $150/casing	$ 300
	b) French drain	
	(.6m x .6m x 47m) = 17m^3 = 22 yd^3	
	gravel fill @ $5/$yd^3$	$ 177
	c) Seed and mulch	
	550 m^2 =	$ 40
	d) Cornermarkers and monuments	
	Polished red granite: 6.7 ft^2 @ $18.30/$ft^2$	$ 122
	e) Surveyor	$ 480
	$60/hr @ 8 hr/trench	
	Total:	$ 1,539
	Cost per year:	$ 154
IV.	**Disposal equipment****	
	1 panscraper, 6 months @ $8000/mo	$ 48,000
	pumping equipment, 12 months @ $500/mo	6,000
		$ 54,000

Table Q.13 (continued)

V.	Additional environmental monitoring	
	10 extra atm. samplers @ 50 samples/yr 100 extra sump samples/yr. $50/sample	$ 30,000
	Subtotal:	$185,644
VI.	Contractor's Fee	
	10%	$ 18,564
	Total per yr:	$204,208
	Total operating costs over 10 years = $2,042,080	
	Purchase and install 10 atm samplers @ $900 apiece = $9,000 Total cost =	$2,051,080

*Ref. 10.

**Ref. 5.

approximately $2.50 per gallon, which includes installation costs and cement. The figure $2.50/gallon to solidify leachate is on the low end of a range of estimates of moderately sized cement solidification systems (maximum throughput of 25,000 gallons) analyzed by Dames and Moore (D&M) for use in solidifing evaporator bottoms at the Maxey Flats disposal facility. (The costs ranged from $2.25 to about $10 per gallon) (Ref. 10). Costs for 55 gallon drums are estimated at $20/drum (Ref. 10).

Disposal trench materials costs are estimated by assuming a disposal trench is operated continuously over a ten year time period. To represent additional equipment requirements, an additional pan scraper is assumed to be leased for 6 months per year.

As can be seen, the costs of solidifying 25,000 gallons of trench water per year would run about $204,208 per year or a total of $2,042,080 over 10 years.

The above costs are for a moderate water accumulation problem involving 25,000 gallons per year over 10 years time, and assumes that the persons maintaining the disposal facility are reasonably diligent in removing any accumulated liquids. It is therefore instructive to examine a potential case in which for some reason liquids are allowed to accumulate over several years prior to processing. This can occur at disposal facilities located in sites having highly impermeable soils as has been previously experienced at Maxey Flats and West Valley.

Table Q.14 summarizes the potential annual costs associated with pumping, processing, solidifying, and disposing of one million gallons of contaminated liquid per year. As shown, the initial installation charge for an evaporator and a demineralizer pretreatment system are estimated to be about $1.75 million, as installed (Ref. 11), while the annual operating charge is estimated to run about $70,000 per year. The assumed evaporator is a 10 gpm forced circulation evaporator/crystallizer having a volume reduction factor of between 178-208 (Ref. 12). The $1.75 million purchase and installation cost does not include the costs of any additional air cleaning system. Operating costs do not include costs for replacing ion exchange media in the demineralizer.

One million gallons of liquid processed per year is somewhat less than the annual quantity of contaminated liquid presently processed at the Maxey Flats disposal site (Ref. 12). Not all of the contaminated liquid processed at Maxey Flats is leachate pumped from the disposal trenches. Some of it is contaminated water from within a storage tank berm area. However, all of the liquid treated is treated as a direct result of the liquid accumulation problem in the disposal trenches. As shown, processing costs carried out over a number of years can grow to be quite expensive--e.g., 10 years of processing would total about $8.5 million.

Experience has shown that unless steps are taken to reduce or eliminate the accumulation rate, processing operations can continue over long time periods. For example, leachate pumping and treating operations at Maxey Flats have been carred out since 1973. However, it has only been within the last few years that the contaminated liquid processing rate has been greater than the accumulation rate (Ref. 12).

From Table Q.15, it can be seen that a complete site restabilization effort carried out over approximately two years could cost in the neighborhood of $1.7 million. This involves stripping off trench caps, compaction of the wastes, replacing and compacting the cap, and placement of vegetation. An extended period of intensive site surveillance would also probably be required to assure that the restabilization program had eliminated the water accumulation problem.

As long as the disposal facility is not placed in a stable condition, additional (contingency) long-term care costs can therefore range from approximately $1.7 million to $10 million. At a site with very permeable soils, water accumulation may not be a special problem, and additional costs could be just those associated with restabilization--i.e., $1.7 million ($167,800/yr). At sites with moderately permeable soils, additional long term costs could include those for a moderate amount of liquid treatment and a restabilization program.

Assuming 10 years of moderate leachate treatment activities along with a restabilization program, total contingency costs over 10 years could be as much as 3.67 million ($367,000/yr). For disposal facilities with very impermeable soils, experience has indicated that it is possible to create a situation where an extensive liquid treatment operation is required. Ten years of such treatment combined with a restabilization program could increase costs by about $10 million ($1,006,900/yr).

Table Q.14 Pumping, Processing, and Solidifying Costs for One Million Gallons of Contaminated Liquid Per Year

I.	**Capital Costs**	
	Purchase evaporator (Ref. 12)	$1,000,000
	Purchase ion-exchange pre-treatment system (Ref. 11)	$ 750,000
	Purchase and install 10 atm. samplers @ $900 apiece (Ref. 11)	9,000
		$1,759,000
II.	**Yearly Costs**	
	1) Equipment	
	Lease pump & hose @ $500/month (Ref. 5)	$ 6,000
	2) Labor Costs	
	2 semi-skilled laborers @ $15,000	
	2 unskilled laborers @ $10,000	
	30,000 + 20,000 =	$ 50,000
	Fringe	5,000
	Overhead	27,500
	Supplies	5,000
	3) Treatment Costs	
	Volume reduction factor = 200	
	Ion exchange 1 E6 gal/yr @$0.10/gallon (Ref. 13)	$ 100,000
	Evaporate 1 E6 gal/year @ $0.35/gallon (Ref. 12)	$ 350,000
	4) Solidification	
	Solidify 5,000 gallons of concentrated bottoms per year. Assume cement solidification, with 1.4 VIF, @ $2.50/gallon and $20 per 55-gallon drum	
	Solidification:	$ 12,500
	728 drums Drum Charge:	$ 2,545
	5) Disposal Costs	
	7,000 gal solified waste per year requires 53 m^3 of disposal space per year or 530 m^3 of disposal space over 10 years. Assume continuously operated 4 m x 19 m x 8 m trench.	
	a) Standpipes	
	30 ft. of 6" pvc pipe @ $7/ft	
	2 standpipes per trench @ $210/pipe	$ 420
	Standpipe casings @ $150/casing	$ 300

Table Q.14 (continued)

b)	French drain (.6m x .6m x 19m) = $7m^3$ = 9 yd^3 gravel fill @ \$5/yd^3	\$ 72
c)	Seed and mulch 154 m^2 = 0.04 acre @ \$295/acre	12
d)	Cornermarkers and monuments Polished red granite: 6.7 ft^2 @ \$18.30/ft^2	\$ 122
e)	Surveyor \$60/hr @ 8hr/trench	480
	Total:	\$ 1406
	Cost per year:	\$ 141
6)	Disposal Equipment Lease 1 pan scraper: 12 months @ \$800/mo (Ref. 5)	\$ 9,600
7)	Additional Environmental Monitoring 10 samplers x 50 samples/yr 300 extra sump samples/yr \$50/sample analysis	\$ 40,000
	Subtotal:	\$ 608,286
Contractor's Fee @ 10%		\$ 60,829
	Total Yearly Costs	\$ 669,115
	Total Operating Costs Over 10 Years:	\$ 6,691,150
	Total Capital Costs:	\$ 1,759,000
	Total Costs Over 10 Years	\$ 8,450,150

5.0 FINANCING FOR CLOSURE AND INSTITUTIONAL CONTROL

The previous section investigated some scenarios for closure and institutional control and estimated potential costs in 1980 dollars. Appendix K of this environmental impact statement investigates a number of potential institutional mechanisms for assuring the availability of funds for closure and long term control. Some of the short-term (e.g., for closure) financial surety mechanisms considered in Appendix K are:

- Surety bonds purchased by a disposal facility operator from a surety company
- Cash deposits to a state or federal agency
- Certificates of deposit

Table Q.15 Site Restabilization Program

I.	Restabilization		
	(from Table Q.8)		$1,127,888
II.	Additional Personnel		
	1 Foreman		$ 28,000
	1 Radiation safety officer		35,000
	1 Radiation safety technician		14,000
	2 Unskilled laborer		20,000
			$ 97,000
			9,700
			53,350
			$ 160,050
		x2 years	$ 320,100
III.	Additional Equipment		0
IV.	Additional Supplies		$ 19,400
V.	Additional Environmental Monitoring		
	10 samplers @ 50 samples/yr		50,000
	$50/sample x 2 years		
			$1,517,388
	Contractors Fee:		$ 151,739
			$1,669,127
	Purchase and install 10 atm samplers @ $900/sampler		9,000
			$1,678,127*

*If the restabilization program is combined with a moderate to large water accumulation program, then additional atmospheric samplers are already included. In this case, total costs = $1,619,127.

- o Deposits of securities to a state or federal agency
- o Secured interests in disposal facility operator's assets
- o Letters or lines of credit from a financial institution
- o Self-Insurance by the disposal facility operator.

Appendix K also investigates longer term financial surety mechanisms such as the current most common arrangement--that is, depositing monies obtained as a surcharge on received wastes into a state operated interest-bearing account. Other potential long-term funding arrangements are also investigated.

The purpose of this section is to provide an illustration of the effect of different funding arrangements (including different assumptions regarding interest rates, inflation rates, and so forth) and thus help to place Section 4 and Appendix K into better perspective. Actual funding arrangements for a particular disposal facility are expected to be fairly complicated and site-specific. A fairly simplified discussion, however, is provided below as an illustration.

5.1 Background

The following subsection provides a background discussion of a number of financial concepts used in this section. Much of the information in this subsection was obtained from information in Appendix E of NUREG/CR-0570 (Ref. 9) and from DOE (Ref. 8).

One important concept is that of the present value of money. The concept of present value allows a systematic treatment of the effects of expenditures, costs, and receipts of revenue over different time periods. The value of money changes as it is moved through time. In general, since presently available money can be put to a useful purpose, money has a greater value in the present than it would at some time in the future. For example, if S is the effective earning rate or interest rate, then the present value of one dollar due one year in the future is $1/(1 + S)$; similarly, the present value of that dollar earned n years in the future is $1/(1+S)^n$ (Ref. 14).

In terms of long-term care costs, the present value of these costs is equal to the capital required in a long term care fund. For example, assume that for each year over a total of n years, a constant amount of money (C) is expended. Then if the net rate of return on capital (the real interest rate) is equal to r, the present value (P) of all future costs is (Ref. 8):

$$P = C \frac{1 - (1+r)^{-n}}{r}$$

Assuming that C=$100,000 and n=100 years, then the present value of all future costs as a function of alternative real interest rates are:

P ($ million)	r (%)
4.31	2.0
5.16	1.5
6.30	1.0
7.85	0.5
10.00	0
13.02	-0.5
17.32	-1.0
23.55	-1.5
32.70	-2.0

In the above example, the real interest rate is defined as the nominal interest rate minus the inflation rate divided by 1 plus the inflation rate, or

$$r = \frac{i - j}{1 + j}$$, where

i = the (nominal) interest rate, or the rate of return on capital invested in normal securities (i.e., bonds, certificates of deposit, and similar financial investments); and

j = the inflation rate, or the annual rate of increase in cost of goods and services, as determined by one or more of the nation's economic indicators.

This formula is an approximation which is somewhat of an overestimate when inflation occurs early in the time period of interest and somewhat of an underestimate when inflation occurs toward the end of the time period of interest.

As shown, the value of the real interest rate has a significant effect on the present value calculated. For example, at a zero net interest rate (interest rate equals inflation rate), the present value is merely the product of the annual costs ($100,000) times the period of interest (100 years), or $10 million. At a net interest rate of +1.0%, the present value drops to $6.3 million; at a rate of +2%, the present value drops to $4.31 million. In other words, at a real interest rate of +2.0%, a total capital of $4.31 million is all that is needed to provide for $100,000 of long term care per year over 100 years. One additional advantage of a net interest rate of +1.0% or higher is that the present value does not increase significantly for time periods beyond 100 years. For example, if (C) is still $100,000, and if r varies between +1% and +2.5%, then the present value over different time periods is as follows:

Present Value ($ million) as Function of R and n

	r (%)			
n (years)	+ 1	+ 1.5	+ 2	+ 2.5
100	6.30	5.16	4.31	3.66
200	8.63	6.33	4.91	3.97
300	9.50	6.59	4.99	4.00
500	9.93	6.66	5.00	4.00
1000	10.00	6.67	5.00	4.00
10^6	10.00	6.67	5.00	4.00

At a negative real interest rate, an opposite trend is seen. For example, at a rate of -1%, the present value is $17.32 million for n = 100 years. For the same negative interest rate and a time period of 200 years, the present value is $64.64 million; at 300 years, the present value is $193.91 million.

Determination of the long-term real interest rate is difficult. The real interest rate is a function of the inflation rate and the nominal interest rate and both of these rates fluctuate both over time and over different areas in the country. The interest rate, of course, varies depending upon the type of security chosen. The inflation rate is a function of the manner in which the rate is calculated--e.g., the types of commodities or services examined when calculating the inflation rate. For example, the change in the consumer price index is one indicator of inflationary trends, and the gross national product (GNP) deflator is another.

To illustrate, Table Q.16 is reprinted from the "Final Generic Environmental Impact Statement on Uranium Milling" (NUREG-0706) and provides a comparison of the long-term government bond rate, the change in the consumer price index, and the imputed real interest rate (Ref. 15). Table Q.17 is reprinted from a report prepared by the International Research and Technology Corporation (IR & T) for EPA regarding financial mechanisms for hazardous waste disposal facilities (Ref. 16). This table was computed under different assumptions than Table Q.16 and illustrates the real interest rate on ten year U. S. Government Securities from 1943 to 1967. These interest rates are seen to fluctuate from -2.89% to +2.36% over a 25-year period, with an average rate of approximately zero. The periods having negative real interest rates coincide with periods which had a low inflation rate at the time the bond was issued, with inflation increasing rapidly over the life of the bond. The period having the high positive interest rate corresponds to a situation in which inflation was higher at the time the bond was issued than over the life of the bond.

Table Q.16 Interest Rates, Inflation Rates, and Real Interest Rates*

Year	Long-Term Government Bond Rates (1+r)	Change in Consumer Price Index (1+i)	Imputed Real Interest Rates (1+I)
1951	1.0257	1.079	.9506
1952	1.0268	1.022	1.0047
1953	1.0294	1.008	1.0212
1954	1.0255	1.005	1.0204
1955	1.0284	.996	1.0325
1956	1.0308	1.015	1.0156
1957	1.0347	1.036	.9987
1958	1.0343	1.027	1.0071
1959	1.0407	1.008	1.0324
1960	1.0401	1.016	1.0237
1961	1.0390	1.010	1.0287
1962	1.0395	1.011	1.0282
1963	1.0400	1.012	1.0277
1964	1.0415	1.013	1.0281
1965	1.0421	1.017	1.0247
1966	1.0466	1.029	1.0171
1967	1.0485	1.029	1.0190
1968	1.0525	1.042	1.0101
1969	1.0610	1.054	1.0066
1970	1.0659	1.059	1.0065
1971	1.0574	1.043	1.0138
1972	1.0563	1.033	1.0226
1973	1.0630	1.062	1.0009
1974	1.0699	1.110	.9639
1975	1.0698	1.091	.9806
1976	1.0678	1.058	1.0093
1977	1.0706	1.065	1.0053
1978	1.0789	1.077	1.0018
1979	1.0874	1.113	.9770
MEAN:1951-79	1.0488	1.039	1.0096
MEAN:1953-73	1.0437	.976	1.0184

*SOURCES: U.S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1970, Bicentennial Edition, Part 2, (U.S. Government Printing Office, Washington, D.C.), p. 1003; September 1975. Board of Governors of the Federal Reserve System, Federal Reserve Bulletin, March 1975, p. A-30, June 1977, p. A-27. U.S. Department of Labor, Bureau of Labor Statistics, Monthly Labor Review, February 1975, p. 117; February 1977, p. 117.

Table Q.17 Real Interest Rate on 10-Year U.S. Government Securities

Year of Issue	Real Interest Rate*
1943	-2.89
1944	-2.45
1945	-2.34
1946	-2.79
1947	-1.74
1948	- .16
1949	- .04
1950	- .76
1951	- .59
1952	.28
1953	.68
1954	.41
1955	.62
1956	.77
1957	1.32
1958	1.01
1959	1.99
1960	2.36
1961	1.11
1962	1.10
1963	.55
1964	.43
1965	- .38
1966	- .77
1967	-1.14

*Derivation: real interest rate equals nominal interest rate minus the inflation rate divided by 1 plus the inflation rate. This formula is an approximation which somewhat underestimates the real interest rate when the bulk of the inflation occurs in the final years and overestimates when the inflation occurs early in the life of the bond.

Source: Nominal Interest Rates from Moody's Investor Services; Inflation Rates from Economic Report of the President (1977); derivation of real interest rates by IR&T.

IR&T also examined the effect of the time period on determining the real rate of return on a variety of securities. Table Q.18 is reprinted from the IR&T report and illustrates the real rate of return (as calculated from their assumptions) on four securities, as calculated from the years 1960 to 1975, and 1965-1975. As shown, the real interest rate can significantly vary depending on the time period over which it is calculated. IR&T also observes that the use of the period 1965 to 1975 may be historically misleading, and states that other than the Great Depression, it would be difficult to find a 10-year period over which common stocks have performed more poorly than that of 1965 to 1975. IR&T observes that merely changing the years considered to the period 1967 to 1977 would significantly improve the performance of common stocks.

Table Q.18 Real Interest Rates on Various Securities

	1960-1975	1965-1975
Long-Term Government Bonds*	- .17	-1.23
State and Local Bonds**	- .44	-2.12
Corporate Bonds†	.52	- .84
Common Stock††	4.8	-2.01

Derivation: Inflation rate based upon GNP deflator, nominal rates of return as indicated in footnotes below.

*Federal Reserve.
**Standard & Poor's 15 Bonds.
†Moody's Corporate Bond.
††Standard & Poor's Composite (includes dividends and capital gains or losses).

It would be a mistake to project negative interest rates extending over extended periods of time such as 50 to 100 years. As stated by IR&T (Ref. 16):

> Current inflation rates are at historically high levels. It probably would be a mistake to project inflation rates using current inflation rates. Any long-term inflation rate of over 10 percent would undoubtedly lead to reforms in both the tax system and in methods of indexing securities. As a result, it would be meaningless to attempt to calculate the

effects of 50-year inflation rates of greater than 10 percent even if they should occur. It also may be noted that if long-term inflation rates of greater than 10 percent occur, and no adjustments to the financial system are made, then the repercussions will extend far beyond trust funds for hzardous waste disposal.

On the other hand, it would also be a mistake to project high real interest rates (e.g., above 2%) for long time periods, especially when one considers the potential effect of several years of inflation during the time period of interest.

In the GEIS on Uranium Mill Tailings (NUREG-0706), NRC used a projected real interest rate of one percent (Ref. 15). For their regulations on hazardous waste management, EPA has determined that use of a zero real interest rate would be appropriate (Ref. 17). However, in determining this rate, the effect of trustee fees was considered. For large amounts of money, these fees can average from 0.5% to 1% of the value of the principal. Such fees, however, would not be applicable to a state-operated fund.

In their analysis of costs for decommissioning a reference burial ground, PNL assumed a real interest rate of 2% (Ref. 9). This was based upon their examination of the real rate of return on various securities. PNL states that the average real return relative to the gross national product deflator on 3- to 5-year U. S. Government securities was 1.43% for the period 1961 to 1976. For the period 1963 to 1976, the average real return on AAA corporate bonds was 1.95%. For the period 1953 to 1975, the average expected real return on 9- to 12-month treasury issues relative to expected inflation rates was about 2.2%. These figures were taken from the 1977 Statistical Abstract of the U.S., and from a June 1977 article by Carlson in the American Economic Review (Ref. 9).

Another consideration is that states may be restricted by law in the types of securities which may be invested in. That is, securities offering very high rates of return may not be allowable. One analysis of a public trust fund (no taxes), illustrates this. At a high nominal rate of return of 10%, a low nominal rate of return of 8%, an inflation rate of 8%, and trustee fees of 0.9%, then the real effective rate of return for the trust fund varies from -0.8% (for a low rate of return) to +1% (for a high rate of return) (Ref. 17).

All things considered, a real interest rate of about 1% is used in this environmental impact statement. (At an average inflation rate of 9% and an average interest rate of 10%, the real interest rate is calculated to be 0.92%)

5.2 Closure

As shown in Section 4.0, example closure costs at the reference facility could range from a low of $1 million (assuming relatively little site stabilization work is performed at closure) to a high of about $3 million (assuming a great

deal of site stabilization work is performed at closure). These figures are in 1980 dollars and the actual closure costs would increase due to inflation. The closure costs for a specific site, of course, are a function of the site environmental characteristics, the facility design and operating practices, and a number of other factors.

For this appendix, the licensee is assumed to bear the costs of the disposal facility. These costs are assumed to be passed on to the disposal facility customer and are represented by a surcharge ($ per cubic meter of waste) on the waste received at the disposal facility. Monies collected through this surcharge mechanism are assumed to be set aside and invested. For example, if a fixed sum (R) is invested into a sinking fund at the end of each year for 20 years (the operating life of the facility), the money accumulated at the end of this time period should be equal to the closure costs (C_o). The relationship between R and C_o is given by (Ref. 16):

$$R = C_o \frac{i}{(1+i)^{IT_o}-1}, \text{ where}$$

i = the average interest rate over (IT_o) years

IT_o = the operating life of the facility

The total costs to the disposal facility customer due to the surcharge is then 20R.

The closure costs, however, are not the costs calculated in 1980 dollars but the 1980 costs inflated to the time of closure. For example, if closure costs in 1980 dollars are C_{80}, and inflation averages $j = 9\%$ over $IT_o = 20$ years, then the costs of closure at the year 2000 is:

$$C_o = C_{80}\,(1 + j)^{IT_o}$$
$$= C_{80}\,(1.09)^{20}$$
$$= 5.60\,C_{80}.$$

Combining equations, the assumed closure surcharge (CS) may be approximated as:

$$CS = \frac{IT_o}{V_w.} \frac{(1+j)^{IT_o}\,C_{80}\,i}{[(1+i)^{IT_o}-1]}$$

There may be a danger, however, that if the disposal facility were to close prematurely, there may be insufficient funds to effect closure. Therefore, in this appendix the projected costs for closure are assumed to be projected by a financial assurance mechanism obtained by the licensee. There is, of course, a fee for financial assurance mechanisms such as surety bonds or letters of credit. This fee is again assumed to be passed onto the disposal facility customer. The total unit costs ($/m^3) for this fee (CF) may be approximated as follows:

$$CF = \frac{IT_o}{V_w} C_{so} (1 + j)^{IT_o} f, \text{ where}$$

f = annual fee for assuring the availability of closure funds.

The total unit closure costs (UCC) are then given as

$$UCC = CS + CF$$

$$= \frac{IT_o \ (1+j)^{IT_o} C_{so}}{V_w} \left\{ f + \frac{i}{[(1+i)^{IT_o} - 1]} \right\}$$

In the case of the reference facility, two closure scenarios are presented: a low scenario which illustrates costs associated with a situation in which most of the closure activities are carried out during site operations, and a high scenario which illustrates costs associated with a situation in which more extensive site activities are carried out during closure. In this case, these extensive activities are illustrated by the assumption of a complete site restabilization program. As discussed earlier in Section 4.0, costs (1980 dollars) on the order of $1 million are associated with the low closure scenario, while costs on the order of $3 million are associated with the high closure scenario.

Assuming that the average inflation rate is 9%, the average interest rate is 10% and the disposal facility is operated for 20 years, than the closure surcharge for the low closure scenario is about $1.96/m^3 ($0.06/ft^3). The closure surcharge for the high closure scenario is about $5.87/m^3 ($0.17/ft^3). Similarly, assuming an effective security bond cost of 1.5%, total costs of a surety mechanism over 20 years would total approximately $1.68 million for the low scenario and/or approximately $5.04 million for the high scenario, assuming an average inflation rate of 9%. This corresponds to unit surety fee costs of $1.68/m^3 ($0.05/ft^3) or $5.04/m^3 ($0.14/ft^3), respectively. These costs would be passed on to the disposal facility customer. It is apparent that disposal facility operating practices in which a low level of activities is required during facility closure would tend to reduce costs to the facility customer.

A low planned level of effort at site closure also helps to provide greater assurance that sufficient funds will be available for closure. This involves less risk to the site owner, and also to the disposal facility operator. This practice also provides greater assurance that the site is in a stable condition prior to license termination. By incorporating disposal facility operating practices whereby efforts are made to place the facility into a stable condition as the site is operated, several years of observation will be available to assess overall site stability. On the other hand, if an extensive restabilization program is implemented during closure, then there would be less assurance that the facility is in a stable condition prior to license termination.

5.3 Institutional Control

Institutional control costs are calculated assuming that money is collected as a surcharge on waste received at the facility and deposited in a state-operated sinking fund. As discussed earlier, for each level of institutional control (high, moderate, and low), costs are divided into 3 time periods: zero to 10 years, 11 to 25 years, and 26 to 100 years. Estimated base costs in 1980 dollars for these time periods for each of the three levels considered are presented in Table 11. As discussed earlier, there are also contingency costs which could be added to the base costs. These contingency costs are a function of assumed site-specific conditions and are applied over the first (0-10 years) time period when a high level of maintenance is most expected.

To calculate the present value of the 100-year institutional control costs in 1980 dollars, the following equation is used (Ref. 10):

$$PV_{80} = C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+i)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n}, \text{ where}$$

i = nominal interest rate

j = inflation rate

C_a = average annual institutional control costs over the first ten years.

C_b = average annual institutional control costs over years 11 to 25.

C_c = average annual institutional control costs over years 26 to 100.

Under the assumption of a high level of maintenance activities,

C_a = C_a(base) + C_a(contingency), where C_a(contingency) is a function of site specific conditions and is estimated based upon the degree of potential water accumulation problems at the disposal facility.

As stated above, PV_{80} is in 1980 dollars. However, institutional control does not start until after the site is closed. Therefore, PV_{80} should be inflated by a factor $(1+j)^m$, where m is the time period between the time the facility opens and the time the closure period is ended. That is, $m = IT_o + IT_c$, where IT_o is the period of operation and IT_c is the period of closure. Assuming an operating period of 20 years and a closure period of 2 years, then in this case m = 22 years. Therefore, the amount that must be accumulated in the sinking fund to pay for institutional control costs is:

$$(1+j)^m \, PV_{80}$$

During the operating life of the site (IT_o years), funds are placed into the sinking fund at a rate of R dollars per year, which is obtained as a surcharge on waste delivered to the site during the operating period. During the closure period, no waste is received and so no surcharge is collected. However, interest is still being accrued upon the funds deposited into the sinking fund. To a first approximation, therefore:

$$PV_{80} \, (1+j)^m = \frac{R \quad (1+i)^{TI_o-1}}{i} \, (1+i)^{IT_c}$$

The total amount of money that must be deposited into the sinking fund is therefore 20R. Dividing 20R by the volume of waste received at the site over 20 years (this is one million m^3 of waste for the reference case) gives the unit long-term care costs in dollars per unit volume of waste. Adding the unit capital costs, operational costs, closure costs and institutional control costs gives the total unit disposal costs.

Combining the above terms, the unit institutional control cost (LTC) is equal to:

$$LTC = \frac{IT_o}{V_w} \frac{PV_{80} \, (1+j)^m \, i}{[(1+i)^{IT_o}-1] \, (1+i)^{IT_c}} \quad \text{,where}$$

$$PV_{80} = C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+i)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n} \text{ , where}$$

$m = IT_o + IT_c$, and.

V_w = the total volume of waste delivered to the disposal facility.

An example of institutional control costs can be calculated for the reference facility. For the purposes of this calculation, the following assumptions are made:

i = 10%;
j = 9%;
IT_o = 20 years; and
IT_c = 2 years

Assuming a high level of institutional control costs and a moderate contingency level,

C_a = \$439,700 + 367,020 = 806,720
C_b = \$302,300
C_c = \$149,600; then
LTC = \$ 34.6 million.

This corresponds to a unit institutional control cost of \$34.6/m^3 (\$0.98/ft^3).

However, if through improvements in waste form and packaging, as well as improvements in facility design and operation, a low level of institutional control was required, then the costs would total approximately \$8.5 million. This corresponds to a unit institutional control cost of \$8.50/ m^3 (\$0.24/ft^3).

For this example, the difference between institutional control costs between a stable and an unstable site is therefore on the order of \$0.74/ft^3. Assuming that these costs are passed on to the customer, then any efforts to improve the stability of the disposal facility at least up to \$0.74/ft^3 would tend to have an overall reduction in costs to a disposal facility customer. A more important consideration, is the relative magnitude of the estimated long-term costs--i.e., \$34.6 million vs \$8.5 million. There is a hazard that if the disposal facility closes earlier than expected, then sufficient funds may not have been accumulated to provide for all long-term care activities. This can result in a burden to future generations. Obviously, there is a much greater risk of long-term burden if the facility is in an unstable condition rather than a stable condition.

6. SUMMARY

The preceeding sections presented some assumptions and calculational procedures which may be used in this environmental impact statement to determine costs for siting, designing, constructing, operating, and closing a radioactive waste disposal facility, as well as costs for 100 years of long-term care. The costs are calculated in three segments:

1. Capital costs, which include costs associated with siting, designing, licensing, and initial construction of the facility.

2. Operational costs, which include costs associated with receipt and disposal of waste, as well as construction of disposal cells.

3. Postoperational costs, which include costs for (a) facility closure, and (b) institutional control by a site owner.

To calculate total capital and total operational costs, "direct" capital and operational costs are first estimated. These costs are then each multiplied by parameters which account for additional indirect costs, cost of money, contingency and profit.

Postoperational costs are broken up into closure costs and institutional control costs. Closure costs are calculated assuming that adequate funds for closure are provided for by the licensee through use of an investment fund (represented as a surcharge on received waste). The availability of funds for closure is assured by a mechanism such as a surety bond. As discussed in Appendix K, there are a number of mechanisms which could be used to provide adequate assurance for site closure. The costs associated with these mechanisms are expected to be in the neighborhood of one to two percent of the principal. Institutional control costs are calculated based on the assumption that a state-operated sinking fund is established and that a surcharge is levied upon the waste received at the disposal facility on a cost per waste volume arrangement.

Total unit disposal costs (UDC) are therefore calculated as:

$$UDC = UDC_c + UDC_o + UDC_p$$

UDC_c = capital unit disposal costs

= 10.38 (direct capital costs)/V_w

UDC_o = operational unit disposal costs

= 1.56 (direct operational costs)/V_w

UDC_p = postoperational unit costs

= (closure costs + institutional control costs)/V_w.

$$= \frac{IT_o \ (1+j)^{IT_o} \ C_{so}}{V_w} \left\{ f + \frac{i}{[(1+i)^{IT_o}-1]} \right\} + \frac{IT_o \ PV_{so} \ (1+j)^m}{V_{w[(1+i)^{IT_o}-1)]} \ (1+i)^{IT_o}}$$

V_w = Volume of waste received over IT_o years (in m^3 or ft^3)

IT_o = site operational life (years)

IT_c = closure period (years)

m = ITo + ITc

C_{80} = closure costs (1980 dollars)

i = nominal interest rate (expressed as a decimal - e.g., 9% = 0.09)

j = inflation rate (expressed as a decimal)

f = annual fee for assuring availability of closure funds (expected to be a few percent per year and expressed as a decimal).

PV_{80} = present value of institutional control costs in 1980 dollars

$$= C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+i)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n}$$

C_a = average annual costs over first 10 years (1980 dollars)

$= C_a(\text{base}) + C_a(\text{contingency})$

C_b = average annual costs over years 11 to 25 (1980 dollars)

C_c = average annual costs over years 26 to 100 (1980 dollars).

For the purposes of this environmental impact statement, contingency costs are optional but when implemented are assumed to occur when a high level of maintenance is assumed to be required at the site. These costs are assumed to occur during the first 10 years of the institutional control period and are a function of site specific conditions. For the purposes of this impact statement, 3 types of contingency actions are estimated:

1. For sites having very permeable soils, a complete site restabilization program.

2. For sites having moderately permeable soils, a moderate water accumulation problem (25,000 gallons per year) plus a complete site restabilization program.

3. For sites having very impermeable soils, an extensive water accumulation problem (one million gallons of contaminated liquid processed per year) plus a complete site restabilization program.

The above equation which determines unit disposal costs is used in this environmental impact statement to help estimate costs of a number of alternatives for management of radioactive waste. Appendix E contains a summary of the unit disposal costs for the reference facility. Appendix F analyzes the effect of options on disposal facility design and operation on unit capital and unit operational costs.

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16. ABSTRACT (200 words or less)

The four volume draft environmental impact statement (DEIS) is prepared to guide and support publication of a proposed new regulation, 10 CFR Part 61, for the land disposal of low-level radioactive waste. The analysis in the DEIS include a systematic analysis of a broad range of alternatives relating to the form and content of waste, the engineering design of disposal facilities, the method of operation of the facilities, institutional controls, financial assurances, and administrative and procedural requirements. From the analysis, four main performance objectives are established in the proposed regulation relating to (1) minimizing long-term social commitment and costs, (2) minimizing long-term environmental releases, (3) minimizing long-term impacts to humans potentially inadvertently intruding into disposed waste, and (4) assuring short-term operational safety. Based upon the analysis and overall performance objectives, a number of technical, financial, procedural, and administrative requirements are also developed.

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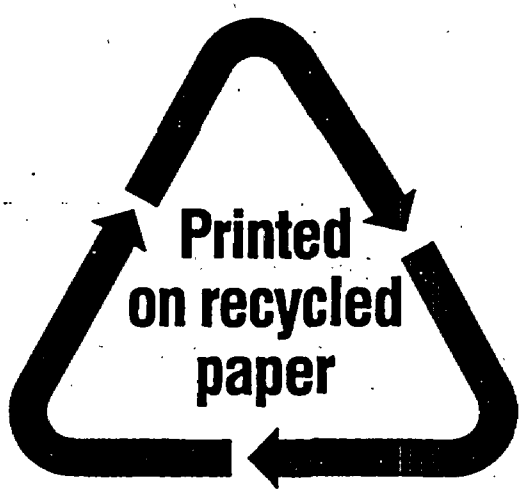

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APP. G-Q

DEIS ON 10 CFR PART 61, "LICENSING REQUIREMENTS FOR LAND DISPOSAL OF RADIOACTIVE WASTE"

SEPTEMBER 1981