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Vol. 3

Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Appendices A-F

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

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Appendix A

(Reserved for Staff Analysis-Public Comments on Draft EIS and Proposed Part 61 Rule)

Appendix B

(Reserved for Public Comments on Draft EIS and Proposed Part 61 Rule)

Appendix C

PUBLIC PARTICIPATION IN THE DEVELOPMENT OF THE LLW DISPOSAL REGULATION

1. SUMMARY

This section provides an overview of the means that NRC has used to provide public participation in the development of the low-level radioactive waste (LLW) disposal regulation.

A broad, flexible program for the orderly development of comprehensive regulations governing the management and disposal of LLW by shallow land burial or other alternative methods was initiated and subsequently announced in the Federal Register on December 7, 1977 (42 FR 61904). This program is currently in progress.

The staff initiated a study to provide a broad analytic base for a waste disposal classification system providing a foundation for the forthcoming regulations and accompanying environmental impact statement (EIS). A document (NUREG-0456) describing the classification system and applications was published in June 1978. A Federal Register notice (43 FR 36722) was issued on August 18, 1978 to announce the availability of the document and to request public comments on the in-progress study. Comments received by the NRC have been used to guide the further development of the methodology and its application to rulemaking.

In an October 25, 1978 Federal Register Advance Notice of Proposed Rulemaking (43 FR 49811), the Commission requested advice, recommendations, and comments on the scope and content of an environmental impact statement to guide and support the development of a regulation, 10 CFR Part 61, for the management and disposal of low-level waste.

The comments received by NRC on the Advance Notice were utilized by NRC staff in scoping the form and content of an EIS and LLW disposal regulation. To help focus development on the draft EIS and proposed LLW disposal regulation, NRC staff prepared a preliminary draft regulation 10 CFR Part 61 (draft dated November 5, 1979). The November 5th preliminary draft regulation received wide distribution and copies were sent to state liaison officers, federal and state agencies, industry, public interest groups, and others. In addition a Federal Register notice (45 FR 13104) was issued on February 28, 1980 to announce the availability of the November 5, 1979 draft document and to request public comments. Comments received have been used during further development of the regulation and preparation of the EIS.

During 1980, the NRC held four regional workshops in Atlanta, Chicago, Denver, and Boston, that provided state officials, industry representatives, waste generators, the public, and private interest groups with an opportunity to comment on the preliminary draft regulation and other issues that need to be addressed and resolved. The comments received at these workshops have been used during further development of the regulation.

In summary, the NRC has continuously sought and obtained a broad range of input from the states, public and industry on the approach, issues and considerations to be addressed in upgrading regulations concerning the management and disposal of LLW. Copies of all comments, transcripts and reports constituting this input have been placed in the Public Document Room of the NRC as part of the record of this rulemaking procedure. This input has been used during the development of 10 CFR Part 61.

2. BACKGROUND

The NRC has been continuously involved in the reexamination of the technical and regulatory bases for low-level waste management. In mid-1976, an NRC Task Force was created to review programs used by the NRC and state governments to regulate disposal of commercial low-level waste. A document entitled, "NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds" (NUREG-0217) was published in March 1977. Publications and recommendations of a wide range of Congressional, technical, industrial, public, and governmental groups provided input to the Task Force Study and were referenced in the Task Force Report.

After concluding that the states (through their regulatory programs) have adequately protected the public health and safety, the Task Force made a number of recommendations regarding federal versus state regulation and other related issues currently affecting commercial burial ground regulation and operation. These recommendations included development of a specific regulatory program for low-level waste disposal including regulations, standards, and criteria; and studies to identify and evaluate the relative safety and impacts of alternative low-level waste disposal methods.

The NRC staff subsequently developed a program plan for low-level waste management. To formulate this program, the staff considered the Task Force recommendations; public comments on the Task Force Report; data gleaned from review of technical documents and participation in conferences, meetings, and discussions attended by industrial, state, and public organizations; and other correspondence and documents. A document describing the program entitled "NRC Low-Level Radioactive Waste Management Program" (NUREG-0240) was published in September 1977. The availability of this document was announced in the Federal Register on December 7, 1977 (42 FR 61904). This program is currently in progress and includes technical studies to prepare a regulatory base, development of regulations, criteria, and supportive environmental impact statements as well as development of criteria and procedures for applicants to prepare license applications and for NRC to make uniform and timely licensing decisions.

3. NOTICE OF DEVELOPMENT OF A RADIOACTIVE WASTE DISPOSAL CLASSIFICATION SYSTEM

In 1974, the Atomic Energy Commission (AEC) proposed to prohibit the disposal of commercially-generated transuranic (TRU) radionuclides by shallow land burial. Upon review of the proposed rule and the comments received from interested parties, the NRC staff determined that the proposed rule was unworkable and initiated development of regulations which would govern the disposal of all radioactive waste--not just TRU-contaminated waste.

The staff initiated a study to provide a broad analytic base for a waste disposal classification system, providing a foundation for the forthcoming regulations and accompanying environmental impact statements. A document describing the classification system and applications, entitled "A System for Classifying Radioactive Waste Disposal--What Waste Goes Where?" (NUREG-0456) was published in June 1978. In an August 18, 1978 Federal Register Notice of the Development of a Radioactive Waste Disposal Classification System (43 FR 36722), the Commission requested comments on NUREG-0456 to guide the further development of the methodology and the completion of the study. Comments were specifically requested in the following areas: the overall approach; the migration pathways and exposure mechanisms; the exposure guidelines; and applications of the methodology.

A total of 17 formal comments were subsequently received on the Notice. Copies of the comments were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61. A summary of the comments received by the Commission is included below, followed by an analysis of comments received as they may relate to development of the regulation governing the management and disposal of low-level radioactive waste.

3.1 Summary of Comments

There was a varied but limited number of comments on the study relating to its use as an analytic base for developing regulations on classification of radioactive waste for disposal. Some of the commenters felt that the overall approach in the study represented a useful and needed contribution to the development of a rational nuclear waste classification system. Several commenters indicated that the models used in the study were adequate, however, this view was not shared by other commenters who cited deficiencies such as the lack of consideration of several important potential pathways and the failure to make sensitivity analyses for pathway models. Some commenters felt that the exposure guidelines were not defensible based on the rationale stated while other commenters considered them to be justified for the purposes used. There were mixed views by several commenters on the reasonableness of assumptions concerning the length of institutional control. Two commenters felt that practical problems inherent in determining radioactivity concentration or activity on a routine basis in shipments of waste to a disposal site would have to be considered in establishing a practical waste classification system. Classification of waste by sources, based on analysis of representative samples from these sources, was suggested by one of the commenters as a practical application of the methodology. Overall, the comments indicated the need for further development of the methodology to provide a practical foundation for a workable regulation on classification of radioactive waste for disposal.

3.2 Analysis of Comments in Specific Areas

3.2.1 Overall Approach

Several commenters felt that NUREG-0456 represented a useful and needed contribution to the development of a rational nuclear waste classification system.

However, one commenter stated that the report did not adequately address the concerns of the public nor demonstrate how the waste classification system would be implemented without undue burden on those directly affected by it. Several commenters felt that the methodology used to develop the classification system is only applicable to generic waste classification and not to the classification or the evaluation of any specific site. Another commenter stated that there should be an effort to systematically identify and/or project all conceivable categories of radioactive waste to include parameters such as source term, waste form, composition, concentration, activity level, radiological hazard, pathway mobility and transportability.

3.2.2 Migration Pathways and Exposure Mechanisms

Several commenters felt that the models were adequate for generating a waste classification system, however this view was not shared by other commenters. One commenter stated that the pathways used are unrealistic and the data produced is ultra-conservative and "out of touch with the real world." Several commenters noted that several important potential pathways did not appear to be considered in the methodology. One commenter expressed some concern that too much emphasis was placed upon the inadvertent intrusion scenario. Deficiencies in the area of hydrology were noted by one commenter who felt that many of the parameters selected were not representative. Several commenters noted the need for sensitivity analyses for pathway models.

3.2.3 Exposure Guidelines

Several commenters felt that the dose guidelines are not defensible based on the rationale stated. One commenter stated that while the 500 mrem/yr annual dose is supported by ICRP, the value could be 10-fold to 30-fold lower when considering U.S. national values. Another commenter noted that the exposure guidelines as used in NUREG-0456 are not conservative enough to be publicly acceptable, although they do present a very small health risk. One commenter pointed out, among other things, that there is no basis for the statement that (a) a whole-body dose-equivalent limit degree of safety, and (b) that 1 mrem/yr/GWe/yr is justified by resulting benefits. On the other hand, one commenter indicated support of the criteria used in NUREG-0456 and considered them to be justified for the purposes used. Another commenter noted that there is a need to establish acceptable dose criteria in order to carry out the methodology as presently designed. This commenter also stated that the suggested 500 mrem/yr peak individual dose rate and the 150 year period of restricted site use are reasonable provided it is emphasized that this is a standard for classification after which ALARA will be applied. One commenter stated "For the determination of de minimus concentrations, the exposure guidelines should be much lower for the sanitary land fills since they are not licensed for radiological considerations. An acceptable exposure level may be such as contained in the EPA safe drinking water regulations."

3.2.4 Applications of the Methodology

Two commenters expressed concern about the practicability of determining radioisotope concentration or activity on a routine basis in shipments of waste to a disposal site. One of these commenters suggested that the classification system should specify which of the three disposal techniques should be used for low-level solidified waste stream categories rather than specify a radioactivity concentration or activity that is permitted to be disposed of in one of these three manners. The other commenter suggested that waste sources could be generically classified by determining, based on analysis of representative samples from these sources, the range of expected activities of key isotopes and comparing these results with isotopic limits established for interfaces for the disposal techniques.

There were mixed views concerning the length of institutional control. One commenter stated that administrative control of the site for 150 years was reasonable and another commenter felt that this assumption builds a considerable degree of conservatism into the results. On the other hand, another commenter stated that people making the initial disposal decision should not plan on use of institutional assistance to maintain controls and protection beyond 100 years.

One commenter felt that some credit should be given for packaging and solidification. This commenter asked for justification of a requirement for solidification if after solidification the waste is treated, for regulatory purposes, as though it had not been solidified.

4. ADVANCE NOTICE OF PROPOSED RULEMAKING ON LLW DISPOSAL REGULATION (10 CFR PART 61)

In an October 25, 1978 Advance Federal Register Notice of Proposed Rulemaking (43 FR 49811), the Commission requested advice, recommendations, and comments on the scope and content of an environmental impact statement (EIS) to guide and support the development of a regulation, 10 CFR Part 61, for the management and disposal of low-level waste (LLW). In this Notice, the Commission identified four potential alternative disposal methods to shallow land burial; i.e., ocean disposal, engineered structures, mined cavities, and intermediate depth burial (disposal with an increased depth of cover (e.g., about 30 feet) over the disposed waste). Specific comments were requested on the following questions:

1. Proposed new 10 CFR Part 61. The Commission has concluded that an environmental impact statement should be prepared pursuant to the National Environmental Policy Act on its actions to develop more explicit criteria and regulations for low-level waste management. The Commission plans initially to consider the environmental impact of low-level waste disposal alternatives and of technical criteria for disposal of radioactive wastes by shallow land burial. An environmental impact statement will be prepared to provide an essential part of the informational and decisional base for the criteria and

rulemaking action. What significant issues should the Commission consider and analyze in-depth in the environmental impact statement? What issues are not significant, or are covered or may be covered in another environmental review, and therefore may be eliminated from analysis in this environmental impact statement? Within this statement, what should the criteria be to distinguish among viable and nonviable alternatives? Do we know enough about certain disposal options to make an informed decision at this time? Should waste segregation be applied to low-level wastes (e.g., separate disposal sites for nonfuel cycle wastes)?

2. Is it desirable to develop explicit criteria and standards for the disposal of low-level wastes? If so, what should be the general format and content of the criteria and standards?

3. What should be considered in developing the criteria for waste performance; site suitability, design, and operations; site monitoring; site decommissioning, postoperational maintenance, and funding? Are there other areas where criteria are needed?

4. What are the advantages and disadvantages of the four alternatives described above? Which of the alternatives should be given the greatest priority in development of regulations?

5. Are there viable alternatives, other than the four alternate methods identified above, which should be further considered in the development of the U.S. Nuclear Regulatory Commission's program? (Those which have been considered were noted earlier in this Notice and are discussed in greater detail in NUREG/CR-0308.)* If so, what is the basis (technical, economic, social, etc.) for considering an additional alternative as a potential candidate?

6. What should be the extent of each state's responsibility for management of the low-level wastes generated by operations within its borders?

A total of 34 formal comments were subsequently received on the Advance Notice. Copies of the comments were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61. A summary of the comments received by the Commission is included below, followed by an analysis of comments received on each specific question of the Advance Notice.

*NOTE: In NUREG/CR-0308 ("Screening of Alternative Methods for Disposal of Low-Level Radioactive Wastes"), a number of potential alternative disposal methods to shallow land burial were considered. Those methods considered to be the most viable for further study included ocean disposal, engineered structures, mined cavities, and intermediate depth burial (disposal with an increased depth of cover--e.g., about 30 feet--over the disposed waste). A followup to this report, in which these alternative disposal methods were analyzed in further detail, has also been published as NUREG/CR-0680 ("Evaluation of Alternative Methods for Disposal of Low-Level Radioactive Wastes").

4.1 Summary of Comments

The respondents to the Advance Notice strongly supported NRC's decision to develop specific criteria and standards for the disposal of LLW. There was also support among the commenters that an EIS should be prepared to provide an essential part of the informational and decisional base for the development of the criteria and standards and for the rulemaking action. Two commenters, however, did not agree with the NRC conclusion that an EIS should be prepared on its actions to develop more explicit criteria and regulations for LLW management.

The commenters were divided on the form and structure of the criteria and standards to be developed by NRC. Some commenters stated that criteria and standards should be specific and detailed. Others suggested the criteria and standards should be minimal and basic and should emphasize the performance objectives to be met by LLW disposal facilities. The commenters also stated that as part of the development of LLW disposal standards and criteria, a system was needed for classifying or segregating the waste based on hazard.

A number of comments were received on NRC's questions regarding alternative disposal methods to shallow land burial. Although the comments in this area were mixed, the most often expressed opinion was that primary consideration should be given to developing requirements for shallow land burial and emplacement of waste into mined cavities. The disposal of wastes into ocean waters was given the lowest priority. Four commenters felt there was no need to establish a priority list of the alternative waste disposal methods to shallow land burial. The most often expressed disadvantage to any alternative method was the potential for increased cost. Approximately 60% of the respondents suggested other potentially viable methods for low-level waste treatment and/or disposal. The methods mentioned most frequently were volume reduction and other advanced processing techniques.

A clear consensus of the extent of the state's responsibilities did not appear in the responses. The issue that appeared in agreement was the need for inter-agency and state cooperation and negotiation. Approximately half of the commenters added that LLW disposal sites should be regionally located and there was no need or desire to have one site in each state.

4.2 Analysis of Responses to Specific Questions

1(a). What significant issues should the Commission consider and analyze in-depth in the environmental impact statement?

The responses to this question were widely varied. The issues most frequently identified by the commenters were: (1) cost benefit analysis, (2) potential effluent releases, (3) geography and geology, (4) ground and surface hydrology, (5) alternative disposal methods, (6) adverse environmental effects, (7) long-term care, (8) state, local and regional conflicts, (9) demography, (10) transportation, (11) monitoring programs, (12) socio-economics, and (13) irreversible and irretrievable commitments.

Other issues that were mentioned by the commenters included: (1) seismology, (2) ecology, (3) radiological background, (4) potential mitigating measures, (5) occupational exposures, (6) onsite accident analysis, (7) alternative siting, (8) need for disposal facilities, (9) short-term vs. long-term productivity of disposal site land, and (10) socio-political issues.

1(b). What issues are not significant, or are covered or may be covered in another environmental review and therefore may be eliminated from analysis in this environmental impact statement?

The issues most frequently identified by commenters as insignificant or issues that should be addressed in other environmental reviews include: (1) transportation routing and accidents, (2) radiation exposures during transportation, (3) site-specific issues, including local ecology, (4) meteorology and climatology, and (5) air quality.

One commenter expressed the opinion that no issue should be dismissed as *a priori* insignificant.

1(c). Within this statement, what should be the criteria to distinguish among viable and nonviable alternatives?

Comments were sparse on this question and a clear consensus of criteria could not be obtained. One possible explanation was a problem with interpretation of the question--e.g. alternatives to be addressed in the EIS vs. the NRC study of alternative disposal methods. The issues that were mentioned most frequently were that disposal sites should be consistent with public health and safety, site operation be an economic benefit, and a comparison should be made of long-term effects and costs of different alternatives. Three commenters stated that the EIS should not attempt to develop such criteria. One of these commenters also stated that such a decision would discourage innovation and improvement of the alternative disposal methods.

1(d). Do we know enough about certain disposal options to make an informed decision at this time?

Of those who commented on this question, about 40% stated that most of the available information was on shallow land burial and an informed decision could probably be made on this disposal method. Three commenters stated that there was sufficient information on all four alternatives to shallow land burial (intermediate land burial, mined cavities, ocean disposal, engineered structures) to make an informed decision after a careful review of each option. Four commenters felt that there was not enough information available to make an informed decision on any of the four options. One of these responders stated "I believe nobody knows this answer for sure. The history of waste management has not been a glorious one. Much of our behavior has been to get the low-level waste out-of-sight and out-of-mind rather than to determine the consequences of our behavior."

1(e). Should waste segregation be applied to low-level wastes (e.g., separate disposal sites for nonfuel cycle wastes)?

Of the responders who commented on this question all but one commenter stated a need for development of a waste classification or segregation policy.

2(a). Is it desirable to develop explicit criteria and standards for the disposal of low-level wastes?

Comments received on this question reflected general support for developing explicit criteria and standards for disposal of low-level waste. Three commenters stated that either explicit criteria are not required or that the criteria and standards should be kept to a minimum.

2(b). If so, what should be the general format and content of the criteria and standards?

The major issues identified by commenters for which explicit criteria and standards were needed included (1) characteristics and performance standards of the waste to be buried, and (2) performance of the disposal method. Other criteria needs frequently mentioned by the commenters include criteria for public health and safety, the ALARA concept, radiation monitoring, recordkeeping, security and safeguards, and environmental studies of specific disposal sites. Several commenters expressed a need for flexible criteria to allow the use of future technologies. Finally, at least two commenters stated that the criteria should stipulate performance standards to be met by disposal methods rather than stipulating specific requirements (e.g., depth of ground-water table, amount of rainfall) for individual disposal methods.

3(a). What should be considered in developing the criteria for waste performance; site suitability; design and operations; site monitoring; site decommissioning, postoperational maintenance, and funding?

The responses to this question were somewhat sparse and scattered, making it difficult to perform a conclusive analysis.

Waste Performance. There were several comments regarding the importance of specific criteria for waste form and packaging for disposal, but few comments on the considerations important to formulating these criteria. Considerations suggested included the chemical stability of the waste as well as the half-life of the radioactive material contained in the waste.

Site Suitability. A majority of those who responded to this question stated four important considerations to site suitability: remoteness, geologic stability, surface and groundwater hydrology, and the ability to enhance containment. Other considerations mentioned by commenters include meteorology, seismology, and radiation background. The commenters were divided on whether population density should affect site suitability. Finally, one commenter stated that site suitability must be weighed against other hazards such as transportation.

Design and Operations. In response to this question, seven commenters stated that the criteria for site design and operations should be one that requires a high degree of containment of the waste. Other considerations mentioned by the commenters included proper packaging, provisions for security and safeguards, provisions for leakage monitoring, and well-defined duties of site personnel.

Site Monitoring. Seven commenters suggested that criteria for site monitoring should include criteria for equipment for detection of potential radionuclide migration by various pathways. Other considerations mentioned by commenters included redundant monitoring systems, a system for waste accountability at the site, and the need for precise instrumentation.

Decommissioning, Postoperational Maintenance. Four responses were received from the public. Of these responses, unanimous support was expressed for a criterion that would state that a disposal site, following closure, would meet a preexisting radiation level with minimal maintenance required. Three commenters suggested that the term site closure should be used in place of the term site decommissioning.

Funding. Three commenters responded to the question regarding specific funding criteria. All of these commenters suggested that funding should be on a user's fee basis.

3(b). Are there other areas where criteria are needed?

Six responses were received which stated that specific radiation dose guidelines need to be established. Other areas where specific criteria were suggested include recordkeeping, waste acceptance criteria, retrievability and isolation, and public acceptance of a disposal site.

4(a). What are the advantages and disadvantages of the four alternatives described above (the four alternative disposal methods to shallow land burial--intermediate land burial, mined cavities, ocean disposal, and engineered structures--identified as most viable in NUREG/CR-0308)?

Fewer than half of the 34 respondents offered comments on all the four alternative disposal methods. A majority of these commenters simply stated a preference for or against a particular disposal method and did not comment on the advantages or disadvantages of the method.

Engineered Structures. Of those who commented on this question, 60% stated a favorable opinion to the emplacement of wastes in engineered structures. The major advantages perceived by the commenters appeared to be (1) ease of recovery, and (2) monitoring capability and safeguard mechanisms can be designed into the structure. As expressed by one commenter, the disadvantages are that above ground structures appear to be an interim rather than a permanent solution and below ground structures would entail an unnecessary complication and expense for use for low-level waste.

Ocean Dumping. Half of the respondents offered a comment on ocean dumping. Most of the comments were against ocean dumping as an alternative method of low-level waste disposal. The major perceived disadvantages are the probability of severe ecological damage, international repercussions, and the issue of dispersal versus containment. The only advantage seen by the respondents appeared to be the comparatively lower cost and ease of disposal. Finally, one commenter stated that it would be illegal and duplicative for the Commission to develop any regulatory program for this alternative disposal method.

Mined Cavities. The comments on this issue were very sparse; thus, a firm conclusion on the commenters' perceptions of the advantages and disadvantages of mined cavity disposal is difficult. Most of the commenters on the potential emplacement of wastes in mined shafts supported this disposal method. The major advantage appeared to be the retrievability of the waste. However, many commenters felt that the method of mined cavities would involve unnecessary expense for use of low-level wastes.

Intermediate Land Burial. The commenters who offered an opinion on this potential disposal method were divided. The comment offered most frequently was that the bulk of the waste would be contained longer, but the increased cost would not be justified by the relatively insignificant benefit.

4(b). Which of the alternatives should be given the greatest priority in development of regulations?

Sixty percent of the respondents offered comment on the question of setting priorities. The majority of these commenters stated that primary attention at this time should be given to establishing criteria for shallow or improved shallow land burial. Approximately one-fourth of the commenters supported the emplacement of wastes in mined cavities and only one commenter felt that priority should be given to ocean dumping. Finally, four commenters generally agreed with one commenter who stated that "the underlying objective of any method of disposal is to keep the waste from entering the biosphere. There is no reason to believe that more than one disposal method could not satisfactorily perform this function."

5(a). Are there viable alternatives, other than the four alternative methods identified above, which should be further considered in the development of the U.S. Nuclear Regulatory Commission's program?

Approximately two-thirds of the commenters commented on this issue. The three alternatives most frequently mentioned were volume reduction and other advanced processing methods, segregation and classification systems, and a de minimus category of wastes. However, none of these three options were mentioned by more than 25% of the commenters. Other potential alternatives mentioned included: (1) solidifying waste into concrete within stainless steel welded liners which are then buried in impermeable clay; (2) reprocessing; (3) shooting rockets filled with waste into the sun; (4) mines sited in desert areas; (5) deep well injection and hydrofracturing; (6) mixing, dilution and dispersion; (7) ocean disposal with reinforced concrete vessels; (8) the use of an increased number and kind of man-made barriers; and (9) a combination of two or more methods. Three commenters felt that there appeared to be no other viable alternatives to the four previously mentioned alternatives.

5(b). If so, what is the basis (technical, economic, social, etc.) for considering an additional alternative as a potential candidate?

The comments received were sparse on the basis for the other viable alternatives. One commenter felt that a combination of advanced processing techniques and disposal on federal lands (which are badly contaminated and beyond the possibility of cleanup) would have the advantage of utilizing the most advanced processing techniques, have the capacity to handle other forms of hazardous wastes, and most importantly would spare public lands.

Another commenter stated that the development of transmutation procedures, solar technologies and sending waste rockets into the sun should all be considered long-term options. Two commenters suggested that volume reduction and a definition of radioactive waste plus a prohibition of burial of material which is only suspected of being contaminated would tend to reduce the volumes of burials. One commenter stated that incineration appears to be the best disposal method for flammable and toxic organic solvents and such waste could be used as a fuel source for large incinerators. Another commenter stated that ocean disposal with reinforced concrete vessels offers a more secure means for collection and transport of low-level wastes.

6. What should be the extent of each state's responsibility for management of the low-level wastes generated by operations within its borders?

A clear concensus of the extent of the state's responsibility did not appear in the responses. About 60% of the commenters responded to this question. Of these, about one-third felt that each state was responsible to pay for the disposal of the waste their state's utilities have generated. Approximately half of the commenters stated that the low-level waste burial sites should be located regionally and not on a state-by-state basis. Several felt that safe disposal of low-level waste was the responsibility of the federal government. Half of the commenters stated the necessity for interagency and state cooperation and negotiations. Several of the commenters felt that licensing and management, siting, environmental monitoring, operations and decommissioning of the burial facility should reside with the state.

Most felt the states should also have an option to transfer regulatory control to the government if and when desired. However, approximately the same number of commenters stated that the government should control licensing, siting, monitoring, and operations of the low-level waste burial facilities. Finally, one commenter stated that "NRC...is responsible for every bit of nuclear waste generated in this country."

4.3 Miscellaneous Comments

In reference to the Federal Register Notice, several of the commenters suggested that it is important for NRC to make clear that these "recent developments" do not reflect that any hazard to public health and safety has resulted from shallow land burial operations. One commenter stated that low-level waste is very dangerous and small amounts of radiation can be carcinogenic. Finally, one commenter expressed a concern that "the NRC schedule for the development of a regulatory program for shallow land burial by 1980 and one alternative by 1981 may be premature in view of the amount of research necessary. Much critical technical information on site selection, waste treatment and packaging, possibilities for segregating wastes, etc., presently being conducted by DOE, USGS, NRC, and EPA will not be available at an early enough date."

5. NOTICE OF AVAILABILITY OF PRELIMINARY DRAFT REGULATION 10 CFR PART 61 FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

The comments received by NRC on the Advance Notice were utilized by NRC staff in scoping the form and content of an EIS and LLW disposal regulation. To help focus development of the draft EIS and proposed LLW disposal regulation, NRC staff prepared a preliminary draft regulation 10 CFR Part 61 (draft dated November 5, 1979). The November 5 preliminary draft regulation received wide distribution and copies were sent to state liaison officers, federal and state agencies, industry, public interest groups, and others. Comments received are being considered in the further development of the proposed regulation and draft EIS.

In a February 28, 1980 Federal Register Notice of Availability of Preliminary Draft Regulation 10 CFR Part 61 for Disposal of Low-Level Radioactive Waste (45 FR 13104), the Commission requested comments on the preliminary draft regulation of November 5, 1979 to be considered during further development of the regulation, preparation of the EIS, and preparation of regulatory guides. In this notice the Commission indicated its interest in establishing a de minimus level (a level of radioactivity in waste that is sufficiently low that the waste can be disposed of as ordinary nonradioactive trash) for short half-lived radioisotopes commonly used in medical, research, and other applications--although this concept was not reflected in the November 5 version of the preliminary draft regulation.

The objectives that the staff had in mind at the time of this notice and which are reflected by the preliminary draft regulation are the following:

1. That LLW disposal facilities are sited, designed, operated, and closed to assure the long-term confinement of the disposed waste with essentially no need for active long-term site maintenance following closure.

2. That the regulation is applicable to a range of potential LLW disposal methods, particularly those investigated in detail during NRC's study of alternative disposal methods to shallow-land burial. These methods include improved shallow-land burial, intermediate land burial (i.e., disposal with about 30 feet of cover material), engineered structures, and mined cavities. Specific guidance for specific disposal methods would be addressed in regulatory guides or appendices to the regulation.

3. That general requirements are in the form of performance objectives, which establish what should be achieved in the disposal of LLW rather than specifying detailed technical specifications for individual disposal methods.

4. That the regulation provides numerical guidance to the extent practical.

5. That the regulation addresses: (1) administrative procedures and institutional considerations; (2) radiological performance objectives; (3) waste form and content; (4) site selection and suitability; (5) site design and operations; (6) environmental monitoring; (7) site closure (decommissioning) and funding; and (8) site surveillance after site closure.

6. That ground-water quality is protected. In preparing the preliminary draft regulation, NRC staff made use of the National Primary Drinking Water Standards for this purpose. This approach is based upon consideration of EPA's proposed regulation 40 CFR Part 250 (December 18, 1978, 43 FR 58946-59028) for the safe disposal of nonradioactive hazardous waste.

7. That protection is provided for the potential unintentional reclaimer to an LLW disposal site. Applicable concepts and methodology for this have been developed through NRC's waste classification study. By applying this methodology, the advantage of particular disposal methods for assuring confinement of particular types and forms of LLW during their hazardous lifetime would be identified.

8. That the use of multiple barriers (natural and man-made, such as waste packaging form, and content) to radioactive waste movement and human contact with waste is emphasized.

9. That the regulation is compatible with standards, criteria, and regulations promulgated by the EPA, including those standards, criteria, and regulations of the EPA Office of Solid Waste and the EPA Office of Radiation Programs.

A total of 33 formal comments were subsequently received on the preliminary draft regulation (draft dated November 5, 1979). Copies of the comments were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61. A summary of the comments received by the Commission is included below, followed by an analysis of comments received on specific sections of the preliminary draft regulation.

5.1 Summary of Comments

There was a wide range of comments concerning the overall content of the preliminary draft regulation. In contrast, all of the comments on the de minimus issue supported establishing de minimus levels for short-lived radioisotopes commonly used in medical, research, and other applications. Some commenters felt that a regulation as complex and restrictive as this one was not justified and would significantly increase waste disposal and operating costs without speeding up the licensing process. Several individual commenters thought that the regulation was too general and lacking in sufficient specificity, particularly in various technical aspects such as waste performance and technical requirements for an LLW disposal facility. Some commenters on waste performance expressed concern that requirements for solidification may be inflexible to some extent, unnecessarily restrictive when applied to institutional waste, and at cross purposes with requirements for volume reduction. Several of the commenters addressed the need for greater specificity for release and exposure limits as well as clarification of vague provisions concerning site investigation, hydrogeology, and surface geology. Several commenters felt that state government should be afforded a greater role in the regulation of LLW disposal in areas such as site selection, testing, inspection, and enforcement. There were mixed views by several commenters on the reasonableness of requirements for site funding. Several commenters took issue with the proposed maximum license period and questioned the technical basis for the period of postclosure observation and maintenance. Overall, the comments generally agreed with the approach and general content of the preliminary draft regulation. They also indicated a need for further improvement in the preliminary draft regulation so that, ideally, the final version will be plainly written in unambiguous, concise language stating clearly defined and scientifically-based requirements that will, in a cost-effective and balanced manner, provide reasonable assurance of LLW confinement, encourage meaningful state participation, and allow timely review and approval of licenses consistent with protection of the public health and the environment. While this goal is formidable, none of the commenters indicated any unsurmountable barriers to its achievement.

5.2 Analysis of Comments on Specific Sections of Preliminary Draft Regulation

5.2.1 Analysis of "SUBPART A: GENERAL PROVISIONS"

61.10 Purpose

The only commenter on this section suggested that it specifically state that the regulations are intended to promote the efficient use of any newly licensed burial capacity.

61.12 Scope

The only commenter on this section suggested that it should address "brokers" and others who may perform decontamination or dismantling for others but use their own license.

61.14 Definitions

A majority of the comments addressed the need for the definitions of several of the terms to be clarified. The most commonly cited terms were low-activity bulk solids, candidate sites, disposal, low-level waste (LLW), site monitoring, waste solidification, and free-standing liquid. Several commenters were concerned by the requirement of at least 3 alternative sites in the definition of slate of candidate sites. One commenter addressed the need for clarification of other terms such as decommissioning, engineered barriers, and environmentally preferred alternative site. Another commenter felt that the duration of funding and an inflation factor should be considered in the definition of funding for decommissioning, postoperational maintenance, surveillance and monitoring. Individual commenters suggested the need for definitions of additional terms such as homogeneous, low-level resins, high-integrity containers, dewatering, LLW disposal site, and de minimus.

61.20 General disposal requirement

Several comments were directed toward the issue of federal or state ownership of low-level waste sites. One of these commenters felt that the language implied a mandatory transfer of control of low-level waste sites from the state to the federal government. Several commenters did not agree with the provision that waste sites should be sited only on federal or state lands. One of these commenters cited the case of deep LLW disposal wells utilized for private industrial use. Another commenter felt that the siting criteria should permit siting anywhere but that title must be transferred to state or federal government prior to issuance of a license. This commenter also suggested that transfer of low-level waste include additional authorized recipients as provided in 10 CFR Part 71. Several commenters asked for clarification of the purpose and extent of the buffer zone area of the disposal facility. Other commenters noted the need to address the issue of mineral rights at the site.

61.22 Exemptions

Several commenters felt that this statement was too broad and that it was not clear on what basis exemptions will be granted. One commenter suggested that exemptions should be emergency based and only when an emergency exists as declared by the President or the Commission itself.

5.2.2 Analysis of "SUBPART B: LICENSE APPLICATION AND ACTIONS ON APPLICATIONS"

61.24 Activities requiring license

The only commenter on this section stated that it seems to include others besides disposal site operators within its scope which would appear to be unnecessary in that they are adequately treated in other parts of Chapter 1 of 10 CFR.

61.26 Notice of intent

Several commenters questioned the purpose of this section. One commenter stated that the affected state should also be notified. Another commenter felt that the method used for early identification of siting activities to ensure participation by all interested parties might be counterproductive. Opinions were expressed by individual commenters that the difference in the months to docketing of an application (1) was difficult to understand and (2) would have the sole result of delaying the time to issuance of a license for a low-level waste disposal facility. Several commenters felt that the requirements for a general description of the decision process used to select the region of interest and the slate of candidate sites needed clarification; one commenter questioned the need for 3 alternative sites in the slate of candidate sites. Another commenter noted the need for clarification in the requirements for (1) the summary description of the proposed project and (2) the description of the applicant's plans to involve state and local government.

61.28 Application for license--financial information

Several commenters thought that the provisions were appropriate and necessary but the need for clarification of ambiguities and the lack of specificity was noted. One commenter felt that the financial amounts involved appear to be reasonable, however several other commenters thought that the requirements for funding seemed prohibitively expensive. Several commenters questioned the basing of a financial charge (to be borne by the site owner) on costs of 100 years of postoperational surveillance and monitoring. One commenter stated that these regulations should exempt any byproduct waste systems that can exhibit adequate long-term containment from requirements for ownership transfer, site inspections, and long-term surveillance fees. Another commenter stated that (1) any perpetual care and maintenance program or closure plan should be left to the government agency which owns the site and the lessee as a matter of contractual negotiation, (2) it is not known whether such surety arrangements are available, and (3) a 1% real rate of interest is unrealistic; however, 2% is a more reasonable figure and justifiable on historic grounds.

61.30 Application for license--safety and environment report.

Several commenters questioned the need for diversity in an applicant's slate of candidate sites. Individual commenters expressed concern over several aspects of information requirements for the disposal facility and its operation including (1) specification of radioactive material, (2) description and analysis of the site, (3) use of engineered and natural barriers, (4) emergency planning, (5) alternative uses of the facility, (6) trained facility personnel, (7) gaseous and liquid effluent control equipment, and (8) state and local government involvement. One commenter felt that additional information should be required regarding nonradioactive toxic and hazardous substances. Another commenter stated that some requirements should be given for the operation of incinerators as well as for calciners. Another commenter felt that the emphasis on NRC decisions as to which multiple site will be used is inconsistent with good regulatory practice which says that regulators will approve, make recommedations or disapprove a proposed applicant action but will not make decisions for an applicant.

61.32 Application for license--site operations manual

A commenter felt that requiring NRC approval of a site operations manual and all changes thereto would delay implementation and discourage initiative toward routine improvement of the manual and its procedures. Another commenter asked if this section restricts periodic changes to properly update the manual to current operational and safety practices or must these necessary changes await the normal long time frame approval process.

61.34 Application for license--site closure and decommissioning plan

One commenter on this section thought that it is an excellent idea to require at least a preliminary plan at the time of license application thereby providing a common basis from which the licensor and licensee can work. Another commenter felt this should not be a separate application but should be part of the operational license application and be invoked at the discretion of the owner and operator acting in concert.

61.36 Filing of applications for licensees; oath or affirmation

One commenter on this section felt that the requirement for 150 copies of the safety and environmental report seemed arbitrary and unnecessary. This commenter suggested that the requirement be standardized at 25 copies each of the necessary documents. Another commenter felt that if a generic finding on the Commission's part is intended that security plans are exempt as stated in footnote (c) then that should be made clear and not be an additional burden placed on the licensee to make application and justification thereof.

5.2.3 Analysis of "SUBPART C: PARTICIPATION BY STATE GOVERNMENTS"

One commenter stated that this subpart restricts the role of state governments in siting and that their role should extend considerably beyond facilitating local government and citizen participation. This commenter expressed specific concerns in this regard in sections of this subpart dealing with (1) filing of proposals for state participation, (2) approval of proposals, and (3) assistance to Agreement States. Another commenter requested clarification of aspects of the above sections as well as another section of this subpart concerning early notice. Other individual commenters stated that (1) the NRC should retain the authority to license waste disposal sites on federally-owned land and (2) licensing or approval to store radioactive wastes generated at a nuclear plant site should rest with the NRC.

5.2.4 Analysis of "SUBPART D: CONDITIONS AND ACTIONS ON LICENSE"

61.52 Issuance of licenses

Individual commenters expressed opinions that (1) the applicant's plans for coping with emergencies include chemical as well as radiological contingencies, (2) postoperational maintenance must include the provision for extended site monitoring to ensure proper containment of wastes, (3) the applicant's postclosure plans address such matters as forestry resource uses and any necessary limitations on uses, (4) this section may preclude Agreement States from licensing burial facilities, and (5) this section infers the possibility that a construction permit may be issued separate from and prior to the issuance of an operating license.

61.54 Receipt of waste

One commenter noted that the notification of the Commission by the licensee prior to receipt of waste was too open-ended with respect to reporting results of demonstration programs carried out to confirm the adequacy of design. Another commenter stated that states ought to be able, with permission of Congress, to limit where waste comes from.

61.56 General license conditions

One commenter on this section questioned whether it precluded Agreement States from licensing burial facilities. Another commenter inquired as to the provisions for financing, operating, and managing a facility upon revocation of a license. Another commenter asked (1) if the requirement for Commission consent in writing, in the form of a license amendment, to a license transfer precludes a licensee from going out of business or declaring bankruptcy, and (2) if the requirement for an NRC-approved program covering the training of facility personnel applies to Agreement States.

61.58 Specific license conditions

One commenter felt that this section is too vague because it does not state acceptable criteria or numerical guidance for the categories of license conditions considered. Another commenter suggested that restrictions as to physical and chemical form and radioisotopic content and concentration of radioactive waste include requirements on segregation of particular kinds of waste by reactivity level and chemical and isotopic composition. Another commenter suggested that restrictions as to the amount of waste permitted per unit volume of emplacement space include radioisotopic in addition to physical and chemical characteristics of the waste.

61.60 Changes, tests, and experiments

One commenter stated that (1) the prior notification requirements for changes in operating procedures is of no real benefit and unnecessarily restrictive, and (2) some of the criteria for prior Commission approval of changes, tests, and experiments are inappropriate and ambiguous. Another commenter suggested that appropriate state agencies should receive copies of the report prepared by the applicant for NRC on changes, tests, and experiments. Another commenter stated that this section was well thought out and workable but appeared to conflict with Section 61.32.

61.62 License renewals.

Several commenters felt that the maximum license period of five years seemed unduly restrictive while requiring a summary report of disposal quantities every five years appeared to be too liberal. These commenters felt that once a site is properly licensed and operated, it will be able to continue to operate over its projected lifetime. Another commenter suggested that appropriate state agencies should receive copies of the report submitted by the applicant to the Commission.

61.64 Amendment of license

One commenter suggested that appropriate state agencies should receive copies of the application for amendment to a license filed with the Commission.

61.66 Application for closure

One commenter suggested that this section would not be as open-ended if specific licensing conditions were stated. Another commenter suggested that appropriate state agencies should receive copies of the application to amend the license for closure filed by the applicant. A third commenter felt that the information submitted in this application should include compatible and incompatible land uses. Another commenter questioned the need for an application and stated that (1) all of this information should be committed to the initial closure plan and (2) the licensee should notify NRC of its intent to implement closure.

61.68 Postclosure observation and maintenance

Several commenters questioned the technical basis for the requirement of a minimum of 5 years for the period of postclosure observation and maintenance. Another commenter stated that the 5 year observation and maintenance period (especially maintenance) is far too short. One commenter did not feel once injection has ceased for a particular disposal well that postclosure observation should be initiated, much less for a period of 5 years. This commenter felt that such disposal wells should be plugged and abandoned in a fashion similar to other industrial disposal wells.

61.70 Termination of license

One commenter felt that clarification was needed for the stipulation that reasonable assurance has been provided by the applicant that the site requires only passive case by the site owner with minimal need for active site maintenance. Another commenter suggested that funds need only be available, not transferred, to the site owner. One commenter suggested that plugging and abandonment procedures for the termination of an LLW disposal well be incorporated within the license.

5.2.5 Analysis of "SUBPART E: TESTS, INSPECTION, AND ENFORCEMENT"

61.72 Tests at licensed disposal facilities

Several commenters felt that there ought to be some test of reasonableness in the tests the Commission may require. One commenter stated that such tests must be permitted to interface with operations or utilize site operator personnel unless NRC pays for the service or loss of business. Another commenter stated that the affected state (regardless of its status as an Agreement or non-Agreement State) must be allowed to do its own monitoring and inspection. Thus the appropriate state agencies would also need site access authorization.

61.74 Commission inspections of disposal facilities

Several commenters suggested that the inference that disposal of waste will be inspected should be removed. Two other commenters felt this section should also authorize state inspection.

5.2.6 Analysis of "SUBPART F: MANIFESTS, RECORDS, REPORTS, QUALITY ASSURANCE, AND AUDITS"

61.78 Manifests

Individual commenters expressed concern about several aspects of the manifest including (1) purpose, (2) format, (3) specificity of data recorded, (4) flexibility of the certification statement, and (5) distribution of copies. One commenter asked how this section would apply in a situation where the operator of the LLW disposal site is the sole generator of the waste. Another commenter stated that any manifest required under NRC regulation should be uniform across all sites, even those in Agreement States, and should be compatible with existing DOT and EPA regulations.

61.80 Maintenance of records and reports

Several commenters expressed divergent views as to the extent of distribution, prior to license termination, of copies of records of the facility location and the quantity of LLW contained in the facility. One commenter suggested that a copy of the annual financial report should also be sent to the appropriate state agency. Individual commenters stated that the requirement for filing of certified financial statements (1) is wholly unjustified, and (2) may pose problems for companies which may treat such statements as proprietary information. Another commenter felt that records kept by the disposal facility operator should also include accurate maps and descriptions of buried trenches or other disposal installations.

61.82 Quality assurance program

The only commenter on this section raised the question as to whether or not a written quality assurance plan would be required.

61.84 Audit requirements for disposal facility operators

The only commenter on this section suggested that the record of the audit program should also be available for state inspection.

5.2.7 Analysis of "SUBPART G: WASTE PERFORMANCE"

61.86 Waste form and packaging

Many of the comments addressed the need for clarification of vague provisions and for definitions of several terms including free-standing liquid, disposal facility, high-integrity containers, homogeneous, low-activity, monolithic, noncorrosive, and container.

The issue of waste solidification received considerable attention from commenters. Several commenters felt that the criteria identified are a step in the right direction. One commenter suggested that packaging requirements for LLW should be consolidated in a single section concerning compaction, solidification of liquids, inactivation of biohazards and similar matters. Other commenters stated that a very careful technical analysis is needed to justify solidification of all LLW in general and of dewatered resin in particular. One of these commenters felt that free-standing liquid requirements for dewatered resins were too stringent to be met practically thereby eleiminating the potential use of high integrity containers and leaving solidification (at significant increase in cost) as the remaining option. Mixed views were taken on the prohibition against immobilization of liquids by only the addition of absorbent materials. However, most of the commenters who disagreed with this provision felt that it was unnecessarily restrictive when applied to institutional wastes. One commenter felt that requiring institutional waste to be in a free-standing form is unnecessarily too restrictive. Several commenters expressed concern over provisions excepting some liquids from solidification requirements when there is specific Commission authorization. In this regard, individual commenters thought that these provisions were too inflexible and should be relaxed to allow consideration of disposal of (1) contaminated oil, and (2) low-level radwaste water into deep disposal wells. Several commenters felt that dry compacted trash should be clearly exempted from the requirement to be in free-standing form. Several commenters felt that application of transportation criteria to waste packages might be irrelevant or unreasonable. One commenter suggested that every attempt should be made to minimize regulations, and particularly, conflicting requirements between DOT and NRC regulations. Individual commenters expressed concern over several other provisions related to physical, chemical, radiological, and biological properties of waste forms accepted for disposal. Other individual commenters suggested that (1) individual glass melting technology be considered and (2) guidance should be given on leachability as well as radiation stability of solidification agents.

61.88 Volume reduction

Individual commenters felt that this section was vague and should contain specifics such as minimum allowable density, types of compactors, etc. One commenter stated that this section should apply at the source of the waste rather than at the disposal site. Individual commenters expressed a concern that requirements for volume reduction may be at cross purposes with requirements for solidification. Another commenter noted that existing regulations or guides regarding dose rate or curie control limitations may preclude volume reduction by any of the existing methods.

61.90 Content of LLW

One commenter asked if a minimum level of radionuclides would be specified. Individual commenters expressed concern that restrictions on chelating agents were unrealistic and could preclude LLW disposal facilities from accepting reactor waste.

5.2.8 Analysis of "SUBPART H: TECHNICAL REQUIREMENTS FOR AN LLW DISPOSAL FACILITY"

61.94 Long-term performance objectives

One commenter felt that there was a contradiction between the concept of containing LLW while at the same time allowing for compliance with existing or proposed release limits. Other commenters suggested greater specificity for release and exposure limits as well as clarification of site maintenance. Another commenter suggested that some recommendation should be made as to how contaminant levels in ground water and potential exposures to individuals should be calculated. One commenter felt that the duration of institutional controls following termination of the license could be left to the discretion of the applicant so long as performance objectives were met.

61.96 Site suitability

Several of the commenters addressed the need for clarification of (1) vague provisions concerning site investigation, hydrogeology and surface geology, and (2) several terms such as complex site, reasonable assurance, unseated fault, and capable fault. Other commenters felt that undue emphasis has been placed on ground-water transport as a major pathway. A provision prohibiting siting in areas subject to significant geologic processes came under heavy criticism from several commenters for being too restrictive and poorly worded. Another provision singled out by several commenters for criticism (such as lack of necessity and rationale) related to prohibiting siting in areas having unacceptable seismic activity. One commenter felt that the requirement to not mask the environmental monitoring and surveillance program may preclude the colocation of a disposal facility with other nearby nuclear facilities. One commenter noted that a prejudgment concerning adverse effects of ground-water intrusion should be avoided since it presumes that stated performance objectives cannot be met if such a ground-water intrusion should occur. Another commenter suggested restructuring of the provision concerning adverse effects of ground-water intrusion, taking into account disposal of low-level radwaste water by injection into ground-water aquifers (deep wells).

61.98 Facility design and operation

Many of the commenters addressed the need for clarification of some vague provisions and terms such as "specified limits" and "minimize." Individual commenters requested clarification of provisions relating to (1) release of nonradiological noxious materials from the facility, (2) design of the facility to enhance and improve the ability of natural site characteristics to confine the waste after disposal, (3) implementation and maintenance of a site-surveillance program, (4) inspection of incoming packages, and (5) controls and procedures for maintenance of a site-specific training program. One commenter noted that daily inspections should be on workdays only and not on holiday or weekend periods. Another commenter felt that the educational and safety criteria for employees at LLW disposal facilities should be those already established in 10 CFR Parts 19 and 20. One commenter noted that many of the operational aspects in this section will require coordination with appropriate state agencies.

61.102 Environmental monitoring--applicant

Several commenters took differing views with regard to the duration of a preoperational monitoring program. One commenter stated that a period of 1 year prior to any major site construction is overly restrictive while another suggested 3 years as the appropriate time. Another commenter felt that the requirement for 1 year of data is reasonable, provided site construction is allowed during this period. One commenter was concerned as to what action levels for the monitoring program are left up to the applicant. Another commenter suggested that this program and results should be coordinated with appropriate state agencies. One commenter felt that the requirement for an environmental monitoring program is applicable for shallow-land burial of radwaste but not necessarily applicable for the deep disposal well method.

61.104 Site closure and stabilization

The comments were addressed principally to the need for clarifying the terms background level and buffer zone. One commenter asked if some sort of duplicate land use recordkeeping system was preferable to a stable long lasting marking device to indicate the location and nature of the LLW disposed of in the facility. Another commenter requested clarification of the provision for a monitoring program on federal land with regard to (1) financial responsibility, and (2) federal-state relations. One commenter asked why it is necessary to provide financial surety arrangements as contained in 61.28 if, as this section implies, a site can be shown to exhibit long-term containment integrity.

5.2.9 Analysis of "SUBPART I: PHYSICAL SECURITY"

One commenter suggested that physical security provisions should be required after site closure as well as during site operations. In this regard, another commenter requested clarification of the provision for fencing (passive barrier) after plant decommissioning. One commenter felt that the provision for communications with law enforcement agencies was too vague. Another commenter stated that the hazard present at a deep disposal well site is minimal from a radiological standpoint and does not justify provisions for, essentially, continuous monitoring of the site.

5.2.10 Analysis of "SUBPART J: REQUIREMENTS ON WASTE PROCESSORS AND INDEPENDENT WASTE PROCESSORS"

Individual commenters stated that (1) regulations concerning radioactive waste packaging by licensees should be placed in 10 CFR Parts 20, 40, 50 and 70; NRC should deal with waste processor requirements when it handles the processor's license--not when a disposal company is attempting to obtain a license; (3) waste generators solidify all liquid wastes by methods that will leave no free liquid; (4) all disposal sites should also be processing sites; and (5) the chief means for volume reduction should be incineration of combustibles with subsequent burial of immobilized ash.

61.112 Operating procedures

Individual commenters noted that requirements for solidification in operating procedures and controls and in measurement and control programs may not be appropriate for all waste categories, i.e., trash.

61.114 Tests

One commenter stated that this section is vague and needs specifics. Another commenter felt that a test for reasonableness should be added.

61.116 Audits

One commenter suggested that copies of audits should be sent to the appropriate state agencies. Another commenter stated that waste generators (1) advise the Commission one month in advance of any packaging of waste so that Commission inspectors may observe their packaging operations, and (2) submit to the Commission a QA program to assure conformance of their waste quality and packaging methods with the requirements of Subpart G.

5.2.11 Analysis of "MISCELLANEOUS COMMENTS"

5.2.11.1 Overall Approach

Individual commenters stated that the general approach in the regulation is encouraging and that it should be written in plain language, eliminating unnecessary repetition, and stating requirements that would (1) be clearly defined and based on scientific requirements providing reasonable assurance of LLW confinement; (2) encourage state participation by including detailed descriptions of the interaction processes with state governments with equal treatment for Agreement and non-Agreement States; and (3) allow licenses to be reviewed and approved in a timely manner consistent with protection of the public health and environment. Other individual commenters felt that (1) the need for regulations as complex and restrictive as those proposed was not established; and (2) the regulations would not speed up the licensing process and would increase significantly waste disposal and operating costs. Several individual commenters suggested consideration of alternatives to the draft regulation such as regional waste disposal sites and processing centers; above ground storage for low concentration, short half-life radioactive material; and alternatives to shallow land burial such as volume reduction and engineered-type storage facilities. One commenter felt that the regulations in their present form will have significant impact on deep injection well disposal of low-level radioactive waste water generated by in situ leach uranium facilities.

5.2.11.2 Technical Content

Individual commenters stated that the regulation was too general and lacking in sufficient specificity in technical aspects such as earth sciences, hydrogeology trench capping methodology and requirements for solidified waste. One commenter stated that the proposed regulation does not provide sufficient flexibility for a waste producer to bury its waste at the site of origin. Other individual commenters felt that (1) a systems approach that can take advantage of present geotechnical knowledge should be used instead of the arbitrary limitation approach; (2) performance objectives should be accompanied by recommended or required methods for demonstrating compliance while avoiding prejudgment of what specific site properties will meet the performance objectives; and (3) the concept of containing LLW while at the same time allowing for compliance with existing or proposed release limits is somewhat contradictory. Several commenters stated that the rule should place more emphasis on measures to restrict onsite reclaimer activities rather than on controlling offsite transport by ground water or erosion. One commenter felt that the regulations ought to require categorizaion (segregation) at the origin and that all waste disposal sites should also be waste processing sites. Another commenter stated that (1) if the intent for the proposed regulations is to apply transport requirements in addition to disposal requirements, it should be clearly stated; and (2) the requirement that evaporator bottoms, filter sludges, resins and sludges all be immobilized by solidification may not always be needed.

5.2.11.3 De Minimus Levels

All of the commenters addressing this issue felt that de minimus levels should be established for short half-lived radioisotopes commonly used in medical, research, and other applications.

5.2.11.4 Institutional Wastes

One commenter stated that (1) there is no need to attempt to solidify the low activity and low volume liquid wastes generated by hospitals and medical research institutions; (2) alternative techniques such as decay, diffusion and incineration should be used when possible to do so safely; and (3) packaging regulations should not be "over-engineered" for institutional waste so as to treat it as though the hazard were equivalent to other low-level wastes.

5.2.12 Analysis of "DRAFT TECHNICAL BASIS FOR SUPPORTING ADDITIONAL TECHNICAL CRITERIA AND REGULATORY GUIDES TO IMPLEMENT 10 CFR PART 61 FOR LAND BURIAL OF LOW-LEVEL WASTES"

This document provides additional guidance and technical criteria for design, operation, closure, and postoperational care of an LLW disposal facility using land burial as a disposal method. Several commenters stated that this document lacked the technical documentation necessary for classification as a technical basis. Individual commenters felt that (1) the purpose of this document needed to be clarified, and (2) the document should be incorporated in the regulations, if the technical basis can be considered requirements. One commenter stated that waste processing ought to be a function at each site and all proven methods, in addition to waste segregation and compaction, ought to be included. Another commenter stated that the relationship between the proposed regulation and other environmental laws or regulations such as the National Environmental Policy Act (NEPA) should be described. Another commenter asked how requirements for an LLW disposal site could be specified when the LLW is not defined as to volume, curies, etc.

5.2.12.1 Introduction

Several commenters felt that values for the thickness of required cover are applied to various modes of disposal without strong justification and that their empirical or experimental bases should be provided. Another commenter asked for specific values for the maximum height and allowable slope of mounded materials. This commenter felt that the passive care required by the site owner after closure should include an active monitoring program to ensure that wastes are being adequately contained.

5.2.12.2 Siting

Several commenters addressed the need for clarifying and justifying various technical concepts such as: small topographic relief; low hydraulic gradient; long residence time; devoid of surface waters; and low population areas. One commenter stated that (1) some thought should be given to site characteristics (or added barriers) which will predispose against other future uses of the site; (2) ambiguous words or unsupported numbers are less valuable than statements of how ion-exchange or retardation properties should be determined and applied; and (3) the statement on predictability of percolating ground water should be strengthened.

5.2.12.3 Design and Operations

Individual commenters felt, with regard to design and operation goals, that (1) it is a great deal more difficult to provide a positive seal above the waste than it is to provide for deflection of the bulk of infiltrated precipitation away from the waste; and (2) the need for active site maintenance by the site owner may not be eliminated since many monitoring programs encompassing a variety of functions are needed. Several commenters stated that the criterion for permeability was ambiguous and needed a technical basis. Individual commenters stated, with regard to keeping water out of buried wastes that (1) issues such as siting in humid environments need more detail; (2) any water contacting the LLW should be collected, analyzed, treated to meet effluent requirements, and released or solidified or disposed of onsite; and (3) a more specific design should be described. One commenter pointed out that there are two ways of keeping water out of buried wastes: (1) enclosing the waste in an impermeable envelope and (2) constructing the surrounding trenches such that the surrounding media has a "wick" effect to draw water away from the trench. One commenter asked for more specific details on design of trench mounds and moisture barriers. Another commenter stated that (1) the basis for specific values assigned to such things as soil permeabilities, cover thickness, thickness of sand drains should be given and (2) there is a need to show that real sites exist which can meet stated criteria (with appropriate engineering). One commenter suggested that the location of low-level waste sites should also be recorded with the appropriate register of deeds as is done with hazardous waste sites.

5.2.12.4 Waste Segregation

Most of the comments were directed to the table entitled, "Radionuclide Concentration Guidelines for Disposal by Shallow Land Burial." Individual commenters stated that the table of radionuclide concentrations (1) should be better defined--as representing average concentrations, not maxima; (2) should be correlated to the disposal techniques and required isolation times; (3) should include, if feasible, LLW containing radium and accelerator produced isotopes; (4) does not agree with the median value levels reported in an AIF/NESP study; (5) could be revised with respect to specific entries for I-129 and transuranic nuclides; and (6) may eventually be the basis of mandatory entries on all waste shipment manifests, even though many of the nuclides are either difficult to identify or are rarely present in typical wastes. Several commenters noted that the basis for these concentrations required further elaboration such as (1) specification of the total concentrations allowable at any one site at any specific time during operation, and (2) recognition that the entries in the table are dictated by predisposal operations (for short-lived isotopes) or post-closure intrusional scenarios (for long-lived isotopes) rather than by water migration. Other individual commenters stated that (1) consideration should also be given to physical form as well as chemical and radionuclide content of the waste and (2) the requirement for sufficient barriers to reclaimer intrusion should be clarified. One commenter noted that it will be extremely difficult to find suitable areas in many humid climates in order to dispose of intermediate depth burial wastes and still maintain a 3 meter clearance to ground water. Another commenter questioned the need for segregating waste in the manner prescribed.

5.2.12.5 Environmental Monitoring Program--Applicant

One commenter stated that the types of data collection recommended are all desirable, however a strong statement should be included regarding how the data will be applied as well as the guidelines on action levels. Another commenter stated that Subtitle C of the Resource Conservation and Recovery Act and rules promulgated thereto specify monitoring requirements in much greater detail than indicated here. One commenter felt that (1) collection of samples of gas emanations at the ground surface might be considered in the monitoring program; (2) the monitoring system should be installed, and baseline and background measurements collected, for at least 2 years before waste emplacement; and (3) sump water samples should be analyzed for nuclides and chemical characteristics. Individual commenters expressed concern regarding (1) the adequacy of only one continuous air monitor during waste disposal operations, and (2) monitoring after disposal during normal hours.

5.2.12.6 Monitoring--Site Owner

One commenter emphasized the need for long-term site monitoring to ensure that the site is operating as designed since the low-level waste site performance will not be known nor collective measures implemented unless the site is adequately monitored. Another commenter wondered if the NRC, EPA or the state should also have inspection rights at the site.

5.2.12.7 Site Closure and Decommissioning Plan

Individual commenters expressed the need for clarification of several aspects of the site closure and decommissioning plan regarding (1) agreements for state or federal government participation; (2) direct gamma radiation from buried wastes; (3) elimination of the potential for erosion or loss of site or LLW integrity; and (4) buffer zone requirements. One commenter requested clarification of other aspects of the plan concerning (1) custodial care by the site owner; (2) site records; (3) investigation of causes of significant increases in environmental sampling results; and (4) evaluation of present and zoned activities on adjoining areas. This commenter also expressed concern regarding (1) appropriate state input to the site closure and decommissioning plan; (2) use of state regulations in establishing acceptable levels for the rate of release of radionuclides through air, ground and surface pathways; (3) elimination of the potential for erosion or loss of site or LLW integrity; and (4) elimination of the need for active water management measures.

6. REGIONAL WORKSHOPS

During 1980 the NRC held four regional workshops in Atlanta, Chicago, Denver, and Boston that provided state officials, industry representatives, waste generators, the public, and private interest groups with an opportunity to comment on the preliminary draft regulation and other issues to be addressed and resolved. After an opening session, each workshop was usually split into two or three concurrent sessions to address institutional, organizational and technical issues. Lists of policy questions developed by NRC were made available to participants at each concurrent session to facilitate an orderly discussion. Following these discussions each session developed findings reflecting the views of participants. These findings were then reported and discussed in a final planning session. Copies of the transcripts and findings of these workshops were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61.

A summary of the workshop findings is included below, followed by an analysis of the findings on specific policy questions considered at each workshop.

6.1 Summary of Findings

6.1.1 Institutional Issues

Institutional issues such as land ownership, postoperational care, institutional controls, and financing were addressed.

The workshops were generally in favor of state ownership of the low-level waste (LLW) disposal site with federal ownership preferred after site closure. It was felt that conveyance of the property from the state to the federal government upon license termination should be optional, not mandatory. In general, private ownership was not favored but approval was given to the continuing involvement of the private sector under license in the management and operations of LLW disposal facilities.

The workshops generally agreed that the licensee would be responsible for decommissioning, final site closure and stabilization, postoperational care, and corrective actions as long as it retained its license. It was felt that the licensee should maintain the site until it could demonstrate that the site required passive care only with a minimal need for ongoing maintenance by the site owner.

There were mixed views concerning how long and to what extent institutional controls can be relied upon to keep people from inadvertently intruding into the disposal site, and to monitor and assess site performance. Individual workshops felt that institutional controls can only be relied on as long as the institution exists and that no fixed number could be specified for the amount of years the site would have to be monitored after which it could be assumed to be safe. At one workshop, about half the participants thought 50 years would be a realistic expectation of government control. However, the majority at another workshop felt that an active institutional control period of 100 years and a 400-year period of passive care are sufficient to protect the public health and safety and to ensure stability of the site.

In general, the workshops felt that the proposed requirements for financial assurance were adequate, although some doubts were expressed concerning surety arrangements for decommissioning, decontamination, closure, and stabilization. Problems relating to open-ended surety requirements were recognized. It was suggested that the NRC should reexamine the appropriateness of a letter or a line of credit as a generally acceptable surety arrangement. A standard specific method of calculating costs was considered inappropriate because such costs would be site-specific.

Workshop participants recommended that the NRC develop a financial assurance system in the regulation that places full responsibility for all closure and postclosure costs with the licensee instead of the taxpayers. Some participants pointed out that none of the existing funding arrangements provide for unexpected remedial activities. These participants felt that the financial assurance mechansims proposed in 10 CFR Part 61 should ensure that the licensee be responsible for maintenance and contingency costs.

For a detailed discussion of workshop comments on financial requirements, see Appendix K.

6.1.2 Organizational Issues

Consideration was also given to organizational issues such as state participation, Federal-Agreement State relations, assistance to non-Agreement States and regional siting.

The majority of the workshops felt that the regulatory provisions for state participation should be left in general terms with it left up to the state as to when or how it wished to become involved. To achieve effective state participation, it was suggested that NRC delineate in this rule possible opportunities for state involvement to highlight to states what their rights are as they negotiate their level of participation. This would help promote state participation at a point early enough to assure that industry and NRC activities would not suddenly be confronted by a last-minute veto or state refusal to own the site because of unresolved concerns that could have been raised earlier in the decision process.

Generally the workshops agreed that it would not be desirable to mandate that Agreement States' licensure and regulatory procedures be identical to NRC procedures. On the other hand, it was felt that it was desirable to assure compliance of Agreement States with minimum federal technical standards.* One workshop suggested that implementation of environmental practices should be left up to the states. Another suggested that in order to simplify the negotiations among the states in a regional compact, Agreement States should comply with NEPA requirements.

It was generally agreed that, at a minimum, there should be federal funding and/or technical assistance to non-Agreement States to help them with organizational aspects of LLW disposal. One workshop recommended that funding and technical assistance be made available to non-Agreement States to the maximum extent possible, to be used in carrying out those investigations, studies, planning activities, regulatory activities and other project components which the state would deem necessary. Another workshop felt that it would be unfair to provide equal federal funding and technical assistance to Agreement States and non-Agreement States if the latter refused to take on regulatory responsibilities assumed by the former. Another workshop felt that the provisions for technical assistance to Agreement States should be clarified to include contract work paid for by the NRC.

One workshop felt that the appropriate geographic scope of the region of interest considered in a site-selection process should be determined by a state individually or by a group of states acting in concert in a given region.

6.1.3 Technical Issues

Technical issues that were examined included: performance objectives; de minimus levels; waste classification; nonradiological hazards; scope of regulatory guides and regulation; criteria for waste form, solidification of liquid wastes, and maximum leach rate; volume reduction; and site characterization.

*These were differences among the workshops on whether states should comply with minimum procedural requirements such as the examination of alternatives to the licensing proposal.

There were mixed views concerning specific aspects of the long-term performance objectives. Several workshops recommended that the criteria for the protection of ground water be clarified. One workshop concluded that the assumptions concerning the nature and duration of the intruder scenario should be more thoroughly explored by NRC. Overall, however, the long-term performance objectives were considered to be suitable.

There was a general agreement with the concept of having a de minimus level of activity for disposal purposes. However, there was a minority opinion at one workshop that no de minimus level should be set and that all levels should be controlled and monitored. There was general agreement at two workshops with the concept of establishing de minimus levels which are waste stream specific, thereby assuring a reasonable balance between practicality and safety. One of those workshops noted that other (nonradioactive) hazardous regulations may apply and be governing for disposal. At one workshop, it was felt that (1) de minimus levels should be established based on the critical organ dose to cover both exempt quantities and low activity, large volume, dry bulk solids; and (2) alternatives for disposing of those wastes below the de minimus level could include sanitary landfills and special sites not governed by 10 CFR 61.

There was general agreement as to the need for guidance on waste classification. There was no agreement, however, on the specifications of the waste categories. One workshop felt that maximum levels of activity for LLW disposal should be based on a design basis incident which should include reclamation of the site for residential or agricultural activity at the end of the period of institutional control. It was generally agreed that the technique for disposal should be geared to the type, form, and volume of materials to be disposed of at the site. Further, it was recommended that flexibility be built into the system so that specific cases can be accommodated. It was felt that regulatory guides are the proper place for specifying the details of a classification system.

Most of the workshops agreed that the co-siting of low-level radioactive waste and hazardous waste disposal sites should not be precluded as long as all hazards are recognized between operations at both sites. However, it was the majority opinion at one workshop to set aside the complex technical and policy issues of dealing with both low-level and hazardous wastes since too little was understood of the complexity of disposal of both types of materials at a single site. One workshop recommended that NRC investigate the possible coordination of its rulemaking with the activities of other applicable agencies.

In general, the workshops recommended that NRC adopt formal rules that establish broad performance objectives and administrative procedures, and set forth more specific program criteria and details in regulatory guides. One workshop felt that subjects for regulatory guides should include but not be limited to, site selection, disposal techniques for various types of waste (e.g., specification of engineering controls and trench operations), monitoring, packaging, site security, and site closure.

The general consensus of one of the workshops on the issues concerning requirements for waste form, solidification of liquid wastes, and maximum leach rate was that specific standards are unnecessary and may be contradictory to the performance criteria approach. It was the general opinion that the specific means of dealing with each of these issues should be left to the designer who would be guided by performance objectives.

There was a consensus at one workshop that recognition of the desirability of volume reduction should be included in the regulation, but requiring volume reduction was not considered appropriate. Another workshop concluded that some minimum acceptable standard be established but that incentives, primarily economic incentives, be the primary mechanism for achieving volume reduction.

Several workshops felt that minimum acceptable elements for site characterization should be set forth in the regulation, but the majority of these elements should be contained in regulatory guidance material as an aid in the siting process. One of these workshops felt that these minimum criteria should not result in the automatic exclusion of major sections of the country or exclude areas where identified shortcomings of a site could be rectified by engineering and site construction techniques.

6.2 Analysis of Findings on Specific Policy Questions

6.2.1 Institutional Issues

1. Who should own land used for disposal of LLW? (federal government, state government, local government, private). Why?

The workshops had extensive discussion on this issue. Comments generally favored state ownership, especially during site operation, with federal ownership preferred after site closure. Some commenters felt that private ownership should not be precluded, but in general, it was not favored.

One workshop stated that state ownership of land used for the disposal of LLW is a desirable prerequisite for licensing sites because it assures state policy input into the licensing process, and the state is more likely to be responsive to citizen concern than either a private operator or the federal government. The workshop also felt that the federal government should provide states with necessary financial and technical assistance since states may not have the technical or financial resources to solve unanticipated problems after site closure. A recommendation was made that the NRC should provide states with further legal clarification on whether state-owned and operated sites can exclude out-of-state wastes. In a minority view, the position was taken that it does not matter who owns the LLW site as long as states have the option to regulate and monitor the site.

2. What are the instances where private land ownership would be acceptable?

Most commenters saw no instances where private land ownership for commercial disposal is acceptable. Other commenters felt that private ownership of the land should not be precluded.

Most of the workshop discussions brought out that the private sector should be involved in the management and operations phase of low-level waste disposal facilities. Several commenters felt that private concerns could own or manage interim and above ground storage facilities but final disposal should only occur on government land.

3. If the land is owned by an organization other than the federal government, should there be a provision for federal government assumption of land ownership at site closure? Why or why not? Would it be useful for the states to have an amendment to federal law giving them an option to retain ownership after closure or transfer ownership to the federal government? Why or why not?

The general conclusion from the workshops was that upon license termination, federal ownership should be optional, not mandatory. The decision to convey the property to the federal government is a state option. Many commenters supported enabling legislation to permit such federal government assumption. It was suggested that such legislation should be introduced at the earliest possible time.

One workshop felt that the federal law should be amended to provide states with the option, but not the mandate, to transfer ownership of the land to the federal government at any time, at the state's decision. This workshop also noted that, since the ultimate purpose of the regulations is to protect the health and environment of the nation's citizens, there should be some form of concurrent state/federal jurisdiction over the land so that if one party fails to adequately control the site, the other party can take necessary remedial actions to protect health and environment.

4. Who should assume and carry out responsibilities for decommissioning, final site closure, and stablization? Postoperational surveillance and monitoring? Postoperational care and corrective actions? Why?

Workshop participants generally agreed that the licensee should be responsible for the facility as long as it retained its license, including decommissioning, final site closure and stablization, postoperational care, and corrective actions. In addition, workshop participants felt that the licensee should maintain the site until it can demonstrate that the site requires passive care only with a minimal need for ongoing maintenance by the site owner. However, the workshop participants felt the postoperational surveillance period should not be less than five years. A member of one workshop suggested that the regulations be changed to require postclosure observation and maintenance by the licensee for at least ten years, based on the experience of several LLW sites which indicate that problems may not arise until six or seven years after site closure.

It was concluded at several workshops that postoperational surveillance, monitoring, care and corrective actions should be the responsibility of the site owner (either federal or state government) with financial responsibility provided through the financial assurance fund collected from the operator during the operating life of the facility. One workshop summary emphasized the need for setting fees for the long-term care fund that would be adequate to cover the costs of all anticipated and unanticipated postoperational activities.

5. How long and to what extent can institutional controls be relied upon to keep people from inadvertently intruding into the disposal site; to monitor and assess site performance; and to carry out site surveillance and monitoring activities (e.g., 100 years? 200 years?). What is the rationale for the interval chosen?

In their discussion, the participants at one workshop recognized the difficulties of developing "perpetual" surveillance and maintenance for a disposal site. Participants also expressed the opinion that no "magic number" could be specified for the number of years the site would have to be monitored, after which it could be assumed to be safe.

Another workshop felt that the length of time necessary to perform monitoring and site surveillance can be determined on a technical basis. It was suggested that this should be calculated on a case-by-case basis depending on the materials disposed of onsite. The workshop concluded that institutional controls can only be relied on as long as the institution exists.

In one workshop, a majority of the group felt that an active institutional control period of 100 years and a 400-year period of passive care were sufficient to protect the public health and safety and to ensure stability of the site. A minority of the group believed that transuranics or other radionuclides, because of their long half-life, should be excluded from sites with such monitoring provisions. Some participants believed that due to the extremely low radioactivity concentration levels of such materials, the surveillance period was sufficient. Concern was voiced that there was a risk of concentrations of nuclides with unacceptable high activity, which would require more extensive site monitoring. However, the majority of the group concluded that this risk was minimal since there is a high probability that these radionuclides would be somewhat evenly distributed throughout the site, and it was believed that if such concentrations did exist, protection could be engineered prior to site closure to minimize the risk from these radionuclides.

At another workshop, about half of the participants felt that a period of 50 years would be a more realistic expectation of government control. Also, since the government cannot guarantee long-term institutional control, several participants urged NRC to strictly observe technical requirements for site selection and maintenance, thus minimizing the likelihood of unplanned remedial actions.

6. Are the proposed requirements for financial assurance adequate? What changes should be considered and why? Should there be a standard, specified method of calculating these costs? If so, what is the rationale?

In general, the workshops felt that the draft regulation's financial assurance section was adequate. However, the group cautioned against open-ended surety requirements and self-insurance. One individual felt that financial surety arrangements should be limited to cash or its equivalent. Other participants suggested that the NRC should reexamine the appropriateness of a letter or a line of credit as a generally acceptable surety arrangement.

One workshop conclusion recommended that any financial assurance arrangement should provide for remedial activities. Participants pointed out that it was naive to assume that there would not be mistakes at an LLW site, and that financial assurance arrangements to provide for long-term surveillance should include adequate funding to pay for unexpected remedial work. Participants also discussed the importance of providing a fund to cover unpredictable contingencies beyond the control of the operator, the state, or the federal government. Some people commented that a portion of the financial assurance funds from all low-level waste facilities could be pooled into one national contingency based on the assumption fund. Such a financial assurance mechansim is based on the assumption that the odds are against all sites experiencing unexpected and costly remedial programs, thereby creating a pool of funds to help pay the costs of these sites that do experience unanticipated costs. The tax consequences of such an approach were also discussed.

One workshop summary concluded that a standard, specific method of calculating costs was inappropriate, because such costs would be site-specific. However, participants recognized the importance of incorporating inflation into the total costs of closure and postclosure care. One person suggested that the government periodically examine the long-term care fund and surety arrangement so that the funds could be revised to keep pace with changes in inflation.

6.2.2 Other Institutional Issues

Several additional issues were addressed at workshops concerning license transferability, disposition of naturally occurring and accelerator produced radionuclides, and regional siting. Participants concluded that if a private operator buys out the private concern which is operating a low-level waste facility, the license to operate the facility should not be transferrable. Regulatory decisions by NRC and EPA over naturally occurring and accelerator produced radionuclides were requested. Participants also expressed support for siting low-level waste facilities on a regional basis. One participant noted that states generating large amounts of low-level waste should consider development of regional sites as they will be technically better prepared to serve in this capacity.

At another workshop, additional discussion was focused on postoperational use of land, the definition of LLW, and the siting of LLW disposal facilities. The participants concluded that it was not clear what, if any, uses of land used for LLW disposal were acceptable after site closure. They requested that NRC provide a more explicit definition of LLW and also develop a straightforward waste classification system. Several participants suggested that the integrity of the geologic medium in which the LLW is buried, and not the depth of the LLW burial, should be used as an indication of how well the possibility of human exposure is minimized.

6.2.3 Organizational Issues

1. Should the provisions for state participation be left in general terms, or should they be refined to specify how and when states should be involved? How can states most effectively participate in the licensing process including development of environmental impact statements and other analyses and assessments? Should states be required to participate? If not, how can they best be encouraged to participate early in the process? Should they be so encouraged? How can NRC minimize the likelihood that a state might enter the process in its final stages, possibly bringing disruption and delay?

The majority of the people attending workshops felt that the provisions for state participation should be left in general terms, with the state being able to determine when and how it wished to become involved. People at one workshop suggested that the provisions for public participation in a state should not be left in broad terms but should specify how and when states, local governments, citizen groups and other public participants should be involved. The participants in this workshop also felt that this participation should generally be limited to a notice and an opportunity to be heard.

Participants at two workshops suggested that the first step for a state involved in the siting process would be to determine if establishment of a site within its boundaries would be a public convenience and necessity. They argued that this finding would have to be made before a state could proceed to determine the technical merits of a site.

The written summary of one workshop generally agreed that most states would probably want to be involved in the siting process from the front end, perhaps even determining potential sites before the industry had proposed a particular site. The findings also pointed out the disadvantages with such an action, i.e., such a well-prepared state would probably be more likely to be chosen as a recipient state because it has already proposed the background work. Workshop participants also acknowledged that a state should participate at an early enough point to assure that industry and NRC activities would not suddenly be mooted by a last-minute state refusal to own a site due to unresolved state concerns that could have been raised earlier.

Participants at another workshop supported the notice requirement embodied in the notice of intent provisions of Section 61.26(b) in the preliminary draft of Part 61. They also felt that the applicant should demonstrate in his license application that the state does not object to the licensing process going forward. This requirement was vaguely akin to the requirement to obtain a certificate of public convenience and necessity from a state power commission prior to the NRC considering an application for a construction permit for a nuclear reactor. They believed that there should be no requirement that the applicant obtain final state approval prior to the license application. Although it was believed that it should be a state option to participate in the licensing process, minimal notice provisions would permit the state the opportunity to be involved at the earliest stages of the proceedings.

This workshop also recommended that the regulation should require that the state consult with local citizens as a precondition for approval of any state plan of participation. The majority at this workshop believed that the appeal process from the denial of a state plan of participation should be specifially articulated. The Commission was encouraged to adopt a simple and speedy appeal process, with the state specifically guaranteed the right to participate at any stage after receipt of notice of intent, whether or not funding is sought from the Commission. This workshop also felt that Section 61.48(b)(1) should be clarified. The phrase which now reads "The proposed activities are authorized by law..." should be changed to read "The proposed activities are authorized by Federal law..."

Another workshop liked the provision under which a state has the opportunity to propose its own format for participation which would then be negotiated with NRC. However, the workshop concluded that to achieve effective state participation, it is essential that NRC fully delineate in this rule possible opportunities, throughout the regulatory critical path from the filing of the notice of intent through to closure and license termination, for state involvement and input. This list of opportunities, which need not be exhaustive, would serve to highlight to states what their rights are as they negotiate their level of participation with NRC.

This workshop felt that non-Agreement States should not be required by NRC to participate in the siting and licensing of an LLW facility. It felt strongly, however, that NRC should invite and encourage state participation beginning with the filing by an applicant of the notice of intent. In order to implement this suggestion, it recommended that NRC add to the proposed rule the following:

- That an applicant be required to file with the state and local community a copy of his notice of intent.
- That NRC, upon receipt of a notice of intent, officially notify in writing the governor, the state, NRC liaison officers, the legislature and other appropriate officials of the impending application. At this time, NRC would also be required to invite and encourage the states' participation.

This workshop also agreed that the best means of protecting the states' rights is the existing regulatory requirement of state ownership of land used for an LLW disposal facility. The workshop recognized the potential problem of federal purchase of a candidate site which is rejected by the state on findings of fact after prelicensing regulatory procedures are completed.

Another workshop felt that the draft regulation should state explicitly the limits of authority that can be delegated by NRC to non-Agreement States pursuant to a state's proposal for participation and that these legal and constitutional limitations should be included in the general provisions. It also concluded that the proposed regulation should allow the applicant adequate notice of the nature and extent of state and local participation. Before the onset of formal NRC licensing proceedings, there should be a reasonable specified interval between the filing of the application and the payment of the application fee to allow state governments to propose, and NRC to accept their plans for participation. After reviewing state participation plans, the applicant should be able to withdraw its application and fee without prejudice.

2. Are the provisions for technical assistance to Agreement States adequate? What changes should be considered?

One of the workshops felt that to avoid confusion any reference to assistance to Agreement States or statutory mandates be removed and incorporated in the part of 10 CFR which relates to Agreement States. It also stated that the NRC should ensure that Agreement and non-Agreement States should be treated equally as a general policy matter.

Another workshop questioned what was meant by "technical assistance." It felt that the draft regulation should explicitly define the term "technical assistance." In particular, it thought the term should include contract work paid for by the NRC.

3. Should NRC have a statutory mandate to require uniformity in the regulations and procedures used by NRC and the Agreement States in licensing LLW disposal sites? Why or why not? Should Agreement States have to assure compliance with minimum federal standards? Should they adopt standard environmental review procedures? Why or why not?

One workshop agreed that there should be minimum technical standards for the disposal of LLW that would apply to Agreement and non-Agreement States. However, it noted that a statutory change might be required to mandate compliance by Agreement States with minimum federal technical standards. The workshop also agreed that it would not be desirable to mandate that Agreement States' licensure and regulatory procedures be identical to NRC procedures; Agreement States, with a transfer of licensing and regulatory authority from NRC, should have the right to develop their own regulatory and licensing procedures.

This workshop extensively discussed the potential problems that could occur because Agreement States are not required to comply with NRC siting and licensing procedures for LLW disposal facilities. There was concern that Agreement States are not required, absent a statutory change, to conduct a full NEPA investigation as NRC is required to perform. Specifically, there was concern that an alternative site analysis would not be performed. This was identified as a particular problem in the siting of an LLW disposal facility within the context of a regional state compact or other regional grouping of states. Differences, not only between Agreement States and NRC non-Agreement State procedures, but also among different Agreement States within the same region, pose even further problems. Participants recognized, therefore, that minimum procedural as well as technical standards may be beneficial, Although this would require statutory change. This workshop emphasized that to the extent possible, maximum flexibility and authority should be preserved for the Agreement States to develop procedures that best meet their unique requirements and needs.

Another workshop concluded that minimum technical licensing standards should be required but licensing procedures should be left up to the state. Participants noted that uniform procedural standards would essentially negate the benefits of Agreement State status. The workshop felt that environmental practices should also be considered, but their implementation should be left up to the states. Participants recommended against requiring state environmental practices to be "equivalent to" federal minimum practices, since this would add another element of dispute and subjectivity. In addition, the workshop felt that the format for the license application should be standard.

Another workshop felt that the regulation should be clear on what NRC will require of the applicant in an environmental assessment. It also suggested that the regulation should be tempered to provide equity to both Agreement States and non-Agreement States to prevent forum shopping by advocates.

4. Should there be federal funding and/or technical assistance to non-Agreement States to help them with the organizational and institutional aspects of LLW disposal, including participation in the NRC licensing process and the development of plans for site closure, stabilization, and/or postoperational monitoring? Why or why not? Should states have federal funding and/or technical assistance for activities related to the development of additional disposal capacity, such as site selection? Why or why not?

At one workshop, representatives of Agreement States were very outspoken in their opinion that federal funding and technical assistance should be made available to Agreement States, since by their very status these states have agreed to take on the regulatory responsiblities over LLW sites. For the same reason, some state participants believed it would be unfair to provide similar aid to non-Agreement States if they have refused to formally take on such regulatory responsibility. While federal funding was considered necessary, the group recognized that by accepting such funds, a state would become beholden to the federal government, thereby losing some of its independent control over an LLW project. Some participants suggested that one method of minimizing this threat would be to have federal funding made available to the state before a specific site has been selected. This would afford the state greater latitude to assess the characteristics of either the entire state or of several potential sites which may be suggested by industry.

Another workshop felt that the regulation cannot provide incentives which appear to promote siting, but, at the same time, it should not discourage state initiative.

The consensus at another workshop was that, at a minimum, there should be federal funding and/or technical assistance to non-Agreement States to help them with organizational aspects of LLW disposal.

One workshop strongly recommended to NRC that funding and technical assistance be made available to non-Agreement States to the maximum extent possible. These funds would be used to carry out those investigations, studies, planning activities, regulatory activities and other project components which the state would deem necessary. This workshop also recommended that:

- o NRC delete the phrase, "Subject to the availability of funds" from Subpart C, Section 61.48, paragraph (b).

- o NRC provide an appeal procedure to a state which believes that insufficient funding or technical assistance are being provided.

- o NRC include language in this rule expressing its intent to make every effort to fund fully all requests deemed essential by the state. The workshop felt that the best hope for siting an LLW facility lies in achieving fullest and earliest state cooperation and that this can best be achieved by removing the financial burden from the states.

5. What is the appropriate geographic scope of the "region of interest" to be considered in a site selection process?

One workshop concluded that the appropriate geographic scope of the "region of interest" should be determined by a state individually or as a group of states acting in concert in a given region. The group felt that the technical analysis of whether an applicant has sufficiently considered alternatives should be left to the Commission.

In another workshop, the conclusion was that in considering the scope of the "region of interest" for selecting an LLW site, the economics of the site would have to be taken into account; i.e., a sufficient amount of waste would have to be generated in the region to meet the economies of scale to make the facility economically viable.

6.2.4 Other Organizational Issues

Several additional issues were addressed at one workshop concerning extent of NRC legal authority, coordination of rulemaking, and scope of access of waste. It was felt that the regulation should clarify, in the general provisions, the extent of the legal authority that NRC has to regulate low-level waste facilities. The workshop also felt that the NRC should coordinate its rulemaking with the activities of other responsible agencies including DOE, SPC, EPA, DOT, and USGS. It suggested in this regard that low-level waste regulations should anticipate compatibility and colocation possibilities with other federal statutes and regulations governing the disposal of hazardous material. Another recommendation by the workshop was that the regulations should provide for a determination of the scope of access and should prevent a state (or other owning or operating authority) from arbitrarily closing or restricting access. The workshop felt that procedures for expanding, restricting, or eliminating access or type of waste accepted should be developed and included in the regulations.

Another workshop addressed additional issues concerning record keeping and local community participation in the regulatory process. The workshop recommended to NRC that full records regarding the type of materials, their composition, and their location within the site; the volumes of material by type; the identity of the shipper and the materials to be shipped; and where they are located or filed, in all cases, within the state after closure. This workshop also recommended that the NRC include in this rule general provisions for local community participation in the regulatory process. It felt that these arrangements could be worked out between the state and the local community.

6.2.5 Technical Issues

1. What are the appropriate performance objectives for the LLW disposal rulemaking? Are any of the objectives now in the draft unnecessary? Why?

In general, the long-term performance objectives were considered to be suitable. However, there were some mixed views concerning specific standards proposed for levels of contamination at the site boundary and for the time after controls are removed.

Several workshops recommended that the criteria for protection of ground water be clarified. At one workshop, it was concluded that relevant EPA standards should be used and that EPA should complete, as soon as possible, its standards for low-level radioactive waste sites. At another workshop, the group was evenly divided between those who supported a requirement that the EPA standards be met at the site boundary and those who supported the requirement that the EPA standards be met at feasible sources of drinking water. There was a consensus that the regulation should be written to specify that the requirement should be met continuously. Another workshop recommended that NRC should consider establishing two ground-water contaminant criteria for the site boundary: (1) for design purposes, a calculated contaminant level using National Primary Drinking Water Standards and (2) for compliance during active site operation, and for the period following site closure until active institutional controls are not required, a readily measurable contaminant level (in pico-curies/liter).

There was considerable discussion at one workshop of the contaminant level allowed for the intruder after 100 years of active control. It was argued that a 25 mrem/yr standard should be used instead of a proposed 500 mrem/yr standard since the intruder, such as a householder, could be in constant rather than intermittent contact. At issue was the reliability of passive controls such that any intruder would be an episodic event. The issue was not resolved and it was concluded that the assumptions concerning the nature and duration of the intruder scenario should be more thoroughly explored by NRC.

2. What de minimus level is appropriate? Where and how should this level be set, and what is the rationale for setting it there? Should NRC establish de minimus levels for LLW below which NRC would not regulate disposal?

There was a general agreement with the concept of having a de minimus level of activity for disposal purposes. However, there was a minority opinion at one workshop that no de minimus level should be set and that all levels should be controlled and monitored. Several workshops addressed the issue of how low de minimus should be. At one workshop it was felt that (1) de minimus levels should be established based on the critical organ dose to cover both exempt quantities and low activity, large volume, dry bulk solids; and (2) alternatives for disposing of those wastes below the de minimus level could include sanitary landfills and special sites not governed by 10 CFR 61 (possible onsite with a shallow earth cover). At two workshops there was general agreement with the concept of establishing de minimus levels which are waste stream specific, thereby assuring a reasonable balance between practicality and safety. One of these workshops noted that other (nonradioactive) hazardous regulations may apply and be governing for disposal.

Two important policy related issues were raised but not conclusively resolved at one workshop. One issue was the preemption of NRC standards over state and/or local standards, in non-Agreement States. The other issue was the equal treatment of all generators with respect to de minimus levels. Specifically, there was a question as to whether the de minimus levels would be directed primarily to benefit the medical community and that industrial generators, especially power plants, would be effectively excluded.

3. How should guidance on the kinds of wastes that should be disposed of in certain types of facilities be implemented by rulemaking? To what extent should NRC consider potential future intrusion and reclamation in developing this guidance?

At two workshops, participants recommended that NRC establish concentration limits or ranges which would be acceptable for a low-level waste land disposal; that these ranges be used to adjust for site-specific conditions; that NRC attempt to give guidance as to which waste streams would be considered for each category of disposal; that flexibility must be built into the system so that specific cases can be accommodated. One of these workshops also recommended that NRC consider impacts of different waste streams and different institutional controls as may be required.

At the other workshop there was no agreement on the specifications of the waste categories. Some parties favored classification by isotope, others by more general categories, and others favored no classification within LLW. All parties recognized the need for greater quality control and compliance with the classification system finally adopted. Participants urged NRC to recognize the potential adverse economic incentive which may arise in a classification system whereby the generator may be inclined to misclassify his waste to permit less costly disposal techniques. It was also concluded that regulatory guides are the proper place for specifying the details of a classification system.

At a third workshop, there was unusual agreement that the concept of a maximum level was necessary to allow design criteria to be met. The consensus was that these levels should be based on a design basis incident which should include reclamation of the site for residential or agricultural activity at the end of the period of institutional control. The viewpoint was expressed that the present allowed levels of transuranics not be increased.

At a fourth workshop, there was general agreement with regard to disposal techniques that site design and layout, trench depth, burial depth, waste containers, etc. all should be selected with the specific waste types and forms to be disposed of, the specific activity and overall planned site capacity and separation in mind. In other words, the technique should be geared to the materials--type, form, and volume--to be disposed of at the site. It was also pointed out that there was nothing in the regulation which would create a necessity for multiple sites, even if multiple techniques were necessary.

4. What considerations of nonradiological hazards in LLW disposal are appropriate in rulemaking? How would this provision of the rulemaking relate to other federal rulemakings for nonradiological hazardous wastes? Should there be joint siting of hazardous and LLW facilities?

Most of the workshops agreed that the co-siting of low-level radioactive waste and hazardous waste disposal sites should not be precluded so long as all hazards are recognized between operations at both sites. However, at one workshop it was the majority opinion to set aside the complex technical and policy issues of dealing with both low-level and hazardous wastes since too little was understood of the complexity of disposal of both types of materials at a single site.

One workshop felt that (1) LLW sites should not accept appreciable quantities of hazardous waste and in no case should an LLW site accept hazardous waste which would compromise the integrity of the site; and (2) hazardous waste sites should accept such waste which is minimally contaminated with radioactive material. Another workshop concurred with the concept of inerting any nonradiological hazard which would adversely affect the radiological safety of the site.

At another workshop the consensus was reached that 10 CFR 61 should not prohibit the licensing of an LLW site adjacent to a hazardous chemical disposal site (or vice versa), but that if colocation of such sites is proposed, the license application should be required to show that possible synergistic effects have been considered in preparing the license application. A consensus was also reached that the regulations (10 CFR 61) should be modified to include those components of the hazardous waste regulations that apply to the chemicals and biological material associated with radioactive waste (i.e., scintillation vials, pathogenic materials). This could be accomplished by including any special requirements in 10 CFR 61, or by reference to the fact that the site must meet the appropriate sections of the EPA's regulations on hazardous waste disposal sites.

One workshop felt that NRC should closely coordinate with other federal agencies regarding definition of radioactive waste. Another workshop took a similar view recommending that NRC investigate the possible coordination of its rulemaking with the activities of other applicable agencies, including DOE, EPA, DOT and DOI regarding: (1) definition of radiological waste, including limits; and (2) siting of combined chemical and radioactive waste operations as provided under co-siting.

5. In what areas should NRC provide specific guidance in the form of regulatory guides for LLW? What level of specificity in the requirements should be incorporated in the regulation, and what level of specificity should be incorporated in the guidance, if any?

The general feeling at one of the workshops was that the regulations, as written, are too specific in many instances. It was felt that the performance criteria should be relied upon to set the basic standard, while specific system elements should be designed with the maximum of flexibility to achieve the performance criteria for a particular site and a given variety of waste types. Regulatory guides were seen as useful additions to the regulation, but only to the extent that the NRC did not treat these guide documents as criteria or specifications to be met.

There was a general consensus at another workshop that the regulation should contain (1) specific references to adopted standards where they exist (i.e., for noxious gases); (2) a list of design considerations where specific numerical values cannot be established--the burden should be placed on the license applicant to show how these issues were considered and evaluated; and (3) a general tightening of the definitions--in many cases definitions would be contained in regulatory guides rather than in the regulation.

Another workshop recommended that NRC adopt formal rules that establish broad performance objectives and administrative procedures, and set forth more specific program criteria and details in a regulatory guide, to be published as a program supplement to the rules. This workshop felt that subjects for regulatory guides should include but not be limited to site selection, disposal techniques for various types of waste (e.g., specification of engineering controls and trench operations), monitoring, packaging, site security, and site closure. Similarly, another workshop recommended that NRC regulatory guides should be developed and should specify the depth of detail expected in procedures and other submissions. This workshop felt that these guides should also recognize the presence and provide guidance for the disposal of naturally occurring radioactive material, such as radium, at the low-level waste disposal facility.

6. Are the criteria for the waste form appropriate? What criteria should be added, and why? What should be deleted, and why?

7. How inclusive should the requirements for solidification of liquid wastes be? Should there be exemptions for small generators? Why or why not? If so, how should such exemptions be provided?

8. Should a maximum leach rate requirement be established in the rulemaking? Why or why not?

The general consensus of one of the workshops on each of these issues was that specific standards are unnecessary and may be contradictory to the performance criteria approach. It was the general opinion that the specific means of dealing with the issue--form, for example--should be be left to the designer who would be guided by performance objectives. This reflected the majority opinion that the performance of the overall system, and not a given single component, was the important issue. Thus in the case of waste form, it was seen that both form and packaging should be treated together in assessing site stability, stability being the primary issue. Performance criteria for site stability should be established, leaving the specifics of form, packaging, etc. to the designer. This same opinion emerged with regard to the issues of solidification of liquid and resin wastes, and soil characteristics.

At another workshop it was recognized that it is desirable to regulate the level of radioactivity at the site boundary and that a systems approach will determine the level of radioactivity in the waste, the containers to be used, the geological medium, and the distance from the burial point to the site boundary--in addition to the leach rate--that will ensure compliance with the regulatory limit at the site boundary.

At another workshop participants recommended that the proposed rules strive for uniformity in LLW site operations, provided that states may exercise their congressionally-mandated prerogatives to require more stringent standards.

9. Should there be a minimum requirement for volume reduction? Why or why not? If such reduction should be required, to what extent should it be required?

There was a general consensus at one workshop that incentives, primarily economic incentives, would be sufficient to cause the appropriate volume reduction. It was pointed out that some generators may not be as motivated as others to respond to such incentives and that their lack of motivation affected other site users. It was concluded, therefore, that some minimum acceptable standard be established but that incentives be the primary mechanism for achieving the volume reduction.

There was a consensus at another workshop that recognition of the desirability of volume reduction should be included in the regulation. However, including volume reduction as a requirement was not considered appropriate. One suggestion was that the possibility of volume reduction should be one of the design considerations included in the review of license applications. This would assist the generator and the disposal site operator to justify the capital cost of compactors, incinerators, and other volume reduction equipment.

10. Should specific elements of site characterization be set forth in the regulation? In the guidance? Why or why not?

At one of the workshops it was felt that minimum acceptable elements should be set forth in the regulation, but the majority of the site elements for characterization should be contained in regulatory guidance material as an aid in the siting process. Again, consistent with the general objective of maximizing flexibility, this approach was seen as giving the designer the latitude to explore and describe the site in the context of its uniqueness. It was felt that basic standards are, however, necessary.

Another workshop recommended criteria constraining site selection. It felt that NRC should establish, in a general form in the regulations and in a specific form in the regulatory guides, minimum geological, hydrological, etc. criteria which would exclude an area from consideration as an LLW site. These minimum criteria should not result in the automatic exclusion of major sections of the country or exclude areas where identified shortcomings of a site could be rectified by engineering and site construction techniques. The workshop also recommended that (1) NRC should examine, in its regulatory guides, those site constraints which could be overcome by specified engineering or construction techniques; and (2) NRC should specify in the regulatory guides site-specific information required in an application, such as the maximum leach rate.

6.2.6 Other Technical Issues

Several additional issues were addressed at the workshops. These issues were site selection process, inventory of radionuclides, site suitability and buffer zone requirements.

One workshop recommended that an applicant can nominate a site for LLW disposal but such a site cannot be considered by NRC in an application unless: (1) a general area reconnaissance survey to determine possible site alternatives, has been performed by the state and/or DOE in coordination, if applicable, with any appropriate federal land manager; and (2) a joint federal-state environmental analysis has been prepared that would include an extensive geologic survey funded by DOE for each site.

Another workshop recommended that a federal centralized data bank be established to contain information on the inventory of radionuclides, chemical form, and the most toxic material in the waste for each low-level waste disposal site.

At another workshop, participants recommended that NRC redraft 61.96d(8) recognizing that some of the lesser severe problems may be engineered out; or that the features listed in 61.96d(8) be reorganized in view of their contribution to low-level waste migration from the facility. The participants also recommended that NRC needs to provide more detailed guidance on requirements for the buffer zone around the low-level waste disposal facility.

LIST OF COMMENTERS ON NOTICE OF DEVELOPMENT OF A RADIOACTIVE WASTE DISPOSAL CLASSIFICATION SYSTEM

43 FR 36722 (8/18/78)

1. ACRS Subcommittee on Waste Management
2. Cornell University
3. Portland General Electric Company
4. ICN Chemical and Radioisotope Division
5. U.S. Geological Survey
6. Pennsylvania Department of Environmental Resources
7. U.S. Bureau of Reclamation
8. U.S. Environmental Protection Agency
9. Utility Waste Management Group
10. Massachusetts Energy Facilities Siting Council
11. Department of Energy Richland Operations Office
12. California Department of Health Services
13. Nuclear Engineering Company, Inc.
14. Department of Energy Office of Nuclear Waste Management
15. Technical Advisory Panel
16. David L. Schreiber
17. James M. Byrne

LIST OF COMMENTERS ON ADVANCE NOTICE OF PROPOSED
RULEMAKING ON LLW DISPOSAL REGULATION (10 CFR Part 61)
43 FR 49811 (10/25/78)

1. Wells Eddleman
2. Bureau of Land Management
3. Connecticut Department of Environmental Protection
4. Portland General Electric Company
5. Armadillo Coalition of Texas
6. California Department of Health
7. Pennsylvania Dept. of Environmental Resources
8. Donald B. Stal
9. Center for Law and Social Policy
10. Utility Waste Management Group
11. Louise Gorenflo
12. Environmental Policy Institute
13. Stark County (Illinois) Zoning and Planning
14. Exxon Nuclear Company
15. Township of Lower Alloways Creek
16. Six Power and Utility Companies
17. Toulon (Illinois) United Methodist Church
18. Texas Department of Health
19. Consolidated Edison Company of New York
20. Kentucky Department for Human Resources
21. Yankee Atomic Electric Company
22. Commonwealth Edison
23. Natural Resources Defense Council, Inc.

24. U.S. Environmental Protection Agency
25. Ohio Environmental Protection Agency
26. Chem-Nuclear Systems, Inc.
27. Westinghouse Electric Corporation
28. Tennessee Valley Authority
29. Ohio Department of Health
30. New York Department of Environmental Conservation
31. Pennsylvania State University
32. HYRE Enterprises, Inc.
33. Atomic Industrial Forum, Inc.
34. Conference of Radiation Control Program Directors, Inc.

LIST OF COMMENTERS ON PRELIMINARY DRAFT REGULATION

10 CFR Part 61 (11/5/79) - 45 FR 13104 (2/28/80)

1. Nevada Division of Health
2. Florida Department of Environmental Regulation
3. Department of Energy, Division of Waste Products
4. Nuclear Safety Associates
5. Natural Resources Defense Council
6. California Energy Resources Conservation and Development Commission
7. West Virginia Geological and Economic Survey
8. Kansas Department of Health and Environment
9. U.S. Geological Survey
10. Tennessee Valley Authority
11. Penberthy Electromelt International, Inc.
12. Travenol Laboratories
13. Arkansas Power & Light Company
14. Duke Power Company
15. North Carolina State University
16. United States Steel Corporation - Texas Uranium Operations
17. Pennsylvania Power & Light Company
18. American Hospital Association
19. Ford, Bacon & Davis Utah, Inc.
20. Department of Energy - Clinch River Breeder Reactor Plant Project Office
21. Atomic Industrial Forum/Utility Nuclear Waste Management Group
22. Consumers Power Company
23. Los Alamos Scientific Laboratory (University of California)
24. Pharmaceutical Manufacturers Association

25. Chem-Nuclear Systems, Inc.
26. Yale University
27. Ralston Purina Company
28. Illinois Department of Public Health
29. Wisconsin Division of Emergency Government
30. Vermont Legislative Council
31. Connecticut Department of Business Regulation
32. U.S. Ecology, Inc.
33. Marvin I. Lewis

Appendix D

LOW-LEVEL WASTE SOURCES AND PROCESSING OPTIONS

This appendix presents a data base on sources of low-level radioactive waste (LLW), in addition to a number of options for processing this waste. The data base includes estimates of:

- o the physical, chemical, and radiological characteristics of LLW projected to be routinely generated during the period from 1980 to the year 2000;
- o the changes in these characteristics under a number of viable waste treatment technology options;
- o the costs for these waste treatment options based upon currently available technology; and
- o data on occupational exposures and environmental releases associated with the waste treatment options.

These characteristics are utilized to determine the performance and technical requirements for acceptable disposal of the wastes, and to determine the environmental impacts of selected disposal alternatives.

Section 1 is an introduction to the appendix and provides a background rationale for the assumptions used in developing the data base. Section 2 describes the waste sources (streams) that will be considered and Section 3 presents the characteristics (including volumes and radioactivity concentrations) of these waste streams prior to waste treatment. This section is followed by Section 4, which very briefly discusses various types of waste processing and treatment options which can be applied to these streams, and selects some specific representative treatment options for further consideration. Section 4 also quantifies several impact measures (occupational exposures, population exposures, costs, and energy use) associated with the selected waste treatment options. Section 5 presents the characteristics of the waste streams after application of the selected waste treatment options. Finally, Section 6 describes some potential waste streams that may be generated in the future, for which projections of waste quantities potentially produced to the year 2000 are considered to be speculative.

1. INTRODUCTION AND BACKGROUND

There are many facilities and diverse processes that generate radioactive waste, ranging from nuclear fuel cycle facilities to medical institutions and industrial facilities. To determine the environmental impacts of disposing of these wastes, their physical, chemical and radiological characteristics are estimated and projected on a regional basis over a time period from 1980 to the year 2000. The radioactive wastes projected in this appendix are then assumed to be disposed into a reference near-surface disposal facility that is typical of existing disposal facilities. (See Appendix E for a description of the reference disposal facility.) This provides a base case against which potential alternatives for waste form and disposal facility design and operation can be analyzed.

The regions considered as part of developing the waste projections are shown in Figure D.1. The five regions range in number from 7 to 14 states each, and correspond to the five NRC regions. Each region could represent a large multistate compact formed for waste disposal.

Projecting regional waste generation to the year 2000 results in an upperbound volume of waste produced during this period of about one million cubic meters (about 35 million ft^3) of waste per region, sufficient to fill a single disposal facility of up to a few hundred acres in size using existing trench disposal practices. Existing commercial disposal facilities range from twenty to a few hundred acres in size. A million cubic meters of waste corresponds to an average of 50,000 m^3 (1.77 million ft^3) of waste disposed per year over a period of 20 years, or about 4167 m^3 (147,000 ft^3) a month. By comparison, the current limitation on monthly receipt at the Barnwell, S.C. disposal site is 200,000 ft^3 per month and this limit will be reduced to 100,000 ft^3/month by October 1981 (Ref. 1).

Within the last few years, a considerable amount of data has been generated on the characteristics of radioactive waste streams. Even so, in some cases the data is rather limited and simplifying assumptions are made as a result. The waste projections are also limited by the inherent variable nature of waste generation. Facilities producing waste may expand, reduce or otherwise modify operations, depending upon governmental, social, or economic influences that are not readily predictable. Future development in waste treatment processes is also expected to alter the characteristics of the waste streams that are produced, as are regulatory requirements and actions.

Given the inherent uncertainties in waste projections over the next twenty years and beyond, NRC staff have concentrated on wastes that are either presently being routinely generated, or are expected within the next few years to be produced in significant quantities. These include wastes from the present once-through uranium fuel cycle, institutional wastes, and radioisotope industrial wastes. There are also a number of other waste streams that may be produced in the future--e.g., wastes produced from recycle of uranium fuel--but the timing for their generation, their production rates, and their characteristics are speculative at this time. These streams are discussed in Section 6 in lesser detail. In any case, new waste streams will be continuously generated as processes change, new facilities are built, and so forth.

Development of the data base has been divided into three components: (1) the characteristics of "untreated" LLW, (2) the waste treatment systems which can be utilized and their potential effects on LLW, characteristics and (3) alternative LLW characteristics under several of these waste treatment options. The waste sources have been subdivided into a number of individual streams, each of which differ significantly in characteristics and generation sources. The

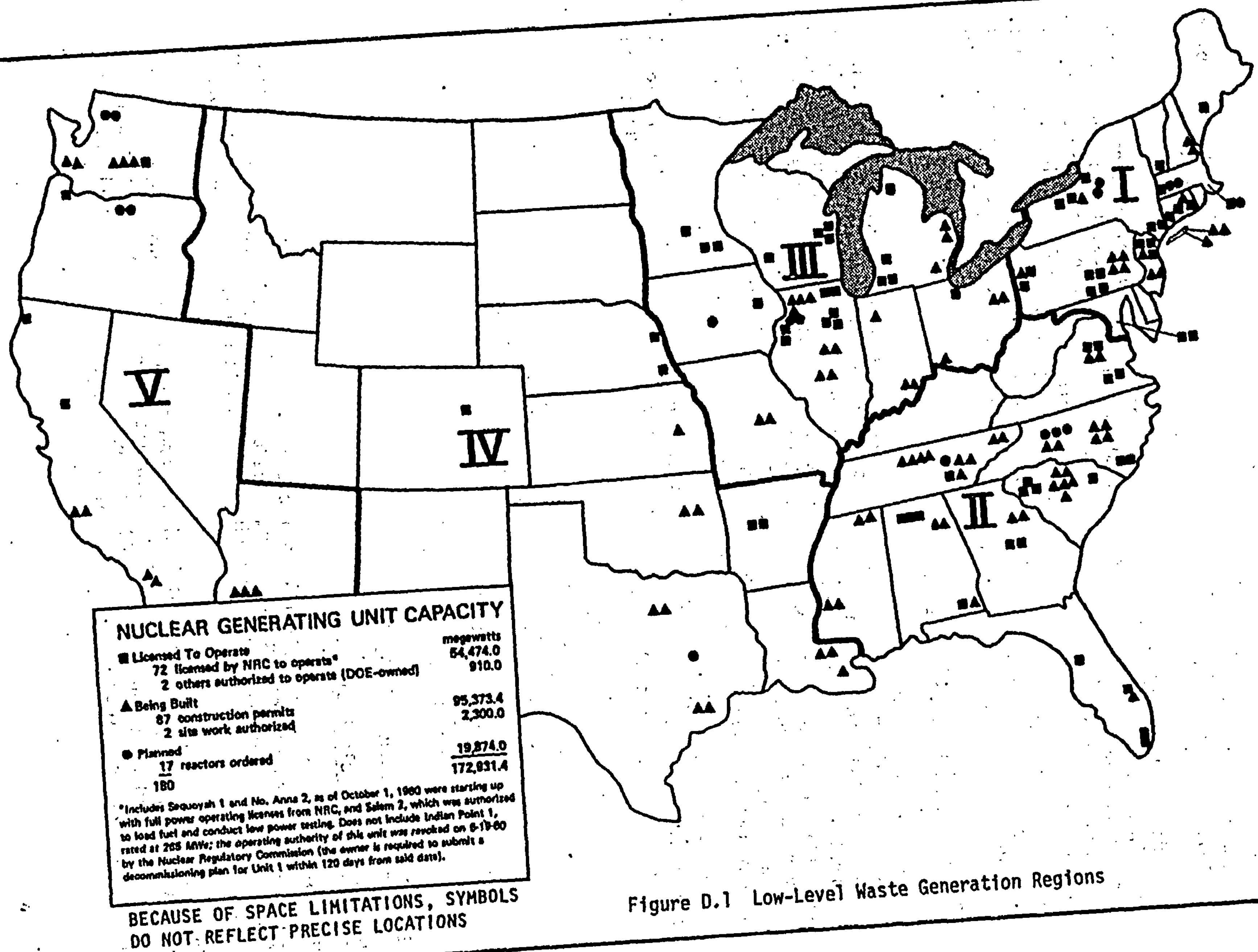

Figure D.1 Low-Level Waste Generation Regions individual waste streams are then regrouped into 4 groups which are distinguished by the macroscopic properties of the wastes. All of these streams are presently being generated and shipped to waste disposal sites or have a reasonably high possibility of being generated by the year 2000.

The detailed breakdown enables (1) rapid and flexible calculation of impacts, (2) incorporation of future waste treatment technologies, (3) a rapid increase in the number of streams considered, and (4) improvements in the accuracy of information in a given stream. It is expected that much additional data on waste characteristics will be acquired over the next few years. Additional waste streams may also be identified. Therefore, the structure of the data base on waste characteristics has been designed to be flexible to incorporate new data in a straightforward manner.

2. WASTE STREAM DESCRIPTIONS

This section provides a description of the waste streams that are presently being routinely generated or are expected to be routinely generated in significant quantities in the relatively near future. Section 2.1 is an overview of current waste generators, which comprise nuclear fuel cycle waste generators and nonnuclear fuel cycle waste generators. Sections 2.2 through 2.5 then provide a more detailed discussion of the waste streams produced by these waste generators. In this appendix, 25 distinct waste streams have been identified and these are summarized in Table D.1.

As shown in the Table, the 25 waste streams may be grouped into the following five major waste sources, which include three generic fuel cycle sources and two generic nonfuel cycle sources:

- Nuclear fuel cycle
  - Central station nuclear power plants
  - Fuel fabrication plants
  - Uranium hexafluoride (UF_6) conversion plants
- Nonnuclear fuel cycle
  - Institutional facilities
  - Industrial facilities

2.1 Overview of Waste Generators

Nuclear Fuel Cycle Facility

Nuclear fuel cycle waste generators include facilities involved in the commercial generation of electrical power through the use of nuclear energy. The current fuel cycle is based upon once-through use of uranium fuel as shown in Figure D.2 (Ref. 2).

The nuclear fuel cycle begins with mining and milling of uranium ore. Uranium ore is generally obtained from either open pit or underground mines and is usually shifted to a centralized mill for processing. Uranium mills convert uranium ore to yellowcake, which primarily consists of U_3O_8. Disposal of

Table D.1 Waste Sources and Streams

Nuclear Fuel Cycle	Abbreviation
Central Station Nuclear Power Plants	
Ion Exchange Resins	IXRESIN
Concentrated Liquids	CONCLIQ
Filter Sludges	FSLUDGE
Cartridge Filters	FCARTRG
Compactible Trash	COTRASH
Noncompactible Trash	NCTRASH
Nonfuel Reactor Core Components	NFRCOMP
Decontamination Resins	DECONRS
Fuel Fabrication Facilities	
Process Wastes	PROCESS
Compactible Trash	COTRASH
Noncompactible Trash	NCTRASH
Uranium Hexafluoride Plants Process Wastes	PROCESS
Nonfuel Cycle	
Institutional Facilities	
Liquid Scintillation Vials	LIQSCVL
Absorbed Liquid Waste	ABSLIQD
Biowaste	BIOWAST
Trash	COTRASH
Industrial Facilities	
Waste from Isotope Production Facilities	ISOPROD
High Activity Waste	HIGHACT
Tritium Production Products Manufacturing Waste	TRITIUM
Sealed Sources	SOURCES
Accelerator Targets	TARGETS
Source and Special Nuclear Material Waste	SSWASTE
Source and Special Nuclear Material Trash	SSTRASH
Low Activity Waste from Various Sources	LOWASTE
Low Activity Trash from Various Sources	LOTRASH

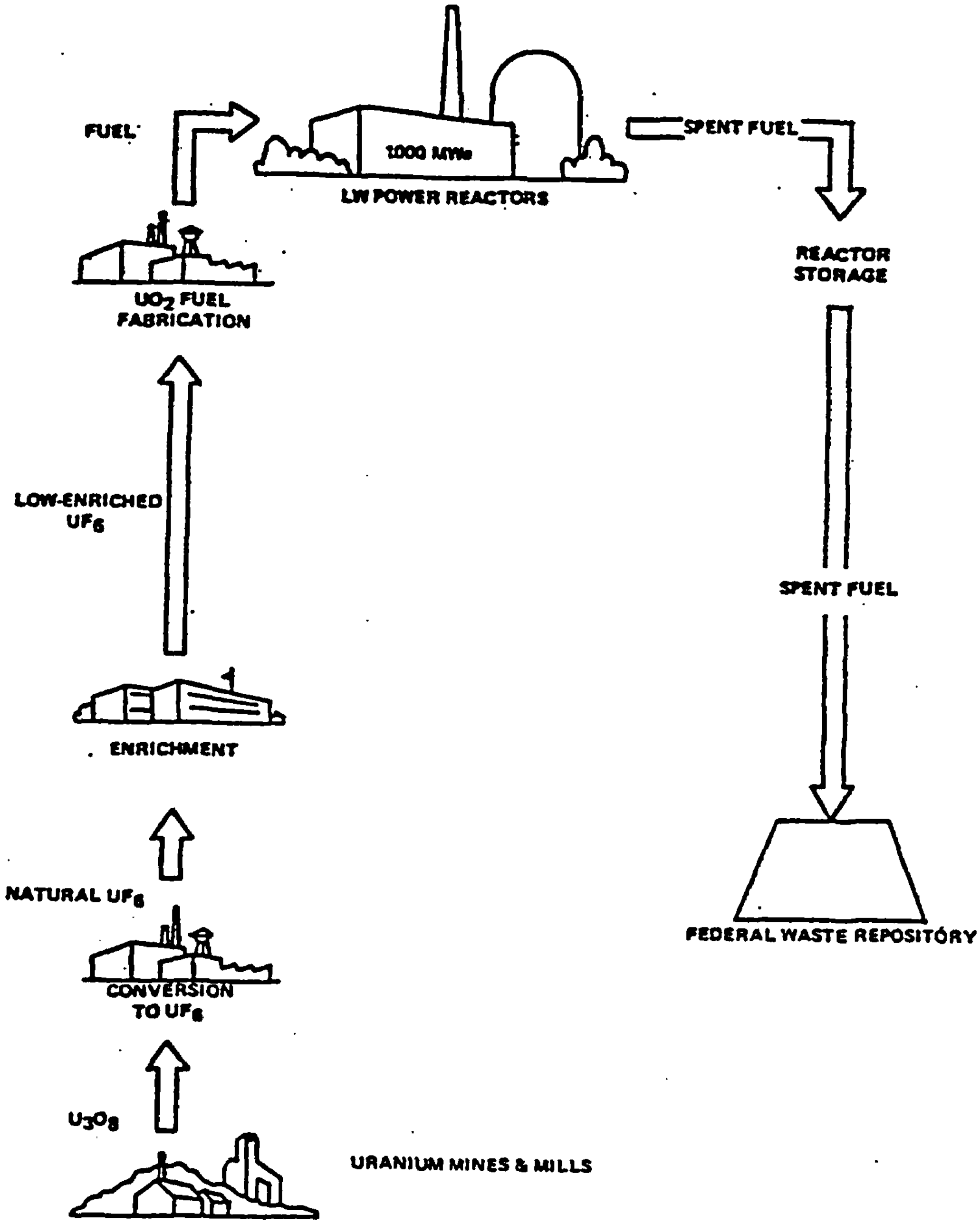

Figure D.2 Once Through Uranium Fuel Cycle liquid and solid wastes generated as part of milling operations has been already addressed in a separate rulemaking action and is not considered further in this appendix. Additional information can be located in NUREG-0706 (Ref. 3).

Yellowcake produced from milling operations is then shipped to conversion plants that convert U_3O_8 to uranium hexafloride (UF_6). The conversion process generates liquid and solid waste streams, most of which are recycled to recover uranium prior to storage in onsite ponds or reuse within the plant. Onsite storage at conversion facilities is presently regulated by NRC under 10 CFR Part 40. Small quantities of low-activity wastes contaminated with natural uranium are shipped offsite to licensed near-surface disposal facilities. These wastes are considered further in this appendix. Currently, there are two UF_6 conversion plants in operation in the United States; one plant is located in Region III and one in Region IV.

Following conversion, natural UF_6 is shipped to enrichment facilities for enrichment in fissile U-235. In this process, the U-235 content of the uranium is raised from natural concentrations (about 0.7 weight percent) to about 2 to 4 weight percent. Currently, three enrichment plants using the gaseous diffusion process are in operation and these are located at Portsmouth, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee. These plants are owned and operated by the federal government and wastes produced from plant operation are not sent to commercial disposal facilities. Hence, waste streams produced from uranium enrichment operations are not considered further in this appendix.

Enriched UF_6 is then shipped to commercial fabrication plants which convert the enriched UF_6 to uranium dioxide (UO_2) powder, produce UO_2 pellets, fabricate fuel rods containing the UO_2 pellets, and combine the fuel rods into fuel assemblies for use in light water reactors. Most of the liquids, sludges, and other wastes produced during the UF_6-to-UO_2 conversion process are presently being stored at the fabrication plants, although some wastes in the form of dry solids (principally CaF_2) contaminated with low levels of enriched uranium are being shipped offsite for disposal. Low-activity waste, principally trash, is also generated during the pelletizing and subsequent fabrication processes, and these waste streams are also shipped offsite for disposal. Table D-2 provides a summary of the current LWR fuel fabrication industry.

Fuel assemblies are then shipped to central station nuclear power plants, utilizing light water power reactors (LWR) for production of electrical power through use of the energy released during fission of the uranium fuel. During operations, waste is generated in a number of forms having specific activities ranging from low to moderately high levels. Much, if not most, of the waste is generated as a result of operating and maintaining plant processes which maintain concentrations of radiocontaminants in the reactor coolant and other process systems to low levels and reduce effluent releases from the plant to acceptable levels. The presence of such radiocontaminants in reactor cooling systems can result from activation of corrosion products or from leakage of fission products out of the fuel rods. The treatment and maintenance operations result in wet wastes such as filter sludges, spent resins, and evaporator bottoms, as well as compactible and noncompactible dry wastes. Liquids such

Table D.2 Current LWR Fuel Fabrication Industry

Licensee and Plant Location	Plant Feed Material	Plant Product	Plant Capacity (MTU/yr)	
			Current	Estimated 1985
Babcock & Wilcox Lynchburg, VA (2)*	UO_2 pellets (UF_6)	Fuel assemblies	230	830**
Babcock & Wilcox Apollo, PA (1)	UF_6	UO_2		†
Combustion Engineering Hematite, MO (3)	UF_6	UO_2		††
Combustion Engineering Windsor, CT (1)	UO_2 powder	Fuel assemblies	150	150
Exxon Nuclear Richland, WA (5)	UF_6	Fuel assemblies	665	1,030#
General Electric Wilmington, NC (2)	UF_6	Fuel assemblies	1,500	1,500
Westinghouse Electric Columbia, SC (2)	UF_6	Fuel assemblies	750	1,600

*NRC Region number.

**Babcock and Wilcox (B&W) plans to expand operations to increase capacity to 1,200 MTU/yr in the early 1990s. The capacity listed in the table for 1985 is an interpolation of present and future capacity. In addition, a UF_6 to UO_2 conversion operation will be added as well as a UO_2 pelletizing operation.

†Currently, the B&W Apollo plant converts UF_6 to UO_2 power and ships the UO_2 to its Lynchburg plant for fabrication into fuel assemblies.

††The Combustion Engineering (CE) Hematite plant produces UO_2, pellets or powder which are then transferred, to the CE Windsor plant for fabrication into fuel assemblies.

#Expanded to 1,030 MTU/yr in 1980.

Source: NRC Data

as evaporation bottoms are solidified, while other wet wastes such as ion-exchange resins are generally dewatered and packaged into containers for shipment. Some compaction is usually performed on compactible trash. The wastes are then generally shipped offsite for disposal.

Currently, there are 74 light water power reactors in operation in the United States, of which 48 are pressurized water reactors (PWR) and 26 are boiling water reactors (BWR). The locations of these operating reactors, as well as the locations of the reactors under construction, are shown in Figure D.1.

The fuel used in the reactors must be periodically replaced. Generally about one-third of the fuel in the reactor core is replaced approximately every 12 to 18 months. Most of this spent fuel is stored at the power stations within large spent fuel holding pools. A small fraction of this fuel, however, is presently stored offsite in fuel pools located within two facilities originally designed to reprocess the fuel. One facility (the Nuclear Fuel Service plant in West Valley, NY) suspended reprocessing operations in 1971 and the other (the General Electric facility in Morris, IL) never became operational. Additional facilities specifically constructed for storage of spent fuel may be constructed in the future; these may be located either at the operating reactors site or at away-from reactor (regional) sites.

Two basic options are available for the disposition of the spent fuel. One option is to treat the spent fuel as high-level waste and dispose of the spent fuel in a federal repository to be constructed and operated by the Department of Energy (DOE). Another option is to recycle the spent fuel as shown in Figure D.3. In this option, spent fuel would be shipped to a reprocessing plant which, using chemical separation processes, would recover residual uranium and plutonium for reuse in reactors. Recovered uranium would be shipped as UF_6 to an enrichment plant for enrichment in U-235. Recovered plutonium would be shipped as plutonium dioxide (PuO_2) powder to a mixed oxide (MOX) fuel fabrication plant where it would be combined with natural UO_2 and fabricated into MOX fuel rods. The MOX fuel rods would then be shipped to a fabrication plant where the MOX fuel rods would be combined with natural uranium fuel rods and assembled into fuel assemblies for reinstallation into LWRs. High level and transuranic wastes generated during reprocessing and MOX fuel fabrication operations would be shipped to a federal repository for disposal.

For the last four years, the policy of the United States as announced by former President Carter has been to defer the uranium recycle option. There are no reprocessing or MOX fuel fabrication facilities operating in the country and spent fuel removed from nuclear power reactors is currently being stored pending operation of a federal repository. It is possible that in the future, the country's policy on uranium fuel recycling may change. However, at present, the timing and extent of future fuel reprocessing and MOX fuel fabrication operations are speculative, as is the quantity of waste to be generated through such operations.

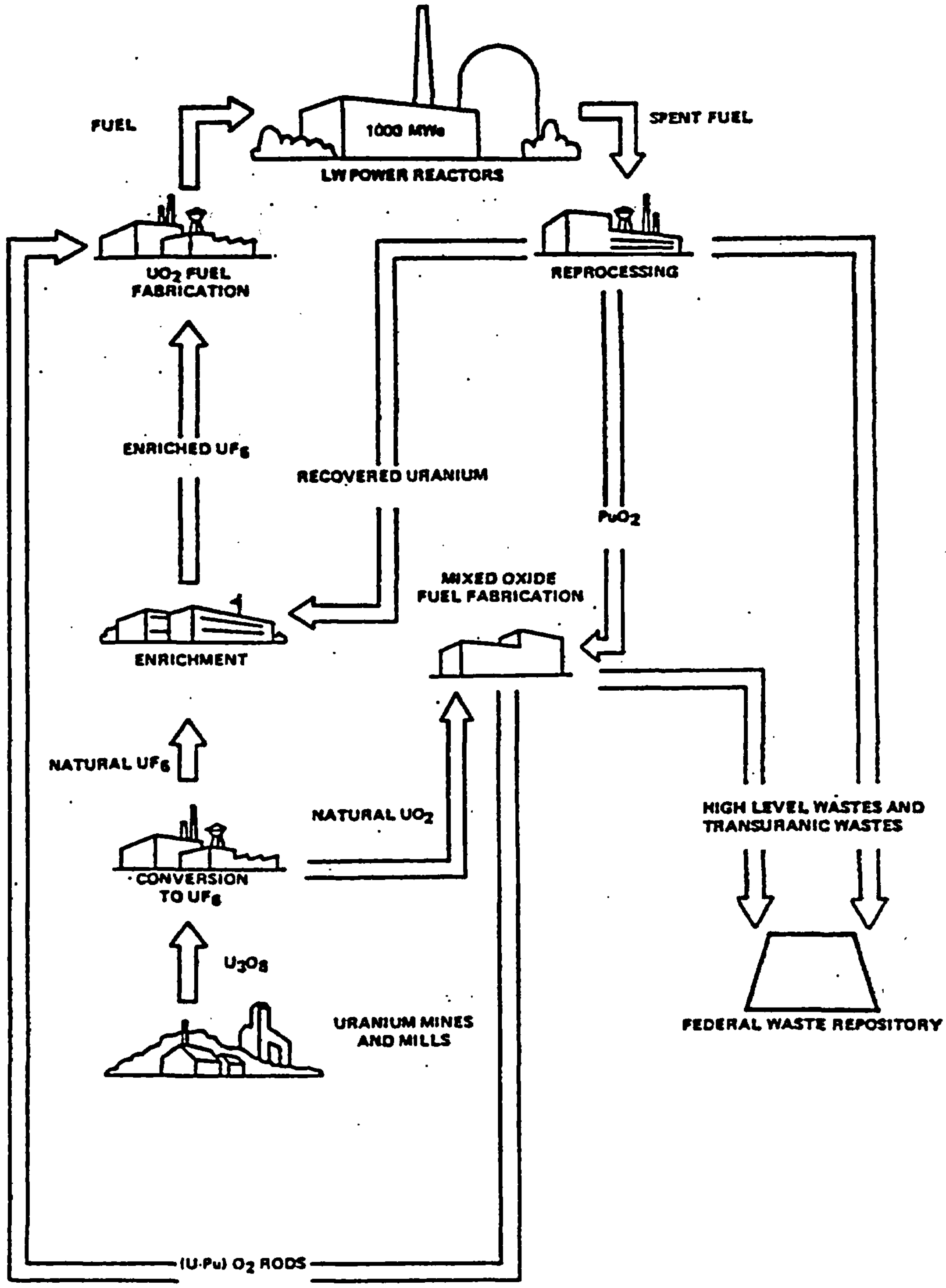

Figure D.3 Uranium and Plutonium Recycle Fuel Cycle

DAMES & MOORE

Nonfuel Cycle Waste Generators

Nonfuel cycle waste generators include approximately 20,000 facilities licensed by NRC or Agreement State agencies to use radioactive materials. Nonfuel cycle waste generators may be classified as either institutional or industrial.

Institutional waste generators include hospitals, medical schools and research facilities, colleges, and universities. Waste generation rates and waste characteristics vary significantly between institutional waste generators and it is therefore difficult to consider each type of institution as a separate waste generator. Therefore, all institutional facilities are considered as a single waste source in this appendix.

Industrial waste generators are also considered as a single waste source for the same reason, and include industries which produce and distribute radionuclides, manufacture materials containing radioisotopes for industrial uses, and use radioisotopes in laboratory studies, instruments, devices, and manufacturing processes. Industrial waste generators have not been surveyed to as great an extent as other types of waste generators.

2.2 Central Station Nuclear Power Plants

Central station nuclear power plants presently in operation in the United States include 74 light water reactors (LWRs) and a single high temperature gas-cooled reactor (HTGR). The waste generated by the single HTGR is volumetrically and radiologically negligible compared with the wastes generated by LWRs (Ref. 4), and is therefore not considered further in this appendix. Electricity for commercial use is also generated as a byproduct of the Hanford "N" plutonium production reactor and the Shippingport light water breeder reactor. Wastes generated by these facilities are disposed in facilities operated by the Deparment of Energy (DOE) and not in commercial disposal facilities.

The majority of the LWR waste streams are generated by operation of in-plant liquid radwaste processing systems. The basic functions of these processing systems are to reduce the accumulation of radioactive contaminants within the plant and to reduce the amount of these contaminants released from the plant. More detailed descriptions of these systems can be found elsewhere (Ref. 5). During these processes, radioactive contaminants are concentrated in several forms.

Two types of LWRs are in operation today: pressurized water reactors (PWRs) and boiling water reactors (BWRs). Waste streams common to PWRs and BWRs can be divided into "process wastes" and "trash." Process waste streams include ion exchange resins, concentrated liquids (evaporator bottoms), filter sludges. Cartridge filters are another form of process waste but are used much more extensively in PWRs than in BWRs. Trash waste streams can be divided into compactible trash and noncompactible trash. Another waste stream common to both types of LWRs and generated on an infrequent basis consists of nonfuel reactor core components. Wastes from future LWR decontamination operations may also be generated. The LWR processing systems that result in the generation of the process waste streams are briefly outlined in Table D.3.

Table D.3 Major Sources of Process Wastes in LWRs

BWRs	PWRs
1. Application of Ion Exchange Resins	
Condensate polishing system	Condensate polishing system
Reactor water cleanup	Chemical and volume control system
Clean radwaste system	Boron control system
Dirty radwaste system	Spent fuel pool cleanup
Chemical waste system	Steam generator blowdown system
Spent fuel pool cleanup	Miscellaneous waste system
	Chemical waste system
2. Sources of Liquids Concentrated by Evaporation	
Regeneration of resins	Regeneration of resins
General decontamination waste liquids	General decontamination waste liquids
System effluents from:	System effluents from:
Clean radwaste	Liquid radwaste
Dirty radwaste	Chemical radwaste
Chemical radwaste	Laundry waste
Laundry waste	Steam generator blowdown
3. Application of Precoat Filters and Cartridge Filters	
Condensate polishing system	Steam generator blowdown
Reactor water cleanup	Condensate polishing system
Spent fuel pool cleanup	Boron control system
Equipment and floor drains	Spent fuel pool cleanup
Chemical waste system	Laundry waste system
Laundry waste system	

Ion Exchange Resins

Processes involving ion exchange media are frequently used in LWRs to remove dissolved radioactivity from liquid streams. Ion exchange media usually consists of organic resins, which can be cation or anion resins, or a mixture of both. Inorganic zeolite ion exchange media has also been used in some cases. The resins (or other ion exchange media) are usually packed into cylindrical tanks (ion exchange columns or demineralizers) and the liquid containing the specific contaminant is passed through the resin column. In this process, dissolved radiocontaminants chemically displace ions in the resin and become physically bound to the resin. When an ion exchange bed can no longer perform its function (following depletion), it is replaced or regenerated. The old bed is typically transferred as a slurry out of the tanks into a shipping container (generally referred to as a liner), where excess water is removed prior to transfer to a disposal facility. Removal of free water is termed dewatering; dewatered ion exchange media however, can still contain between 42 and 55% water by weight (Ref. 6), in addition to interstitial liquid. In general, the liners are transported in casks that are shielded for radiation protection.

Concentrated Liquids

Concentrated liquid waste may be produced by the evaporation of a wide variety of LWR liquid streams. Many systems generating these liquid streams are interrelated (see Table D.3). The waste consists of liquids with an elevated suspended and dissolved solids content, and also consists of sludge resulting from supersaturation during evaporation. Newer LWR plants, especially PWRs, often have several evaporators, each dedicated to concentrating a particular liquid stream. Existing PWRs usually concentrate boric acid waste solutions to about 11% solids by weight, and BWRs usually concentrate liquids containing sodium sulfate to about 25% solids by weight (Ref. 6). Other types of solutions (e.g., laundry liquids, laboratory drains) are concentrated to about 25% solid by weight (Ref. 6). These concentrated liquids are currently solidified in various matrix materials including urea-formaldehyde and cement prior to transfer to a disposal facility.

Filter Sludge

Filter sludge is waste produced by precoat filters and consists of filter aid and waste solids retained by the filter aid. Diatomaceous earth, powdered mixtures of cation and anion exchange resins, and high purity cellulose fibers are common filter aids. These materials are slurried and deposited (precoated) as a thin cake on the initial filter medium (wire mesh, cloth, etc.). The filter cake removes suspended solids from liquid streams. Precoat filters using powdered resins also remove dissolved solids but are not as effective as mixed bed ion exchange columns (deep bed demineralizers) due to the shorter contact time of the liquid with the resin. Precoat filters are used much more extensively in BWRs than in PWRs (see Table D.3). Precoat filtration may be used in conjunction with ion exchange columns and evaporation, or it may be the only form of treatment removing suspended solids from a particular liquid stream.

Cartridge Filters

Cartridge filters contain one or more disposable filter elements. These elements may be typically constructed of woven fabric, wound fabric, or pleated paper supported internally by a stainless steel mesh as well as pleated or matted paper supported by an external stainless steel basket. Paper filter elements are often impregnated with epoxy. Woven fabric filters are typically constructed of cotton and nylon. Cartridge filters are effective in removing suspended solids, but do not have the ion exchange capability of precoat filters or demineralizers. They are used much more extensively in PWRs than BWRs, and their typical uses in LWRs are similar to those of precoat filters (see Table D.3). Many plants use cartridge filters in conjunction with ion exchange columns, evaporators, and precoat filters. Currently, these cartridge filters are usually packed in 55-gallon drums (between 3 to 12 per drum) prior to transfer to a disposal facility (Ref. 6).

Trash

Trash is the most varied waste stream generated by LWRs and can contain everything from paper towels to irradiated reactor internals. Some of the materials that have been identified in the past as having been shipped as trash are listed in Table D.4.

A recent survey (Ref. 6), found that compactible and noncompactible items are frequently shipped in the same container and that packaging small pieces of activated metal with relatively innocuous materials is common. Such factors make characterization of trash difficult. In general, compactible trash contains more combustible material (e.g., paper, plastic), and noncompactible trash contains more metallic components (e.g., pipes and failed equipment). It is usually assumed that the volume percentage of compactible trash and combustible trash are the same. Similarly, the volume percentage of noncompactible trash and noncombustible trash are assumed to be the same.

Other Waste Streams

Nonfuel reactor components consist of fuel channels, control rods, control rod channels, shim rods, in-core instrumentation, and flux wires. Many of these components are exposed to the primary reactor coolant and all are exposed to the in-core neutron flux.

LWR decontamination waste is expected to be produced in the future by routine full-scale decontamination of LWR primary coolant systems. The components included in these systems include the reactor core, the reactor pressure vessel, system piping, various pumps, and turbines. The purpose of decontamination is to reduce in-plant occupational radiation exposures by removing crud accumulated on surfaces that are in contact with the primary coolant. It is expected that typical waste streams generated during these future routine decontamination operations will include such streams as ion-exchange resins used to process the decontamination solutions and solidified evaporator bottoms. The wastes are projected to contain large quantities of chelating agents.

2.3 Other Nuclear Fuel Cycle Facilities

Other nuclear fuel cycle waste streams considered in this appendix include process wastes from uranium hexafluoride conversion (UF_6) plants and fuel fabrication facilities, and trash from fuel fabrication facilities. These wastes are generally not well characterized. No data could be found for trash from UF_6 conversion facilities.

Table D.4 Material Shipped as LWR Trash

Material	BWRs C*	BWRs N*	PWRs C	PWRs N
Anti-contaminant clothing			X	
Cloth (rags, mops, gloves)	X		X	
Conduit				X
Contaminated dirt	X	X		
Contaminated tools and equipment				
Hand tools	X	X		
Eddy current equipment				X
Vessel inspection equipment				X
Ladders		X		X
Lighting fixtures				X
Spent fuel racks				X
Scaffolding		X	X	
Laboratory equipment			X	X
Filters				
Filter cartridges	X	X		
HEPA filters		X	X	X
Respirator cartridges	X			
Glass	X	X	X	
Irradiated Metals				X
Flux wires				X
Flow channels		X		
Fuel channels		X		X
In-core instrumentation				X
Poison channels		X		
Shim rods				X
High density concrete block				X
Miscellaneous metal	X	X		X
Aerosol cans		X		
Buckets	X			
Crushed 55-gal drums		X		
Fitting		X		
Pipes and valves		X		X
Miscellaneous wood	X	X	X	X
Paper	X		X	
Plastic				
Bags, gloves, shoe covers	X	X	X	
Sample bottles	X			
Rubber	X			X
Sweeping compounds		X		

*C: compactible, combustible;
N: noncompactible, noncombustible.

Processed uranium ore or yellowcake containing about 0.7 percent fissile U-235, must be enriched in U-235 content prior to utilization as fuel in LWRs. Prior to enrichment by the gaseous diffusion process (the major technology currently used for enrichment), the uranium must be converted to UF_6, which is an easily-volatilized compound suitable for this process. During this process in UF_6 conversion facilities, liquid and solid wastes are generated. Many of these waste streams are recycled in the plant to recover uranium. Some process wastes, however, are shipped for disposal. These wastes consist primarily of calcium fluoride generated in hydrogen fluoride gas scrubbers, bed materials from fluidized bed reactors, and lime from treatment of liquid effluents.

Fuel fabrication is the final step before uranium fuel is utilized in LWRs. In fuel fabrication facilities, enriched UF_6 from gaseous diffusion plants is converted into a solid form (usually uranium dioxide) and then into fuel pellets, fuel rods, and finally fuel assemblies. A large portion of the wastes generated during these operations are recycled to recover uranium. Process wastes shipped for disposal include limestone used in calcium fluoride, scrubbers, calcium fluoride, oxides from calciners, filter sludges, and small amounts of oils. Trash shipped for disposal includes paper, plastic, equipment, and miscellaneous combustible materials.

2.4 Institutional Facilities

Institutional waste generators include colleges and universities, medical schools, research facilities, and hospitals. These institutions use radioactive materials in many diverse applications. Sealed sources and foils are widely used as integral parts of analytical instruments and irradiators. Labelled pharmaceuticals and biochemicals are used in nuclear medicine for therapy and diagnosis, and in biological research to study the physiology of humans, animals, and plants. Radioactive materials are also used by many other academic disciplines such as chemistry, physics, and engineering. Radioactive waste streams are also produced by institutions as a byproduct of research using neutron activation analysis, particle accelerators, and research reactors.

Based upon information received from surveys (Refs. 7, 8), institutional wastes may be classified into four volumetrically significant groups: liquid scintillation vials containing scintillation fluid (shipped with absorbent materials), other liquids (solidified or shipped with absorbent materials), biological wastes (shipped with absorbent materials and lime), and trash. In addition to these streams, institutional facilities generate two volumetrically smaller waste streams, accelerator targets and sealed sources, that have been included under the next section on industrial wastes.

Liquid scintillation counting techniques are used to some extent by nearly all fuel cycle and nonfuel cycle waste generators; however, applications in biological research produce the major volumes of waste scintillation vials and fluids. The vials are made of glass and occasionally polyethylene, and are usually about half full of counting fluid. Flammable organic solvents (e.g., toluene, benzene, xylene) comprise the major constituents of scintillation fluids (Refs. 7, 8).

Absorbed liquids have not been as well characterized as liquid scintillation vials, in part because the composition of absorbed liquids is not constrained by the requirements of liquid scintillation counting techniques. Approximately 50 percent of these absorbed liquids are scintillation fluids (Ref. 7). The remaining liquids are aqueous and organic solvents generated by diverse preparatory and analytical procedures such as wastes from elution of Tc-99m generators, radioimmunoassay procedures, and tracer studies.

Biological wastes are generated primarily through research programs at universities and at medical schools. The waste consists of animal carcasses, tissues, animal bedding, and excreta, as well as vegetation and culture media. Radioactive excreta from humans undergoing diagnostic or therapeutic procedures that use radioactive materials are not included since virtually all such materials are discharged to sewers (Ref. 8).

Institutional trash consists almost entirely of materials that are both compactible and combustible. It generally consists of paper, rubber or plastic gloves, disposable and broken labware, and disposable syringes.

2.5 Industrial Facilities

Wastes from industrial facilities may be grouped into five streams that are relatively small in volume but high in activity: medical isotope production wastes, highly activated wastes, tritium manufacturing wastes, sealed sources, and accelerator targets. In addition, there are two groups of industrial facilities that generate four volumetrically significant waste streams containing relatively low levels of radioactivity: (1) facilities using source and special nuclear materials (generating trash and other miscellaneous wastes), and (2) other facilities that use radioactive material and generate low specific activity wastes containing less than 3.5 Ci/m^3 (0.1 Ci/ft^3). Waste from these facilities is also divided into trash and miscellaneous other wastes.

Medical isotope production wastes result from production of fission isotopes for medical use through irradiation of very highly enriched uranium. Although some institutions using large quantities of radioactive materials in research and medical applications produce their own radioactive isotopes, most of these radionuclides are produced by industrial radioisotope generators. The wastes generated consist of paper, plastic, glass, metal, and aqueous solutions of inorganic salts. The aqueous solutions are solidified in small metal containers and packed with low-specific-activity trash in common containers (55-gallon drums) for shipment.

The high-specific-activity industrial waste stream is a generic stream that includes miscellaneous wastes of relatively high activity, which is arbitrarily defined as an activity that exceeds 3.5 Ci/m^3 or 0.1 Ci/ft^3. High-specific-activity industrial wastes are expected to include activated metal and equipment produced by accelerators, activated metal and equipment from research reactors and subcritical assemblies, and activated metal from neutron generators.

Tritium is the most widely used of all radioisotopes. In addition to applications in biological research and medicine, it is used in a wide variety of products, most commonly in illuminators. Although tritium is a naturally occurring isotope, artificial production of tritium is more economical than enrichment of natural tritium. The waste generated during manufacturing of tritium products is assumed to consist of lithium fluoride, trash, plastic, glass, and a small quantity of metal. It is also assumed to contain waste chemicals that are generated by conversion of tritium gas to tritiated water and by incorporation of tritium into chemical compounds.

Sealed sources containing radioactive materials other than source and special nuclear materials are encapsulated to prevent leakage of the radioactive material. Low-activity sealed sources and foils are also used as calibration and reference standards for many types of radiation detectors. High-activity sealed sources are used in neutron generators as both generators and targets, and in medical and industrial irradiators. Other examples of industrial sources include density gagues, well logging sources, radiography sources, x-ray fluorescence tubes, static eliminators, and so forth. This waste stream includes industrial sealed sources as well as sealed sources from institutions.

Accelerator targets are used to produce radionuclides by direct bombardment with charged particle beams or by indirect reactions of the target fragments with other materials. Accelerator targets are also used to study nuclear reactions and to produce and study the properties of various subatomic particles. Targets from institutional sources are also included in this waste stream. Spent targets are commonly made of titanium foils containing absorbed tritium.

Source and special nuclear material wastes are produced outside the nuclear fuel cycle by industries that process and fabricate depleted uranium and manufacture chemicals or products containing uranium. Although little information is available, it appears that most of the waste is generated through processing of depleted uranium. These wastes are distinguished from other non-fuel cycle wastes by the almost complete absence of radionuclides other than those included in the definitions of source and special nuclear materials. They are considered as two streams: trash and other miscellaneous wastes.

The last group of waste streams are low specific activity wastes containing less than 3.5 Ci/m^3 or (0.1 Ci/ft^3). The major contributors to this group of streams are the industrial equivalents of institutions. Such waste is generated by pharmaceutical companies, independent testing laboratories, and analytical laboratories. The characteristics of low specific activity industrial wastes are expected to resemble those of institutional wastes; however, since the limited data available is insufficient to justify separate waste streams for scintillation fluids, adsorbed liquids, and biowastes, they are also considered as two streams: trash and other miscellaneous wastes.

3. WASTE CHARACTERISTICS

This section presents information on the volumes and radiological characteristics of the waste streams projected to be generated to the year 2000. The waste streams considered are those discussed in the previous chapter. Information on the packaging characteristics of these waste streams can be found in Section 4.

The following symbols will be used for the major waste generators for the remaining discussion in this appendix:

Symbol	Facility
P	PWRs
B	BWRs
L	LWRs
F	Fuel Fabrication Facilities
U	UF_6 Conversion Plants
I	Institutional Facilities
N	Industrial Facilities

The waste streams outlined in the previous section will be discussed in four major groups: LWR process wastes, trash, low specific activity wastes, and special wastes. These groups and the waste streams that make up each group are presented in Table D.5.

These streams are combined into these four groups based upon similarities in their macroscopic characteristics. For example, LWR process wastes are usually wet wastes that have comparatively higher specific activities than either the trash group or the low specific activity group. The trash group is self-evident and contains most of the combustible LLW generated. The low specific activity waste group includes all the streams containing comparatively small activities that are not included in the LWR process waste group or the trash group. The "special" waste group contains streams that contain relatively high concentrations of radioactivity and are small in volume when compared with the other three groups. This grouping of waste streams simplifies the application of generic waste treatment technologies and disposal procedures to general groups, thereby increasing the flexibility of the data base.

As shown in Table D.5, six of the waste streams have been separated into two components, and the additional six streams resulting from this separation have been denoted by a plus sign after the waste generator symbol (I or N) instead of the usual minus sign. These streams are industrial SSTRASH, industrial LOTRASH, institutional COTRASH, institutional LIQSCLV, institutional ABSLIQD, and institutional BIOWAST. The reason for this separation is to identify the volumes of waste from generators that can more easily implement their own waste treatment processes (e.g., comparatively large facilities, denoted by a minus sign), and the waste from those generators that cannot do the same (e.g., comparatively small facilities, denoted by a plus sign).

The waste streams that are not considered in detail in this appendix (e.g., decommissioning and reprocessing wastes) can be classified as a fifth group of wastes. These streams are briefly discussed in Section 6.

Table D.5 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

3.1 Volume Projections

This section discusses NRC staff estimates of waste volumes expected to be routinely generated on a regional basis and disposed through the year 2000, considering current waste generation rates as well as projected waste generation growth rates. The regions used in the projections correspond to the five NRC regions as shown in Figure D.1. In developing the projections, nuclear fuel cycle waste volumes were assumed to be proportional to the nuclear electrical generation capacity. Nonfuel cycle waste volumes were assumed to grow at a linear rate based upon a least squares fit of existing data on individual waste streams.

3.1.1 Fuel Cycle Wastes

Projections of nuclear electrical generation capacity were principally based upon a review of information on nuclear power stations currently built and operable, under construction, planned or on order (Refs. 9-12). Projections made by NRC licensing staff regarding start-up times were also used to supplement the basic information (Ref. 13). Based upon this data, two scenarios were developed for central station nuclear power plant construction--a "low" scenario and a "high" scenario. The low scenario assumes that construction continues on power reactors that are already under construction but that any additional construction of power reactors essentially ceases until at least the late 1980s. The high scenario assumes that construction commences on a number of additional plants, including those units planned as of the beginning of 1980, as well as plants for which construction has been deferred indefinitely. The projected regional capacity by the year 2000 for both scenarios is presented in Table D.6. Also shown, in parentheses, is the number of LWRs projected to be operating. As shown, the total U.S. capacity by the year 2000 is projected to range between 146,000 and 169,000 MW(e).

Table D.6 Projected LWR Capacity by the Year 2000, in MW(e)

	Low Scenario*		High Scenario*	
Region	PWR	BWR	PWR	BWR
1	17,691(20)	12,216(14)	22,411(24)	14,516(16)
2	38,958(39)	17,239(16)	44,058(43)	18,173(17)
3	18,785(21)	13,550(18)	22,295(24)	13,550(18)
4	8,901(8)	3,078(3)	8,091(8)	4,228(4)
5	15,580(14)	1,165 (2)	18,100(17)	3,719(4)
	97,805(102)	47,248(53)	114,955(116)	54,186(59)
	146,333(155)		169,141(175)	

*Note: Since the original projections were made, construction of a 907 MW(e) PWR (North Anna Unit 4 in Region II) has been definitely cancelled. Startup of another facility--Allens Creek, a 1150 MW(e) BWR located in Region IV--has been delayed by two years.

It is believed that the projections in Table D.6 effectively provide a lower and upper bound of the generating capacity that would be available by the year 2000. As of June 30, 1979, 27 units were listed as "planned," representing a capacity 32,726 MW(e) (Ref. 9). Of these 27 units, 19 had definite projected start-up dates. Only one year later, 11 of these original 27 units had been canceled (13,202 MW(e)). Out of the remaining 16 units, three have been deferred indefinitely; only five (5,910 MW(e)) are listed as having definite start-up dates, (Ref. 12). Of these five units, applications for construction have been submitted to NRC for only three of them (Allens Creek Unit 1, Pebble Springs Units 1 and 2), and no construction permits for these three units have to date been issued. It would not be surprising, therefore, if no more than half of the planned units discussed above were actually constructed by the year 2000. The slowdown in construction of and planning for new nuclear generating facilities is probably due to a number of reasons--e.g., a lessening in the demand for additional electrical generating capacity, the slowdown in the economy coupled with the large costs of constructing a nuclear power station, and public concern over the safety of nuclear power.

It is possible that interest in building new nuclear generating units may increase in the future. However, it takes a number of years to construct and license a nuclear power station. Assuming that it requires a conservative minimum of 12 years from the time of initial application to start-up of a single unit, an application would have to be tendered by no later than 1988 in order to be operating by the year 2000.

Therefore, only those planned units for which an application has already been received by NRC or received within the next few years could realistically contribute to the waste generated by LWRs by the year 2000. Finally, any delays in the start-up times for units currently planned or under construction would act to further reduce the amount of waste produced by LWRs by the year 2000.

A summary of volumes and gross specific activities of LWR waste streams projected to be generated on a "per MW(e)-yr" basis is presented as Table D.7. The data used to construct this table were principally obtained from ONWI-20 (Ref. 6), and are averages based upon NRC staff estimates of the use of condensate polishing systems (CPS) as part of water treatment in LWRs. For the table, 60% of BWRs were assumed to use deep-bed CPS and 40% precoat CPS; about half of PWRs were assumed to use CPS and about half were not. The volumes shown, with the exception of cartridge filters, are for "untreated" wastes. Concentrated liquids (evaporator bottoms) are reported as generated prior to solidification. Resins and filter sludges are reported as dewatered, and the trash streams are reported as generated prior to such processing options as incineration or compaction. The volumes for cartridge filters are given as packaged for shipment.

Projected volumes of activated nonfuel core components (e.g., poison curtains, flow channels, and control rods) are difficult to characterize. LWR core components are replaced on an infrequent basis, and frequently, small components are shipped to disposal facilities by placing the components in the middle of

Table D.7 Summary of Principal LWR Waste Streams

Waste Type	Volumes (m^3/MW(e)-yr) BWR	PWR	Activity (Ci/MW(e)-yr) BWR	PWR
Resins	0.081	0.081	1.14	0.40
Concentrated Liquids	0.223	0.124	0.20	0.11
Filter Sludge	0.179	.002	1.40	0.006
Cartridge Filters	0	.011	0	0.12
Trash				
Total	0.326	0.326	0.402	0.063
Compactible	0.221	0.215	0.005	0.005
Noncompactible	0.105	0.111	0.397	0.058
Totals:	0.808	0.478	3.29	0.699

a container of otherwise low activity material such as trash. For this appendix, LWRs were projected to generate about 1 m^3 (35 ft^3) of core component waste per GW(e)-yr at a gross specific activity of about 113 Ci/m^3 (4000 Ci/ft^3). This projection was based upon a review of disposal facility radioactive shipment records (Ref. 14). NRC staff believe that these projections are likely to be conservative, as the noncompactible trash stream discussed above probably already contains activated core components (i.e., core components are to a certain extent counted twice in this appendix).

Other waste streams that are difficult to project will be generated by periodic decontamination of the primary coolant systems of LWRs. The purpose of such full-scale primary decontamination operations is to reduce plant personnel exposure by removing crud accumulated on surfaces in contact with the primary coolant. Although full-scale primary coolant decontamination operations have not been routinely performed in the past, NRC has fairly recently (October 1980) published an environmental statement regarding such an operation being performed at the Dresden Unit 1 nuclear power station. Dresden 1 is a 200 MW(e) dual-cycle BWR which over its 20 year operating life, has built up a thin layer of radioactive oxide deposits (principally Co-60) over the inner surfaces of pipes, valves, pumps, etc. In the decontamination process for Dresden Unit 1, a decontamination solution is circulated and flushed through the coolant system, which dissolves the crud deposits. The decontamination solution is then removed from the coolant system and processed through an evaporator. The evaporator bottoms are then solidified in vinylester (a synthetic polymer), which are then shipped offsite for disposal. Since the solidified waste will contain a large quantity of chelating agents, the waste will be disposed only at a disposal facility located in an arid environment and segregated from other waste by at least 3 meters of soil (Ref. 15).

Although the Dresden-1 decontamination operation can be considered in many respects a prototype of future primary coolant plants, it is still difficult to project future volumes and other characteristics of decontamination wastes. There may be a number of possible decontamination processes utilized--e.g., from dilute chemical processes on an annual basis to more concentrated processes at intervals of several years--and the waste streams generated may vary in kind (e.g., resins, solidified liquids) and in volume from operation to operation and plant to plant. Other plant-specific factors which would influence the volumes, radioactivity content, and other characteristics of the wastes generated would include the operating history of the plant (e.g., history of fuel failures), the design of the plant and liquid clean-up and processing systems, the chemistry of the primary coolant, and the length of time between decontamination operations. Institutional matters such as the policies of a specific utility could also be a consideration.

Notwithstanding this uncertainty, NRC staff believe that wastes generated from routine full-scale decontamination of reactor primary coolant systems should be represented in the low-level waste source data base. For this appendix, it is assumed that every operating LWR undergoes a full-scale primary coolant decontamination operation every 5 to 10 years using a dilute chemical decontamination process (Ref. 16). This results in BWR and PWR resin waste streams of approximately 95 and 47.5 m^3, respectively, per operation. This assumes that the volumes of contaminated liquid generated per operation are 760 m^3 and 380 m^3, respectively, and assumes that approximately 0.125 m^3 of dewatered resin is required to process 1 m^3 of contaminated liquid. Contained in these resins will be significant quantities of chelating agents and other decontamination chemicals.

Projections for fuel fabrication wastes were obtained from ONWI-20 (Ref. 6), and are estimated to be about 122 m^3 per GW(e) of installed LWR capacity. The estimated average activity of these wastes is 8.5 E-4 Ci/m^3. Fuel fabrication process wastes were estimated to be about 15% of this total volume. Of the remaining volume, approximately 85% is estimated to be combustible and 15% noncombustible. Uranium conversion waste projections were obtained from References 2 and 28, and supplemented by data obtained from disposal facility records (Ref. 5). The estimated volume and activity are 9.6 m^3/GW(e) and 3.8 E-4 Ci/m^3, respectively.

3.1.2 Nonfuel-Cycle Wastes

Projections of total activities, volumes, and regional dependency through the year 2000 for nonfuel-cycle wastes were developed from a number of sources. Included are medical and bioresearch wastes, wastes from production of medical isotopes, industrial high-activity wastes, industrial tritium wastes, and industrial low-activity wastes. Starting with 1980 waste generation rates, nonfuel-cycle wastes volumes and activities are assumed to increase at linear rates calculated by assuming least-squares fits to existing data.

Projections of medical and bioresearch wastes, including dry solids, scintillation vials, absorbed liquids, biological wastes (animal carcasses, tissues, etc.), and accelerator targets, were derived principally using NUREG/CR-0028 (Ref. 7) and its follow-up report NUREG/CR-1137 (Ref. 8). Based upon this data, total volumes of medical and bioresearch wastes in 1980 were estimated to be 19,120 m^3, while total activity was estimated to be 4412 Ci. Total volumes and activities are estimated to increase at a rate of 1280 m^3 and 295 Ci per year. Dry solids constitute 42% of the total volume, scintillation vials 39%, absorbed liquids 10%, biological wastes 9% and accelerator targets 0.2%. Fifty-six percent of the activity is projected to be contained in accelerator targets. The regional distribution of medical and bioresearch wastes are assumed to correspond to the institutional population surveyed (Ref. 8)--i.e., Region 1: 31%; Region 2: 22%; Region 3: 27%; Region 4: 8%; and Region 5: 12%.

A summary of estimated current and projected future volumes and activities in industrial wastes is provided as Table D.8. Compared to institutional wastes (medical and bioresearch wastes) and fuel cycle wastes, less information is available for industrial waste streams. Consequently, industrial waste streams are more difficult to characterize.

Table D.8 Estimated Current and Projected Future Volumes and Activities of Industrial Waste Streams

Waste Streams	Volumes (m^3) Current	Volumes (m^3) Added per year	Gross Specific Activity (Ci/m^3)
Medical isotope production waste:			
	192.6	13.8	573
Industrial high-activity waste (> 3.5 Ci/m^3):			
o Sealed sources	5.3	.36	5700
o Other high activity waste	74.4	5.0	210
Industrial low-activity waste (< 3.5 Ci/m^3):			
o Source and special nuclear material	12,050	807	0.03
o Other low activity waste	4,608	309	0.03
Industrial tritium waste:			
	99.3	6.7	2326

Estimates of medical isotope production waste were based upon consideration of disposal facility radioactive shipment records (Ref. 14). Wastes from this source are generated in Region 1.

Industrial high and low activity wastes were somewhat arbitrarily divided at a concentration level of 3.5 Ci/m^3 (0.1 Ci/ft^3). Estimates of industrial high and low activity wastes were based upon consideration of disposal facility radioactive shipment records (Ref. 14). The regional distribution of these wastes was assumed to be the same as that of the medical and bioresearch waste streams.

Industrial tritium manufacturing waste volumes were estimated from a number of sources as described in Reference 14. For this appendix, three quarters of the tritium waste was assumed to be generated in Region 1, the region with the major user of tritium. The remainder was assumed to be divided equally among the other 4 regions.

3.1.3 Volume Projections to the Year 2000

The total untreated waste volumes projected to be generated to the year 2000 are summarized in Table D.9. In generating this table, the waste volumes projected to be generated in Regions 4 and 5 were found to be significantly less than the other three regions and so were combined into one region. The following assumptions have been used in estimating these waste stream volumes:

- o The P-IXRESIN, B-IXRESIN, P-FSLUDGE, and B-FSLUDGE waste stream volumes are assumed to be "dewatered" volumes.
- o The P-CONCLIQ and B-CONCLIQ waste streams are assumed to be concentrated to the levels currently practiced in the industry; the solids content (by weight) of these streams range from 2% to 20% in PWRs and 7 to 50% for BWRs with an average of about 11% for PWRs and 25% for BWRs (Ref. 6).
- o The P-FCARTRG waste stream is that of the packaged waste.
- o None of the LWR trash waste streams are assumed to be treated by compaction or by incineration.
- o The I-LIQSCVL, I+LIQSCVL, I-ABSLIQD, and I+ABSLIQD waste stream volumes represent volumes prior to packaging. Estimated shipping volumes include two volume parts absorber to one volume part waste (Ref. 8).
- o For calculational convenience, the fraction of the liquid scintillation vial fluid volume currently estimated to be shipped as part of the ABSLIQD waste stream (about 50% by volume) has been included in the LIQSCVL waste streams. The volume of the LIQSCVL stream represents the volume of the vials containing the scintillation fluid; the actual fluid volume is assumed to be one-half of the vial volume (Ref. 17).

Table D.9 "Untreated" Waste Volumes Projected to be Generated to the Year 2000 per Region (m^3)

	REGION 1		REGION 2		REGION 3		REGION 4	
	VOL	%	VOL	%	VOL	%	VOL	%
P-IXRESIN	6.93E+03	.79	1.30E+04	1.34	6.59E+03	1.00	8.14E+03	1.25
P-CONCLIQ	4.87E+04	5.54	9.12E+04	9.45	4.63E+04	7.06	5.72E+04	8.79
P-FSLUDGE	8.56E+02	.10	1.60E+03	.17	8.14E+02	.12	1.01E+03	.15
P-FCARTRG	4.35E+03	.50	8.16E+03	.84	4.14E+03	.63	5.12E+03	.79
B-IXRESIN	2.10E+04	2.39	2.51E+04	2.60	2.05E+04	3.12	9.67E+03	1.49
B-CONCLIQ	5.79E+04	6.59	6.93E+04	7.17	5.64E+04	8.60	2.67E+04	4.10
B-FSLUDGE	4.65E+04	5.30	5.57E+04	5.77	4.54E+04	6.92	2.14E+04	3.30
P-COTRASH	8.49E+04	9.66	1.59E+05	16.47	8.07E+04	12.31	9.97E+04	15.33
P-NCTRASH	4.36E+04	4.96	8.16E+04	8.45	4.14E+04	6.32	5.12E+04	7.87
B-COTRASH	5.74E+04	6.54	6.87E+04	7.12	5.60E+04	8.54	2.65E+04	4.07
B-NCTRASH	2.72E+04	3.10	3.26E+04	3.38	2.66E+04	4.05	1.26E+04	1.93
F-COTRASH	4.72E+04	5.37	1.18E+05	12.22	0.	0.	7.08E+04	10.88
F-NCTRASH	8.34E+03	.95	2.09E+04	2.16	0.	0.	1.25E+04	1.92
I-COTRASH	4.36E+04	4.97	3.10E+04	3.21	3.80E+04	5.79	2.81E+04	4.33
I+COTRASH	4.36E+04	4.97	3.10E+04	3.21	3.80E+04	5.79	2.81E+04	4.33
N-SSTRASH	8.98E+04	10.22	1.80E+04	1.86	3.59E+04	5.48	3.59E+04	5.52
N+SSTRASH	8.98E+04	10.22	1.80E+04	1.86	3.59E+04	5.48	3.59E+04	5.52
N-LOTRASH	1.52E+04	1.73	1.01E+04	1.05	1.52E+04	2.32	1.01E+04	1.56
N+LOTRASH	1.52E+04	1.73	1.01E+04	1.05	1.52E+04	2.32	1.01E+04	1.56
F-PROCESS	1.56E+04	1.78	3.91E+04	4.05	0.	0.	2.34E+04	3.61
U-PROCESS	0.	0.	0.	0.	1.41E+04	2.14	1.41E+04	2.16
I-LQSCNVL	1.52E+04	1.73	1.08E+04	1.12	1.33E+04	2.02	9.83E+03	1.51
I+LQSCNVL	1.52E+04	1.73	1.08E+04	1.12	1.33E+04	2.02	9.83E+03	1.51
I-ABSLIQD	1.73E+03	.20	1.23E+03	.13	1.51E+03	.23	1.12E+03	.17
I+ABSLIQD	1.73E+03	.20	1.23E+03	.13	1.51E03	.23	1.12E+03	.17
I-BIOWAST	4.87E+03	.55	3.46E+03	.36	4.24E+03	.65	3.14E+03	.48
I+BIOWAST	4.87E+03	.55	3.46E+03	.36	4.24E+03	.65	3.14E+03	.48
N-SSWASTE	3.17E+04	3.61	6.34E+03	.66	1.27E+04	1.93	1.27E+04	1.95
N-LOWASTE	1.81E+04	2.06	1.21E+04	1.25	1.81E+04	2.76	1.21E+04	1.85
L-NFRCOMP	6.48E+02	.07	1.04E+03	.11	6.22E+02	.09	5.77E+02	.09
L-DECONRS	7.35E+03	.84	1.22E+04	1.27	8.05E+03	1.23	7.35E+03	1.13
N-ISOPROD	5.20E+03	.59	0.	0.	0.	0.	0.	0.
N-HIGHACT	8.09E+02	.09	5.74E+02	.06	7.04E+02	.11	5.22E+02	.08
N-TRITIUM	2.65E+03	.30	2.09E+02	.02	2.09E+02	.03	4.18E+02	.06
N-SOURCES	5.78E+01	.01	4.10E+01	.00	5.04E+01	.01	3.73E+01	.01
N-TARGETS	4.16E+02	.05	2.95E+02	.03	3.62E+02	.06	2.68E+02	.04
TOTAL	8.78E+05		9.66E+05		6.56E+05		6.50E+05	

- The I-BIOWAST and I+BIOWAST stream volumes represent volumes prior to packaging for shipment. Estimated shipping volumes are 0.92 volume parts lime and/or absorbent material to one volume part waste (Ref. 29).

- The N-SSWASTE and L-LOWASTE waste stream volumes represent volumes shipped for disposal.

- The L-DECONRS stream volume is composed of "dewatered" ion exchange resins that are projected to be generated during postulated future routine LWR decontamination activities.

- The N-ISOPROD stream volume represents the waste volume as packaged for shipment. Each package is assumed to contain a small volume of liquid solidified in cement within a metal canister which is then packaged with trash in a 55-gallon drum.

- All other industrial waste stream volumes are assumed to be as shipped for disposal.

3.2 Radionuclide Concentrations

This section discusses the available information and the procedures used in estimating the radioactive concentrations of the waste streams projected to be generated between the years 1980 and 2000 for the untreated waste streams presented in Table D.5. Additional information can be found in Reference 5.

Low-level radioactive wastes contain a large number of naturally occurring and man-made radionuclides at the time they are produced. Many of these radionuclides are very short lived and are not a long-term radiological concern. Other isotopes with half lives up to a few years may reach the disposal site but decay to insignificant levels shortly thereafter.

Two criteria were used in selecting the radionuclides considered: (1) its half life must be more than a few years (five years was used as a general guide) and (2) it must be present in comparatively significant quantities in LLW. The biological toxicities of radionuclides were also considered. Radionuclides that will be considered in this appendix are presented in Table D.10.

The sources of data on the concentrations of the radionuclides listed in Table D.10 include:

- computer-assisted calculations (Refs. 18-20);
- surveys of waste generators (Refs. 6-8, 21);
- disposal site records (Refs. 5, 14); and
- radiochemical analyses (Refs. 24-28).

Data from these sources suffer several limitations. Nonetheless, NRC staff believe that the data is generally conservative and is sufficiently accurate to make decisions regarding performance objectives and technical criteria for LLW management and disposal.

Table D.10 Radionuclides Considered in Waste Streams

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-135	3.0×10^6	Fission; daughter Xe-135
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-240	6,580	Multiple n-capture
Pu-241	13.2	Multiple n-capture
Pu-242	2.79×10^5	Muitiple 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

For example, computer calculations, which are often employed in predicting the radioactivity of wastes generated by "burn-up" of nuclear fuels, are based on fuel compositions, consumption (burn-up) rates, and elemental compositions of neutron-irradiated materials. While such calculations can be reasonably accurate, they are not as well-suited to determining the range of radioactivity concentrations produced by variations of operating conditions at a given reactor nor to representing wastes generated by typical reactors for purposes of analyzing disposal impacts.

A common limitation of obtaining concentrations of individual radionuclides obtained in surveys and from disposal facility radioactive shipment records is that they are frequently derived by application of predetermined distributions to the total gross beta/gamma activities obtained during screening measurements made at the time the wastes are shipped for disposal. These measurements are usually made with relatively unsophisticated instruments and are generally conservative since they include the activities contributed by very short-lived radionuclides.

The concentrations of several of the radionuclides listed in Table D-10 have been measured in samples of LWR process wastes (Refs. 22-25). These samples include those taken from smaller and older reactors, as well as those taken from reactors with a history of fuel failure problems, and are thus believed to be conservative with respect to future LWR wastes. Since radioactive concentrations vary with a reactor's operational cycle (fluctuation in power level, shutdowns and refueling), a larger number of samples would be useful to more accurately determine average concentrations.

Furthermore, the sensitivities (minimum detection limits) of the analytical procedures for the radionuclides of interest are not identical but vary with the type and energy of the radiation and with the presence of chemical and radiochemical interferences.

An additional point to be considered in using currently available radionuclide concentrations in the various waste streams is that the processes generating these wastes and the controls on these processes are likely to change. It is probable that the future distribution of radioisotopes will be away from fission products (e.g., Cs, Sr) and toward corrosion products due to improved fuel cladding properties.

The approach developed to estimate radionuclide concentrations in LLW to the year 2000 seeks to minimize the limitations of the available data through use of averaging procedures that reflect the quantity and quality of the available data. A discussion of the methodologies used to arrive at these estimates is presented in the following sections. The details of the calculations as well as a complete data compilation are contained in NUREG/CR-1759 (Ref. 5). The estimated radioactive concentrations for the untreated waste streams given in Table D.5 are presented in Tables D.11 through D.14.

3.2.1 Central Station Nuclear Power Plants

The LWR process waste streams (all waste streams except trash, core components, and decontamination wastes) are the best characterized of all the LLW streams.

Table D.11 Group 1 - Untreated Isotopic Concentrations (Ci/m³)

TOTAL	P-IXRESIN 3.36E-02	P-CONCLIQ 1.09E-01	P-FSLUDGE 1.06E+00	P-FCARTRG 1.86+00	B-IXRESIN 4.63E+00	B-CONCLIQ 2.77E-01	B-FSLUDGE 5.24E+00
H-3	2.66E-03	3.45E-03	2.59E-03	1.15E-03	1.92E-02	6.24E-04	1.26E-02
C-14	9.74E-05	1.27E-04	9.55E-05	4.25E-05	1.19E-03	3.89E-05	7.78E-04
FE-55	2.34E-03	2.27E-02	3.10E-01	5.55E-01	9.48E-01	7.60E-02	1.44E+00
NI-59	2.79E-06	2.71E-05	3.71E-04	6.60E-04	9.80E-04	7.85E-05	1.49E-03
CO-60	4.53E-03	4.40E-02	6.00E-01	1.07E+00	1.59E+00	1.27E-01	2.41E+00
NI-63	8.61E-04	8.36E-03	1.14E-01	2.04E-01	2.15E-02	1.72E-03	3.25E-02
NB-94	8.84E-08	8.58E-07	1.17E-05	2.09E-05	3.09E-05	2.48E-06	4.70E-05
SR-90	1.94E-04	2.52E-04	1.89E-04	8.40E-05	3.64E-03	1.18E-03	2.37E-03
TC-99	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
I-129	2.44E-06	3.16E-06	2.37E-06	1.06E-06	2.04E-04	6.65E-06	1.33E-04
CS-135	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
CS-137	2.19E-02	2.85E-02	2.14E-02	9.54E-03	2.04E+00	6.65E-02	1.33E+00
U-235	4.71E-08	6.15E-08	1.46E-07	3.64E-07	5.33E-08	3.44E-08	3.32E-07
U-238	3.71E-07	4.84E-07	1.15E-06	2.87E-06	4.20E-07	2.71E-07	2.61E-06
NP-237	9.06E-12	1.18E-11	2.81E-11	7.02E-11	1.02E-11	6.61E-12	6.38E-11
PU-238	2.60E-05	5.12E-05	4.76E-05	2.51E-04	8.34E-05	1.99E-04	4.66E-04
PU-239/240	1.82E-05	3.31E-05	1.55E-04	3.80E-04	5.34E-05	9.43E-05	2.36E-04
PU-241	7.94E-04	1.44E-03	6.75E-03	1.66E-02	2.60E-03	4.60E-03	1.15E-02
PU-242	3.99E-08	7.25E-08	3.39E-07	8.34E-07	1.17E-07	2.06E-07	5.18E-07
AM-241	1.87E-05	2.99E-05	2.64E-04	1.64E-04	2.32E-05	1.20E-04	1.56E-04
AM-243	1.26E-06	2.02E-06	1.78E-05	1.10E-05	1.57E-06	8.10E-06	1.05E-05
CM-243	9.92E-09	1.17E-08	3.10E-07	1.93E-07	2.70E-08	2.59E-07	2.97E-07
CM-244	1.38E-05	1.92E-05	1.77E-04	1.10E-04	1.82E-05	2.05E-04	2.24E-04

Table D.12 - Group 2 Untreated Isotopic Concentrations (Ci/m³)

TOTAL	P-COTRASH 2.28E-02	P-NCTRASH 5.25E-01	B-COTRASH 2.35E-02	B-NCTRASH 3.79E+00	F-COTRASH 5.58E-06	F-NCTRASH 5.33E-06	I-COTRASH 1.13E-01	N-SSTRASH 1.12E-05	N-LOTRASH 3.53E-02
H-3	3.04E-04	6.99E-03	6.75E-05	1.09E-02	0.	0.	9.13E-02	0.	2.85E-02
C-14	1.12E-05	2.57E-04	4.17E-06	6.73E-04	0.	0.	5.26E-03	0.	1.64E-03
FE-55	5.97E-03	1.37E-01	6.01E-03	9.69E-01	0.	0.	0.	0.	0.
NI-59	7.11E-06	1.64E-04	6.21E-06	1.00E-03	0.	0.	0.	0.	0.
CO-60	1.15E-02	2.65E-01	1.01E-02	1.62E+00	0.	0.	1.04E-02	0.	3.25E-03
NI-63	2.19E-03	5.05E-02	1.36E-04	2.19E-02	0.	0.	0.	0.	0.
NB-94	2.25E-07	5.18E-06	1.96E-07	3.16E-05	0.	0.	0.	0.	0.
SR-90	2.22E-05	5.11E-04	1.27E-05	2.05E-03	0.	0.	1.45E-03	0.	4.53E-04
TC-99	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	3.39E-09	0.	1.06E-09
I-129	2.78E-07	6.41E-06	7.14E-07	1.15E-04	0.	0.	0.	0.	0.
CS-135	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	0.	0.	0.
CS-137	2.51E-03	5.78E-02	7.14E-03	1.15E+00	0.	0.	4.56E-03	0.	1.42E-03
U-235	7.89E-09	1.82E-07	1.22E-09	1.97E-07	1.18E-06	1.13E-06	0.	2.36E-06	0.
U-238	6.22E-08	1.43E-06	9.60E-09	1.55E-06	4.40E-06	4.20E-06	0.	8.80E-06	0.
NP-237	1.52E-12	3.49E-11	2.35E-13	3.78E-11	0.	0.	0.	0.	0.
PU-238	5.97E-06	1.38E-04	2.30E-06	3.71E-04	0.	0.	0.	0.	0.
PU-239/240	5.53E-06	1.27E-04	1.16E-06	1.86E-04	0.	0.	0.	0.	0.
PU-241	2.41E-04	5.55E-03	5.63E-05	9.08E-03	0.	0.	0.	0.	0.
PU-242	1.21E-08	2.79E-07	2.53E-09	4.08E-07	0.	0.	0.	0.	0.
AM-241	3.96E-06	9.12E-05	9.67E-07	1.56E-04	0.	0.	4.82E-06	0.	1.51E-06
AM-243	2.67E-07	6.15E-06	6.52E-08	1.05E-05	0.	0.	0.	0.	0.
CM-243	2.74E-09	6.30E-08	1.93E-09	3.12E-07	0.	0.	0.	0.	0.
CM-244	2.61E-06	6.00E-05	1.49E-06	2.41E-04	0.	0.	0.	0.	0.

Table D.13 Group 3 - Untreated Isotopic Concentrations (Ci/m³)

	F-PROCESS	U-PROCESS	I-LQSCNVL	I-ABSLIQD	I-BIOWAST	N-SSWASTE	N-LOWASTE
TOTAL	1.08E-04	3.80E-04	9.60E-03	1.99E-01	2.06E-01	2.17E-04	2.11E-02
H-3	0.	0.	5.01E-03	1.42E-01	1.75E-01	0.	1.63E-02
C-14	0.	0.	2.51E-04	8.16E-03	1.01E-02	0.	9.36E-04
FE-55	0.	0.	0.	0.	0.	0.	0.
NI-59	0.	0.	0.	0.	0.	0.	0.
CO-60	0.	0.	0.	3.12E-02	3.99E-03	0.	1.47E-03
NI-63	0.	0.	0.	0.	0.	0.	0.
NB-94	0.	0.	0.	0.	0.	0.	0.
SR-90	0.	0.	4.34E-03	4.34E-03	8.33E-03	0.	1.31E-03
TC-99	0.	0.	0.	1.02E-08	6.51E-09	0.	7.76E-10
I-129	0.	0.	0.	0.	0.	0.	0.
Cs-135	0.	0.	0.	0.	0.	0.	0.
CS-137	0.	0.	0.	1.37E-02	8.76E-03	0.	1.04E-03
U-235	2.30E-05	1.65E-05	0.	0.	0.	4.60E-05	0.
U-238	8.54E-05	3.64E-04	0.	0.	0.	1.71E-04	0.
NP-237	0.	0.	0.	0.	0.	0.	0.
PU-238	0.	0.	0.	0.	0.	0.	0.
PU-239/240	0.	0.	0.	0.	0.	0.	0.
PU-241	0.	0.	0.	0.	0.	0.	0.
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	0.	0.	0.	0.	0.	0.	0.
AM-243	0.	0.	0.	0.	0.	0.	0.
CM-243	0.	0.	0.	0.	0.	0.	0.
CM-244	0.	0.	0.	0.	0.	0.	0.

Table D.14 Group 4 - Untreated Isotopic Concentrations (Ci/m^3)

TOTAL	L-NFRCOMP 4.04E+03	L-DECONRS 1.56E+02	N-ISOPROD 1.50E+01	N-HIGHACT 2.10E+02	N-TRITIUM 2.33E+03	N-SOURCES 5.76E+03	N-TARGETS 8.04E+01
H-3	0.	1.08E-02	4.20E-02	0.	2.33E+03	8.63E+02	8.04E+01
C-14	2.59E-01	5.13E-04	4.51E-05	1.32E-02	0.	5.76E+01	0.
FE-55	2.23E+03	4.05E+01	0.	1.15E+02	0.	0.	0.
NI-59	1.40E+00	4.49E-02	0.	6.56E-02	0.	0.	0.
CO-60	1.60E+03	7.28E+01	0.	8.48E+01	0.	1.73E+03	0.
NI-63	2.09E+02	3.69E+00	0.	1.06E+01	0.	2.30E+02	0.
NB-94	8.19E-03	1.42E-03	0.	4.47E-04	0.	0.	0.
SR-90	0.	4.28E-02	6.27E+00	0.	0.	1.15E+03	0.
TC-99	0.	1.20E-05	3.27E-04	0.	0.	0.	0.
I-129	0.	3.34E-05	2.72E-06	0.	0.	0.	0.
CS-135	0.	1.20E-05	3.27E-04	0.	0.	0.	0.
CS-137	0.	3.18E-01	8.73E+00	0.	0.	1.15E+03	0.
U-235	0.	6.84E-05	1.02E-05	0.	0.	0.	0.
U-238	0.	5.40E-04	3.81E-05	0.	0.	0.	0.
NP-237	0.	1.32E-08	5.33E-13	0.	0.	0.	0.
PU-238	0.	1.34E+00	1.97E-04	0.	0.	0.	0.
PU-239/240	0.	1.77E+00	5.55E-05	0.	0.	0.	0.
PU-241	0.	3.55E+01	7.10E-03	0.	0.	0.	0.
PU-242	0.	3.87E-03	9.57E-08	0.	0.	0.	0.
AM-241	0.	5.29E-03	1.10E-05	0.	0.	5.76E+02	0.
AM-243	0.	3.59E-04	1.25E-06	0.	0.	0.	0.
CM-243	0.	3.46E-04	1.65E-04	0.	0.	0.	0.
CM-244	0.	3.27E-03	2.88E-07	0.	0.	0.	0.

This situation allows the 23 radionuclides (Pu-239 and Pu-240 cannot be distinguished by radiochemical methods and are considered here as a single isotope) listed in Table D.10 to be divided into three groups: (1) radionuclides for which a representative set of data is available and for which the number of measurements are believed to be sufficient to allow averaging; (2) radionuclides for which a representative set of data is available but for which the number of measurements are believed to be insufficient to allow direct averaging; and (3) radionuclides that have not been measured or for which there is some concern regarding the representativeness of the existing data.

Radionuclides in the first group include Co-60, Cs-137, U-238, Pu-238, Pu-239/240, Am-241 and Cm-244. These radionuclides are hereafter referred to as the "basic" isotopes. (The comparatively short-lived isotope Cm-242 is also included as a basic isotope and used to estimate the concentrations of other curium isotopes in some waste streams as described below.) The estimated concentrations of these basic isotopes were calculated as the geometric means of the measured concentrations in each waste stream with the exception of Cm-243 and Cm-244 in PWR filter sludge (see below).

The geometric average is calculated as the (n)th root of the product of the (n) data points. The use of geometric means rather than arithmetic means allows representative estimates to be made from sets of data that contain a few concentrations that are several orders of magnitude greater than the majority in the set and that would dominate the average if arithmetic means were used.

The difference in results obtained from arithmetic and geometric means is readily illustrated by considering a set of data consisting of 20 values of 1 and one value of 1000. The arithmetic average of these 21 values is 48.6 and the geometric average is 1.39. The geometric average is clearly more representative of the typical value. Variations of this magnitude have been observed in radionuclide concentration of waste streams at several LWRs (Ref. 22-24). Geometric averages are therefore a compromise between the impracticality of investigating the conditions under which each sample was collected and the use of uncharacteristically high arithmetic means.

The second and third groups of radionuclides were "scaled" to the above list of basic radionuclides. The scaled radionuclides and the basic radionuclides are given in Table D.15.

The second group of radionuclides--those for which the number of measurements is considered to be insufficient to allow direct geometric averaging--consists of H-3, C-14, Fe-55, Ni-63, Sr-90, I-129, Pu-241, and Pu-242. The concentrations of these radionuclides were calculated by "scaling" to the concentration of an appropriate basic isotope. These radionuclides were paired on the basis of a common source and/or method of production. For example, activated corrosion products (Fe-55 and Ni-63) are scaled to Co-60, which is also an activated corrosion product; fission products Sr-90, I-129, and H-3 (H-3 is also produced by activation) are scaled to Cs-137, which is also a fission product; and Pu-241 and Pu-242 are scaled to Pu-239/240, the nuclides from which they originate through multiple neutron capture. Carbon-14 is rather difficult to categorize; it was scaled to Cs-137.

Table D.15 Basic and Scaled Radionuclides for LWR Process Waste Streams

Basic Isotope	Scaled Isotopes
Co-60	Fe-55, Ni-59, Ni-63, Nb-94
Cs-137	H-3, C-14, Sr-90 Tc-99, I-129, Cs-135
U-238	U-235, Np-237
Pu-238	--
Pu-239/24	Pu-241, Pu-242
Am-241	Am-243, Cm-242*
Cm-242	Cm-243, Cm-242*
Cm-244	--

*Only for the P-FSLUDGE waste stream.

Scaling was accomplished using data for samples that were analyzed for both the radionuclide to be scaled and the appropriate basic isotope. The ratio of the concentration of the radionuclide to be scaled to that of the basic isotope was calculated for each data pair. A "scaling factor" for each of the radionuclides in this second group was then calculated as the geometric average of each set of ratios. (The scaling factors were calculated by reactor type only (BWRs and PWRs), rather than by reactor type and by waste stream like the basic radionuclides.) The computed scaling factors were then applied to the geometric averages of basic radionuclides to obtain the estimated concentrations of the scaled radionuclides given in Table D.11. A special scaling factor was calculated by this procedure for Cm-242 in PWR filter sludge using Cm-242/Am-241 data pairs for PWR cartridge filters.

The third group of radionuclides consists of Ni-59, Nb-94, Tc-99, Cs-135, U-235, Np-237, Am-243, and Cm-243. For these radionuclides, concentrations obtained from computer calculations (Ref. 31), (Ni-59 and Nb-94) or from other information (Ref. 27), were ratioed to the mean concentrations of the basic isotopes to obtain scaling factors. In the case of U-235, an average enrichment of 2% was assumed, and was then used as described above to estimate concentrations from U-238 concentrations in each stream. (A 2% enrichment was assumed to account for burnup during reactor operation.)

The radioactive concentrations of BWR and PWR trash were estimated by assuming that the radioactivity of the trash is proportional to the activity of the BWR and PWR process waste streams, respectively. Accordingly, the estimated concentrations (Table D.12) and the as-generated volumes of LWR process wastes were used to calculate normalized isotopic distributions from the volume-weighted average concentration of each radionuclide in BWR and PWR process wastes. These distributions were then applied to the average gross activities estimated to be contained in PWR compactible and noncompactible trash (0.0228 Ci/m^3 and 0.525 Ci/m^3 and of BWR compactible and noncompactible trash, (0.0235 Ci/m^3 and 3.79 Ci/m^3) (Ref. 6, 14). The resultant concentrations, presented in Table D.12, are conservative since they are based on total activities that include the contributions of short-lived radionuclides.

The radionuclide concentrations of LWR nonfuel reactor components (L-NFRCOMP), are given in Table D.14 and were estimated by assuming that the total activity is due to neutron activation of steel components. A normalized distribution calculated from ORIGEN calculations of the radioactivity of highly activated metals (Ref. 31) was applied to a total estimated gross radioactivity of 4040 Ci/m^3 (Ref. 14).

Given the uncertainties involved with projecting characteristics of future LWR decontamination wastes, it is difficult to estimate radionuclide concentrations of these wastes. For the purposes of this appendix, however, the radionuclide concentrations of LWR decontamination wastes, given in Table D.14, were calculated from available data on radionuclide concentrations in crud deposits in LWR cooling systems (Refs. 22-24, 26). Scaling procedures similar to those used for LWR process wastes were used, although no differentiation was made between BWR and PWR wastes. The basic crud isotopes are Co-60, Cs-137, U-238, Pu-238, Pu-239/240, Am-241, Cm-242 and Cm-244. Sufficient data is available for Sr-90 and Pu-241 in LWR crud to allow calculations of scaling factors as geometric means of ratios as described for LWR process wastes. Results of the analysis of a single sample (Ref. 28) were used to scale Fe-55 and Ni-63 to Co-60. Scaling factors for the remaining radionuclides were calculated as geometric means of the corresponding scaling factors for BWR and PWR process wastes. After applying these scaling factors to the concentrations of the basic crud isotopes, the concentrations of all 23 radionuclides were normalized and applied to a total estimated activity (Ref. 5) of 156 Ci/m^3 to obtain the concentrations given in Table D.14.

Use of this procedure to estimate radionuclide concentrations in the L-DECONRS stream results in estimated transuranic concentrations in considerable excess of 10 nCi/gm. Thus, the L-DECONRS stream as postulated would not be acceptable for disposal at existing LLW disposal facilities. Use of crud scrapings to estimate concentrations is believed to be conservative and perhaps overly conservative, since data from the Dresden 1 decontamination operations indicates that the generated decontamination waste will have transuranic concentrations less than 10 nCi/gm (Ref. 15). Despite this, however, NRC staff believe that the low Dresden 1 transuranic concentrations may not be indicative of all future decontamination operations. As discussed in Section 3.1.1, the characteristics of future decontamination wastes are uncertain and may be a function of a number of plant-specific conditions. Some of these include the type and size of the reactor, the operating history of the plant, the design of the plant and liquid clean-up and processing systems, the chemistry of the primary coolant, the type of decontamination operation performed, and the length of time between decontamination operations. Thus, it would appear to be appropriate to determine radionuclide concentrations in future full-scale decontamination waste streams on a plant-specific basis.

For the purposes of this environmental impact statement, however, it is useful to use crud scraping data to estimate radionuclide concentrations in potential future LWR decontamination waste streams. Such concentrations are believed to be bounding and furthermore can be used to analyze disposal impacts from a relatively small volume of transuranic-contaminated waste.

3.2.2 Other Nuclear Fuel Cycle Facilities

These waste streams consist of process wastes and trash from uranium conversion and fuel fabrication plants. Little data is available on the radionuclide concentrations of these streams, although U-235 and U-238 were the only radionuclides identified as being included in these waste streams.

Radionuclide concentrations in fuel fabrication wastes were determined based on data obtained from radioactive waste shipment records (RSRs) of waste shipped to the Maxey Flats disposal facility. The masses of special nuclear material reported in the RSRs were used to calculate concentrations of U-235 in each waste stream. Concentrations of U-238 were then calculated by assuming that the uranium in these wastes contained 4% by weight U-235. The estimated concentration of fuel fabrication wastes are given in Tables D.12 and D.13.

The concentrations of U-235 and U-238 in uranium conversion process waste were calculated from data given in Reference 28. It was assumed that the uranium was unenriched (0.711 percent U-235 by weight). Estimated concentrations are given in Table D.13.

3.2.3 Institutional Facilities

The most complete set of data available for institutional waste volumes and radionuclides were obtained during surveys of these generators conducted by the University of Maryland. However, in the published form (Refs. 7, 8), the data is not suitable for estimating the radionuclide concentrations in each waste stream. For the purposes of this appendix (Ref. 5), the survey data was reformatted and additional analysis performed (Refs. 21, 29). The results of this analysis, presented in Table D.16, combined with the estimated volumes of each waste stream (Refs. 7, 8, 14), were used to estimate the radionuclide concentrations in institutional waste streams given in Tables D.12 and D.13. The methodology employed is briefly described below.

The data presented in Table D.16 was compiled for the survey data base by summing the total reported activity of each radionuclide shipped to disposal facilities, as well as the total volume of all wastes reported to contain each radionuclide. The form of the data did not allow these summations to be made for individual waste streams, but did allow determination of whether a

Table D.16 Radionuclide Distribution in Institutional Wastes in 1977

Nuclide	Waste Fraction* (ft³)	Dry Solids	Liquid Scint. Vials	Absorbed Liquids	Biological Wastes	Total Activity Shipped (mCi)
H-3	159,697	X	X	X	X	236,151
C-14	158,060	X	X	X	X	13,488
Na-22	96,539	X		X	X	207
P-32	148,684	X	X	X	X	24,729
P-33	15,020	X	X	X	X	18
S-35	140,729	X	X	X	X	12,649
Cl-36	45,974	X	X	X	X	14
Ca-45	135,238	X	X	X	X	2,041
Sc-46	26,962	X		X	X	128
Cr-51	146,634	X	X	X	X	9,918
Mn-54	14,903	X		X	X	8
Fe-59	37,958	X		X	X	268
Co-57	37,600	X		X	X	212
Co-60	22,979	X		X	X	3,341
Ga-67	34,730	X		X	X	2,319
Se-75	79,046	X	X	X	X	948
Rb-86	64,239	X	X	X	X	226
Sr-85	42,931	X		X	X	309
Sr-90	13,997	X	X	X	X	573
Nb-95	10,976	X		X	X	136
Mo-99	13,674	X				15,080
Tc-99m	38,348	X		X	X	19,903
In-111	15,175	X		X	X	179
Sn-113	15,175	X		X	X	194
I-125	148,442	X	X	X	X	47,882
I-131	69,693	X		X		6,620
Xe-133	6,234	X				1,356
Cs-137	15,086	X		X	X	1,101
Ce-141	32,856	X		X	X	175
Yb-169	8,490	X		X	X	315
Tl-201	15,667	X		X	X	565
Others	116,895	X	X	X	X	3,760

*Total volume of shipped waste reported to contain a given isotope. Total volume of shipped waste was 185,160 ft³.

Source: Reference 21.

radionuclide was present in a given stream. (In Table D.16, an "X" indicates that an isotope was reported in the stream indicated.) The total activity of each radionuclide was then divided by the total volume of waste reported to contain that radionuclide to obtain initial radionuclide concentrations.

Radionuclide concentrations in each institutional waste stream were derived from the initial concentrations by consideration of: the as-shipped volume of the waste stream relative to the total volume of all four streams (42.3% trash, 38.5% liquid scintillation vials, 10% absorbed liquids and 9% biowaste) (Ref. 14); the presence or absence of a radionuclide in the stream; and the fraction of the as-shipped volume which consists of radioactive waste. The following assumptions were then applied.

- One-half the volume of liquid scintillation vials is occupied by scintillation fluids; one-half the volume of absorbed liquids is scintillation fluids and one-half is aqueous liquids (Ref. 7).
- The tritium and C-14 activities of liquid scintillation fluids are 10 nCi/cm^3 and 5 nCi/cm^3, respectively (Refs. 7, 8).
- All Mo-99 and Tc-99m have decayed to Tc-99 prior to shipment.
- The activity of Co-60 in biowaste is one-fifth its activity in the other waste streams (Ref. 29).
- Institutions shipped 6230 m^3 of trash containing 30 mCi of Am-241 (Ref. 29).

The radionuclide concentrations in institutional wastes estimated by this procedure are given in Tables D.12 and D.13.

3.2.4 Industrial Facilities

The radionuclide concentrations of industrial wastes were estimated based upon a number of information sources available to NRC (Ref. 14). Radionuclide concentrations are presented in Tables D.12, D.13, and D.14. The details of the calculations can be found in Reference 5.

Medical isotope production (N-ISOPROD) wastes, which are assumed to consist of trash and solidified aqueous liquids, are considered as a single waste stream (see Section 2.5). The radionuclide concentrations of the N-ISOPROD stream are not well characterized. Data obtained from available disposal facility RSRs for the radionuclides of interest are limited to the combined Sr-90/Cs-137 radioactivity, grams of U-235, and waste volumes. In order to estimate the concentrations of the remaining radionuclides, the waste density was assumed to be 1.6 g/cm^3 and the total activity of alpha-emitting transuranic radionuclides was assumed to be 1 nCi/g. (Existing isotope production wastes have been measured to have transuranic concentrations less than 1 nCi/gm.) The radionuclides were then divided into three groups: (1) activation and fission products, (2) uranium, and (3) transuranium radionuclides. Information regarding the radionuclide distribution in spent fuel was used to obtain normalized distributions of activation and fission products and of transuranics (Ref. 5). These distributions were used with the combined activities of Sr-90 and Cs-137 obtained from the Maxey Flats data and the assumed activity of the alpha-emitting transuranics to calculate the radionuclide concentrations given in Table D.14.

Industrial high activity wastes (N-HIGHACT) consist of neutron irradiation capsules, activated components from research reactors, and other activated waste materials. The radionuclide concentrations of these wastes (Table D.14) were calculated using scaling factors developed for highly activated metals from decomissioning activities (Ref. 31).

The total radioactivity of industrial tritium manufacturing wastes N-TRITIUM, 2330 Ci/m^3, is assumed to be due to tritium (Ref. 14).

Estimation of the activity of sealed sources and foils (N-SOURCES) and the isotopic distribution of this activity is difficult since they are shipped for disposal infrequently and at irregular intervals. Scaling factors were assumed and applied based on several sources (Ref. 5).

Accelerator targets (N-TARGETS) consist of tritium absorbed on titanium foils. Since there is no indication that induced activities are present (Ref. 8), the total activity of 80.4 Ci/m^3 contained in this waste stream is assumed to be only tritium (Ref. 14).

The only radionuclides identified in source and special nuclear material wastes (N-SSWASTE) are U-235 and U-238. The wastes are generated primarily during processing of metals and compounds containing depleted uranium. The uranium isotopes are conservatively assumed to be present in the same ratio as in natural uranium; thus, 4.3% of the total activity is assumed to be due to U-235 and 95.6% due to U-238.

The types of materials comprising the industrial low activity waste stream (N-LOWASTE) are the industrial equivalents of institutional wastes--i.e., trash, liquid scintillation vials, absorbed liquids, and biowastes. As discussed in Section 2.5, these types of wastes are not sufficiently well-characterized to be considered as separate streams. It was therefore assumed that these industrial wastes have the same distribution of radionuclide concentrations as institutional wastes. Concentrations of individual radionuclides were then estimated using volume-weighted averaging analogous to that used for LWR trash.

4. WASTE PROCESSING OPTIONS

There are many processing technologies currently available that can be utilized to alter and/or improve the performance characteristics of radioactive waste forms. This section briefly considers several of these technologies and presents their estimated impacts on waste generators and/or disposal facility operators. The discussion in this section is obtained from the more detailed treatment provided in Reference 5. Additional information can be found in the references to this appendix.

In order to assess the comparative effects of the waste processing options considered in this appendix four impact measures are quantified in this section. These impact measures are occupational exposures, population exposures, costs, and energy use. Only incineration is assumed to result in potential significant population exposures as a result of processing. Other processes, including evaporation, compaction, solidification, and packaging, are assumed not to result in potentially significant additional population exposures to those.

Waste processing options are considered in three sections in this appendix. Section 4.1 addresses processes that result in a reduced volume of waste after processing. Section 4.2 addresses processes that result in an increased volume of waste after processing. Section 4.3 briefly discusses the possible use of high-integrity packages for containment of radionuclides during transportation and after disposal.

4.1 Volume Reduction

There are three basic processes that can be applied to waste streams that result in overall waste volume reduction: (1) physical processes such as compaction, (2) thermal processes such as evaporation, and (3) incineration and other related combustion processes. Each of these processes produces a concentrate stream and an effluent stream. The respective concentrate streams are compressed wastes concentrated liquids or crystals, and ash. The respective effluents displaced are air, vapor, and gas and vapor. The activity per unit volume of the concentrate stream is usually higher than that of the untreated waste with the possible exception of volatile nuclides such as tritium, carbon, and iodine that may be entrained as vapor and/or combustion products in the effluent stream.

The volume reduction factor (VRF) is defined in this appendix as the ratio of the waste volume that is input to the process (untreated volume) to that of the concentrated (treated) waste volume.

4.1.1 Compaction

Compaction is an often-used method--particularly at nuclear fuel cycle facilities--of reducing the volume of waste streams containing compressible material such as paper, plastic, glass, wood, and light-gauge metal. Most of the volume reduction is attained by compressing the waste to reduce its void volume. The term compactor is usually applied to hydraulic or mechanical rams that compress wastes into 55-gallon steel drums. The drums are then used as disposal containers. Typical hydraulic rams generate 20,000 to 30,000 pounds of force, and are fitted with shrouds and simple air filtration systems to minimize release of airborne radioactivity.

Most compactors now in use can achieve average volume reduction factors of about two. Newer compactors, which place a metal inner sleeve inside the drum during compaction, are capable of a volume reduction factor of about four (Ref. 10). Industrial hydraulic presses similar to those used to crush automobiles may be useful for compacting heavier gauge metal items such as pipes, tools, cans, drums, and scaffolding.

In this appendix, three types of compactors are considered: compactor/shredders that can be utilized to achieve volume reduction factors of around 1.5 to 2; improved compactor/shredders that can achieve volume reduction factors of about 4; and industrial hydraulic presses that are assumed to be capable of achieving volume reduction factors of about 6. In the analysis, the compactor/ shredders and improved compactor/shredders are assumed to be operable as an option by any facility capable of implementing its own processing system (fuel cycle facilities and large institutional and industrial facilities). Industrial hydraulic presses, however, are assumed to be operable only at a centralized waste processing facility.

The waste streams to which these compaction techniques are applied, and their unit impact measures, are summarized in Table D.17.

Table D.17 Compaction Techniques and Impacts

Compaction Technique	Cost* per m^3	Man-Hours* per m^3	Fuel Use* Gallons per m^3	Waste Streams	Volume Reduction Factor
Compactor/shredder	$ 335	15	4.6	P-COTRASH	2.0
				B-COTRASH	2.0
				F-COTRASH	1.5
				I-COTRASH	2.0
				N-SSTRASH	1.5
				N-LOTRASH	2.0
				I-LQSCNVL	1.28
Improved compactor/ shredder	$ 503	15	4.6	I+COTRASH	4.0
				N+SSTRASH	3.0
				N+LOTRASH	4.0
Industrial hydraulic press	$1006	15	4.6	P-NCTRASH	6.0
				B-NCTRASH	6.0
				F-NCTRASH	6.0

*Cost and man-hours are given in unit volume of input volume (untreated) waste. Impact measures were developed based upon data obtained from Reference 32.

4.1.2 Evaporation

Evaporators concentrate liquid wastes by heating them to vaporize the volatile components. The vaporized water generally contains greatly reduced quantities of dissolved solids, suspended solids, and radioactivity relative to those found in the input waste stream. In the nuclear industry the vaporized water is normally condensed and collected, and then either discharged or recycled after testing to determine whether the condensate requires additional treatment. The concentrated solution (bottoms) left in the evaporator retains virtually all of the solids and radioactivity and is solidified and shipped to a disposal facility.

Evaporators can be categorized according to their methods of heat transfer (Ref. 33). Natural circulation evaporators use convection as the means of heat transfer. Forced circulation evaporators (Figure D.4) use pumps to improve the flow of liquid over the heating surfaces. Fluidized-bed dryers produce dry salts by injecting atomized waste liquids onto a hot bed of inert granules that is suspended (fluidized) in a stream of hot air (Refs. 34, 35). The liquids flash-evaporate on contact with the hot bed, leaving behind a residue of dry solids. The inert carrier process (Ref. 36) uses a hot bath of inert fluid recirculating at high velocities as the heat exchanger. Solidification in bitumen can also be considered as a form of evaporation. The ideal evaporator produces a condensate that is free of radioactivity while attaining the maximum volume reduction of the input waste liquid.

In this appendix, evaporator/crystallizers (Ref. 33) (Figure D.5) are assumed to be utilized as an option to further concentrate the already concentrated liquid waste streams of LWRs. For the reference representative evaporator/crystallizer, the volume reduction factors assumed in this appendix are 6.0 and 2.4 for the P-CONCLIQ and B-CONCLIQ streams, respectively. The impact measures are $690, 4.42 man-hours, and 56.3 gallons of fuel per m^3 of untreated input waste liquid (Ref. 32).

4.1.3 Incineration

Incinerators and related devices decompose combustible waste materials by thermal oxidation. Combustion or incineration involves complete oxidation of wastes by burning in an excess of oxygen (air). Pyrolysis involves partial oxidation in an oxygen-deficient atmosphere. Oxidation can also be accomplished by introducing combustible wastes and air into a bath of molten salt. Alternatively, acid digesters oxidize wastes in a hot mixture of concentrated nitric and sulfuric acids.

The various types of incinerators, pyrolyzers, and other such devices currently used or being developed for volume reduction of radioactive waste are too numerous (Ref. 32) to be considered here individually. Two reference types of representative incinerators have been selected for discussion in this appendix: pathological incinerators and fluidized bed incinerators. The reference pathological incinerator is considered for optional use by large institutional waste generators such as hospitals and biomedical research facilities. The reference fluidized bed incinerator is considered for optional use by fuel cycle waste generators or by operators of a potential regional waste processing facility incinerating wastes from small waste generators. The waste streams treated with these two types of incinerators and the resultant unit impact measures are presented in Table D.18.

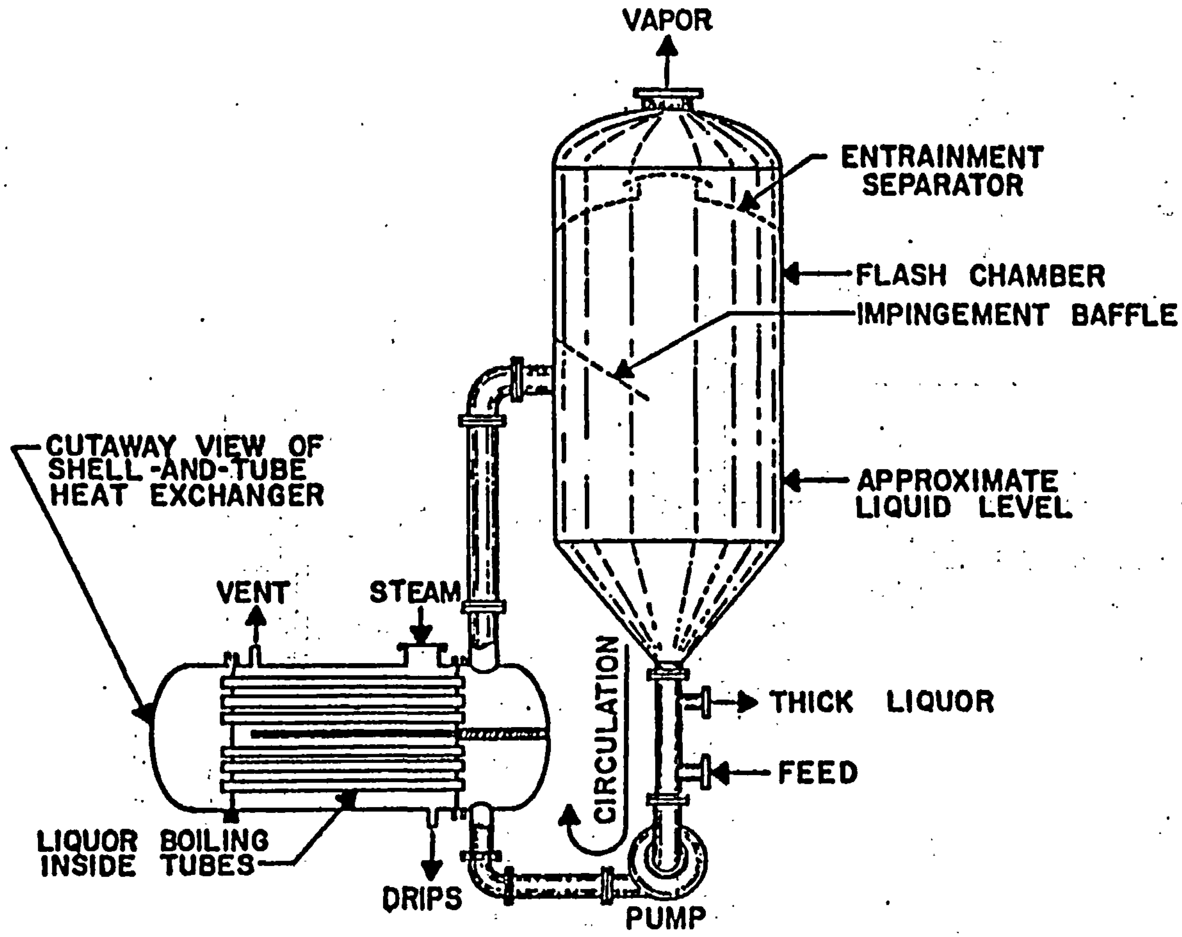

Figure D.4 Forced-Circulation Evaporator With An External Horizontal, Submerged-Tube, Two-Pass Heater

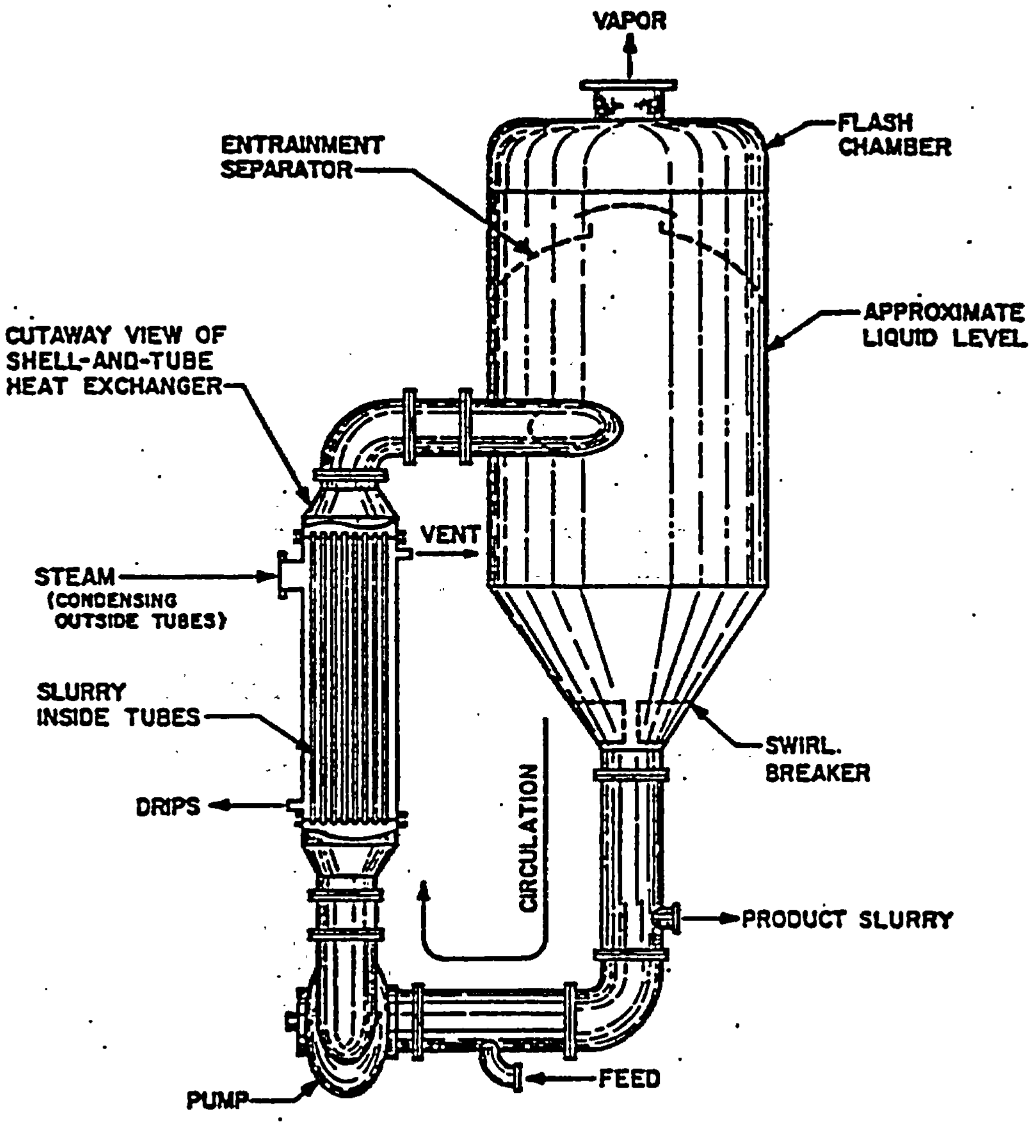

Figure D.5 Evaporator/Crystallizer

Table D.18 Incineration Techniques and Impacts

Incineration Technique	Cost* per m^3	Man-Hours* per m^3	Fuel Use* Gallons per m^3	Waste Streams	Volume Reduction Factor
Pathological incinerator	$2,060	8	116	I-COTRASH	20.0
				N-SSTRASH	10.0
				N-LOTRASH	20.0
				I-LQSCNVL	4.52
				I-ABSLIQD	100.0
				I-BIOWAST	15.0
Fluidized bed incinerator (at facilities)	$1,938	6.12	129	P-IXRESIN	18.0
				P-CONCLIQ	8.0
				P-FSLUDGE	5.0
				B-IXRESIN	18.0
				B-CONCLIQ	6.4
				B-FSLUDGE	5.0
				P-COTRASH	80.0
				B-COTRASH	80.0
				F-COTRASH	40.0
				L-DECONRS	18.0
Fluidized bed incinerator (at regional processing center)	$1,039	5.35	72	I+COTRASH	80.0
				N+SSTRASH	40.0
				N+LOTRASH	80.0

*Cost and man-hours are given in unit volume of untreated waste. Impact measures are based upon data obtained from References 32, 37, and 39.

Pathological incinerators are typically multiple-chamber, hot refractory hearth incinerators (Figure D.6) and are normally operated with less sophisticated off-gas treatment systems (Ref. 37). Airborne releases are principally controlled through control of the rate of input feed. They are designed primarily for the incineration of animal carcasses and operate at approximately 900 to 1000°C. Pathological incinerators may also be used by institutional waste generators for volume reduction of other biowastes, scintillation fluids, organic liquids, and trash. Aqueous liquids can also be evaporated on the refractory hearth.

Fluidized bed incinerators (Figure D.7) operate by injecting combustible wastes into a hot bed of inert granules fluidized by a stream of hot gas. They operate on the same principle as fluidized bed dryers or calciners which have been used

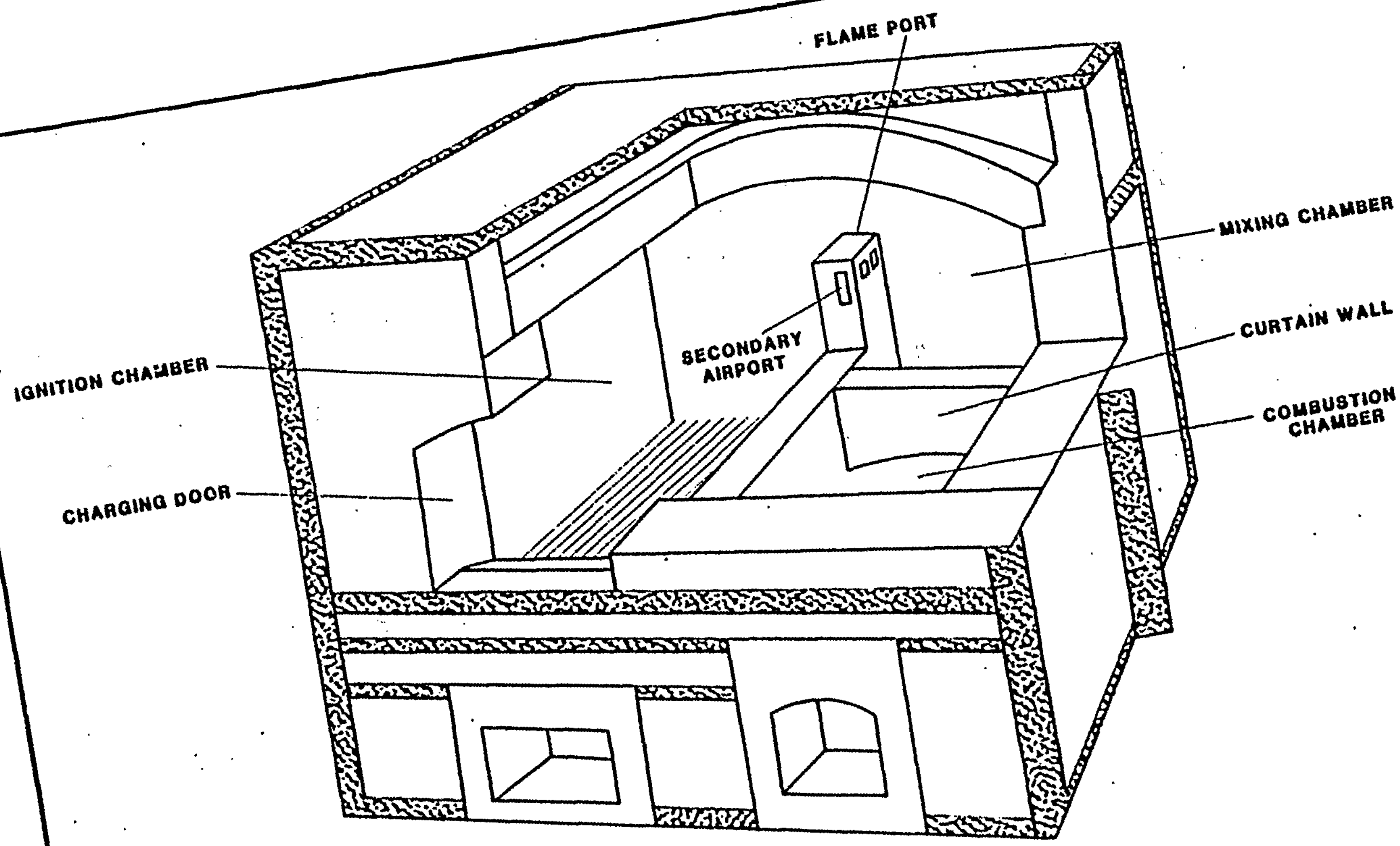

Figure D.6 Multiple Chamber Retort Incinerator

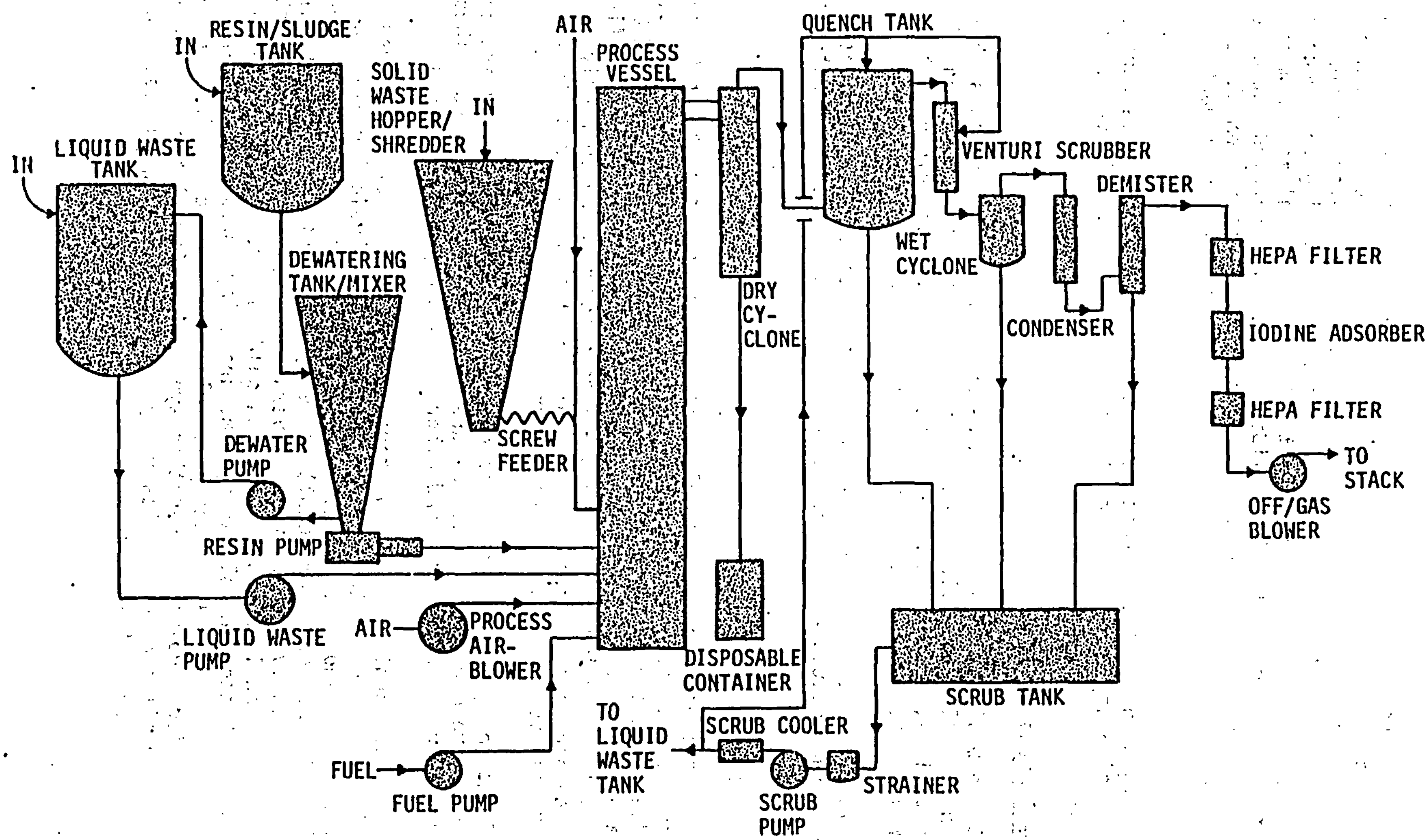

Figure D.7 Flow Diagram of Calciner/Incinerator for many years in nonnuclear industries to produce dry solids from liquid wastes by complete evaporation of the water. Typical fluidized bed incinerators can burn trash, organic solvents, and ion exchange resins. Wastes are normally screened to remove metal objects and shredded before entering the process vessel. The process vessel is maintained at 800 to 1000°C. Residual ash from the combustion process is collected for solidification. Ash carried out of the process vessel with the hot effluent gas stream is separated from the effluent gas by an off-gas treatment system, and also collected for subsequent solidification.

Recent investigations (Ref 38) indicate that thermal combustion is apparently the most effective way of removing chelating agents and organic chemicals from waste streams.

4.2 Volume Increase

There are three basic processes that can be applied to waste streams that result in an overall waste volume increase: solidification, addition of absorbent materials, and packaging. The activity per unit volume of the product stream is generally lower than that of the input waste.

The volume increase factor (VIF) is defined in this appendix as the ratio of the volume of the treated waste product to the volume of the input untreated waste.

4.2.1 Solidification

This section considers a number of solidification processes that can be applied to waste streams such as LWR process wastes (concentrated liquids, resins, filter sludges, and cartridge filters), or dry salts and ashes produced by calciners and incinerators. Cartridge filters are assumed to be solidified by pouring the solidification agent into the spaces between the currently utilized shipping containers and the cartridges. This results in no change to the currently shipped volume of the waste stream.

The solidification agents or techniques considered in this appendix are selected from those that are currently in use or are being actively marketed. These include cement, urea-formaldehyde and other synthetic polymer systems.

Absorbents such as vermiculite and diatomaceous earth are not considered to be solidification agents since they do not chemically or physically bind the wastes. Both cement and urea-formaldehyde solidification systems are currently used by LWRs. Bitumen (another agent) and vinyl ester-styrene (a synthetic polymer) are being actively marketed. Several bitumen solidification systems (which are widely used in Europe) have been sold but are not yet operational in this country. Synthetic polymer systems are being currently used in LWRs, including the Dresden-Unit 1 nuclear power plant, where decontamination solutions are to be solidified. Polyester (another synthetic polymer) has been evaluated in laboratory and pilot plant studies using simulated LWR liquid wastes and may be routinely used in the future.

In the analyses to determine the performance and technical requirements for disposal of LLW, three solidification scenarios are postulated:

- Solidification Scenario A assumes continuation of existing practices resulting in waste performance characteristics that are comparatively less desirable than the following two solidification scenarios. This is simulated by assuming that 50 percent of the waste stream is solidified using urea-formaldehyde systems and the other 50 percent using cement systems.

- Solidification Scenario B assumes improved waste performance characteristics over the previous case. This is simulated by assuming that 50 percent of the waste stream is solidified using cement systems and the other 50 percent using synthetic polymer systems.

- Solidification Scenario C assumes further improved waste performance characteristics achievable with currently available technology. This is simulated by assuming that the waste stream is all solidified using synthetic polymer systems.

These solidification processes, volume increase factors, and the unit impact measures associated with the processes are summarized in Table D.19.

Table D.19 Solidification Techniques and Impacts

Solidification Technique	Cost* per m^3	Man-Hours* per m^3	Fuel Use* Gallons per m^3	Waste Streams	Volume Increase Factor
Scenario A	$1,282	24	40	P-CONCLIQ	1.4
				B-CONCLIQ	1.4
Scenario B	$1,873	24	40	P-IXRESIN	1.65
				P-CONCLIQ	1.82
				P-FSLUDGE	1.65
				B-IXRESIN	1.65
				B-CONCLIQ	1.56
				B-FSLUDGE	1.65
				I-ABSLIQD	1.65
Scenario C	$2,445	24	40	P-IXRESIN	2.00
				P-CONCLIQ	2.00
				P-FSLUDGE	2.00
				B-IXRESIN	2.00
				B-CONCLIQ	2.00
				B-FSLUDGE	2.00
				I-ABSLIQD	2.00
				All Ash	2.00

*Cost and man-hours are given per unit volume of treated waste. Impact measures are developed References 32 and 41-43.

4.2.2 Absorbent Materials

Absorbent materials such as diatomaceous earth or vermiculite are currently added to several institutional waste streams to minimize potential transportation impacts. These streams include liquid scintillation vial (LSV) waste, absorbed liquid waste, and biowaste. Existing commercial disposal facility operators require that these wastes be packaged with specified proportions of waste to absorbent material before they are accepted for disposal (Refs. 1, 40). For example, LSV waste is required to be packaged using sufficient absorbent material to absorb twice the total volume of the liquid in the package (Ref. 40). Lime is frequently added to the biowaste stream. Double packaging of these waste streams is also used for additional safety. For the liquid scintillation vial and the absorbed liquid waste streams, a volume increase factor of 3.0 is assumed. For the biowaste stream, a volume increase factor of 1.92 is assumed.

The practice of packaging wastes with absorbent material increases the difficulty of processing these wastes with currently available methods, if delivered to a centralized processing facility. This is because many of the common absorbent materials, an integral part of the waste stream when the package leaves the waste generator, are not incinerable; absorbents that are incinerable are either not cost-effective or not compatible with the waste streams. Other processing techniques are either not compatible with the waste streams (e.g., cement solidification of liquid scintillation vials) or would result in an increase of the volume of the waste, and as a consequence would not be cost-effective. Therefore, these wastes would have to be processed by the waste generator. While many waste generators are capable of implementing their own waste processing alternatives, such as solidification instead of use of absorbent material, there is no alternative cost-effective treatment method (other than the use of absorbents) for small waste generators such as individual physicians, small medical groups, and small colleges for several waste streams. Therefore, the option of processing at a regional center was not implemented for the I+LQSCNVL, I+ABSLIQD, and I+BIOWAS waste streams.

4.2.3 Packaging

Waste packaging also results in an overall increase in waste volume where the complete container volume is not utilized. Generally the waste generator attempts to minimize void volume within containers. For purposes of determining the performance objectives and technical requirements for disposal, the waste volume increase due to packaging (which results in decreased radionuclide concentrations) is conservatively neglected. Moreover, there is little applicable data available on the packaging efficiency of waste streams. The uncertainties in other estimates in this appendix partially compensate for exclusion of packaging efficiency from volume calculations.

Five generic types of waste containers were considered in this appendix: large wooden boxes (128 ft^3), small wooden boxes (16 ft^3), 55-gallon drums (7.5 ft^3), small liners (55 ft^3), and large liners (170 ft^3).

4.3 High Integrity Containers

It has been standard practice in the past to assume no confinement capability following disposal for the containers in which wastes are shipped to disposal facilities. There is little data available, but the data that does exist indicates that there is great variability in the length of time in which the containers retain their form and/or integrity after disposal.

There are many variables that may affect the integrity of currently used waste containers after disposal. These variables include the stability of the waste form (compactibility, resistance to biologic attack, etc.), the void volume of the container (packaging efficiency), the characteristics of the disposal facility site (natural elements such as precipitation and humidity), the depth of disposal (static soil pressures), and the chemical characteristics of the surrounding soils and wastes (corrosiveness). Because of the many unquantifiable and site specific variables, no attempt has been made in this appendix to estimate and incorporate a confinement capability for typical containers.

However, the concept of a high-integrity container (HIC) may be considered as an alternative to waste processing as a means of improving the waste form. In this case, the container would be constructed in a much more robust manner than the containers generally used to transport wastes to disposal facilities. The HIC would be designed to resist crushing from static loads and corrosion from the contained wastes as well as the surrounding soils. The HIC would therefore provide the needed support to disposal cell covers to minimize subsidence and to reduce infiltration. In addition, since the wastes would be contained inside the HIC, leaching of radionuclides from the HIC would be negligible as long as the HIC retained its integrity. (Note that corrosion of a portion of an HIC, which could compromise its ability to withstand leaching, would not be expected to generally reduce its ability to provide structural support for the disposal cell covers.)

Since HICs have not been extensively used for packaging wastes for disposal, there is less data with which to compare other impact measures such as costs or occupational exposures. These, however, may be discussed in a qualitative manner using solidification of LWR ion-exchange resins and filter media as an example. Use of an HIC would be expected to be more expensive than merely dewatering the resins and filter media but less expensive than solidification. This is because no new equipment would need to be installed at the waste generator's facility. Additional expenses would involve construction and certification of HICs. Since unlike solidification, there would be no increase in waste volume using HICs, transportation costs and disposal costs would probably be lower than the solidified case. Occupational exposures from waste processing operations at the waste generator would not be expected to vary significantly from those received during management of LWR process wastes under existing practices. The same types of waste handling, processing, transport and disposal operations would be carried out; one is merely substituting one container design for another. Finally, unlike solidification, there would be no decrease in land use efficiency at a disposal facility compared with the dewatered case. The energy use would also probably be lower than for the solidified case.

Use of HICs as an alternative to solidification of ion-exchange resins and filter media is allowed by the South Carolina Department of Health and Environmental Control, the state agency regulating disposal of waste at the Barnwell, S.C. disposal facility. Performance criteria for HICs for the Barnwell facility have been drafted by South Carolina and these are listed in Table D.20.

Table D.20 State of South Carolina Criteria for High Integrity Containers

The general criteria for high integrity containers to be used for high concentration waste forms is as follows:

1. The container must be capable of maintaining its contents until the radionuclides have decayed approximately 300 years, since two of the major isotopes of concern in this respect are strontium-90 and cesium 137 with half-lives of 28 and 30 years, respectively.

2. The structural characteristics of the container with its contents must be adequate to withstand all the pressure and stresses it will encounter during all handling, lifting, loading, offloading, backfilling, and burial.

3. The container must not be susceptible to chemical, galvanic or other reactions from its contents or from the burial environment.

4. The container must not deteriorate when subjected to the elevated temperatures of the waste streams themselves, from processing materials inside the container, or during storage, transportation and burial.

5. The container must not be degraded or its characteristics diminished by radiation emitted from its contents, the burial trench or the sun during storage.

6. All lids, caps, fittings and closures must be of equivalent materials and construction to meet all of the above requirements and must be completely sealed to prevent any loss of the container contents.

Source: Reference 45.

One HIC design which has been recently approved by the South Carolina Department of Health and Environmental Control is currently being marketed. The HIC is constructed principally of polyethylene and is currently available in designs ranging from 2.4 m^3 (84 ft^3) to 9 m^3 (316 ft^3). Given adequate lead time for fabricating, special designs are advertised as being available upon request. Costs for a HIC are estimated to run approximately 75% to 85% higher than an equivalently sized carbon steel liner (Ref. 44).

5. ALTERNATIVE WASTE SPECTRA

This section describes the four waste spectra that are utilized in the EIS to help determine the performance objectives and technical requirements for acceptable disposal of LLW. The concept "spectrum" as used here denotes the total volume and properties of the waste streams (the 36 streams given in Table D.5) generated between the years 1980 and 2000 after they have been processed by a set of selected waste treatment options. Each spectrum corresponds to a general level of waste performance in terms of waste stability, resistance to wind mobilization, resistance to leaching, and physical, chemical, and radiological properties that can be achieved by establishing operational and/or administrative requirements. The spectra differ significantly in waste volumes, radioactive concentrations, and performance.

5.1 Waste Spectra Descriptions

The radioactive concentrations of each waste stream for each spectrum depends on the change in the volume of the stream during processing. Whenever a process is applied to a waste stream that results in volume reduction of the stream, its concentrations are increased accordingly. Similarly, whenever a process is applied that results in a volume increase, the concentrations are decreased accordingly. The minute quantities of radionuclides that are lost during these processes (e.g., the radionuclides may become attached to the process vessel walls) have been conservatively neglected.

The four waste spectra are used to consider the range in waste performance that can be achieved through alternative operational and/or administrative requirements. With each respective spectra, increased waste processing is assumed. This results in waste forms having greater stability, better leaching characteristics, lessened dispersibility, lower volumes, and higher concentrations. The effect of these alterations in waste form and radionuclide concentrations on radiological impact measures such as groundwater migration and to exposures to potential inadvertent intruders may be compared against costs and other nonradiological impact measures.

In developing the spectra, it was recognized that a considerable amount of change is currently taking place in existing waste processing and packaging techniques. This relatively rapid change makes it difficult to characterize current waste processing and packaging practices. For example, due to the current limitation in disposal capacity, there is increased use of volume reduction procedures (such as use of compactors) by waste generators. In addition, license conditions at two disposal facilities are requiring that resins and filter media be either solidified or placed into high integrity containers prior to disposal.

Therefore, the first two spectra were estabished to more or less straddle existing practice. Spectrum 1 represents existing or past practices while Spectrum 2 represents in many respects the direction that waste processing and packaging practices seem to be headed. Waste Spectra 3 & 4 represent more extreme waste processing and packaging practices.

The general assumptions made in these spectra are presented below.

Waste Spectrum 1

This spectrum assumes a continuation of past or existing waste management practices. Some of the LWR waste streams are solidified (P-CONCLIQ, B-CONCLIQ, L-DECONRS). However, no processing is performed on combustible wastes or streams containing chelating agents or organic chemicals. The following general assumptions are made:

- o LWR resins and filter sludges are assumed to be shipped to disposal facilities in a dewatered form.
- o PWR cartridge filters are packaged for shipment by placing the filters within in a 55-gallon drum. The resulting void spaces within the waste container results in a structually unstable waste form.
- o LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified. The solidification binders used are assumed to be half cement and half urea-formaldehyde (solidification Scenario A).
- o No special effort is made to compact trash.
- o Institutional waste streams are shipped to disposal facilities after they are packaged with currently utilized absorbent materials.
- o Resins from LWR decontamination operations (L-DECONRS stream) are solidified in a synthetic polymer (solidification Scenario C).
- o Four relatively high activity waste streams principally containing activated metal (P-NCTRASH, B-NCTRASH, L-NFRCOMP, and N-HIGHACT) are assumed to be packaged according to existing practice--i.e., waste streams are placed into containers and the interstitial spaces filled with material such as compressible waste forms. Although the waste itself is stable, the packaging practice results in an unstable waste form.

<u>Waste Spectrum 2</u>

This spectrum assumes that LWR process wastes are solidified using improved solidification techniques (solidification Scenario B). LWR concentrated liquids are additionally reduced in volume through an evaporator/crystallizer. Routine compaction is performed on all compactible trash. For certain streams (see below), half of the trash volume is compacted at the facility generating the waste and the other half at a centralized processing facility. The following general assumptions are made:

- o All LWR concentrated liquids are evaporated to 50 weight percent solids, and all LWR process wastes are solidified using solidification Scenario B. In the case of cartridge filters, the solidification agent fills voids in the packaged waste but is assumed to not increase the volume of the waste stream.
- o At large facilities, liquid scintillation vials are crushed and packaged in absorbent material (the I-LIQSCVL stream).

- All compactible trash streams are compacted; the P-COTRASH, B-COTRASH, F-COTRASH, I-COTRASH, N-SSTRASH, and N-LOTRASH streams are compacted at the source of generation; the I+COTRASH, N+SSTRASH, and N+LOTRASH streams are compacted at a centralized regional processing facility.
- Liquids from medical isotope production (N-ISOPROD) are solidified using solidification Scenario C.
- The P-NCTRASH, B-NCTRASH, L-NFRCOMP, and N-HIGHACT streams are assumed to be stabilized. Instead of packaging these waste streams in easily degradable trash, void spaces between the waste and the container are filled with a nondegradable material such as sand.

Waste Spectrum 3

In this spectrum, LWR process wastes, including filter cartridges, are solidified assuming that further improved waste 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 (fuel cycle trash, LWR decontamination resins, institutional wastes from large facilities and industrial trash from large facilities), and some at a centralized regional processing facility (institutional and industrial trash from small facilities). All incineration ash is solidified using solidification Scenario C. The B-NCTRASH, P-NCTRASH, L-NFRCOMP, and N-HIGHACT streams are again assumed to be stabilized through improved packaging.

Waste Spectrum 4

This spectrum assumes extreme volume reduction. All wastes amenable to evaporation or incineration with fluidized bed technology are calcined and solidified using solidification Scenario C. LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All non-compactible wastes are reduced in volume at a centralized processing facility using a large hydraulic press. The L-NFRCOMP and N-HIGHACT streams are stabilized. This spectrum represents about the maximum volume reduction that can currently be practically achieved.

5.2 Spectrum Data File Components

For each of the four waste spectra, a data file was constructed consisting of three major groups of waste form and packaging parameters:

- Volume reduction and volume increase factors;
- Waste form behavior indices (six indices total); and
- Waste processing procedures;

The first three groups of parameters are discussed in this section. Another group of parameters which are used to estimate population exposure, occupational exposures, and costs of waste transportation to a disposal facility are described in Appendix G.

Volume Reduction and Volume Increase Factors

These factors were previously introduced in Section 4. The volume reduction factor (VRF) is the ratio of the volume of the untreated input waste to the volume of the treated waste product. It is used in quantifying the effects of the volume reduction processes discussed in Section 4.1. The volume increase factor (VIF) is defined as the ratio of the volume of the product waste stream to the volume of the input waste stream. It is used in quantifying the effects of the volume increase processes discussed in Section 4.2.

The volume reduction and volume increase factors associated with each of the 36 waste streams for each of the 4 waste spectra considered in this appendix are presented in Table D.21.

Waste Form Behavior Indices

The effects of different waste performances discussed above must be included in the impact analyses. One such tool is quantifying these properties through discrete indices that trigger specific computational procedures in the impacts analyses. This is the approach adopted in this appendix. Additional information regarding this approach may be found in Section 3 of Appendix G.

The characteristics important in determining the effects of different waste behavior include the flammability of the waste form at the time of disposal, the dispersibility of the waste form several decades after disposal, the structural stability of the waste, the resistance of the waste form to leaching, the accessibility of the radionuclides to transfer agents such as wind or water, and the relative mobility of the radionuclides (the presense or absence of chelating agents or organic chemicals). These six properties were quantified through six waste form behavior indices defined in Table D.22 and discussed below.

The flammability index ranks waste forms according to their flammability prior to disposal. Waste forms that will not burn even on prolonged exposure to open flame and moderately intense heat (Refs. 45, 46) are assigned an index of (0). Those waste forms that will sustain combustion are assigned an index of (3). Between these extremes are two additional flammability categories. Waste forms that will ignite but will not sustain burning under these conditions are assigned an index of (2). Waste forms consisting of a mixture of materials with flammability indices (0) and (2) (e.g., solidification Scenarios A and B) are assigned an index of (1).

The dispersibility index is a qualitative measure of the potential for suspension of radioactivity, should the waste form be exposed to wind after a significant period (on the order of 100 years). Waste forms which are judged to have a

Table D.21 Volume Reduction and Increase Factors

	SPECTRUM 1		SPECTRUM 2		SPECTRUM 3		SPECTRUM 4	
STREAM	VRF	VIF	VRF	VIF	VRF	VIF	VRF	VIF
P-IXRESIN	1.00	1.00	1.00	1.65	1.00	2.00	18.00	2.00
P-CONCLIQ	1.00	1.40	6.00	1.82	6.00	2.00	8.00	2.00
P-FSLUDGE	1.00	1.00	1.00	1.65	1.00	2.00	5.00	2.00
P-FCARTRG	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
B-IXRESIN	1.00	1.00	1.00	1.65	1.00	2.00	18.00	2.00
B-CONCLIQ	1.00	1.40	2.40	1.56	2.40	2.00	6.40	2.00
B-FSLUDGE	1.00	1.00	1.00	1.65	1.00	2.00	5.00	2.00
P-COTRASH	1.00	1.00	2.00	1.00	80.00	2.00	80.00	2.00
P-NCTRASH	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00
B-COTRASH	1.00	1.00	2.00	1.00	80.00	2.00	80.00	2.00
B-NCTRASH	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00
F-COTRASH	1.00	1.00	1.50	1.00	40.00	2.00	40.00	2.00
F-NCTRASH	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00
I-COTRASH	1.00	1.00	2.00	1.00	20.00	2.00	20.00	2.00
I+COTRASH	1.00	1.00	4.00	1.00	80.00	2.00	80.00	2.00
N-SSTRASH	1.00	1.00	1.50	1.00	10.00	2.00	10.00	2.00
N+SSTRASH	1.00	1.00	3.00	1.00	40.00	2.00	40.00	2.00
N-LOTRASH	1.00	1.00	2.00	1.00	20.00	2.00	20.00	2.00
N+LOTRASH	1.00	1.00	4.00	1.00	80.00	2.00	80.00	2.00
F-PROCESS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
U-PROCESS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
I-LQSCNVL	1.00	3.00	1.28	3.00	4.52	2.00	4.52	2.00
I+LQSCNVL	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00
I-ABSLIQD	1.00	3.00	1.00	1.65	1.00	2.00	100.00	2.00
I+ABSLIQD	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00
I-BIOWAST	1.00	1.92	1.00	1.92	15.00	2.00	15.00	2.00
I+BIOWAST	1.00	1.92	1.00	1.92	1.00	1.92	1.00	1.92
N-SSWASTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-LOWASTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-NFRCOMP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-DECONRS	1.00	2.00	1.00	2.00	18.00	2.00	18.00	2.00
N-ISOPROD	1.00	1.30	1.00	2.00	1.00	2.00	1.00	2.00
N-HIGHACT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-TRITIUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-SOURCES	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-TARGETS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table D.22 Waste Form Behavior Indices

Parameter	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 = slight 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

low probability of becoming suspended into respirable particles are assigned an index of (0). Those waste forms that have a high potential of becoming suspended into respirable particles are assigned an index of (3). Waste forms that tend to crumble or fracture extensively and those 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).

<u>The leachability index</u> is a qualitative measure of the waste form's resistance to leaching and is determined by the solidification procedures used. Unsolidified waste forms, which are assumed to be readily leached, are assigned an index of (1). Solidification scenarios A, B, and C (discussed in the previous section) are assigned an index of 2, 3, and 4, respectively.

<u>The chemical content index</u> denotes whether the waste form may contain chelating agents or organic chemicals that may increase the mobility during leaching and subsequent migration from the disposal cell. An index value of (0) indicates a likelihood that these chemicals or agents are absent, whereas an index value of (1) indicates a likelihood of their presence.

<u>The stability index</u> denotes whether the waste form is likely to reduce in volume after disposal due to compressibility, large internal void volumes, and/or chemical and biological attack. With the exception of waste streams packaged in high integrity containers (assigned an index of 1), no credit is taken for the waste containers. An index value of (0) indicates the likelihood of structural instability, whereas a value of (1) indicates a structurally stable waste form.

The last index, <u>the accessibility index</u>, ranks the waste forms according to the accessibility of the radionuclides to transfer agents such as wind or water. It essentially denotes a correction factor in the analyses for activated metals or metals having fixed surface contamination. Surface contaminated wastes and waste containing radioactivity in readily soluble forms are assigned an index of (1). The waste forms that are almost exclusively activated metals with imbedded radioactivity not readily accessible to the elements are assigned an index of (3). Other waste forms (e.g., noncompactible trash that contains a lot of equipment) are assigned an index of (2).

A single waste property may determine the value of more than one index and a single performance characteristic may be described by more than one index. For example, in Spectra 1 and 2, the tendency of combustible materials in the trash waste streams to decompose contributes to both the dispersibility and the instability of these streams. On the other hand, the ability of a waste form to retain the radioactivity it contains is described by both its leachability and its accessibility. In this case, leachability is based on the properties of the waste binder (solidification agent) while accessibility is based on the properties of the waste itself.

Waste behavior indices that have been assumed for each of the 36 waste streams for each of the four spectra are presented in Table D.23.

<u>Processing Impacts</u>

Processing impacts in addition to those associated with treatment operations performed in Spectrum 1 include population exposures, occupational exposures, costs, and energy use.

Population impacts from processing depend primarily on the radioactive contents of the waste streams and secondarily on the location at which the processing

Table D.23 Waste Form Behavior Indices for Waste Spectra 1-4

	SPECTRUM 1						SPECTRUM 2						SPECTRUM 3						SPECTRUM 4					
INDEX I	4	5	6	7	8	9*	4	5	6	7	8	9*	4	5	6	7	8	9*	4	5	6	7	8	9*
P-IXRESIN	2	1	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-CONCLIQ	1	1	2	0	1	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-FSLUDGE	1	3	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-FCARTRG	2	2	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	2	0	4	0	1	1
B-IXRESIN	2	1	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
B-CONCLIQ	1	1	2	0	1	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
B-FSLUDGE	1	3	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
P-NCTRASH	0	0	1	0	0	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
B-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
B-NCTRASH	0	0	1	0	0	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
F-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
F-NCTRASH	0	0	1	0	0	2	0	0	1	0	0	2	0	0	1	0	0	2	0	0	1	0	1	2
I-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
I+COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N-SSTRASH	2	2	1	0	0	1	2	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N+SSTRASH	2	2	1	0	0	1	2	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N-LOTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N+LOTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
F-PROCESS	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1
U-PROCESS	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1
I-LQSCNVL	3	3	1	1	0	1	3	3	1	1	1	1	0	0	4	0	1	1	0	0	4	0	1	1
I+LQSCNVL	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1
I-ABSLIQD	3	3	1	1	1	1	3	1	3	1	1	1	1	0	4	0	1	1	1	0	4	0	1	1
I+ABSLIQD	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1
I-BIOWAST	2	3	1	1	0	1	2	3	1	1	0	1	0	0	4	0	1	1	0	0	4	0	1	1
I+BIOWAST	2	3	1	1	0	1	2	3	1	1	0	1	2	3	1	1	0	1	2	3	1	1	0	1
N-SSWASTE	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1
N-LOWASTE	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	1	1
L-NFRCOMP	0	0	1	0	0	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
L-DECONRS	2	0	4	1	1	1	2	0	4	1	1	1	1	0	4	0	1	1	1	0	4	0	1	1
N-ISOPROD	1	1	3	1	0	1	1	0	4	1	1	1	1	0	4	1	1	1	1	0	4	1	1	1
N-HIGHACT	0	0	1	0	0	3	0	0	1	0	1	3	0	0	1	0	1	3	0	0	1	0	1	3
N-TRITIUM	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1
N-SOURCES	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
N-TARGETS	0	0	1	0	1	1	0	0	1	0	1	1	0	0	1	0	1	1	0	0	1	0	1	1

*I4=Flammability index, I5=dispersability index, I6=leachability index, I7=Chemical content index, I8=stability index, and I9=accessability index.

takes place. Only incineration (pathological incinerators and incinerator/ calciners) were assumed to result in a release of radioactivity which could result in potentially significant additional population exposures. Occupational exposures depend on the environment in which the waste processing is being performed in addition to the waste activity. The cost of waste processing also depend on the size of the facility as well as the specific process being utilized.

In order to account for these variations, four indices have been assigned to each waste stream in each spectrum and are utilized in the calculation of waste processing impacts. The values of these indices trigger specific calculational procedures in the calculation of the impact measures.

The first index denotes the volume reduction process (if any) utilized for the waste stream. An index value of (0) implies no volume reduction. Index values of (1), (2), and (3) indicate routine compaction, improved compaction, and hydraulic press compaction, respectively. An index value of (4) indicates evaporation, and index values of (5), (6), and (7) indicate incineration using a pathological incinerator, fluidized-bed calcination at a small facility, and fluidized-bed calcination at a large facility, respectively.

The second index denotes the solidification processes (if any) applied to the waste stream. An index value of (0) indicates an unsolidified waste form. Index values of (1), (2), and (3) indicate use of solidification Scenarios A, B, and C, respectively.

The third index denotes whether the processing (if any) takes place at the waste generator or at a centralized processing facility. An index value of (0) indicates no processing; an index value of (1) indicates processing by the waste generator; and an index value of (2) indicates processing at the centralized processing facility.

The last index indicates the environment of the location at which the processing is assumed to occur. An index value of (0) indicates no processing; an index value of (1) indicates an urban environment; and an index value of (2) indicates a rural environment.

The values assigned for these indices for all the waste streams and the waste spectra considered in this report are presented in Table D.24. More information on the calculation of the waste processing impacts can be found in References 5 and 46, as well as Appendix G.

5.3 <u>Waste Volumes and Radionuclide Concentrations</u>

The "untreated" waste volumes projected to be generated to the year 2000 for each of the 4 regions considered in this appendix (USNRC Regions 4 and 5 were combined into one region for purposes of this appendix) were presented in Table D.9. The waste stream volumes after processing for each of the 4 spectra for each region may then be determined by multiplying the volume of each stream in Table D.9 by the appropriate volume increase factor and dividing by the volume reduction factor given in Table D.21.

Table D-24 Processing Indices

INDEX	SPECTRUM 1 P S L E*	SPECTRUM 2 P S L E*	SPECTRUM 3 P S L E*	SPECTRUM 4 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

*P = Volume reduction process index, S = solidification process index, L = waste processing location index, E = processing environment index

The regional volumes are useful but it is difficult to directly use the regional volumes in the analysis to determine acceptable performance objectives and technical criteria for LLW disposal. What is needed is a normalized set of volumes which represents the waste contributed by all the regions and which can be used to compare the costs and impacts of one alternative against another. To do this, the volumes for each of the 4 regions are summed for each waste stream and each waste spectra as shown in Table D.25. (As shown, about 3.62 million m^3 (127.8 million ft^3) of waste is projected to be generated in the United States to the year 2000.) These waste volumes are then normalized to one million m^3 for waste spectrum one as shown in Table D.26. One million m^3 bounds the projected waste volumes projected to be generated by a single region. As shown, the range in waste processing options considered results in a total volume reduction from Spectrum 1 to Spectrum 4 by about a factor of 4.

Radionuclide concentrations for any waste stream may then be obtained by multiplying the untreated waste concentrations (e.g., Tables D.11 through D.14) by the volume increase and dividing by the volume reduction factors for the processed volume of interest. This may be performed for the regional volumes, the normalized volumes, and for any of the four spectra. In general, radionuclides potentially lost from the waste forms during processing operations are conservatively not considered when determining processed waste concentrations. An exception is loss of tritium and carbon-14 from the processed waste form due to airborne releases of these two radionuclide from processing options involving incineration and calcination. As discussed in Appendix G and in Reference 46, the assumed release fractions for tritium and carbon-14 from waste forms processed by incineration or calcination are as follows:

	Release Fraction	
Nuclide	Pathological Incinerator	Calciner
H-3	0.90	0.90
C-14	0.75	0.25

The amounts of these two radionuclides contained in the final processed form are reduced appropriately.

Finally, two sets of concentrations are used in this environmental impact statement, depending upon the radioactivity exposure pathways considered. To evaluate impacts due to potential operational accidents or to a potential inadvertent intruder following the end of active institutional controls, spectral concentrations are used which are calculated using the untreated concentrations in Tables D.11 through D.14 as modified by the appropriate volume increase and reduction factors for the waste spectrum considered. This corresponds to the concentrations of the waste delivered to the disposal facility each year during its 20 year operating life, and neglects the radioactive decay that takes place after generation and prior to disposal.

Table D.25 Cumulative Waste Volumes (m^3)

	SPECTRUM 1		SPECTRUM 2		SPECTRUM 3		SPECTRUM 4	
STREAM	VOLUME	% VOL	VOLUME	% VOL	VOLUME	% VOL	VOLUME	% V
P-IXRESIN	3.46E+04	.96	5.71E+04	2.26	6.93E+04	3.88	3.85E+03	.4
P-CONCLIQ	3.41E+05	9.43	7.38E+04	2.92	8.12E+04	4.55	6.09E+04	7.0
P-FSLUDGE	4.28E+03	.12	7.06E+03	.28	8.56E+03	.48	1.71E+03	.2
P-FCARTRG	2.18E+04	.60	2.18E+04	.86	2.18E+04	1.22	2.18E+04	2.5
B-IXRESIN	7.62E+04	2.11	1.26E+05	4.98	1.52E+05	8.54	8.47E+03	.9
B-CONCLIQ	2.94E+05	8.14	1.37E+05	5.41	1.75E+05	9.81	6.57E+04	7.6
B-FSLUDGE	1.69E+05	4.67	2.79E+05	11.04	3.38E+05	18.94	6.76E+04	7.8
P-COTRASH	4.24E+05	11.74	2.12E+05	8.40	1.06E+04	.59	1.06E+04	1.2
P-NCTRASH	2.18E+05	6.02	2.18E+05	8.62	2.18E+05	12.20	3.63E+04	4.2
B-COTRASH	2.09E+05	5.77	1.04E+05	4.13	5.22E+03	.29	5.22E+03	.6
B-NCTRASH	9.90E+04	2.74	9.90E+04	3.92	9.90E+04	5.54	1.65E+04	1.9
F-COTRASH	2.36E+05	6.52	1.57E+05	6.23	1.18E+04	.66	1.18E+04	1.3
F-NCTRASH	4.17E+04	1.15	4.17E+04	1.65	4.17E+04	2.34	6.95E+03	.8
I-COTRASH	1.41E+05	3.89	7.04E+04	2.79	1.41E+04	.79	1.41E+04	1.6
I+COTRASH	1.41E+05	3.89	3.52E+04	1.39	3.52E+03	.20	3.52E+03	.4
N-SSTRASH	1.80E+05	4.97	1.20E+05	4.74	3.59E+04	2.01	3.59E+04	4.1
N+SSTRASH	1.80E+05	4.97	5.99E+04	2.37	8.98E+03	.50	8.98E+03	1.0
N-LOTRASH	5.06E+04	1.40	2.53E+04	1.00	5.06E+03	.28	5.06E+03	.5
N+LOTRASH	5.06E+04	1.40	1.27E+04	.50	1.27E+03	.07	1.27E+03	.1
F-PROCESS	7.82E+04	2.16	7.82E+04	3.09	7.82E+04	4.38	7.82E+04	9.1
U-PROCESS	2.81E+04	.78	2.81E+04	1.11	2.81E+04	1.57	2.81E+04	3.2
I-LOSCNVL	1.47E+05	4.08	1.15E+05	4.56	2.17E+04	1.22	2.17E+04	2.5
I+LQSCNVL	1.47E+05	4.08	1.47E+05	5.84	1.47E+05	8.26	1.47E+05	17.1
I-ABSLIQD	1.68E+04	.46	9.22E+03	.36	1.12E+04	.63	1.12E+02	.0
I+ABSLIQD	1.68E+04	.46	1.68E+04	.66	1.68E+04	.94	1.68E+04	1.9
I-BIOWAST	3.02E+04	.83	3.02E+04	1.19	2.09E+03	.12	2.09E+03	.2
I+BIOWASR	3.02E+04	.83	3.02E+04	1.19	3.02E+04	1.69	3.02E+04	3.5
N-SSWASTE	6.34E+04	1.75	6.34E+04	2.51	6.34E+04	3.55	6.34E+04	7.3
N-LOWASTE	6.03E+04	1.67	6.03E+04	2.39	6.03E+04	3.38	6.03E+04	7.0
L-NFRCOMP	2.89E+03	.08	2.89E+03	.11	2.89E+03	.16	2.89E+03	.3
L-DECONRS	7.00E+04	1.93	7.00E+04	2.77	3.89E+03	.22	3.89E+03	.4
N-ISOPROD	6.75E+03	.19	1.04E+04	.41	1.04E+04	.58	1.04E+04	1.2
N-HIGHACT	2.61E+03	.07	2.61E+03	.10	2.61E+03	.15	2.61E+03	.3
N-TRITIUM	3.48E+03	.10	3.48E+03	.14	3.48E+03	.19	3.48E+03	.4
N-SOURCES	1.87E+02	.01	1.87E+02	.01	1.87E+02	.01	1.87E+02	.0
N-TARGETS	1.34E+03	.04	1.34E+03	.05	1.34E+03	.08	1.34E+03	.1
TOTALS	3.62E+06		2.53E+06		1.79E+06		8.59E+05	

Table D.26 Normalized Waste Volumes (m^3)

	SPECTRUM 1		SPECTRUM 2		SPECTRUM 3		SPECTRUM 4	
TREAM	VOLUME	% VOL	VOLUME	% VOL	VOLUME	% VOL	VOLUME	% VOL
-IXRESIN	9.58E+03	.96	1.58E+04	2.26	1.92E+04	3.88	1.06E+03	.45
-CONCLIQ	9.43E+04	9.43	2.04E+04	2.92	2.24E+04	4.55	1.68E+04	7.08
-FSLUDGE	1.18E+03	.12	1.95E+03	.28	2.37E+03	.48	4.73E+02	.20
-FCARTRG	6.02E+03	.60	6.02E+03	.86	6.02E+03	1.22	6.02E+03	2.53
-IXRESIN	2.11E+04	2.11	3.48E+04	4.98	4.22E+04	8.54	2.34E+03	.99
-CONCLIQ	8.14E+04	8.14	3.78E+04	5.41	4.84E+04	9.81	1.82E+04	7.65
-FSLUDGE	4.67E+04	4.67	7.71E+04	11.04	9.35E+04	18.94	1.87E+04	7.87
-COTRASH	1.17E+05	11.74	5.87E-04	8.40	2.93E+03	.59	2.93E+03	1.23
-NCTRASH	6.02E+04	6.02	6.02E+04	8.62	6.02E+04	12.20	1.00E+04	4.22
-COTRASH	5.77E+04	5.77	2.88E+04	4.13	1.44E+03	.29	1.44E+03	.61
-NCTRASH	2.74E+04	2.74	2.74E+04	3.92	2.74E+04	5.54	4.56E+03	1.92
-COTRASH	6.52E+04	6.52	4.35E+04	6.23	3.26E+03	.66	3.26E+03	1.37
-NCTRASH	1.15E+04	1.15	1.15E+04	1.65	1.15E+04	2.34	1.92E+03	.81
-COTRASH	3.89E+04	3.89	1.95E+04	2.79	3.89E+03	.79	3.89E+03	1.64
+COTRASH	3.89E+04	3.89	9.73E+03	1.39	9.73E+02	.20	9.73E+02	.41
-SSTRASH	4.97E+04	4.97	3.31E+04	4.74	9.93E+03	2.01	9.93E+03	4.18
+SSTRASH	4.97E+04	4.97	1.66E+04	2.37	2.48E+03	.50	2.48E+03	1.04
-LOTRASH	1.40E+04	1.40	7.00E+03	1.00	1.40E+03	.28	1.40E+03	.59
+LOTRASH	1.40E+04	1.40	3.50E+03	.50	3.50E+02	.07	3.50E+02	.15
-PROCESS	2.16E+04	2.16	2.16E+04	3.09	2.16E+04	4.38	2.16E+04	9.10
-PROCESS	7.77E+03	.78	7.77E+03	1.11	7.77E+03	1.57	7.77E+03	3.27
-LOSCNVL	4.08E+04	4.08	3.19E+04	4.56	6.01E+03	1.22	6.01E+03	2.53
+LQSCNVL	4.08E+04	4.08	4.08E+04	5.84	4.08E+04	8.26	4.08E+04	17.16
-ABSLIQD	4.63E+03	.46	2.55E+03	.36	3.09E+03	.63	3.09E+01	.01
+ABSLIQD	4.63E+03	.46	4.63E+03	.66	4.63E+03	.94	4.63E+03	1.95
-BIOWAST	8.34E+03	.83	8.34E+03	1.19	5.79E+02	.12	5.79E+02	.24
+BIOWAST	8.34E+03	.83	8.34E+03	1.19	8.34E+03	1.69	8.34E+03	3.51
-SSWASTE	1.75E+04	1.75	1.75E+04	2.51	1.75E+04	3.55	1.75E+04	7.38
-LOWASTE	1.67E+04	1.67	1.67E+04	2.39	1.67E+04	3.38	1.67E+04	7.01
-NFRCOMP	7.98E+02	.08	7.98E+02	.11	7.98E+02	.16	7.98E+02	.34
-DECONRS	1.93E+04	1.93	1.93E+04	2.77	1.07E+03	.22	1.07E+03	.45
-ISOPROD	1.87E+03	.19	2.87E+03	.41	2.87E+03	.58	2.87E+03	1.21
-HIGHACT	7.21E+02	.07	7.21E+02	.10	7.21E+02	.15	7.21E+02	.30
-TRITIUM	9.63E+02	.10	9.63E+02	.14	9.63E+02	.19	9.63E+02	.41
-SOURCES	5.16E+01	.01	5.16E+01	.01	5.16E+01	.01	5.16E+01	.02
-TARGETS	3.71E+02	.04	3.71E+02	.05	3.71E+02	.08	3.71E+02	.16
OTALS	1.00E+06		6.99E+05		4.94E+05		2.38E+05	

Ground-water impacts, however, are dependent upon the total inventory of radioactive waste delivered to the disposal facility over its 20 year operating life. However, only part of the total inventory is delivered to the disposal facility each year, and radioactive decay reduces the facility inventory during operation. For example, assuming that 1/20 of the total inventory is delivered to the disposal facility each year, then by the time the facility is filled to capacity, the waste delivered the first year will experience 20 years of radioactive decay while the waste delivered the final year will only have decayed one year or less.

To evaluate ground-water impacts, then, it is calculationally convenient to decay the radionuclides in the wastes delivered each year to the end of the operating life of the facility. This produces a total decayed radionuclide inventory which accounts for 20-year time of waste delivery to the disposal facility, and from which a set of decayed "untreated" waste concentrations can be calculated. This is accomplished by taking the projected untreated volumes generated during each year for each waste stream (Table D.9), obtaining the total activity of each radionuclide by multiplying by untreated waste concentrations (Tables D.11 through D.14), multiplying this total activity by an appropriate (radionuclide specific) decay factor, summing these modified total waste stream activities, and dividing this sum by the total untreated waste volumes.

The decayed untreated waste concentrations thus obtained are presented in Tables D.27 through D.30. These decayed untreated concentrations may then be used to determine decayed processed concentrations either on a normalized or regional basis in a similar manner as discussed earlier.

6. OTHER POTENTIAL WASTE STREAMS

This section contains a discussion of waste streams other than the basic streams discussed in Sections 1 through 5 and which: (1) are not currently being sent to LLW disposal facilities, (2) are nonroutine, or (3) are very speculative in terms of timing or waste generation rates. Wastes that fall into this cateory include those from:

- U.S. government operations:
- Decontamination of the Three Mile Island Unit 2 nuclear generating station;
- Transuranic-contaminated wastes, including wastes from potential recycle of nuclear fuel;
- Operations at independent spent fuel storage installations;
- Decommissioning of uranium fuel cycle facilities; and
- Manufacturing process tailings contaminated with low levels of residual uranium and thorium.

These potential waste streams are discussed in the following subsections:

Table D.27 Group 1 Decayed Isotopic Concentrations (Ci/m^3)

	P-IXRESIN	P-CONCLIQ	P-FSLUDGE	P-FCARTG	B-IXRESIN	B-CONCLIQ	B-FSLUDGE
H-3	1.84E-03	2.39E-03	1.79E-03	7.97E-04	1.34E-02	4.35E-04	8.78E-03
C-14	9.73E-05	1.27E-04	9.54E-05	4.25E-05	1.19E-03	3.89E-05	7.77E-04
FE-55	7.30E-04	7.08E-03	9.67E-02	1.73E-01	2.99E-01	2.39E-02	4.54E-01
NI-59	2.79E-06	2.71E-05	3.71E-04	6.60E-04	9.80E-04	7.85E-05	1.49E-03
CO-60	2.17E-03	2.11E-02	2.88E-01	5.14E-01	7.70E-01	6.15E-02	1.17E+00
NI-63	8.15E-04	7.92E-03	1.08E-01	1.93E-01	2.04E-02	1.63E-03	3.08E-02
NB-94	8.84E-08	8.58E-07	1.17E-05	2.09E-05	3.09E-05	2.48E-06	4.70E-05
SR-90	1.63E-04	2.12E-04	1.59E-04	7.07E-05	3.08E-03	9.97E-05	2.00E-03
TC-99	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
I-129	2.44E-06	3.16E-06	2.37E-06	1.06E-06	2.04E-04	6.65E-06	1.33E-04
CS-135	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
CS-137	1.86E-02	2.43E-02	1.82E-02	8.12E-03	1.74E+00	5.67E-02	1.13E+00
U-235	4.71E-08	6.15E-08	1.46E-07	3.64E-07	5.33E-08	3.44E-08	3.32E-07
U-238	3.71E-07	4.84E-07	1.15E-06	2.87E-06	4.20E-07	2.71E-07	2.61E-06
NP-237	9.06E-12	1.18E-11	2.81E-11	7.02E-11	1.02E-11	6.61E-12	6.38E-11
PU-238	2.45E-05	4.83E-05	4.49E-05	2.37E-04	7.88E-05	1.88E-04	4.40E-04
PU-239/240	1.82E-05	3.31E-05	1.55E-04	3.80E-04	5.34E-05	9.43E-05	2.36E-04
PU-241	5.63E-04	1.02E-03	4.79E-03	1.18E-02	1.85E-03	3.28E-03	8.20E-03
PU-242	3.99E-08	7.25E-08	3.39E-07	8.34E-07	1.17E-07	2.06E-07	5.18E-07
AM-241	1.85E-05	2.96E-05	2.61E-04	1.62E-04	2.29E-05	1.19E-04	1.54E-04
AM-243	1.26E-06	2.02E-06	1.78E-05	1.10E-05	1.57E-06	8.09E-06	1.05E-05
CM-243	8.52E-09	1.01E-08	2.66E-07	1.66E-07	2.33E-08	2.23E-07	2.56E-07
CM-244	1.06E-05	1.47E-05	1.36E-04	8.44E-05	1.40E-05	1.58E-04	1.72E-04

Table D.28 Group 2 Decayed Isotopic Concentrations (Ci/m^3)

	P-COTRASH	P-NCTRASH	B-COTRASH	B-NCTRASH	F-COTRASH	F-NCTRASH	I-COTRASH	N-SSTRASH	N-LOTRASH
H-3	2.11E-04	4.84E-03	4.70E-05	7.60E-03	0.	0.	5.95E-02	0.	1.86E-02
C-14	1.12E-05	2.57E-04	4.17E-06	6.72E-04	0.	0.	5.25E-03	0.	1.64E-03
FE-55	1.86E-03	4.27E-02	1.89E-03	3.05E-01	0.	0.	0.	0.	0.
NI-59	7.11E-06	1.64E-04	6.21E-06	1.00E-03	0.	0.	0.	0.	0.
CO-60	5.52E-03	1.27E-01	4.89E-03	7.84E-01	0.	0.	4.41E-03	0.	1.38E-03
NI-63	2.07E-03	4.78E-02	1.29E-04	2.08E-02	0.	0.	0.	0.	0.
NB-94	2.25E-07	5.18E-06	1.96E-07	3.16E-05	0.	0.	0.	0.	0.
SR-90	1.87E-05	4.30E-04	1.07E-05	1.73E-03	0.	0.	1.19E-03	0.	3.71E-04
TC-99	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	3.39E-09	0.	1.06E-09
I-129	2.78E-07	6.41E-06	7.14E-07	1.15E-04	0.	0.	0.	0.	0.
CS-135	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	0.	0.	0.
CS-137	2.14E-03	4.92E-02	6.09E-03	9.81E-01	0.	0.	3.78E-03	0.	1.18E-03
U-235	7.89E-09	1.82E-07	1.22E-09	1.97E-07	1.18E-06	1.13E-06	0.	2.36E-06	0.
U-238	6.22E-08	1.43E-06	9.60E-09	1.55E-06	4.40E-06	4.20E-06	0.	8.80E-06	0.
NP-237	1.52E-12	3.49E-11	2.35E-13	3.78E-11	0.	0.	0.	0.	0.
PU-238	5.64E-06	1.30E-04	2.17E-06	3.51E-04	0.	0.	0.	0.	0.
PU-239/240	5.53E-06	1.27E-04	1.16E-06	1.86E-04	0.	0.	0.	0.	0.
PU-241	1.71E-04	3.93E-03	4.01E-05	6.47E-03	0.	0.	0.	0.	0.
PU-242	1.21E-08	2.79E-07	2.53E-09	4.08E-07	0.	0.	0.	0.	0.
AM-241	3.92E-06	9.02E-05	9.56E-07	1.54E-04	0.	0.	4.76E-06	0.	1.49E-06
AM-243	2.67E-07	6.14E-06	6.51E-08	1.05E-05	0.	0.	0.	0.	0.
CM-243	2.35E-09	5.41E-08	1.66E-09	2.69E-07	0.	0.	0.	0.	0.
CM-244	2.00E-06	4.60E-05	1.15E-06	1.86E-04	0.	0.	0.	0.	0.

Table D.29 Group 3 Decayed Isotopic Concentrations (Ci/m³)

	F-PROCESS	U-PROCESS	I-LQSCNVL	I-ABSLIQD	I-BIOWAST	N-SSWASTE	N-LOWASTE
H-3	0.	0.	3.27E-03	9.26E-02	1.14E-01	0.	1.06E-02
C-14	0.	0.	2.51E-04	8.15E-03	1.01E-02	0.	9.35E-04
FE-55	0.	0.	0.	0.	0.	0.	0.
NI-59	0.	0.	0.	0.	0.	0.	0.
CO-60	0.	0.	0.	1.32E-02	1.69E-03	0.	6.23E-04
NI-63	0.	0.	0.	0.	0.	0.	0.
NB-94	0.	0.	0.	0.	0.	0.	0.
SR-90	0.	0.	3.55E-03	3.55E-03	6.82E-03	0.	1.07E-03
TC-99	0.	0.	0.	1.02E-08	6.51E-09	0.	7.76E-10
I-129	0.	0.	0.	0.	0.	0.	0.
CS-135	0.	0.	0.	0.	0.	0.	0.
CS-137	0.	0.	0.	1.14E-02	7.26E-03	0.	8.62E-04
U-235	2.30E-05	1.65E-05	0.	0.	0.	4.60E-05	0.
U-238	8.54E-05	3.64E-04	0.	0.	0.	1.71E-04	0.
NP-237	0.	0.	0.	0.	0.	0.	0.
PU-238	0.	0.	0.	0.	0.	0.	0.
PU-239/240	0.	0.	0.	0.	0.	0.	0.
PU-241	0.	0.	0.	0.	0.	0.	0.
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	0.	0.	0.	0.	0.	0.	0.
AM-243	0.	0.	0.	0.	0.	0.	0.
CM-243	0.	0.	0.	0.	0.	0.	0.
CM-244	0.	0.	0.	0.	0.	0.	0.

Table D.30 Group 4 Decayed Isotopic Concentrations (Ci/m^3)

	L-NFRCOMP	L-DCONRS	N-ISOPROD	N-HIGHACT	N-TRITIUM	N-SOURCES	N-TARGETS
H-3	0	7.51E-03	2.74E-02	0	1.52E+03	5.63E+02	5.24E+01
C-14	2.59E-01	5.12E-04	4.51E-05	1.32E-02	0	5.75E+01	0
FE-55	6.98E+02	1.27E+01	0	2.97E+01	0	0	0
NI-59	1.40E+00	4.49E-02	0	6.56E-02	0	0	0
CO-60	7.70E+02	3.50E+01	0	3.60E+01	0	7.34E+02	0
NI-63	1.98E+02	3.49E+00	0	9.95E+00	0	2.16E+02	0
NB-94	8.19E-03	1.42E-03	0	4.47E-04	0	0	0
SR-90	0	3.61E-02	5.14E+00	0	0	9.42E+02	0
TC-99	0	1.20E-05	3.27E-04	0	0	0	0
I-129	0	3.34E-05	2.72E-06	0	0	0	0
CS-135	0	1.20E-05	3.27E-04	0	0	0	0
CS-137	0	2.71E-01	7.24E+00	0	0	9.53E+02	0
U-235	0	6.84E-05	1.02E-05	0	0	0	0
U-238	0	5.40E-04	3.81E-05	0	0	0	0
NP-237	0	1.32E-08	5.33E-13	0	0	0	0
PU-238	0	1.26E+00	1.84E-04	0	0	0	0
PU-239/240	0	1.77E+00	5.55E-05	0	0	0	0
PU-241	0	2.52E+01	4.75E-03	0	0	0	0
PU-242	0	3.87E-03	9.57E-08	0	0	0	0
AM-241	0	5.23E-03	1.09E-05	0	0	5.69E+02	0
AM-243	0	3.59E-04	1.25E-06	0	0	0	0
CM-243	0	2.98E-04	1.38E-04	0	0	0	0
CM-244	0	2.51E-03	2.11E-07	0	0	0	0

6.1 U.S. Government Operations

Since the first commercial LLW disposal facilities were opened in 1962 (at Beatty, Nevada and Maxey Flats, Kentucky), considerable volumes of wastes generated by U.S. Government agencies have been shipped to commercial disposal facilities. Most of this waste was produced by laboratories operated by or under contract to the Atomic Energy Commission (AEC). One of the original intents of this practice was to help provide some initial business to the then beginning commercial disposal industry. This practice was continued by the AEC's successors, the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE), until October 1979, when it was discontinued by DOE to help alleviate the shortage in commercial LLW disposal capacity (Ref. 47). Currently, all wastes generated by DOE facilities are disposed in DOE disposal sites. Small quantities of wastes produced by other government agencies such as the Department of Defense (nonclassified waste only) or the U.S. Department of Agriculture, however, are still occasionally shipped to commercial LLW disposal facilities.

6.2 Three Mile Island Unit 2 Decontamination

The March 28, 1979 accident at the Three Mile Island (TMI) Unit 2 nuclear power station has resulted in damage to the reactor core as well as generation of significant quantities of contaminated water. Removal of damaged core components and other plant equipment, processing of the contaminated water, and decontamination of contaminated plant equipment and surfaces is projected to take about 5 to 9 years. Over this time period, radioactive wastes in various solid forms will be generated. NRC has prepared and published a programmatic environmental impact statement (PEIS) related to decontamination and disposal of radioactive wastes resulting from the accident (NUREG-0683, Ref. 48). In this document, NRC staff investigated a wide variety of decontamination and waste processing alternatives. Bounding (probable minimum and probable maximum) volumes of wastes projected to be delivered to LLW disposal facilities as a result of these decontamination operations and waste processing alternatives have been set out in the PEIS. A summary of these projections excerpted from the PEIS is included in this appendix as Table D.31.

The range in projected volumes reflects the fact that the actual volumes of waste generated will depend upon decisions regarding which decontamination and waste treatment alternatives are implemented. In many cases, such decisions will be made as the decontamination operations progress.

The decontamination and waste treatment operations will also generate some volumes of waste that will not be disposed at near-surface disposal facilities. These include fuel or pieces of fuel removed from the reactor, other transuranic-contaminated wastes (if generated), and some very high specific activity ion-exchange media wastes generated as a result of treating contaminated reactor building water.

6.3 Generation of Transuranic-Contaminated Waste

This section discusses the past and potential future generation and disposal of waste containing or contaminated with transuranic radioisotopes (isotopes

Table D.31 Volumes of TMI-2 Packaged Solid Waste to be Disposed of at a Commercial Low-Level Waste Disposal Site

Type of Package	Package Volume (ft^3)	Best-Case Conditions: Number of Packages	Best-Case Conditions: Shipped Volume (ft^3)	Worst-Case Conditions: Number of Packages	Worst-Case Conditions: Shippe Volume (ft^3)
55-Gallon Drums					
Low activity	7.5	3,200	24,000	15,400	115,50
Intermediate activity	7.5	502	3,765	1,707	12,80
LSA Boxes*					
Low activity	80	1,042	83,360	2,128	170,24
Contaminated Equipment	70	86	6,020	293	20,51
and Hardware, Mirror Insulation	80	53	4,240	-	-
EPICOR II Resins					
1st stage**	50	49	2,450	49	2,45
2nd stage	50	14	700	14	70
3rd stage	175	6	1,050	6	1,05
Reactor Building Cleanup					
Filters†	10	11	110	11	11
2nd stage	50	2	100	4	20
3rd stage	190	1	190	2	38
Primary System Cleanup†					
Filters††	10/7.5/150	16	990	57	1,34
2nd stage	50	4	200	44	2,20
3rd stage	190	3	570	12	2,28
Total		128,260			329,76

*Low specific activity.

**Will require special disposal procedures (e.g., deeper burial) if disposed of at a commercial disposal site.

†If any of these wastes contain fuel debris or greater than 10 nCi/gm transurani materials, they would not be accepted at a commercial LLW facility.

††Primary system cleanup generated 3 filter types.

having atomic numbers greater than that of uranium, which has an atomic number of 92). To put this discussion into perspective, however, a brief backround is needed regarding past and probable future government disposal policies toward TRU waste.

Background

At one time, transuranic waste was disposed at near-surface disposal facilities operated by the AEC in addition to 5 of the 6 commerical disposal facilities. However, in 1970, the AEC initiated a policy whereby most government-produced waste containing TRU isotopes in concentrations greater than 10 nanocuries per gram of waste material were placed into retrievable storage pending transfer to a repository for ultimate disposal. The 10 nanocurie per gram limit was based upon rough comparison with the potential hazards of upper concentration levels of naturally occurring radium in the earth's crust. However, TRU waste generated as a result of AEC (and later DOE) contracts with private contractors (and some DOE prime contractors) was still sent to commercial disposal facilities

Retrievable storage of commercially-generated TRU waste (pending development of an ultimate repository of the waste) by the Federal government was the intent of a rule proposed in 1974 (Ref. 47). Under this rule, commercial TRU waste would have been consigned to retrievable storage facilities operated by the federal government pending the development of a facility for the ultimate disposition of the waste. A sensitivity level of 10 nanocuries per gram was proposed for measurements to determine the presence or absence of TRU contamination. At the time of the proposed rule, it was expected that commercial recycle of plutonium mixed oxide (MOX) fuel for use in breeder reactors and in light-water reactors would greatly increase in the near future. It was expected that significant additional volumes and quantities of TRU waste material would therefore soon be generated.

Persons commenting on the 1974 proposed rule were generally favorable to the overall concept that the Federal Government should accept title to high-level and transuranium waste and be responsible for its subsequent storage, treatment, and disposal. The draft environmental impact statement (Ref. 50) that was published to support the proposed TRU rule was withdrawn by the Energy Research and Development Administration (ERDA) when the AEC was reorganized to form ERDA and NRC. Also, the AEC's General Manager did not produce the packaging requirements and a schedule of fees necessary for its implementation. The 1974 proposed rule was consequently not adopted by NRC. On the other hand, the retrievable storage policy adopted for government-produced TRU waste is still in effect at sites operated by the Department of Energy (DOE), the successor organization to ERDA.

Individual state initiatives have resulted in a 10 nanocurie per gram disposal limit for TRU waste at all operating commercial low-level waste disposal facilities. Although at one time, five of the six commercial LLW disposal sites accepted TRU waste for disposal (the Barnwell, South Carolina facility has never accepted TRU waste for disposal), this practice has been discontinued. The last commercial facility to accept TRU waste for disposal was the facility located in the center of the Hanford Reservation near Richland, Washington and operated by the Nuclear Engineering Company (NECO) (now U.S. Ecology, Inc.). From 1976 to 1979, the NECO-Richland facility was the only commercial disposal facility accepting TRU waste for disposal. TRU waste acceptance at the NECO-Richland facility in concentrations exceeding 10 nCi/gm was prohibited by the state of Washington in November 1979 (Ref. 43).

In November 1979, the NRC requested that DOE finalize and implement its plans for routine acceptance of commercial TRU waste for retrievable storage pending disposal into a repository (Ref. 51). These plans have been under development by both DOE and its predecessor, the Energy Research and Development Administration and AEC. NRC requested DOE to provide NRC with details on technical criteria for TRU waste storage, including waste form and content, packaging and storage charges. DOE responded that it was their view that they do not have legal authority to accept commercial TRU waste for storage. As a result of the foregoing, there is no means for long-term storage or disposal of TRU waste available to commercial generators. Each licensee must provide his own storage for an indeterminate time.

<u>TRU Waste Generation</u>

Compared to operations conducted by the Department of Energy (DOE), there has been only relatively small quantities of transuranic (TRU) waste generated by the commercial sector. Major sources of transuranic wastes that have been delivered in the past to commercial disposal facilities have included waste from:

- DOE and its successors, the Energy Research and Development Administration (ERDA) and the Atomic Energy Commission (AEC);
- DOE, ERDA, and AEC contractors;
- Reprocessing of spent uranium fuel at the West Valley, New York commercial fuel reprocessing plant.
- Research and development of plutonium fuels, including fabrication of small quantities of mixed-oxide (MOX) fuels for test purposes in light water reactors; and
- Research studies of irradiated reactor fuel.

Within the last few years, the amount of transuranic waste delivered to commerci disposal facilities has been further reduced to even lower levels and has been finally discontinued. This has been caused by a number of factors. One factor was the policy announced by AEC in 1970 whereby AEC-produced TRU waste in concentrations greater than 10 nCi/gm were consigned to retrievable storage at AEC facilities pending the availability of a repository for the ultimate disposition of the waste. TRU waste generated as a result of AEC (and later DOE) contracts with private companies, however, was still sent to commercial disposal sites. The only commercial reprocessing facility ever to operate in the United States was the facility operated by Nuclear Fuel Services (NFS) near West Valley, New York. In 1972, this facility was shut down and has not operated since. In 1976, President Carter announced a national policy of deferment of commercial fuel reprocessing. This poilcy of deferring fuel reprocessing has halted most of the mixed oxide fuel research and development work in the commercial sector. Prior to the cutoff of TRU disposal at the NECO-Richland site, most commercial mixed oxide fuel fabrication test facilities had an active program underway for facility clean-up and decontamination.

Table D.32 is a summary of the quantities of plutonium delivered to the NECO-Richland site during the years 1976 through 1978, and the year 1979 to May 24 (Ref. 18). Most of the TRU waste generated was from clean-up and decontamination of former plutonium research laboratories and small-scale MOX fuel fabrication facilities. Small quantities of waste (e.g., Battelle Columbus Laboratory) were also generated from burn-up studies of LWR fuel. Not shown on this table are some very small quantities of wastes contaminated with Pu-238 (estimated at less than 5.7 m^3/year) and produced from the manufacture of radioactive power sources. Significant quantities of TRU waste shipped to the NECO-Richland site during this time period were owned by DOE--i.e., 75% in 1976, 31% in 1977, 25% in 1978, and 69% in 1979 up to May 24. Much of the other plutonium contaminated wastes--even if not directly owned by DOE--were generated as a direct result of DOE-contracted work.

Future generation of TRU waste is speculative but may arise from three basic sources: decontamination of existing small scale plutonium research and fuel fabrication facilities, studies of irradiated LWR fuel, and recycle of spent uranium fuel.. Based on information received by NRC staff from industry and DOE, it appears that decontamination of existing plutonium fuel fabrication facilities would generate approximately 4960 m^3 of waste over an approximate 3-year time period. These wastes are expected to have low radiation levels permitting contact handling of waste packages. Following these decontamination and decommissioning activities, potential TRU waste volumes are projected to drop to low levels (approximately 75 m^3) (Ref. 52), and would result primarily from destructive examination of reactor fuels. These wastes are expected to have high-surface radiation levels and would require remote handling. Plutonium-238 contaminated waste from manufacture of heat sources would also be expected to continue at a rate of about 5.7 m^3 per year. Of course, the current prohibition of commercial TRU disposal combined with the DOE position on TRU waste acceptance has a great effect on the timing of the generation of such waste. Any waste generated would have to be stored onsite.

Finally, significant quantities of TRU waste could be generated in the future through implementation of a plutonium-based nuclear fuel cycle--that is, through reprocessing of irradiated LWR fuel to extract residual fissile uranium and plutonium and through fabricating the received uranium and plutonium into mixed oxide fuel for reuse in LWRs. Potential volumes and activities of wastes that would be generated by uranium recycle operations have been estimated by a number of groups, including NRC (Ref. 2), DOE (Ref. 54), and the national laboratories, (Refs. 55, 56). Most of the waste thus generated would be contaminated with (or suspected of being contaminated with) transuranic isotopes and would not be acceptable at current operating disposal facilities.

Table D.32 Grams of Plutonium Delivered to NECO-Richland Disposal Facility Between 1/1/76 and 5/24/79

	1979	1978	1977	1976
Babcock and Wilcox Lynchburg, VA	52 (J)	270 (J)	35 (J)	--
Babcock and Wilcox Leechburg, PA	--	27 (G)	414 (J)	7074 (B) 630 (G) 945 (J)
Westinghouse Cheswick, PA	--	152 (G)	222 (G)	273 (G)
General Electric Vallecitos, CA	350 (G)	1006 (G) 2268 (J)	120 (J) 810 (J)	117 (J)
Battelle Columbus, OH	29 (G) 98 (H)	22 (G) 18 (H) 268 (J)	--	--
Battelle (PNL) Richland, WA	--	--	10 (G) 113 (J)	21 (J)
Kerr-McGee Cimmaron, OK	--	77 (J)	49 (J)	1798 (B) 474 (J)
Nuclear Fuel Services Erwin, TN	--	594 (J)	--	76 (J)
Allied General Nuclear Services Barnwell, SC	--	20 (J)	--	--
US Army Material Command	--	--	--	1 (B)
Lovelace Foundation, Albq. NM	--	--	*	*
LFE Environmental, Rich., CA	--	*	*	--
General Atomic Company San Diego, CA	--	--	--	*
Total	529	4870	2242	12330
(B)	-	--	--	--
(G)	379	1207	701	8873
(H)	98	18	--	988
(J)	52	3645	1541	2489
% of Total: (B) + (G)	90%	25%	31%	75%
% of Total: (H) + (J)	10%	75%	69%	75%

(B) DOE-Owned, Lease Agreement - Nonwaiver of Use Charge.
(G) DOE-Owned Production and Research Programs.
(H) Owned by Ohter U.S. Government Agencies.
(J) Privately Owned (Domestic).
*Less than 1 gram.
**To 5/24/79.

In any case, the timing of the generation of such waste is very speculative. The current policy of the United States is to defer processing of spent light-water reactor fuel. Spent uranium fuel removed from nuclear power reactors is presently stored without attempting to extract the residual fissile uranium and plutonium for use. Even if the national policy regarding recyle of uranium fuel were to change within a short time period, it would still be several years before significant quantities of wastes would be produced. Of the three commercial reprocessing plants that have been constructed in the United States--that is, at West Valley, New York, Morris, Illinois, and Barnwell, South Carolina--only the West Valley plant has ever operated. This plant, however, has not operated since 1972. None of the three facilities could operate today without some modification. Of the three, the Barnwell facility would require the least construction--principally construction of a waste solidification facility, a facility for conversion of liquid plutonium nitrate to solid plutonium oxide, and probable installation of additional airborne effluent treatment systems. The Morris facility would require major changes in the design of the processing operations. The West Valley plant would require considerable modification to meet seismic and radiation shielding requirements. In addition, the operator of the West Valley plant--Nuclear Fuel Services, Inc.--has previously (in 1976) expressed a desire not to continue in the reprocessing business.

There are currently no large-scale commercial facilities for fabrication of mixed-oxide fuel, although a number of small scale commercial laboratories and research facilities are in existence that have in the past fabricated small batches of MOX fuel for experimental use in LWRs. Such large scale facilities would have to be constructed if extensive recycle activities were to proceed.

Finally, there are a number of institutional considerations. Licensing for construction of new uranium recycle facilities or modification of old ones would be required. Such licensing would include regulatory review, publication of environmental impact statements and other environmental assessments, and possible hearings. DOE would have to finalize and implement plans for acceptance of TRU and high-level waste for retrievable storage pending disposal into a repository. The costs for such retrievable storage have not been developed by DOE and, as discussed earlier, DOE has taken the position that it does not have legal authority to accept commerical TRU waste for storage. In addition, no final decision has been made regarding criteria for high-level and TRU waste form characteristics for disposal.

6.4 Independent Spent Fuel Storage Facilities

As there is at this time neither an ongoing nuclear fuel reprocessing industry or a federal high-level waste repository, spent nuclear fuel removed from nuclear power plants must be safely stored. This spent fuel is currently being stored in fuel pools located within nuclear power stations as well as within two facilities originally designed to process the spent fuel: the General Electric (GE) reprocessing plant located near Morris, Illinois, and the Nuclear Fuel Servces (NFS) reprocessing plant located near West Valley, New York. The GE facility never became operational and the NFS facility suspended reprocessing operations in 1971. As of the end of 1979, the total amount of spent fuel stored in the Morris and West Valley plants corresponded to about 9 percent of the total U.S. commercial inventory of stored LWR fuel (Ref. 58).

The existing storage capacity for spent LWR fuel is not likely to be adequate until a repository or an ongoing fuel reprocessing industry is developed. Additional storage capacity has been provided through fuel storage densification in existing fuel storage pools. Alternatives that may be used to provide needed additional storage capacity in the future include construction of new pools at power plants, expansion of storage capacity in the West Valley and Morris facilities, use of the fuel storage capacity of the uncompleted Barnwell, South Carolina reprocessing plant, or construction of new independent spent fuel storage facilities. Dry storage concepts for aged spent fuel are also being developed and are of interest for use at either reactor sites or away-from-reactor independent storage facilities. Recently, NRC published a new set of regulations, 10 CFR Part 72, that established rules for licensing independent spent fuel storage facilities, if and when they are constructed (Ref. 49).

Wastes from storing spent LWR fuel would primarily arise from treatment of the storage basin water, receiving and unloading spent fuel, and plant ventilation systems. These wastes include spent resins, filter sludges and miscellaneous trash, and are similar in composition to wastes produced from other light-water reactor operations.

Waste volumes generated to the year 2000 from LWR spent fuel storage are expected to be relatively small. Most of the waste volumes generated would continue to be included with other wastes shipped from power plants. Only small quantities of wastes are produced by the current two facilities practicing away-from-reactor storage. LLW generated at the West Valley plant is disposed onsite at the colocated LLW disposal site. At the Morris plant, low specific activity trash is currently shipped to an LLW disposal site. Liquid wastes and filter sludges generated from backflushing and regenerating the fuel pool water filter system are stored in a large (2.6 million liter capacity) low activity waste (LAW) tank. The LAW tank was originally constructed and intended to store low-level liquids generated during the operation of the reprocessing plant. Eventually, General Electric plans to install a solidification system to solidify the liquids and other wet wastes and send the solidified waste material to an LLW disposal facility (Ref. 59).

DOE has developed an estimate of the annual volumes of waste that could be generated from a large (3000 MTHM) independent spent fuel storage installation, assuming that one is constructed (Ref. 54). These volumes are listed in Table D.33 and are based upon a conservative (in terms of waste generation) assumption of an operating mode in which one-sixth of the storage capacity is replaced each year. The total volume of waste produced from such a large facility is comparable to the annual generation rate of a single 1000 MW(e) light water reactor.

At this time, NRC has not received any application for construction and operation of an independent spent fuel storage facility. The timing for future construction of a storage facility (and associated waste volume generation) is speculative.

6.5 Decommissioning of Nuclear Fuel Cycle Facilities

Nuclear fuel cycle facilities will eventually reach the end of their useful lives and would then be considered candidates for decontamination and decommissioning.

Table D.33 Estimated Annual Waste Volumes Generated from Assumed Operation of a 3,000 MTHM Spent Fuel Storage Facility

Waste Category	Volume (m^3)
Compactible and Combustible Wastes	
Combustible trash	630
Ventilation filters	23
Liquids and Other Wet Wastes	
Bead resins	2
Filter precoat sludge	8
Sulfate concentrate	7
Miscellaneous solution concentrates	10
Noncombustible material	
Noncombustible trash	51
Failed equipment	19
Total	750

In some cases, decontamination and decommissioning activities may merely involve removing enough residual contamination to allow safe modification and reuse as a nuclear facility. In other cases, the facility may be decontaminated to the point that it can be released for unrestricted use.

The timing and extent of potential decontamination and decommissioning activities at a nuclear installation are believed to be speculative at this time. The timing and extent of decommissioning activities may depend upon other factors than the useful life of a nuclear facility--e.g, upon economic decisions or regulatory requirements. It is considered unlikely that significant volumes of wastes from decommissioning nuclear fuel cycle facilities will be produced prior to the year 2000. Nonetheless, NRC staff has investigated the potential volumes, activities, and other characterisitics of wastes generated from decommissioning of a number of different types of nuclear fuel cycle facilities, and these volumes and activities can be briefly investigated to help gauge the potential impacts of future waste streams. Waste streams considered include those generated from decommissioning: (1) light water reactors; (2) uranium fuel fabrication plants, and (3) uranium fuel recycle facilities.

6.5.1 Decommissioning of Light Water Reactors

A significant source of waste to be generated in the future will be from decommissioning light water power reactors. The volumes and activities which will be produced are speculative to a high degree, and will depend upon such factors as the length of service life of a plant prior to decommissioning, the size and design of a plant, the operating history of the plant, and the decommissioning mode undertaken (e.g., immediate dismantlement after shutdown vs. deferring dismantlement for up to several years following shutdown).

Pacific Northwest Laboratories (PNL) has recently completed a pair of studies on the technology safety, and costs of decommissioning a large reference PWR (Ref. 33) and a large reference BWR (Ref. 60). The model for the reference PWR is the Portland General Electric Company Trojan Nuclear plant having a generating capacity of 1175 mW(e) (3500 MW(t)), and using a Westinghouse four-loop nuclear steam supply system. The model for the reference BWR is the Washington Public Power System's Nuclear Project No. 2 (WPPSS-2) at Hanford, Washington. This 1155 MW(e) unit (3320 MW(t)), which is expected to start operation in 1982, uses a General Electric BWR-5 nuclear steam supply system. The plant uses a Mark-II containment.

A summary of the waste volumes and activities estimated by PNL for the two reference LWRs is provided in Table D-34. The volumes and activities are projected from an assumption of immediate dismantlement of the plant following 40 calendar years of operation at 75% of full power, or 30 effective full power years (EFPY). Dismantlement of the reference PWR is projected to require 4 years, while dismantlement of the reference BWR is projected to require 3-1/2 years.

The volumes and activities summarized in Table D-34 should be should be interpreted with some care. Actual volumes and activities from decommissioning a given LWR may be highly site specific and a function of such factors as the size and design of the unit, the rated power level, the amount of time spent at full power, and the time between shutdown and dismantlement. However, it is apparent that on the order of 99% of the activity from decommissioning wastes will be contained in activated metal. Relative volumes and activities for various activated metal components are shown in Table D-35. As shown, specific activities of BWR activated components are estimated to vary by four orders of magnitude, while PWR components by six orders of magnitude. Of special interest for disposal purposes are the BWR core shroud and the PWR core should and lower grid plate.

NRC staff does not expect that volumes and activities of decommissioning wastes generated to the year 2000 will be significant compared to other routinely generated LWR waste streams. In any case, the characteristics of actual waste generated from a particular LWR would be analyzed as part of a decommissioning environmental impact statement prepared for that facility. The volumes and activities estimated by PNL are for large modern units and such units are not expected to undergo decommissioning until well after the year 2000. Reactors potentially dismantled prior to the year 2000 are expected to be considerably smaller in capacity, have shorter operating lives than the reactors used as models for the PNL studies and are expected to generate considerably lower waste volumes and/or activites.

Table D.34 Summary of Wastes From Decommissioning a Reference PWR and a Reference BWR

Waste Stream	Volume (m^3)	Activity (Ci)
Reference 1155 MW(e) BWR:		
Activated metal	138	6,552,310
Activated concrete	90	170
Contaminated metal	15,543	8,574
Contaminated concrete	1,676	55
Dry solid waste (trash)*	3,386	--
Spent resins	42	228
Filter cartridges†	--	--
Evaporator bottoms††	519	43,753
Reference 1175 MW(e) PWR:		
Activated metal	418	4,841,230
Activated concrete	707	2,000
Contaminated metal	5,465	900
Contaminated concrete	10,613	100
Dry solid waste (trash)*	1,418	--
Spent resins**	30	42,000
Filter cartridges†	8.9	5,000
Evaporator bottoms††	133	--

*Volumes shown are as generated and prior to additional treatment such as compaction or incineration. Most of the trash is considered to be combustible.

**BWR spent resins actually include spent resins and filter sludge. Volumes shown are dewatered volumes.

† PWR filter cartridge volumes are as solidified in concrete in 55-gallon drums. Filter cartridges are assumed not to be used in the BWR wet waste treatment system.

††PWR and BWR evaporator bottom volumes are as generated prior to solidification.

Table D.35 Volumes and Activities of Decommissioned LWR Activated Metals

Component	Disposal Volume (m^3)*	Activity Ci	Specific Activity (Ci/m^3)
Reference BWR:			
Steam separator assembly	10	9,600	960
Fuel support pieces	5	700	140
Control rods and in-core instruments	15	189,000	12,600
Control rod guide tubes	4	100	25
Jet pump assemblies	14	20,000	1,429
Top fuel guide	24	30,100	1,254
Core support plate	11	650	59
Core shroud	47	6,300,000	134,043
Reactor vessel wall	8	2,160	46
Total	138	6,552,310	
Reference PWR:			
Pressure vessel cylindrical wall	108	19,170	178
Vessel head	57	<10	.18
Vessel bottom	57	<10	.18
Upper core	11	<10	.91
Support assembly			
Upper support columns	11	<100	9.1
Upper core barrel	6	<1,000	167
Upper core grid plate	14	24,310	1,736
Guide tubes	17	<100	6
Lower core barrel	91	651,000	7,154
Thermal shields	17	146,100	8,594
Core shroud	11	3,431,100	311,909
Lower grid plate	14	553,400	39,529
Lower support columns	3	10,000	333
Lower core forging	31	2,500	81
Miscellaneous internals	23	2,000	87
Reactor cavity liner	15	<10	.7
Total	485	4,841,320	

*Disposal volumes include the disposal container after the activated metal components have been cut into manageable pieces.

There are a number of early low power units generally constructed as demonstration projects forerunning larger, more economical to operate units with capacities on the order of several hundred to a thousand MW(e). Although utilities would generally prefer to keep the older units operable for as long as they are cost-effective, costs of upgrading the older units to meet new NRC safety requirements may result in some of the older plants being decommissioned prior to the year 2000, and prior to the end of their otherwise servicable lives.

A specific example is the Indian Point Unit 1 plant located near Buchanan, New York. This 175 MW(e) (600 MW(t)) PWR was shut down in October 1974 by its utility, Consolidated Edison, due to inability to meet new NRC requirements on emergency core cooling systems (ECCS). Consolidated Edison has recently determined that the cost of upgrading the plant to meet the new ECCS and other requirements would be greatly in excess of the possible economic gain, and have announced their intention of decommissioning the unit. The proposed timing and mode of decommissioning (safe storage, immediate dismantlement, or deferred dismantlement) however, has not yet been finalized.

6.5.2 Decommissioning of Uranium Fuel Fabrication Plants

A relatively minor source of decommissioning waste, compared to decommissioning light water reactors, will be wastes from decommissioning uranium fuel fabrication facilities. Potential waste volumes from decommissioning a relatively large fuel fabrication facility plant have been estimated by Pacific Northwest Laboratories (PNL) (Ref. 61), and estimates based upon this study are summarized in Table D.36. In the PNL study, a model plant is assumed that is based upon an existing facility operated by the General Electric Company in Wilmington, North Carolina. The plant is assumed to be operated for 40 years at a production rate of 1000 metric tons of uranium oxide fuel per year. Feed to the plant is enriched UF_6. All of the calcium flouride (CaF,) wastes and other conversion process sludges that are generated during the process converting UF_6 to UO_2, are assumed to be stored onsite in large lagoons until decommissioning.

As shown in Table D.36, the calculated volumes of wastes generated from decommissioning the plant include trash and other miscellaneous material from decontaminating buildings and other facilities, as well as several thousand cubic meters of low activity bulk solid material such as CaF_2. The total quantity of uranium contained in the 1091 m^3 of miscellaneous trash is projected by PNL to be approximately 270 kg. The concentration of uranium in the 27,000 m^3 of low activity material is expected to be low.

These estimated quantities should be used with some care. For example, the timing of future fuel fabrication plant decommissioning activities is very speculative, and would probably depend more on economic than safety considerations. Although the amount of fuel fabrication capacity would naturally be a function of nuclear power plant capacity, the total potential decommissioning volume would not be expected to be a strong function of capacity. Rather, total volumes of waste material obtained from decommissioning fuel fabrication plants would be more of a function of the number of plants operating and the design of individual plants rather than a function of the total throughput of uranium feed through the plants.

Table D.36 Waste Volumes Generated From Decommissioning a Model 1000 MT UO_2/yr Fuel Fabrication Plant

Wastes from decommissioning buildings and other site structures:

Waste Category	Volume m³)
Hoods, equipment and components	764.4
Pipe, conduit, duct, trays, fixtures, etc.	118.52
HEPA and roughing filters	51.66
Concrete rubble	39.66
Contaminated liner and soil materials	91.0
Miscellaneous	25
Total	1,091

Low-activity bulk solids:

Waste Category	Volume (m^3)
Chemical sludge	1,282
Contaminated CaF_2	25,296
Other miscellaneous contaminated material	3,206
Total	29,784

Projected volumes of CaF_2, and other chemical sludges produced from UF_6 conversion are also speculative. The rate of production of UF_6 conversion sludges at a facility is a strong function of the design of the conversion process used at the facility. Space limitations at an individual plant may result in process sludges being transferred to LLW disposal facilities during plant operation rather than being left onsite in lagoons for later consideration. Existing and future sludge lagoons at fabrication facilities may, rather than being collected and delivered to an LLW disposal facility during decommissioning, be disposed in-place or treated to recover the contained uranium.

6.5.3 Decommissioning Uranium Fuel Recycle Facilities

Should uranium recycling be eventually adopted as a national policy, then uranium recycle facilities that would be constructed would eventually require decommissioning. Such decommissioning activities would occur relatively remote from today--at least beyond the year 2000. Volumes and activities of wastes that would result in decommissioning some reference uranium fuel recycle facilities have been estimated by PNL. In NUREG-0278 (Ref. 61), the technology, safety, and costs of decommissioning a 1500 MTHM/year fuel reprocessing plant are assessed, using the uncompleted Barnwell, South Carolina reprocessing plant owned by Allied-General Nuclear Services as a model (Ref. 62). In NUREG/CR-0129 (Ref. 63), the technology, safety and costs of decommissioning a small mixed-oxide fuel fabrication plant are assessed.

A potential source of wastes that may be generated in the next few years would be from decommissioning the Nuclear Fuel Services (NFS) reprocessing plant located in West Valley, New York. The reprocessing plant has not operated since 1972 and NFS announced in 1976 their intention to withdraw from the nuclear fuel reprocessing business. The eventual disposition of the facility, which includes a fuel reprocessing plant, 600,000 gallons of liquid high-level waste stored in a tank, and a waste disposal area, is being addressed at this time. Fairly recently, DOE published a report that addressses alternatives for eventual disposition of the site, including full or partial decommissioning or continued use as some manner of nuclear production or research facility (Ref. 57). After completion of this study of alternatives, which was mandated by Congress, legislation was passed in 1980 (The West Valley Demonstration Project Act) that charges DOE with the responsibility to develop, construct, and operate a high-level liquid waste solidification project at the West Valley plant. This project will solidify the 600,000 gallons of liquid high-level waste presently stored in underground tanks to a final form acceptable for disposal into a federal repository. Decontamination of existing facilities to prepare for the project as well as activities during the waste solidification project and final decontamination of facilities at the end of the project will generate substantial volumes of low-level waste. Much if not most of this waste is expected to be contaminated with transuranic radionuclides. DOE has not yet determined where these wastes will be disposed, but it appears that most of it will be consigned to a federal (DOE) disposal area.

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Appendix E

DESCRIPTION OF A REFERENCE DISPOSAL FACILITY

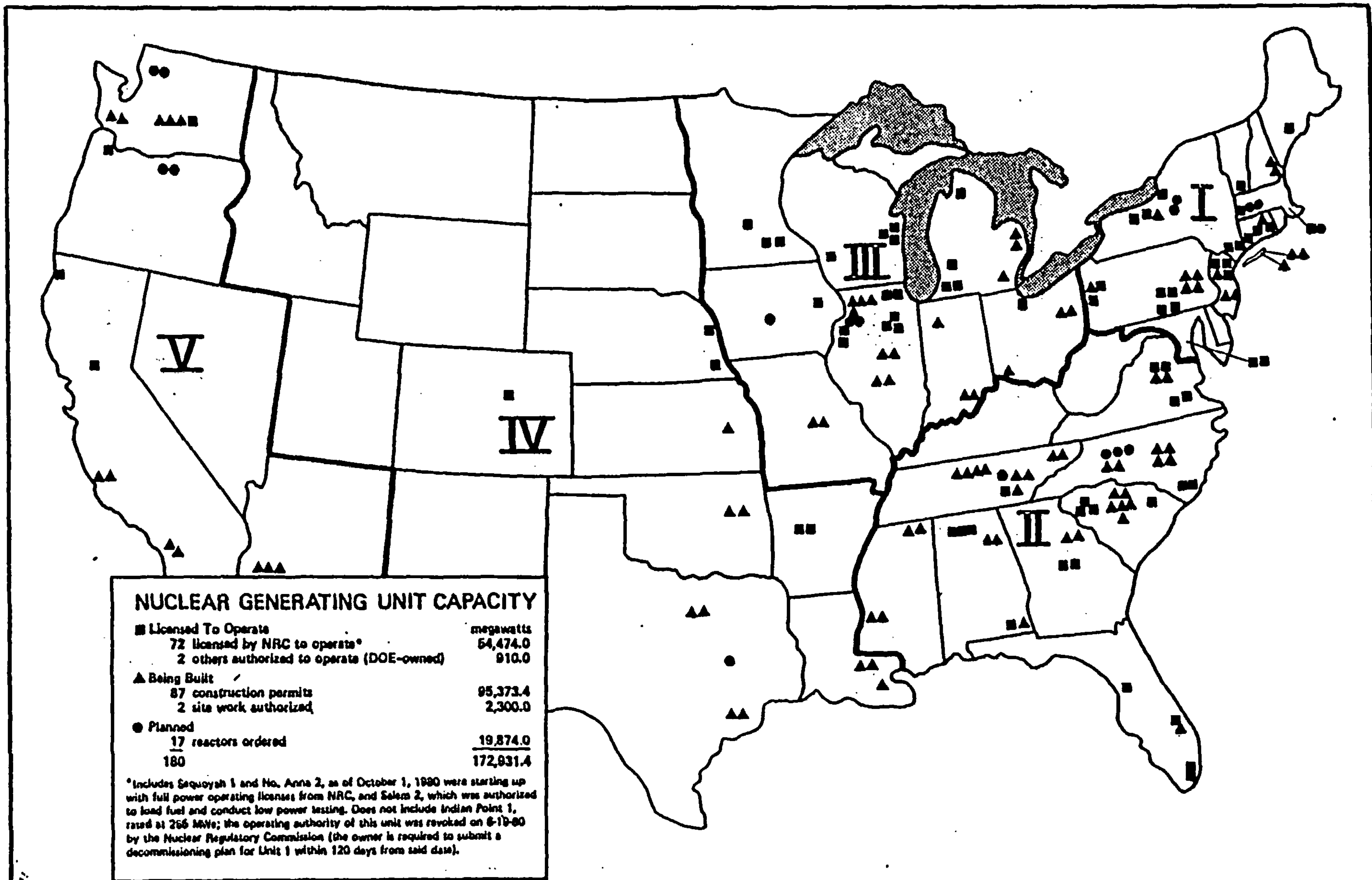
INTRODUCTION

This appendix provides a description of a reference near-surface disposal facility which is located in a humid environment in the eastern United States. The disposal facility is representative of existing disposal facility design and operating practices and is used to determine base case costs and impacts of waste disposal. The costs and impacts of alternative disposal facility designs and operating practices as well as alternative waste forms may be then assessed against those of the base case.

For purposes of this environmental impact statement, NRC staff has divided the continental United States into 4 regions corresponding to the states making up the U.S. NRC Regions. These regions are termed in this environmental impact statement: (1) the northeast region (NRC Region 1); (2) the southeast region (NRC Region 2); (3) the midwest region (NRC Region 3); and (4) the western region (NRC Regions 4 and 5). These regions are shown in Figure E.1. Within each region a hypothetical near-surface disposal facility site is assumed to be located having environmental characteristics typical of the region. The sites, however, are not intended to represent any particular locations within the regions. The specific environmental conditions described for each regional site do not correspond to any existing disposal facility site. In addition, the volumes of low-level waste (LLW) projected to be generated within each region over the next 20 years are estimated (see Appendix D), thus providing a source term for regional waste disposal.

However, the purpose of this environmental impact statement is to develop overall performance objectives and technical criteria for LLW disposal rather than performing a generic environmental assessment of regional disposal of LLW. To develop these overall performance objectives and technical criteria, a cost-benefit evaluation is made of alternative waste forms and disposal facility design and operating practices. To focus on this cost-benefit analysis in Chapters 4, 5, and 6 of this statement, NRC staff also developed a reference radioactive waste source term based upon an average of the volumes of waste projected to be generated in the four regions. This reference source term was then normalized to a total 20-year volume of one million m^3 of LLW, and is given in Appendix D.

This reference source term is then assumed to be disposed into a reference disposal facility which is conservatively assumed to be sited in a humid environment. NRC staff anticipates that over the next 20 years, over three-quarters of the waste generated in the United States will be generated in humid environments--i.e., in the eastern and humid midwestern sections of the country. Regional disposal of waste therefore implies that most of the waste generated in humid environments would also be disposed in humid environments.



BECAUSE OF SPACE LIMITATIONS, SYMBOLS DO NOT REFLECT PRECISE LOCATIONS

Figure E.1 U.S. NRC Regions

Potential ground-water impacts from existing or future disposal facilities are a strong function of actual site-specific meterological and geohydrological conditions, and would be analyzed by NRC on a case-by-case basis. However, potential ground-water impacts (and actions required to protect ground water) at a humid site are generally expected to be greater than those at an arid area. Some of the conditions at an eastern humid site which would indicate this include the relatively higher annual precipitation, shallower depth to ground water, and relatively shorter distances from the disposed waste to the point of ground-water discharge into surface streams.

Of the four hypothetical regional disposal facilities developed in this environmental impact statement (see Appendix J), three (northeast, southeast, and midwest) are located in humid environments. However, site-specific conditions such as amount of percolation, soil cation exchange capacity, speed of ground water, and population density vary somewhat from one site to the next. For this environmental impact statement, environmental conditions corresponding to the southeastern site were assumed, principally because of the rather high percolation assumed for this site in addition to the moderate permeability and ion-exchange capacity of the site soils. The staff believed that these conditions would enable a clearer comparison of the alternatives considered. Otherwise, there was really no compelling reason to choose one site over another. The site environmental conditions of the referenced (southeast) site are described in this appendix. The site environmental conditions of the other three sites are described in Appendix J.

The reference facility and site are used to analyze and to develop overall LLW disposal performance objectives and technical criteria in Chapters 4 through 6. Following this analysis, the unmitigated impacts of applying these performance objectives and technical criteria to the 4 regional disposal facilities are addressed in Chapter 10.

In developing the reference disposal facility, NRC staff was influenced by past history and experience at shallow land burial disposal facilities, and by the desire to emphasize potential long-term costs and radiological impacts in this environmental impact statement. For example, a great deal of experience has been gained over the years regarding handling and disposal of radioactive material. Safe working procedures have been recognized and developed such as the need to maintain strict control of potential site contamination to help minimize personnel exposures and potential offsite radioactivity releases during site operations. In addition, based on past experience with shallow land burial facilities as well as with nonradioactive solid and hazardous (chemical) waste disposal facilities, a number of criteria and recommendations regarding the siting of disposal facilities have been developed by the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), and others. Many if not most of these criteria and recommendations involve the application of common sense. An example of a good reference in this regard is the USGS Open-File Report No. 74-344 ("Storage of Low-level Radioactive Wastes in the Ground, Hydrogeologic and Hydrochemical Factors") prepared by USGS for EPA (Ref. 1).

NRC believes that the development of good siting criteria and good operational practices are important considerations in radioactive waste disposal. However, as stated above, the development of good siting criteria and operational radiation safety practices are to a large part an application of common sense. The main focus of this environmental impact statement, therefore, is the potential long-term costs and impacts of waste disposal--in particular, the potential long-term costs and radiological impacts associated with slumping, subsidence, and other potential site instability problems--as well as methods which can be used to mitigate these potential problems. NRC has previously stated that an overall objective for waste disposal is to close a disposal facility so that it is left 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 (see Appendix I).

In this appendix, therefore, the reference disposal facility is developed assuming that an application for a new facility is received, and NRC's Low Level Waste Licensing Branch Technical Position on disposal facility closure and stabilization (Appendix I) is applied during the subsequent regulatory application review and licensing process. A number of common sense siting considerations and radiation safety practices are also assumed. However, given these siting considerations and radiation safety practices, no special effort is assumed to be made in the reference facility to ensure long-term site stability. This is used to provide a base case level of long-term costs and radiological impacts against which measures to achieve site stability, to minimize radiological impacts, and to ensure adequate funding can be assessed. Many of these measures (e.g., compaction of backfill material and trench caps, and disposal of more stable waste forms) are already being applied today. They have not been assumed for the base case facility, however, in order that the need to incorporate them into technical criteria can be analyzed as a part of this EIS.

The reference facility is sized to accept a relatively large quantity of waste--i.e., 50,000 m^3 of waste per year over a 20-year operating life, or a total volume of one million m^3. This corresponds to approximately one-quarter of the total volume of LLW projected to be generated in the United States to the year 2000. Disposal of a million m^3 of waste in the reference facility described in this appendix will require up to a few hundred acres of land, which corresponds to an approximate upper bound of the land area of current commercial disposal facilities.

The remainder of this appendix is divided into six sections which describe: (1) the lifespan of a reference facility, (2) basic considerations and assumptions regarding the siting of the facility, (3) the environmental characteristics of the disposal facility site, (4) the reference disposal facility design parameters, (5) the basic operational procedures utilized at the reference facility, and (6) the reference facility costs. A list of references is provided in Appendix E, Section 7.

1. REFERENCE FACILITY LIFESPAN

This section provides an overview of the assumed lifespan of the reference disposal facility described in this appendix, including siting, licensing, operation, and eventual closure of the facility. The lifespan is described based upon consideration of existing disposal facilities, existing NRC regulations and licensing procedures, and the existing Low Level Waste Licensing Branch Technical Position "Low Level Waste Burial Ground Site Closure and Stabilization" (see Appendix I). The lifespan can be conveniently separated into 5 phases as summarized in Figure E.2 and discussed in more detail below.

Figure E.2 Life Cycle of a Typical Near-Surface Disposal Facility

Number of Years	Activity	Description
1-2 years	Site Selection and Characterization	Site selection and characterization activities are carried out by the applicant in coordination with NRC, and state and local governments. A preferred site is selected and the site characterized in detail. A license application is prepared which includes a preliminary closure plan, environmental report, arrangement for government ownership of the land, lease arrangements for use of the site, and financial arrangements to cover the costs of closure and post-closure activities.
1-2 Years	Preoperational Licensing	The application is submitted to NRC (including a license fee) and docketed. A notice of receipt of the application is published in the <u>Federal Register</u> and an opportunity for requesting hearings is provided. State and local government officials are notified. An analysis of the application is carried out by the NRC licensing staff including preparation of an environmental impact statement. If no hearings are requested and upon a satisfactory licensing finding, NRC takes action to issue the license. A Notice of Issuance is published in the <u>Federal Register</u> and state and local government officials are notified. If hearings are requested, hearings are held including any Commission reviews and appeals. Upon resolution of all hearings and appeals and upon a satisfactory finding, NRC issues the license, notices issuance, and notifies officials.

Figure E.2 (Continued)

Number of Years	Activity	Description
20-40 Years	Construction and Active Disposal Operations	Upon issuance, the operator begins operations to construct the facility and to receive and dispose of waste. On a periodic basis, (about every 5 years, or as stated in the license), NRC reviews the licensee's program including the preliminary site closure plan, financial arrangements for closure and postclosure activities, and continued assessment of environmental impacts.
1-2 Years	Site Closure and Stabilization	During the operating phase, the site is generally stabilized (e.g., trench caps are put in place) as it is filled. At closure, final site stabilization activities are carried out. Facilities not needed for postclosure activities are decontaminated and dismantled. Costs for closure are provided by financial arrangements of the operator. Upon satisfactory closure, NRC terminates the license and control of the site revert back to the government landowner.
100 years	Institutional Control	The landowner carries out custodial care of the site which includes continued government ownership and control of the site and carrying out activities such as posting, maintaining site security, monitoring of the environment, and carrying out any maintenance activities such as correction of subsidence depressions in trench covers due to consolidation of the waste. The terms and conditions of the lease and financial arrangements of the operator and owner provides funds to cover the costs of these activities.

The 5 phases include: (1) site selection, (2) preoperational activities, (3) disposal operations, (4) site closure, and (5) an institutional control period. The overview is intended to provide a backdrop for the discussion in the subsequent sections regarding such activities as siting, designing, operating, and closing the disposal facility, as well as funding for closure and for institutional control. The overview helps to place the timing and extent of these activities into perspective.

As part of the discussion on the lifespan of the reference facility, reference is made to interactions between an applicant or licensee and a regulatory (licensing) agency. The applicant submits an application to a licensing agency which is then reviewed in accordance with licensing procedures established by the licensing agency. For the purposes of this appendix, the licensing agency is assumed to be NRC and the licensing procedures described are those of NRC.

1.1 Site Selection and Characterization Phase

Once the need and desire to operate a waste disposal facility has become established, the potential applicant embarks on a site selection study which is assumed to last approximately 1 to 2 years. The intent of the site selection study is to review and evaluate potential locations for a disposal site through a systematic process, and to gather sufficient data to support a license application. There are a number of methods or procedures by which the site selection study may be carried out. A brief outline of a method assumed to be used by the potential applicant is described below.

For the purposes of this appendix, the potential applicant is assumed to first establish a region of interest within which the potential applicant would propose locating a near-surface disposal facility. Depending upon the particular circumstances, this region of interest may be of a variable size--e.g., encompassing a single state or potentially a multiple-state region. From within this region of interest, the potential applicant selects a number of candidate areas within which perhaps 8 to 12 potential sites may be identified. This list of potential sites is then narrowed down to a slate of alternative candidate sites (3 to 5 sites) from which a most-favored site is eventually selected.

In arriving at a slate of candidate sites, the potential applicant principally uses reconnaissance level information in obtaining needed hydrologic, geologic, demographic and other data. That is, use is made of such information as relevant scientific literature (e.g., topographic, geologic, water resource, biotic, and demographic maps, as well as aerial photographs), reports of government or private research agencies, consultation with experts, and short-term field investigations, as well as analyses performed using such information. The amount of information collected and the extent of analyses conducted increases as the potential applicant moves from consideration of the region of interest to the slate of candidate sites. In analyzing the data, eliminating unfavorable areas, and eventually arriving at the slate of candidate sites, the potential applicant is assumed to use a number of common sense siting considerations such as avoiding heavily populated areas, fractured media, active faults, or floodplains. These and other basic siting considerations are discussed in more detail in Appendix E, Section 2. An additional consideration, which is assumed to be of importance to a potential applicant, is the availability of a good local road network. Socio-economic factors such as current land use and the availability of labor or local utility services are also important considerations to the potential applicant.

To assist in selecting a most-favored site from the slate of candidate sites, the potential applicant is assumed to drill a small number of subsurface reconnaissance wells at each of the slate of candidate sites. This is to help determine the agreement between the regional hydrologic data base and more specific site conditions. Several of these reconnaissance wells are later converted into monitoring wells at the candidate site eventually proposed in the application for license (see Appendix E, Section 1.2).

The potential applicant is now assumed to purchase the site (approximately 200 acres) most favored among the slate of candidate sites and to initiate the detailed subsurface investigation of the site. From this field investigation, the potential applicant is assumed to prepare such items as detailed boring logs, numerous cross-sections of the site geology, a site topographic map with a scale no greater than 1 inch = 100 ft, and a site potentiometric surface map for each aquifer of interest. In addition, the potential applicant is assumed to define the engineering and material properties of the soil units used for disposal, backfill, or trench caps, and to prepare a site drainage drawing.

It is assumed that a range of 25 to 50 wells of variable depths are drilled to determine the subsurface conditions of the site. Many of the peripherally located wells are assumed to be subsequently converted into ground-water monitoring wells. The potential applicant commences preoperational monitoring of the site, which helps to provide the data needed to support the license application as well as the baseline from which the effects of site construction and waste disposal are identified. The preoperational monitoring program includes periodic collection of surface water, ground water, biota, soil, and airborne particulate samples by an appropriate method (e.g., grab, continuous or composite sampling). Ground water levels and stream flows are measured periodically. Site meteorological data--particularly precipitation, wind speed and direction at various heights, temperatures, and soil moisture data--are also measured.

Throughout the site-selection phase, the potential applicant is assumed to have had a series of discussions with state representatives regarding custodianship of the disposal facility, and with funding mechanisms for long-term care of the facility.

During the final year of the site-selection phase, the investigations performed at the favored and candidate sites are assumed to have sufficiently and favorably progressed so that the potential applicant has reasonable confidence that there are no insurmountable technical or political problems. The potential applicant is then assumed to reach a management decision to proceed with the undertaking and preparation of a license application is initiated.

1.2 Preoperational Phase

This phase of the facility life span is assumed to last approximately two years and mainly consists of submittal of a license application to NRC and subsequent review by NRC licensing staff. During the review period, the applicant continues with the preoperational environmental monitoring program.

Upon receipt of the application, NRC would docket the application. If the application is incomplete, NRC would notify the applicant of the items needed to complete the application. In addition, upon docketing the application, NRC would notify the governor and the state legislature of the state in which the proposed site is located that a license application had been received. It is expected that this notification would be only a formality as considerable prior contact with state representatives by the applicant is highly probable.

The application would include a safety analysis part and an environmental report pursuant to 10 CFR Part 51. The environmental report would include a detailed description of the proposed action, a statement of its purposes, a description of the environment affected, and a description of the potential effects of the facility on that environment. As part of this, the proposed site (previously termed the most favored site among the slate of candidate sites) is described in detail. The potential environmental consequences and methods to mitigate these consequences are addressed, as well as alternatives to the proposed action, including alternative sites.

Also included with the license application is a preliminary site closure plan. This plan will include a detailed plan for waste emplacement, expected capacity of the site, the planned site contours and drainage systems during operations as well as the final site contours, and delineation of the buffer zone. The closure plan will include: (1) estimated costs of labor, equipment and material for closure and stabilization, and (2) long-term labor and material costs for eventual site surveillance, monitoring, and control by the site owner.

Once the complete application has been received and docketed by NRC, the receipt of the application is announced in the Federal Register in compliance with Part 2 of the Commission's regulations. A press release is also issued. In the Federal Register notice, opportunity is provided for persons with an interest in the proposed action to request a hearing. If such a hearing is to be held, NRC will appoint an Atomic Safety and Licensing Board (ASLB) to review the licensing action. Meanwhile, the application is reviewed by NRC licensing staff and a safety evaluation report is prepared. If the information contained in the application is insufficient to prepare the safety evaluation report and reach a decision, additional information may be requested from the applicant.

Under existing NRC regulations in 10 CFR 51, issuing a license for a waste disposal facility constitutes a major federal action according to the National Environmental Policy Act of 1969. Accordingly, an environmental impact statement (EIS) is prepared by the NRC staff and a draft published for public comment. Based upon public comment received and perhaps based upon additional information obtained from the applicant, a final EIS is prepared and published. Upon consideration of the final EIS, NRC staff will make decisions regarding the application and, if a license is granted by the Commission, any license conditions that the staff believe are necessary. If a hearing is held, NRC licensing staff would recommend a course of action (i.e., either rejecting the application, or granting a license subject to conditions) to the ASLB. Testimony would be presented and intervenors would be given an opportunity to cross-examine witnesses. The ASLB will review all testimony but ultimately would reach a decision on the application. This decision may be appealed to the Atomic Safety and Licensing Appeal Board, then to the Commission, and finally to the courts. Hearings, including preparation and presentation of testimony and preparation of the hearing record leading to a decision would last approximately one year.

After resolution of any hearings and appeals, the NRC staff may issue a license. Before the license can be issued, however, ownership of the disposal facility site must be transferred to either the state or federal government and an acceptable funding arrangement must be provided.

For purposes of this appendix, the facility site is assumed to be transferred by the applicant to the control of an agency of the state in which the site is located. The state is assumed to enter into a lease arrangement with the applicant. The terms and conditions of the lease are assumed to be reviewed on a 10-year basis, with the exception of funding arrangements, which are assumed to be reviewed on a 5-year basis.

Funding arrangements are established as part of the lease, and include specific arrangements to provide funds for: (1) disposal facility closure and stabilization; and (2) long-term site surveillance and control by the site owner (in this case the state). The availability of funding for facility closure and stabilization is assumed to be assured through a surety bond acquired by the applicant. This surety bond would be used by the state to close the site should the applicant default (e.g., go out of business). Otherwise, the applicant would pay for final site closure. (As discussed in Appendix K, in many cases existing disposal facilities did not provide for the specific availability of funds for site closure. Financial assurance, however, is part of the NRC Low Level Licensing Branch Technical Position on Site Closure and Stabilization and is presently being applied to operating sites.) Funding for long-term care and surveillance is assumed to be provided by a surcharge on waste received and disposed at the facility. Monies collected from this surcharge are placed into an interest-bearing state account which is dedicated to the long-term care of the facility. (Also see Appendix Q for a discussion of the funding assumptions used in the numerical analyses.)

1.3 Operational Phase

The licensee is now able to commence construction at the site. Construction at the site may be divided into two activities: facility construction, and operational construction and site utilization.

Facility construction is assumed to include erection of a security fence around the restricted area, a perimeter gravel road, and a number of support structures including an administration building, a warehouse, a garage, a health physics facility, and an initial waste disposal cell. It is expected that construction of the required facilities for the disposal site will consume a few months to a year. At the point when the licensee is ready for waste acceptance, NRC would inspect the site to ensure that the facility is constructed in accordance with the license. If NRC is satisfied that this is the case, the licensee would be allowed to begin to receive and dispose of waste. Operational construction continues through the operational phase of the site and includes such activities as trench excavation, waste emplacement, backfilling, construction of trench caps, and maintenance of site drainage patterns. Internal access roads would also be laid out as needed by the licensee.

During the operational phase, waste is received by the licensee, inspected for compliance with federal regulations and license conditions, and disposed. Groundskeeping, maintenance, environmental monitoring, recordkeeping and other support activities also are performed during this phase. A small security force is assumed to be present to help control access to the site. During this phase, funds are collected as part of a lease arrangement with the state as a surcharge on the waste received from customers. These funds are placed into state-controlled interest-bearing accounts for long-term site care.

The licensee's operations are periodically inspected by NRC inspectors for compliance with license conditions and NRC regulations. In addition, the licensee would periodically submit an application for license renewal, at which time additional site data gathered during facility operations, the licensee's operations, and the license conditions are formally reviewed by NRC licensing staff. NRC anticipates that these license renewal activities would normally occur at approximately 5-year intervals. With each license renewal application, the licensee provides an updated site closure plan with special attention paid to potential revisions in long-term funding arrangements.

Approximately one year before the site is filled to capacity, the licensee submits a final site closure plan for review by NRC. This final closure plan would include a description of final estimates of costs, environmental impacts, data needs, material and equipment needs, planned documentation and quality assurance, as well as a detailed plan of trench locations and elevations in expected capacities, planned surface contours, and buffer zones. The final plan would also include a schedule for implementation of any remaining uncompleted plan elements, and a description of the mechanics of orderly transfer of control of the site to the site owner.

1.4 Site Closure Phase

Upon review and acceptance of the site closure plan by NRC, the site closure plan is implemented by the licensee. Final site closure, including any remaining site stabilization and contouring, will be carried out during this period. The type of activities in this phase may also include decontamination of facilities, equipment, and land, as well as decommissioning of buildings (dismantlement of the majority of structures). Surveys of the site are carried out to ascertain the acceptability of the site surface with respect to surface contamination for the institutional control period. It is expected the closure phase will last one to two years. The funding for site closure activities is assumed to come from either the licensee or from the surety funds provided for as part of the closure plan.

1.5 Institutional Control Period

After the site has been closed, the disposal license is assumed to be terminated and the responsibility for the site passed to the site owner. This phase is termed the institutional control period and may be divided into two periods: the active institutional control period and the passive institutional control period. At the beginning of the active institutional control period, the license is terminated and control over the site is transferred back to the owner (in this case, the state government). The active institutional control period is anticipated to last up to one hundred years while the passive institutional control period has an indefinite duration. During the active institutional control period, the site owner would be engaged in the normal activities of land ownership including routine inspections, fence maintenance, trench cap repairs, vegetation control, and monitoring activities. Funds for these activites are provided by the monies collected as a surcharge on received wastes and placed into an interest-bearing state account dedicated for this purpose. Cost estimates for these activites are provided in Appendix E, Section 6. During the passive institutional control period, the site owner is assumed to hold the title and do little or no site inspection or maintenance.

2. BASIC SITING CONSIDERATIONS

Radioactive wastes have been buried in near-surface disposal facilities since World War II. Between World War II and 1962, the United States Government was the principal entity involved in near-surface disposal of radioactive waste. Since 1962, six commercial disposal sites have been licensed and have operated within the United States. The federal and commercial disposal facilities have provided over 35 years of experience. Based upon observed performance of these facilities, specific recommendations made by federal regulatory agencies and panels of experts, and existing regulations promulgated for environmental protection, some basic siting considerations become apparent.

Among the important federal agencies and groups which have addressed basic radioactive waste disposal facility siting considerations are the U.S. Geological Survey, U.S. Environmental Protection Agency, and the National Research Council (Refs. 1-4). Basic low-level radioactive waste disposal facility design considerations have also been addressed by NRC (Refs. 5-6). Siting requirements developed by EPA for nonradioactive solid and hazardous waste disposal may also be considered (Refs. 7-10), as well as criteria on flood plain management and protection of wetlands (Refs. 11-14). Siting criteria for radioactive and nonradioactive solid and hazardous waste disposal have also been developed by the states (Refs. 15-16). Siting criteria recently promulgated by NRC for disposal of uranium mill tailings may also be considered (Ref. 17).

2.1 Hydrologic Considerations

Based on past experiences at disposal sites, the observed underlying causes for some difficulties experienced, and recommendations made by organizations such as those described above, there appears to be at least six basic hydrologic factors which should be considered during site selection. These six hydrologic factors are:

1. The subsurface media in which disposal is made should be relatively homogeneous and lacking elements of lithological complexity or highly unpredictable geometries.

2. The waste disposal cells should be located above the highest seasonal water table.

3. The surface of the disposal site should be devoid of significant surface water features such as swampy conditions, large scale hydrologic depressions which do not allow rapid drainage, wetlands, and ponds.

4. The site should not be located in a floodplain. Investigations should be able to demonstrate that no waste disposal will occur within a 100-year floodplain.

5. Sites should be located outside of coastal hazard areas.

6. Sites should have long ground-water travel times between disposal cells and potable drinking water supplies or ground-water discharge areas. Ground-water travel times in excess of the period of radiological hazard are obviously preferrable; however, shorter ground-water travel times may be acceptable given suitable hold-up by waste form and packaging, by engineering barriers, and/or by site characteristics such as extremely low ground-water flux or high sorption.

Simple subsurface media is preferred for disposal sites so that reliable transport predictions can be made and a representative monitoring network established. Should a source term (i.e., trench leachate) become available for transport at a disposal site, a reliable prediction can provide a description of the probable levels of contamination potentially released offsite. These predictions of radionuclide transport can be checked against monitoring data throughout the operational period.

Should calculations and measurements indicate the potential for significant releases (i.e., in excess of applicable standards), remedial measures could be performed to mitigate the potential effects of offsite subsurface contaminant migration. Conversely, at a site where the substrate was characterized by extreme heterogeneity (e.g., multiple discontinuous layering of materials with highly variable permeabilities), prediction monitoring and remedial control of contaminant transport may be difficult.

As long as the waste is kept above the highest generally observed water table, the probability of significant contact time between waste and ground water can be kept low by engineering design and construction. The greater the volume of water in contact with disposed waste, the longer the time of contact and the greater the extent of leaching of radiocontaminants that can be expected. This is clearly an undesirable situation.

Avoiding significant surface water features such as wetlands, swamps, bogs, and other stagnant water conditions serves three major purposes: (1) protection of important wildlife habitats, (2) protection against intrusion of significant quantities of water into the disposal cells, and (3) avoidance of short ground-water travel times to drinking wells or discharge areas.

The federal government has provided direction with respect to avoidance of flood plains (Refs. 8, 10 and 11). Among the obvious reasons for avoiding siting within a floodplain are the probability of floods and erosion. It is clearly not advisable to construct a disposal facility in a floodplain where floodwaters could potentially inundate the site and carry waste packages away. Additionally, an area susceptible to flooding generally implies a relatively high susceptibility for large-scale erosion which can compromise the integrity of the disposal cells. Avoiding coastal high hazard areas is also intended to prevent significant flooding or erosion of the disposal site.

Finally, a long ground-water travel distance between disposal cells and the nearest receptor point or discharge area is desired so that radioactive decay, dispersion, and/or retardation can reduce potential impacts resulting from potential offsite contamination. For example, it may not be desirable to locate a new disposal facility within close proximity (e.g., 500 meters) of a municipal drinking water well field. Similarly, given the desire for a long ground-water travel time, it may not be advisable to locate a site within close proximity to a perennial surface stream.

2.2 Geologic Considerations

In many ways, geologic siting considerations overlap many of the hydrological considerations. However, these considerations are not necessarily directly related to water and its contact with waste. Among the basic "common sense" considerations with respect to site geology are:

1. Disposal within horizons containing highly fractured, jointed, or cavernous media should be avoided.

2. Disposal at sites with significant topographic relief which may result in slope failures, extreme erosion rates, etc., should be avoided.

3. Disposal in areas where active fault zones have been identified should be avoided.

The rationale is straightforward. Disposal within horizons containing highly fractured media introduces substrate complexity and an enhanced secondary permeability. Substrate complexity results in reduced ability to reliably predict, monitor or mitigate contaminant transport. This results in decreased ability to mathematically model the site and to perform environmental monitoring with some appreciable level of confidence. Highly fractured media also enhances unpredictable contaminant transport.

The rationale behind avoiding significant topographic relief relates to the desire to avoid slope instability, and to the ability to manage surface water, prevent erosion, and construct disposal cells having reliable performance. With respect to surface water management, a slight to moderate slope aids in the runoff of surface water and minimizes infiltration into the disposal cells. However, if the slope is too steep, then the higher velocities associated with runoff water may produce accelerated erosion or may necessitate surface runoff control systems that require active maintenance. In addition, local floodings could be a problem during periods of high flow. Construction and management of acceptable disposal cells can also be difficult on steep slopes.

Although ground acceleration from earthquakes should not normally adversely impact a disposal site, seismic activity can pose problems under certain circumstances. At a typical near-surface disposal facility consisting of burial trenches, three seismic concerns can potentially impact the performance of the site. The three major seismic concerns are liquefaction, structural damage, and horizontal/vertical displacement.

Liquefaction appears to be of concern only if wastes in the disposal cells in the unsaturated zone move downward into liquefying deposits below the disposal cells. Potential structural damage at a "burial trench" facility could occur to the supporting structures during site operations. However, potential environmental releases would be expected to be minimal as all or nearly all of the radioactive material at the facility would be in a solid form. If engineered structures are employed as disposal cells, and the integrity of these disposal cells is considered the major barrier against long-term release of radionuclides, then these structures may have to be designed to withstand the expected maximum ground motion for the particular region. The third concern for "burial trench" facilities is anticipated to result from horizontal or vertical fault displacements on the scale of feet or tens of feet which could expose waste or otherwise compromise the integrity of the trench caps. This type of occurrence is expected to occur only in the vicinity of an active fault zone, which should be identifiable and avoided during site selection.

2.3 <u>Demographic and Nonradiological Environmental Considerations</u>

Principal demographic and nonradiological siting considerations include the following:

1. Areas of high population density should be avoided.

2. Areas which have high recreational potential should be avoided.

3. Historic areas or areas which constitute habitats of unique or endangered flora or fauna should be avoided.

4. Areas with a potential for significant economic development of natural resources should be avoided.

Areas of high population density should be avoided to minimize the potential for intentional or unintentional intrusion and reduce potential impacts from waste disposal. Areas containing scenic vistas or recreational lands such as lakes, national parks, and forest preserves should be avoided in compliance with existing federal laws and regulations. In addition, the disposal facility should not be located where nearby facilities or activities could adversely impact the long-term performance capability of the site.

3. DISPOSAL SITE ENVIRONMENT

In this section, the environment of the reference disposal facility site is described. The description is meant to be representative of the southeastern United States but should not be construed to represent any existing site or any particular location, or NRC advocacy of any particular site or location. The site environment includes information on meteorology, hydrology, topography, soils, geology, seismicity, ground water, surface water, background radiation, demography, and resources. The section is divided into five subsections: meteorology, hydrogeology, demography, ecology and natural resources.

3.1 Meteorology

The reference disposal facility is assumed to be located within a humid subtropical climatic regime. The annual average precipitation at the site over the past twenty years has been 1168 mm (46 in), with an annual range of 838 to 1473 mm (33 to 58 in). Four distinct seasons are observed at the site, although the winters are somewhat short and mild with an average temperature of 9°C (48°F). The summers within the region of the site are characterized by warm weather with temperatures generally averaging between 24° and 27°C (75° and 81°F). The temperature characteristics of the site are given in Figure E.3.

The relatively mild temperature variation observed at the site suggests that large-scale desiccation and frost-heaving of trench caps are not likely to occur. The highest intensity storms result from the remnants of inland travel of hurricanes and tropical storms. The maximum 24-hour rainfall recorded at the site over the last twenty years is 152 mm (6 in). Snowfall at the site is generally light and rarely exceeds three inches for one snowfall. The average snowfall is 12 mm (0.5 in). Snowfall is generally observed during the months of January and February. Precipitation event intervals for the reference disposal site are shown in Figure E.4.

A water balance calculation for the site is presented in Table E.1. This calculation has been described by others (Ref. 18) and is used to determine monthly quantities of precipitation, evapotransportation, run-off and infiltration (percolation) at the reference disposal site. As shown in the table, approximately 180 mm (7 in) out of an annual 1168 mm of precipitation percolates into the site soils.

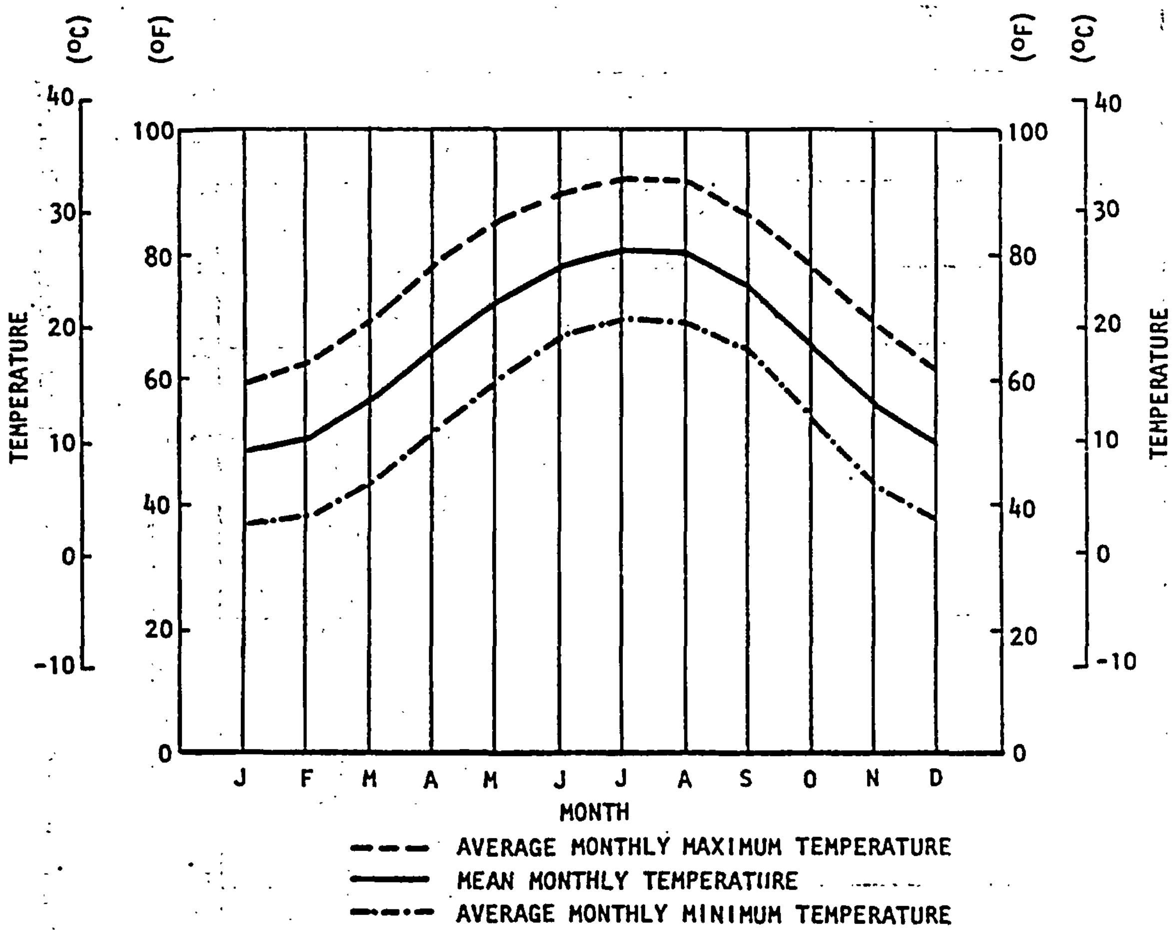


Figure E.3 -Mean Monthly Temperature - Reference Disposal Facility

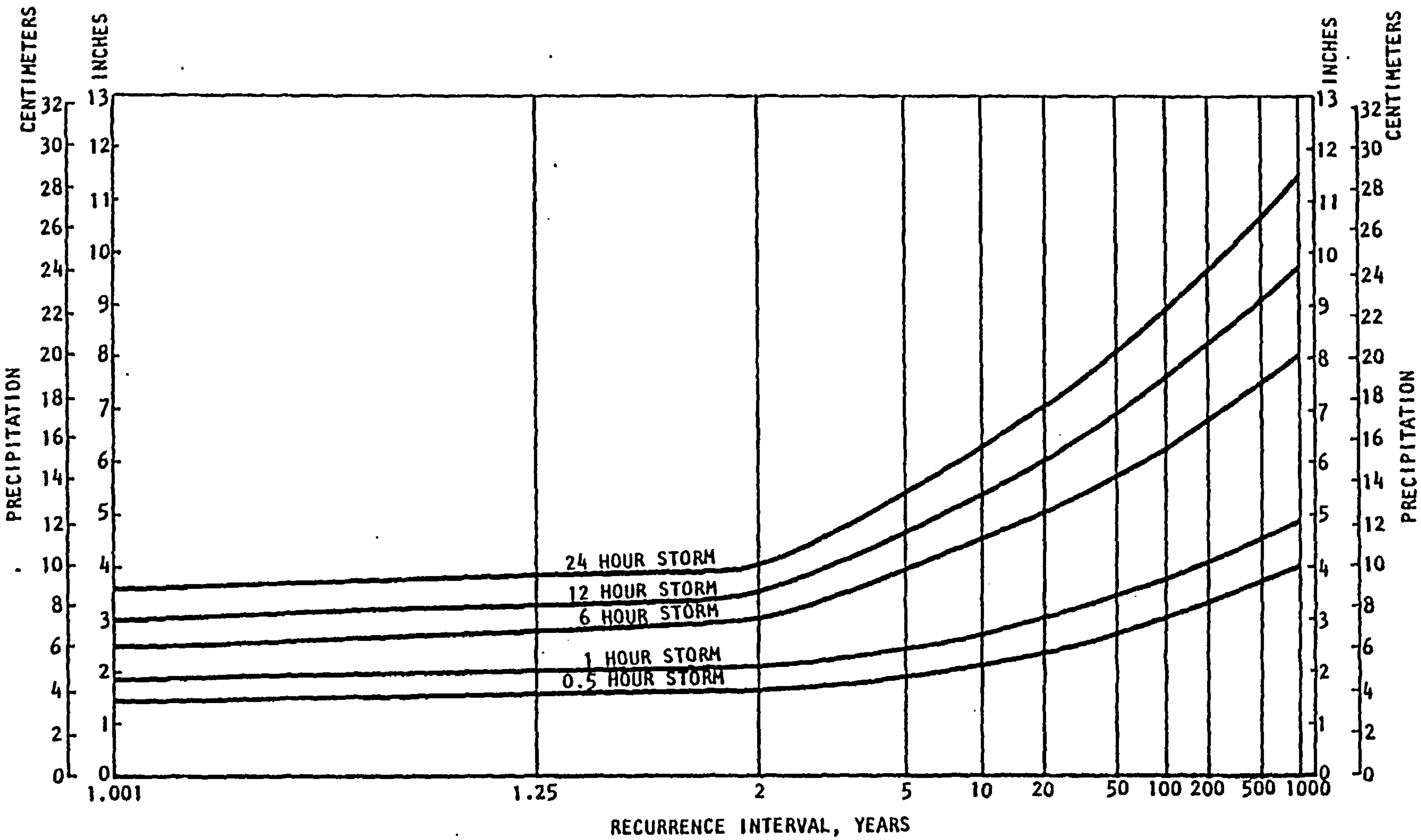


Figure E.4 Precipitation Event Recurrence Intervals - Reference Disposal Facility

Table E.1 Water Balance Calculation for Reference Disposal Facility

	J	F	M	A	M	J	J	A	S	O	N	D	Annua
PET	13	15	37	65	115	158	172	157	114	64	29	13	952
P	80	100	96	84	82	102	149	147	103	64	77	81	1168
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	151
I	69	86	83	72	71	90	131	129	91	56	66	70	1014
I-PET	56	71	46	7	-44	-68	-41	-28	-23	-8	37	57	62
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	107	63	29	13	915
PERC	56	71	46	7	0	0	0	0	0	0	0	0	180

S_M = Maximum soil moisture storage (mm)

P = Precipitation (mm)

C = Surface runoff coefficient (dimensionless)

R = Surface runoff (mm)

I = Infiltration (mm)

PET = Potential evapotranspiration (mm)

I-PET = Difference between (I) and (PET) (mm)

CNS = Cumulative sum of negative (I-PET) (mm)

S = Soil moisture storage (mm)

dS = Change in soil moisture storage (mm)

AET = Actual evapotranspiration (mm)

PERC = Percolation into ground-water system (mm)

The prevailing winds at the site are south-southwesterly with an average wind speed of 13 km/hr (8.8 mph). The wind rose for the site is presented in Figure E.5. The average humidity at the site is 78%, with an average low of 68% usually occurring in January and an average high of 88% occurring in August.

Tornado activity within the immediate area of the site proper is moderate with an estimated occurrence of one tornado every 500 years. Within 50 km (31 mi) of the site, the occurrence frequency of tornadoes is on the order of once every fifty years.

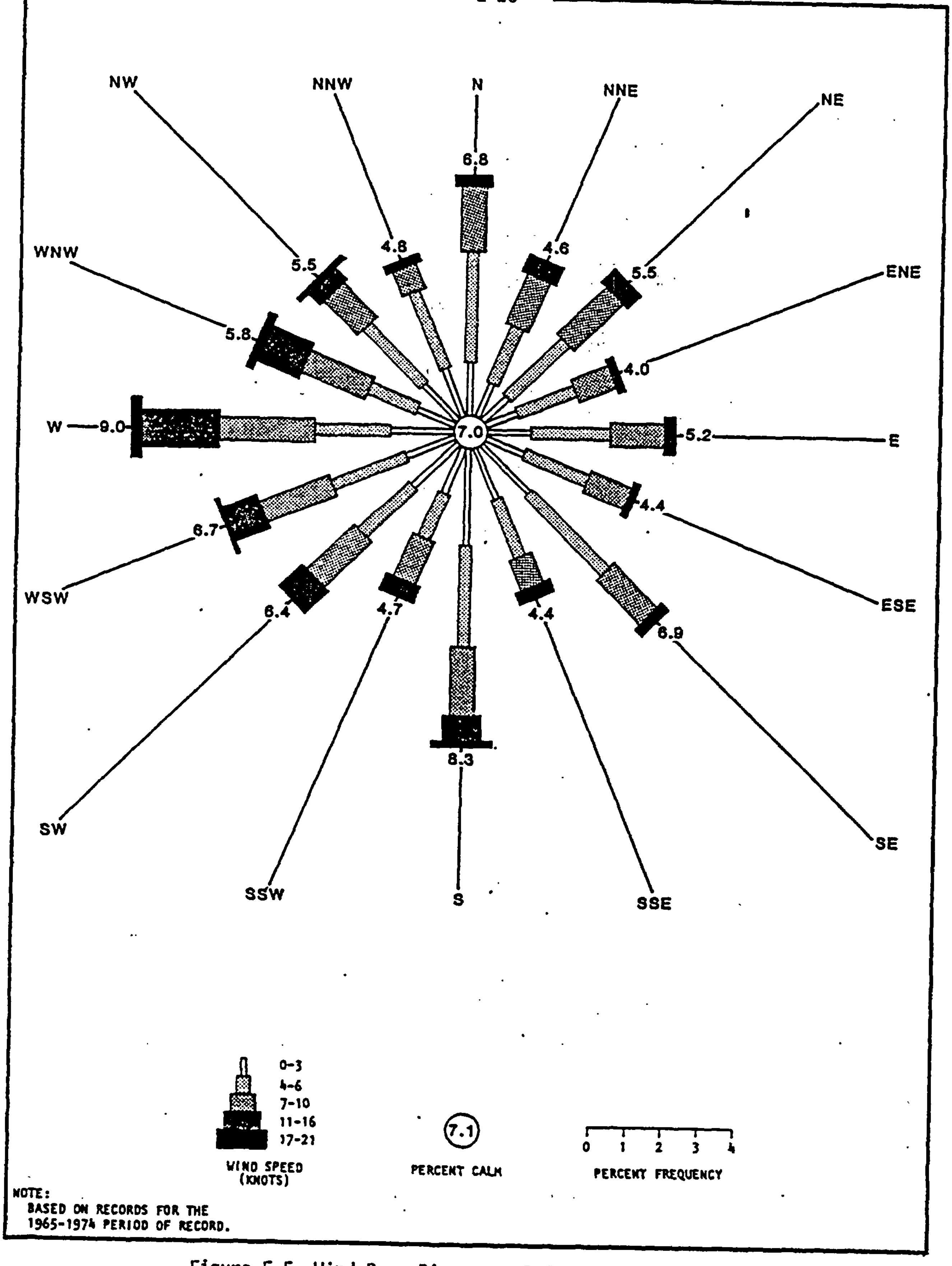


Figure E.5 Wind Rose Diagram - Reference Disposal Facility

The air quality at the site is quite good with concentrations of all major pollutants below USEPA standards (see Table E.2). The good air quality is largely due to a lack of point sources of pollution near the site. The only major point source of airborne pollutants is a coal-fired electrical generating station located 43 km (27 mi) to the northeast of the site. Farming activity on land adjacent to the site is also a source of air pollutants.

Table E.2 Air Quality at the Reference Disposal Facility

Pollutant	Concentration (mg/m^3)	USEPA Standard
Suspended particulates		
24-hr average	90	150
annual average	45	60
SO_2 (annual average)	20	60
NO_X (annual average	28	100
Hydrocarbons		
3-hr average	70	160
annual average	68	-

3.2 Hydrogeology

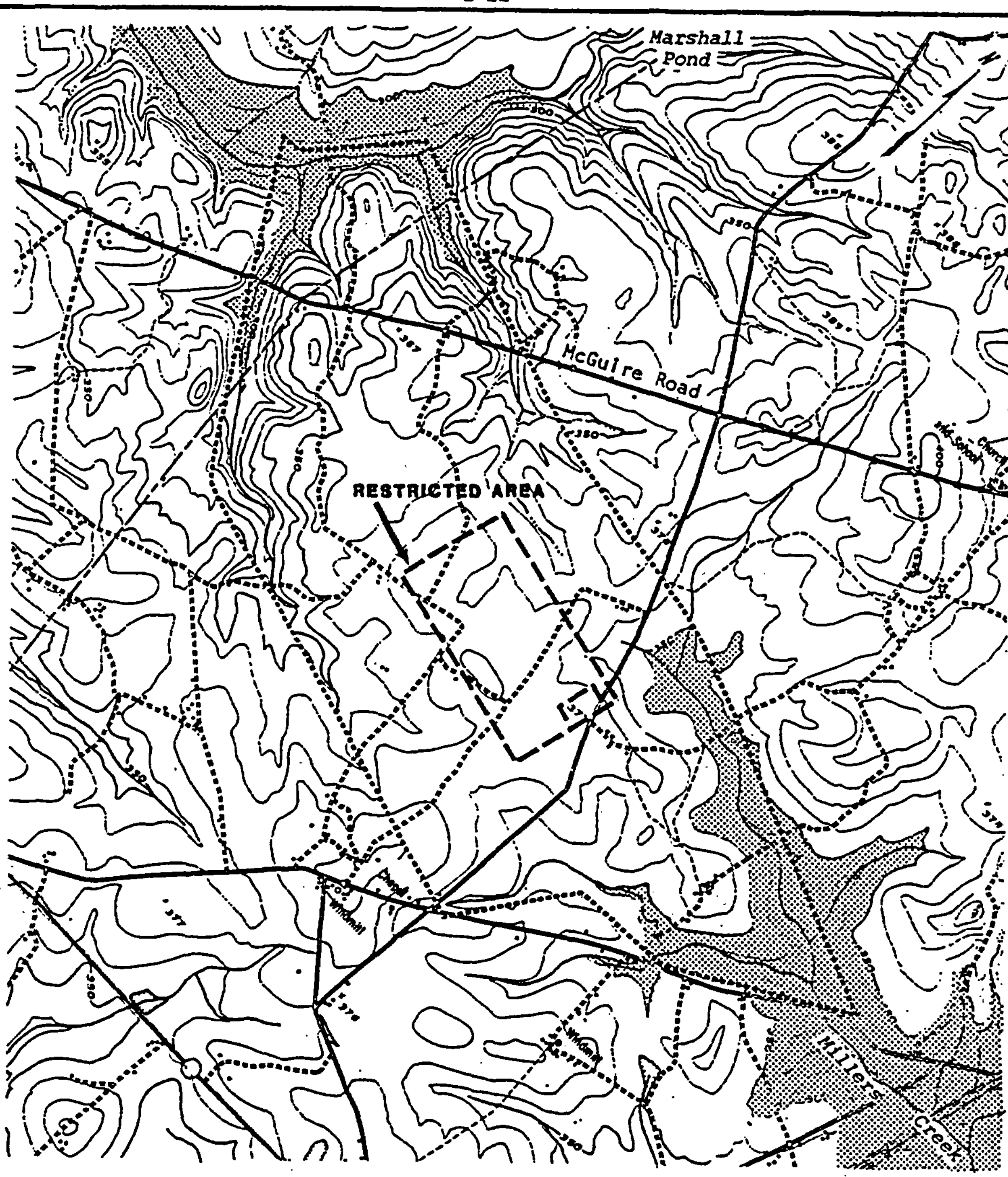
The elements of site hydrogeology discussed in this section include topography, geology, soils, seismicity, background radiation, ground water and surface water.

3.2.1 Topography

The site is located within the Liptone Upland segment of the Coastal Plain physiographic province at elevations ranging from 120 to 122 m (394 to 400 ft) above mean sea level (msl) (Figure E.6). The site vicinity is characterized by gently rolling hills with broad summits and by relatively flat-lying fields bordered by somewhat broad drainage depressions. In general, natural surface drainage at the site is good. As a result of the low topographic relief at the site, the probability of mass wasting and other significant erosional events is low. The local drainage system is dendritic with a typical perennial stream spacing of 1,000 to 2,000 m or more (3,280 to 6,560 ft).

3.2.2 Soils

The soils covering the reference disposal facility site are predominantly sandy loam and loamy sand. In engineering terms, these soils may be described as medium-dense silty sands and clayey sands. The surficial soils generally consist of 0 to 8 cm (0 to 20 in) of topsoil mixed with silty sand.



0 500 1000
SCALE IN METERS
0 1000 2000
SCALE IN FEET

KEY:

500 YEAR FLOODWAY

Figure E.6 Topographic Map - Reference Disposal Facility

This surficial soil layer is underlain by 10 to 12 m of sandy clay sand from the Schwinn formation (Figure E.7). This sandy clay layer has an average permeability of about 5×10^{-6} cm/sec. Underlying this layer of sandy clay are unconsolidated and semiconsolidated sediments of the Eocene age Stablehead Formation. This sedimentary layer generally consists of fine-to-coarse sands which are locally partially cemented with occasional thin lenses of silt present. This sandy layer from the Stablehead Formation is approximately 12 to 14 m (39 to 46 ft) thick. The average permeability of this horizon is 1×10^{-4} cm/sec.

3.2.3 Geology

The geologic profile of the site is provided in Figure E.7. The site is underlain by 22 to 24 m of colluvium (see previous discussion for soils description). Underlying the colluvium is a cherty limestone (Winston Road) member of the lower Stablehead Formation. The limestone has an average permeability of approximately 10^{-2} cm/sec and forms the basal portion of the unconfined aquifer. Solution features in the limestone are minor and are not of the type which would result in sinkhole development. Underlying the Stablehead are Semour and Wrigley Clay members of the Brittle Limb Formation. The Seymour member is typically a well-bedded, fine to coarse grained, calcareous sand with clay lithofacies occurring as beds or lenses. The upper most portion of the Seymour in the site area consists of several thin limestone layers underlain by a clay layer. The Wrigley member consists chiefly of a calcareous, marine clay. The total thickness of the Brittle Limb Formation in the site area is about 45 meters. The clayey basal member of the Brittle Limb Formation serves as an aquiclude to deeper aquifers.

3.2.4 Seismicity

The reference disposal facility site is located within an area having a peak estimated horizontal ground acceleration of 0.11 G with a recurrence interval of more than 500 years. Capable faults have not been identified in the general vicinity of the site. The probability of significant ground displacement at the site is quite low.

3.2.5 Ground Water

The depth to ground water from the original ground surface at the site ranges from 12 to 17 m (40 to 55 ft). The aquifer is unconfined and is generally a subdued replica of the local topography. Well yields in the unconfined aquifer are typically in the range of 1-10 gpm. Larger capacity uses are satisfied by deeper wells into the confined aquifer. The ground-water quality is fair (it meets the National Primary Drinking Water Standards); however, the local consumptive use of water for potable purposes is low and consists of 6 domestic wells within 5 km (3.2 mi) and 60 wells used for farming and livestock. The closest down gradient well is located 1.4 miles from the site. Recharge to the local ground-water system primarily results from infiltration of precipitation. The closest major withdrawal location is 36 km (22.5 mi) to the northeast where water is pumped from the lower confined aquifer for a municipal drinking water supply.

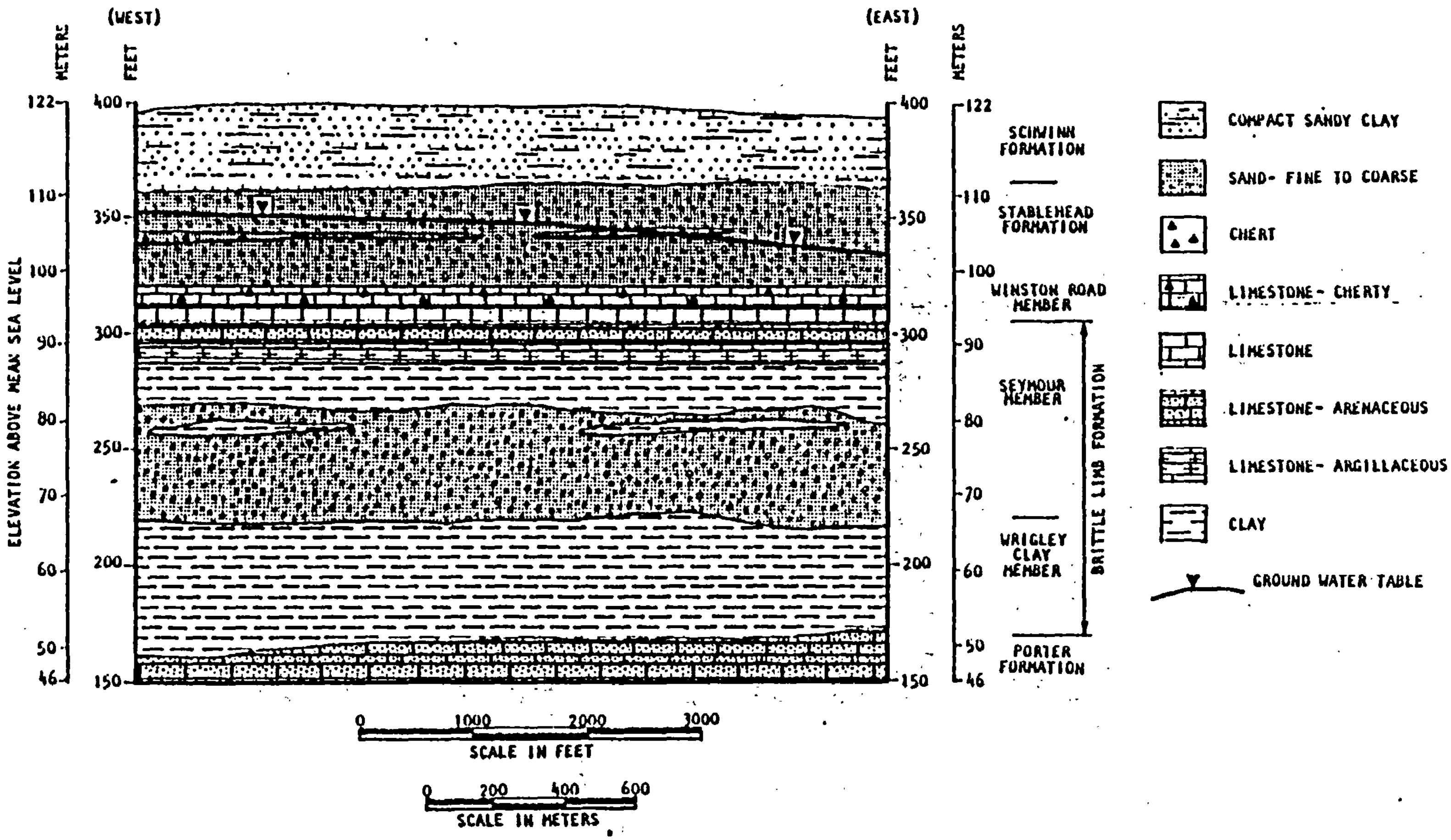


Figure E.7 Geologic Profile - Reference Disposal Facility

3.2.6 Surface Water

The nearest perennial stream to the site is Millers Creek which is located approximately 1000 m (3300 ft) to the southeast of the site (Figure E.6). This is the nearest point of ground-water discharge, at an approximate elevation of 295 ft msl. The other major stream in close proximity to the site is the Signal Branch of Basie Creek which is located approximately 2000 m (6600 ft) north of the site. Millers Creek discharges into the Bigard River which subsequently drains into the Parker River which ultimately empties into the Atlantic Ocean by way of Feather Bay. The Signal Branch has an average discharge of 0.028 m^3/s (1 ft^3/s); this stream drains into the Basie Creek and the Turner River, which eventually drains into the Pepper River and ultimately into the Atlantic Ocean.

3.2.7 Background Radiation

Background radiation at the disposal site is composed of terrestrial radiation and cosmic radiation. Terrestrial radiation at the site is a direct function of the geology of the site area, while cosmic radiation is a direct function of the topographic elevation and geographical location of the site (e.g., latitude and longitude). Background gamma radiation at the site is estimated to be about 10 uR/hr with about half of the radiation from terrestrial sources and half from cosmic sources. Background levels of radiation in surface water and ground water are quite similar with an average preoperational tritium concentration of 350 pCi/l, a gross alpha concentration of 4 pCi/l, and a gross beta concentration of 12 pCi/l.

3.3 Demography

The site is located in a rural area which is characterized by agricultural land, forests, some small industrial development, and some small residential communities. The population distribution within an 80.5 km (50 mi) radius of the site is shown in Table E.3. The total population within 8 km (5 mi) of the site is only 1,685, with a density of 8.6 people/km^2 (21.5 people/mi^2). Approximately 50 km to the northeast of the site is the city of Hawkinsville with a population of 175,000 (see Figure E.8); a cluster of smaller suburban communities surround Hawkinsville. There are five small rural communities (each with a community population of less than 2,000) within 20 km (12.5 mi) of the site. Within 2 km (1.25 mi) of the site are approximately 45 residences, two churches, one schoolhouse, and two windmills.

The economic base of the area is primarily agricultural. The total labor force within 48 km (30 miles) of the site is estimated to be 75,000 full time workers. Of that total, 50% of the work force is devoted to manufacturing (predominantly electronics, textile, and light equipment), 35% to farming (cotton, soybeans), 5% in retail sales labor, 5% in construction, and 5% employed by public utilities.

Table E.3 Population Distribution of the Reference Disposal Facility

	Existing-1980			Projected-2010	
Radial Distance from Site Miles	Population Number	Average Density per mi^2 (per km^2)	Cumulative Population	Population Number	Cumulative Population
0-5	1,685	21.5 (8.6)[P]	1,685	2,024	2,024
6-10	6,602	28.0 (10.8)	8,287	8,115	10,139
11-20	26,667	28.3 (10.9)	34,954	36,000	46,149
21-30	117,920	75.1 (29.0)	152,874	124,995	171,134
31-40	191,200	87.3 (33.7)	344,794	203,435	374,569
41-50	90,460	18.0 (7.0)	435,254	104,933	479,502

3.4 Ecology

3.4.1 Terrestrial Ecology

Much of the general area of the reference disposal facility is composed of undeveloped woodland, which is dominated by long leaf pine (Pinus palustris) and turkey oak (Quercus laevis). The herbaceous layer is mostly turkey oak saplings, but bluejack (Q. marilandian), post oak (Q stellata) and long leaf pine are also important. In addition to the pine-upland hardwoods found near the disposal facility, two other forest communities are found: bottomland hardwoods along Signal Branch and bluff hardwoods along the steeper slopes of Millers Creek. Water oak, black gum and tupelo gum (Nyssa aquatical) are the dominant overstory species in the bottomlands. Moist ground conditions result in substantial understory and ground cover. The bluff hard woods are characterized by hickory (Carya) and northern red oak (Quercus borealis). Understory speicies include water oak, northern red oak, ash (Fraxinus), and mulberry (Morus rudea).

Nestronia (Nestronia umbellula), a deciduous shrub that is considered to be threatened in the state, is expected to occur in the pine-upland hardwoods. It also may be found in the transition zone between these woods and the

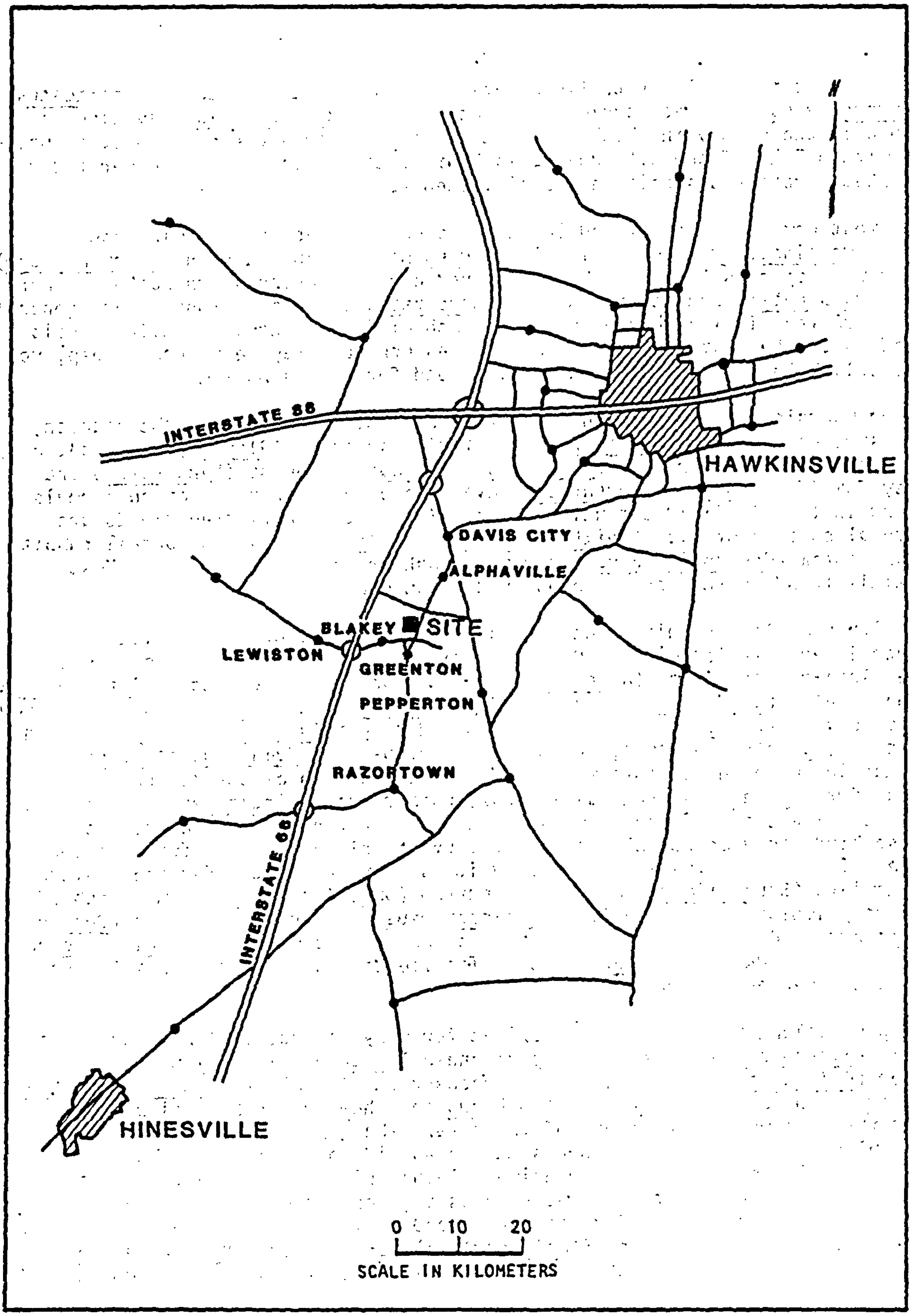


Figure E.8 Site Vicinity Map

bottomlands found closer to Signal Branch. While the bald eagle (Haliacetus leucocephalus) and red-cockaded woodpecker (Picoides borealis) may also be found in the county in which the site is located, they are not expected onsite or within 5 km of the site due to lack of suitable habitat. No other federally or state protected species are anticipated to inhabit the area.

The most common mammals found in the pine communities are the pine mouse (Pitymys pinetorum), fox squirrel (Sciurus niger), and raccoon (Procyon lotor). Burrowing species that have been observed are the southeastern pocket gopher (Geomys pinetis) and eastern mole (Rattus rattus). Gopher tunnels are generally over 100 feet in length and dug at a depth of 6 to 8 inches. While tunnels leading to the resting chambers of the eastern mole may be 6 inches deep, most are only 1 to 2 inches deep, and may extend for over a half mile.

Other mammals associated with the hardwood communities include the raccoon, opossum, woodrat (Neotoma floridana), flying squirrel (Glaucomys volans), gray squirrel, and swamp rabbit (Sylviagus aquaticus). Bobcat (Lynx rufus) and gray fox (Urocyon cineroargenteus) have also been observed. Common mammals found in the old field communities, and also in the cultivated fields are several species of mice (Reixthrodontomys and Peromyscus), cottontail rabbit, least shrew (Cryptotis parva), striped skunk, raccoon and opossum. Most mammals found in this area are not underground burrowers.

As with mammals, the different vegetative communities provide habitat for several varieties of birds. Common species of the pine communities include the slate-colored junco (Junco hyemalis), brown-headed nuthatch (Sitta pusilla), pine warbler (Dendroica pinus), bluejay (Cyanocitta cristata), and common crow (Crovus brachyrhynchos. The golden-crowned knight (Regulus satrapa), common flicker (Colaptes auratus), and pileated woodpecker (Hylatomus pileatus) are common in the hardwood forests. Predatory birds such as the red-shouldered hawk (Buteo lineatus), red-tailed hawk, Coopers hawk (Accipiter cooperii), and barred owl are also found in moderate numbers in these latter woodlands. These birds feed on rodents and other terrestrial vertebrates found in the area. The open fields and edge communities provide habitat for the eastern meadowlark (Sturnella magna), field sparrow (Spizella pusilla), mockingbird (Mimus polyglottos), robin (Turdis migratorius), and common grackle (Cassidix mexicanus). Dominant raptors in these areas are the marsh hawk (Circus cyaneus) and sparrow hawk (Falco sparverius). The fields also provide hunting areas for the other hawks mentioned.

The pine upland forests provide habitat for many snakes, including the corn snake (Elaphe guttata), northern pine snake (Pituophis melanoleucus), black racer (Coluber constrictor), and diamondback rattlesnake (Crotalus adamanteus). The burrow of a gopher tortoise (Gopherus polyphemus) has been also observed near the northwestern boundary of the site. The gopher tortoise is an accomplished burrower; its tunnels may be as wide as 12 inches, and generally as long as 35 feet. Many other animals temporarily or permanently use these burrows, including numerous insects, opossum, and diamondback rattlesnakes. The more common reptiles of moister hardwood communities are the dusky salamander (Desmognaturs), cricket frog (Acris gryllus), brown snake (Natrix taxispilota), and eastern box turtle. Active farming limits the diversity and abundance of the resident herptiles in cultivated areas. Species that were commonly found in the old field communities that may wander into cultivated fields include the southern toad (Bufo terrestris), six line racerunner (Cnemidophorus sexlineatus) and eastern hognose snake (Heterodon playrhinos). This latter species is known to burrow in search of food.

In general (with the exception of the upland pine areas) the biomass of southeastern forests and fields is high, compared to many other regions in the United States. Mild climate and sufficient rainfall promotes rich, stratified vegetative growth, which provides suitable habitat and abundant food source for many herbivores and omnivores. Primary and upper level carnivores, in turn, rely on the abundance of these species.

3.4.2 Aquatic Ecology

Primary producers of the two nearby creeks (Millers Creek and Signal Branch) include booth algae and macrophytes (aquatic vascular plants). Periphyton (attached algae) are more common in the flowing waters of these streams; however, increased turbidity or organic loading can quickly reduce the abundance and types of algae found.

Eight genera of aquatic plants were identified within the nearby creek water. These plants are most abundant in areas of reduced current flow. The plants found, in descending order of abundance, are:

Common Name	Scientific Name	Relative Abundance
Water milfoil	Myriophyllum sp.	Most abundant
Hornwort	Ceratophyllum sp.	Most abundant
Alligator weed	Alternanters sp.	Very abundant
Water weed	Anacharis sp.	Abundant
Duck potato	Sagittaria sp.	Not abundant
Pickerel weed	Pontederia sp.	Scarce
Cattail	Typha sp.	Scarce

No endangered or threatened plant species are expected to occur. A significant diversity of invertebrate species are also found in these waters. The three most abundant groups, comprising just over 5 percent of the total number of insects sampled, are mayflies (Ephemeroptera), beetles (Coleopter), and waterfleas (Cladocera).

Approximately 38 species of fish are known to occur in the surface water system. The most abundant fish are shiners (Notropis sp), minnows (Cyprinidae sp.), sunfish (Centrarchidae sp.), and darter (Etheostoma sp). Common recreational species include largemouth bass (Micropterus salmoides), pickerel (Esox sp.), channel catfish (Ictalurus punctuatus), black crappie (Poxomis nigromaculatus) and sunfish. Two nearby ponds are more popular fishing areas, however, than Millers Creek and Signal Branch. Although several anadromous species do spawn in the rivers, no major spawning activity is noted in the above creeks. No protected fish species have been recorded for these waters.

3.5 Natural Resources

The principal nonagricultural natural resources within the vicinity of the site are minerals and land.

3.5.1 Minerals

The predominant mineral resources within 50 km of the site are dimension stone, crushed stone, sand and gravel, and clay. Development of extensive mining efforts for metals has not been made in the area of the site. There are no known precious metals or fossil fuel mineral deposits within 8 km of the site. Withdrawing the surficial sandy layers at the site for industrial use is not cost-effective due to their poor construction quality. Sand is mined at a local borrow pit. This borrow pit produces an average of 680 metric tons (750 short tons) annually. A kaolin (clay) borrow pit is operated approximately 16 km (10 mi) to the southwest of the site. There is little potential at the site for cost-effective withdrawal of kaolin for construction-grade clay, although limited quantities are available for onsite use. The principal dimension stone mined in the state is limestone. However, the small thickness and poor quality of the limestone formation beneath the site makes it generally unattractive to major dimension stone producers.

3.5.2 Land

Within an 81 km (50 mi) radius of the site, there are three principal categories of land use: (1) woodland, (2) farmland, and (3) developed land. Approximately 25% of the land area is woodland (both private and government preserves), 55% is farmland (with an approximate 50:50 mixture of row crops and pasture), and 20% is developed land (light industry and residential dwellings). The area occupied by the site had been used for farming in the past. However, for the last several years the land has been lying uncultivated and a thick secondary growth has grown up.

4. REFERENCE FACILITY DESCRIPTION

The description of the reference disposal facility is divided into two sections: (1) the basic site design, and (2) the support facilities and structures.

4.1 Basic Design

To provide a base case against which alternatives can be analyzed in this environmental impact statement, the disposal facility is assumed to have a total capacity of up to one million m^3 (35.3 million ft) of waste which is delivered to the disposal site at an annual average rate of 50,000 m^3 (1.77 million ft^3) and randomly disposed into shallow land burial trenches having a design which is typical of current practices. This results in a base case amount of land which is committed for waste disposal. Alternatives considered in this environmental impact statement for waste form and disposal facility design and operation will vary the amount of land committed for waste disposal. For example, increased processing and volume reduction of waste decreases the amount of land needed for waste disposal, while the alternatives considered in this environmental impact statement for facility design and operation may, depending upon the specific alternative considered, either increase or decrease the amount of land committed.

To develop the disposal facility, the licensee is assumed to purchase a plot of land covering 81 ha (200 acres), of which 60 ha (148 acres) is turned over to state ownership. This 60 ha of land is then leased back to the licensee and is used by the licensee for the reference disposal facility. The remaining 21 ha (52 acres) is retained by the licensee for possible future use.

A conceptual layout of the reference disposal facility is illustrated in Figures E.9 and E.10. As shown in the figures, the disposal facility may be divided into two basic areas: a "restricted area" and an "administration area". Pursuant to Part 20 of the Commission's regulations, the restricted area is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. The restricted area includes a "disposal area", in which disposal of radioactive waste takes place, as well as an "operational area". As shown, the restricted area includes a buffer zone between the disposal trenches and the restricted area fence of 30 m (100 ft). As shown in Figure E.9, the operational area is located along the eastern side of the disposal facility and is used as a borrow area for cask storage and for other miscellaneous functions. The operational area includes two facilities, a decontamination facility and a garage, which are used to support waste disposal operations. The administration area is located near the eastern corner of the disposal facility and is considered uncontrolled by the licensee for purposes of radiation protection. The adminstration area includes support facilities plus parking space for employees as well as for incoming waste delivery vehicles. A more detailed discussion regarding the functions of the support facilities and structures is provided in Appendix E, Section 4.2.

The reference facility occupies a total of 60 ha (148 acres), including the disposal area, operational area, and administration area. As is the case at existing disposal facilities, however, considerably less than the total site acreage is used for waste disposal. For example, specific areas of a particular disposal site may not be suitable for waste disposal due to geohydrological or topographical reasons--e.g., parts of a particular site might have excessively steep slopes or high water tables. The administration area occupies 3.7 ha (9.1 acres), and is assumed to be a constant for all waste form and facility design and operation alternatives considered in this environmental impact statement. The area of the land committed for waste disposal--that is, the land actually containing disposed radioactive waste--varies according to the alternatives considered, but covers 35 ha (87 acres) at the reference facility. This area was calculated assuming random disposal (50% utilization of disposal space) of one million m^3 of waste into trenches having average dimensions of 180 m long by 30 m wide by 8 m deep, and having an average spacing of 3 m between each trench. The committed land use rate--that is, the unit volume of waste disposed per unit area of land--is estimated to be 2.88 m^3/m^2 (9.45 ft^3/ft^2). The remaining 21.3 ha (53 acres) includes the operational area and the 30 m buffer zone as well as any excess land within the disposal area used for roads, working areas, and so forth.

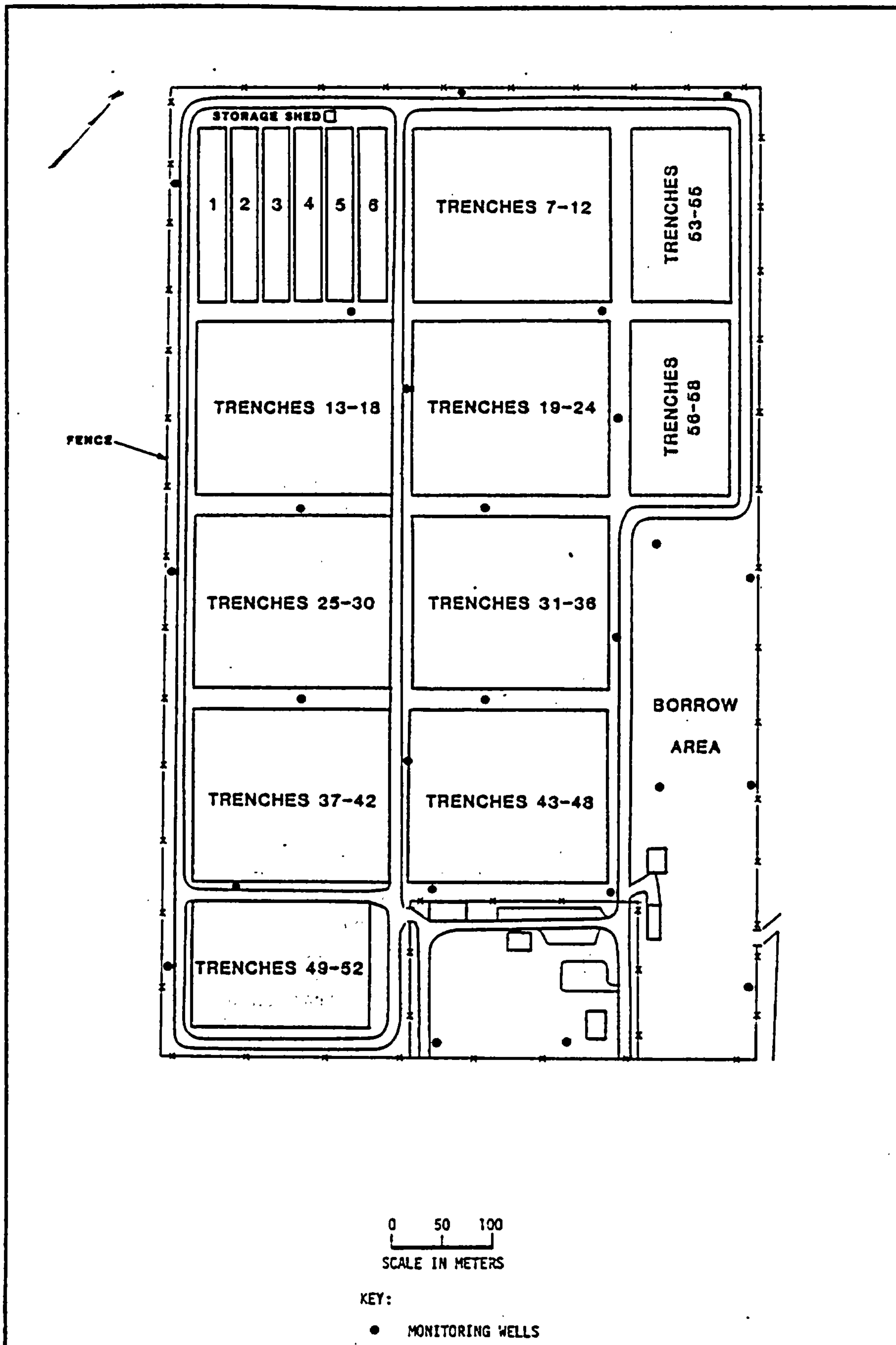


Figure E.9 Reference Disposal Facility Layout

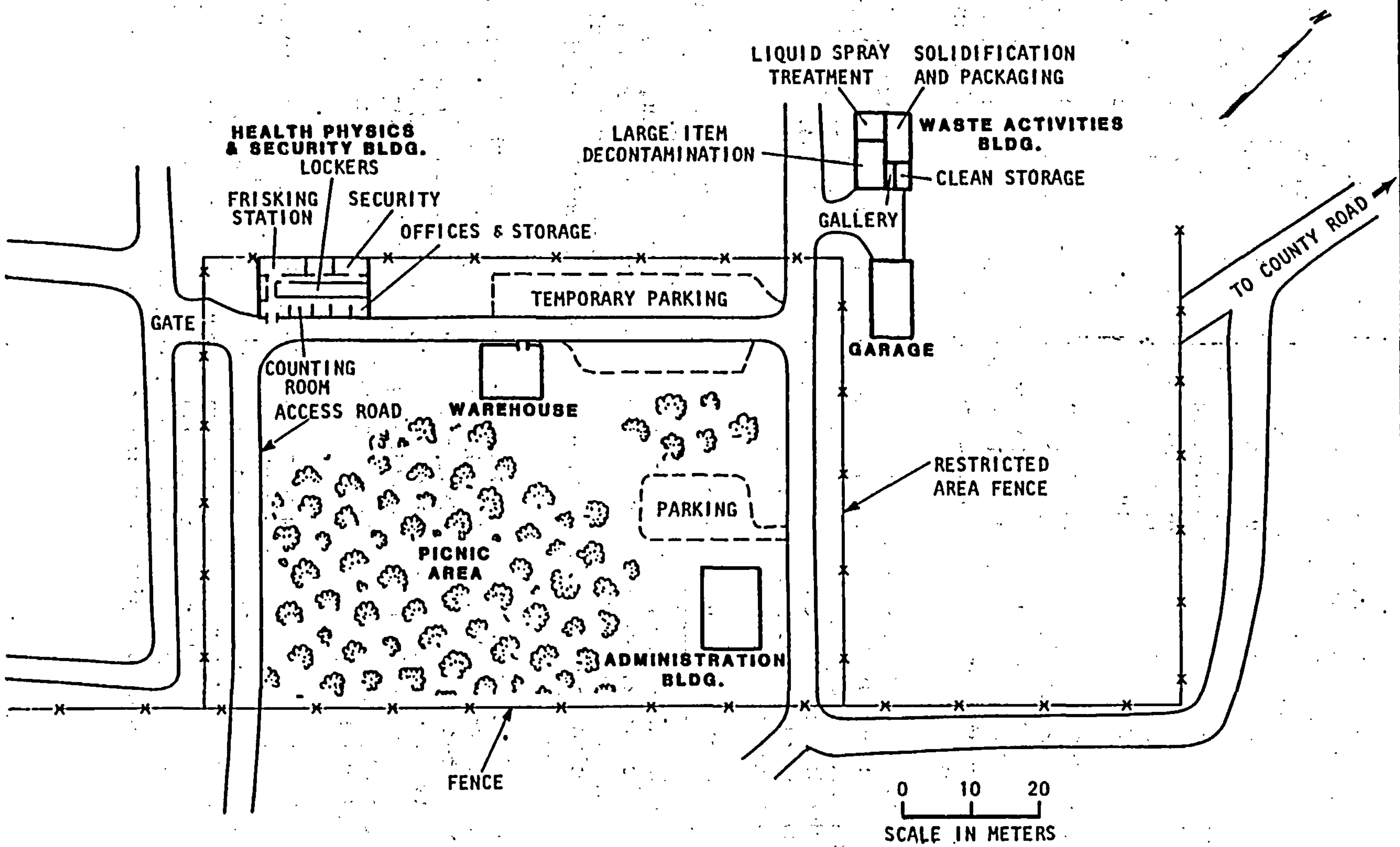


Figure E.10 Reference Disposal Facility Support Facilities

The entire site is surrounded by a 2.4 m (8 ft) high chain-link fence topped with three strands of barbed wire. A 2.4 m high fence also separates the administration area from the restricted area. Access to the disposal site is via a state highway running close to the site from which two short gravel roads lead onto the disposal facility. There are no rail facilities at the site. Incoming waste delivery and employee vehicles enter the site through one of two gates located in the administration area. These gates are locked at night and at other times such as holidays when the site is not being operated. Access to the restricted area is controlled by security check points near the gates in the fence separating the administration area and the restricted area.

For security purposes, a narrow gravel road runs alongside the inside of the fence surrounding the restricted area. Other onsite gravel roads wide enough to accommodate two small vehicles lead to the active disposal areas and are constructed by the licensee as needed. A lighting system is provided in the operational and administration area. There are no other lights installed in the interior of the restricted area.

The disposal area at the reference facility includes 58 disposal trenches. The average disposal trench is assumed in this appendix to be 180 m (591 ft) long, 30 m (100 ft) wide, and 8 m (26 ft) deep (Figure E.11). However the length and width of the disposal trenches may vary somewhat (about ± 10 m). The rather large trench sizes assumed in this appendix are representative of recent trends at existing disposal sites.

The site soils are cohesive, but not cohesive enough to allow vertical-walled excavations. Therefore, trench wall slopes of 1 horizontal to 4 vertical (1:4) are employed. In some circumstances, (e.g., when extensve sloughing occurs) more gentle slopes are employed. The trenches are separated by 3 m thick walls. These inter-trench walls are able to support only light vehicles. Other vehicles, including heavy construction and transport vehicles, require a more substantial substrate.

As a trench is constructed, the locations of the four corners of the trench are surveyed and referenced to a bench mark. An approximate one degree slope is provided in the bottom of a trench from end to end and from one side toward a 0.6 m x 0.6 m (2 ft x 2 ft) gravel-filled French drain. The French drain runs the entire length on the lower elevation side to provide for collection of any liquid drainage that might occur. A gravel-filled sump is located at the low corner of the trench.

Each trench is equipped with a minimum of three 0.15 m (6 in) diameter polyvinyl chloride (pvc) standpipes located within the French drain and standing along the sidewalls of the trench. The bottom three feet of each standpipe is fitted with either a slotted pvc pipe screen or a wound mesh pvc screen. Two of the three standpipes are located at each end of the excavation. The third standpipe is usually located at the trench midpoint (also standing in the French drain). These pvc standpipes function as observation wells or sumps.

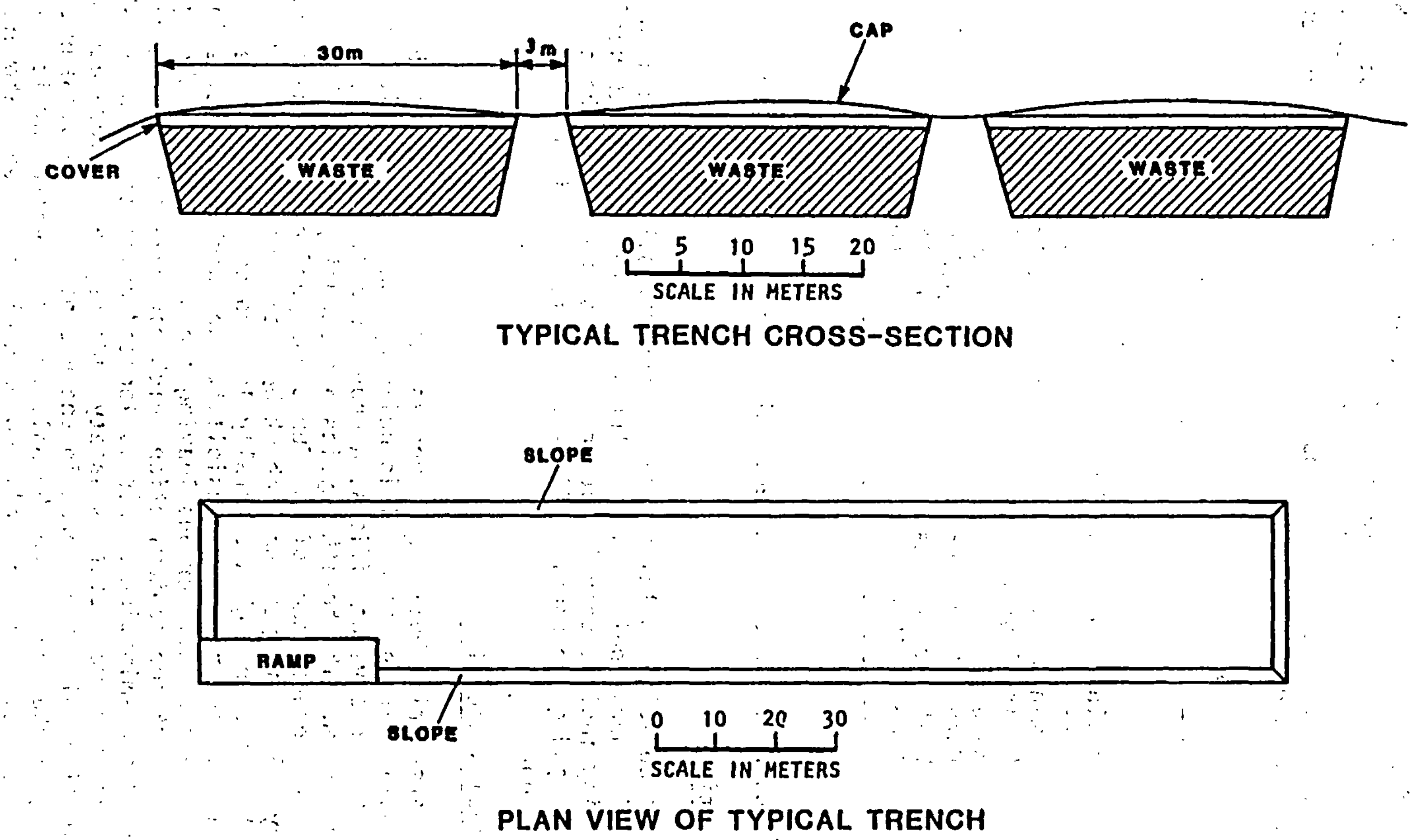


Figure E.11 Typical Trench Details

4.2 Support Facilities and Structures

The support facilities include: (1) an administration building, (2) a health physics/security building, (3) a warehouse, (4) a garage, (5) a waste activities building, and (6) a storage shed. All structures at the site are one-story metallic structures on concrete pad foundations. The building areas for these five major structures are listed below:

Building or Facility	Area m^2	Area ft^2
Administration	625	6,725
Health Physics/Security	800	8,610
Warehouse	470	5,060
Garage Mechanics	420	4,520
Waste Activities	560	6,025
Storage Shed	80	860

The functions of each of the support facilities are described below.

4.2.1 Administration

The administration building contains office space for site management and other administrative personnel working at the site. The activities performed within this building include coordination of waste shipments to the site, billing customers, and other routine file work. Site records are also stored within this building.

4.2.2 Health Physics/Security

The health physics/security building serves as the focal point for the majority of disposal activities at the site. This building houses a security section, a counting room, health physics offices, a change room/locker room, a lunch area, and a supply room. The health physics and security personnel are housed in the same facility because many of the functions performed by these personnel are complimentary. Security personnel check both site personnel and visitors into and out of the site through a centrally-located checkpoint. The health physics personnel have the prime responsibility for checking vehicles into and out of the disposal area. All persons leaving the site must pass through a frisker station to check for contamination which may have been picked up onsite. A safety decontamination shower is located adjacent to the frisker location. Emergency equipment such as safety ladders, respiratory equipment, and anti-contamination suits are stored in the vicinity of the frisker station. The employee change/locker room down the hall from the health physics offices includes both a street clothes ("clean") and work clothes area. Showers are also located in this section of the building.

4.2.3 Warehouse

The warehouse is used to store supplies used onsite. This facility is located within the administration area so that delivery trucks need not enter the disposal area. Among the stored items in this warehouse are cables, hooks, drums, bags, and other miscellaneous hardware. Casks and site vehicles are stored in the operational area.

4.2.4 Garage

Only vehicles and equipment that have been surveyed and decontaminated to within specified limits (see Appendix E, Section 5.2.5) are allowed to use the garage. The garage is large enough to hold two vehicles at a time for maintenance. Mechanic's tools, spare parts, oil, and fuel (adjacent to the building in underground tanks) are also stored in the garage.

4.2.5 Waste Activities

This building houses several functional areas, including: (1) a large item decontamination bay, (2) a control room for the decontamination bay, (3) a liquid treatment system, (4) a waste solidification, packaging, and overpacking area, (5) a supply room, and (6) a small waste storage area.

The decontamination bay is used for washing down (decontaminating) large pieces of equipment (including trucks if necessary) through the use of a high-pressure recirculating water supply system. Contamination levels in these decontamination liquids are generally quite low; however, water treatment is applied to recirculating fluids. Small-scale decontamination of tools and other small items may be accomplished within the solidification staging area. The solidification area includes batch concrete mixing equipment for solidification of small quantities of low-activity liquids. A small storage area is provided for occasional temporary storage of shipments received from common carriers. A loading dock is located along the southern corner of this building.

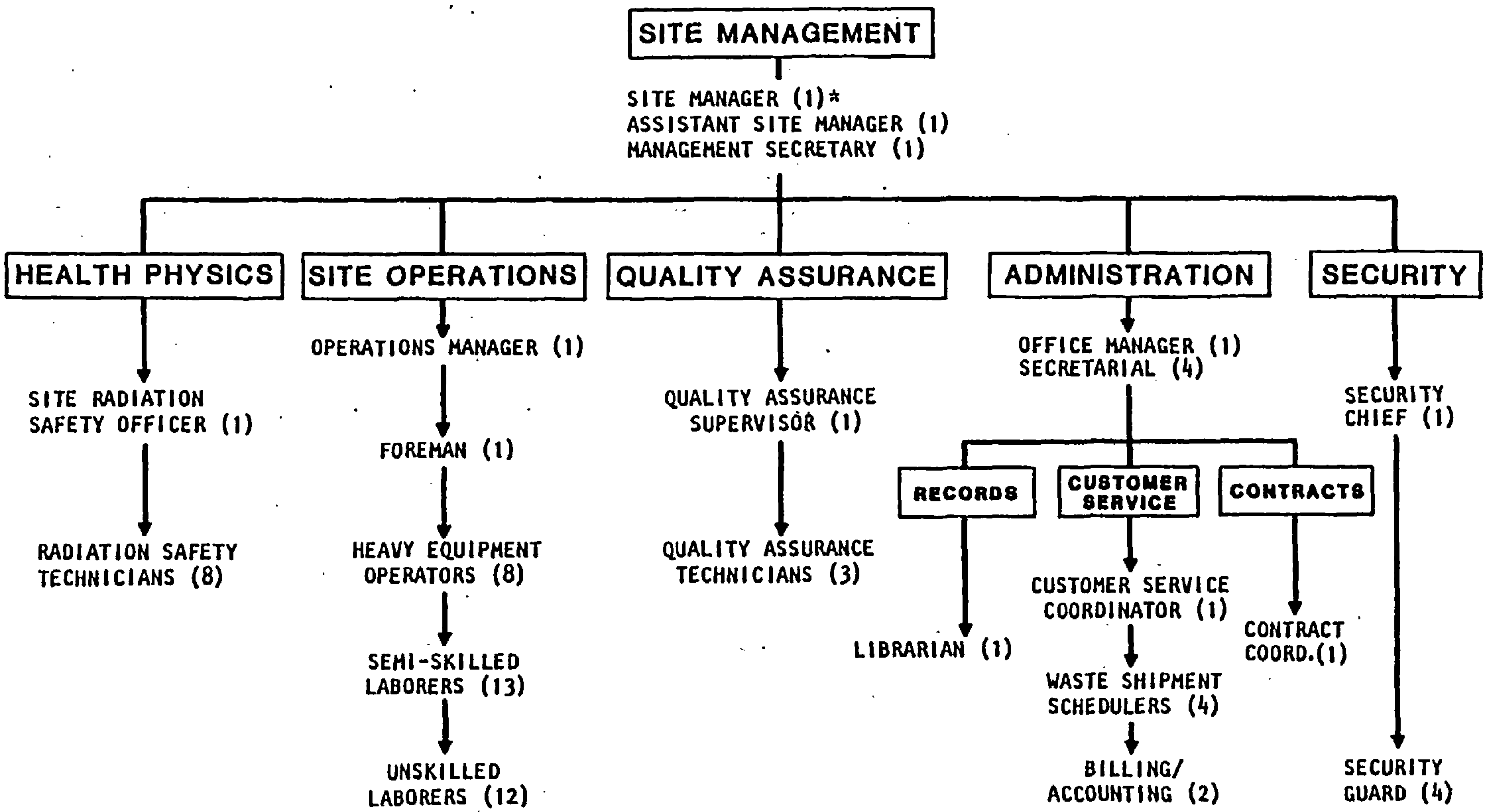
4.2.6 Storage Shed

A storage shed is used to store supplies and miscellaneous tools used at the disposal trenches. This shed is portable and is usually located close to the active disposal trenches.

5. SITE ADMINISTRATION AND OPERATIONS

5.1 Site Administration

The organizational structure of the reference disposal facility is described in this section. One of the primary functions of the site organization is to provide managerial controls for the safe handling of radioactive materials at the disposal facility. An organizational chart is included in Figure E.12, which has been developed considering administrational and organizational structures at existing disposal facilities. The organization chart does not



* NUMBER IN PARENTHESES EQUALS NUMBER OF PERSONNEL IN EACH JOB DESCRIPTION.

Figure E.12 Organization Chart - Reference Disposal Facility necessarily represent the sole or best manner in which the administration of a disposal facility may be organized. It does, however, provide a point of reference against which the operation of the facility may be described. Table E.4 contains a list of site personnel and their assumed annual salaries.

Table E.4 Reference Disposal Facility Payroll

No.	Job	Annual Salary($)	Extended Total($)
	<u>Senior Staff</u>		
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
	<u>Support Staff</u>		
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
	<u>Staff</u>		
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

5.1.1 Corporate Management

The disposal facility is assumed to be operated for profit by a small corporation which is engaged in other nuclear-related business activities in addition to operating the disposal facility. The home office of the corporation is located offsite in another state. Overall control of radiation health and safety at the corporate level is under the control of the senior radiation safety officer, who is responsible for conducting periodic reviews of site operations for compliance with health and safety regulations and license conditions, including periodic site inspections and audits.

5.1.2 Site Management

Operations at the disposal facility are under the overall direction of the site manager and the assistant site manager. Beneath this level of site management, the administration of the disposal facility is organized into five parallel divisions: site operations, health physics, quality assurance (QA), administration, and security.

5.1.3 Site Operations Division

This division controls such activities as trench construction, waste handling and disposal operations, and site groundskeeping and maintenance, and is under the direction of the operations manager. The site foreman assists the operations manager and is in daily contact with the site labor force. The foreman is responsible for work assignments, crew coordination, maintaining proper operating readiness of equipment, and general supervision of onsite burial and maintenance operations. The work force, under the control of the operations manager and site foreman, is composed of 8 heavy equipment operators, 13 semi-skilled laborers, and 12 unskilled laborers. Heavy equipment operators are responsible for the operation and routine maintenance checks of equipment used at the site for waste disposal and maintenance operations. Semi-skilled laborers have a variety of functions at the site, including maintenance of site buildings and site property, operation of agriculture equipment, some heavy equipment operation, and some handling of waste material. Some of these laborers double as equipment mechanics when necessary. Unskilled laborers perform manual waste handling activities and other general support functions including maintenance of the facility buildings and grounds. The duties of the semi-skilled and unskilled laborers are rotated to control and minimize individual radiation exposures.

5.1.4 Health Physics Division

This division is under the direction of the site radiation safety officer (RSO), who is responsible for ensuring that proper radiation work procedures are used, that adequate monitoring for radiation hazards is provided, and that personnel training, equipment, and techniques provide control of radiation exposure during site operations. Besides the radiation safety controls, the RSO is also responsible for coordination of the site-safety training programs with the QA division, and for implementation of site emergency plans, procedures, and drills. The RSO reports directly to the site management as well as to corporate management, particularly the senior radiation safety officer.

Routine health physics functions such as environmental and personnel monitoring are conducted by the 8 health physics technicians under the supervision of the RSO. Their duties also include inspections of incoming and outgoing vehicles as well as site surveys for control of radioactive contamination.

5.1.5 Security Division

The primary responsibility of the security division is to control personnel and vehicle access to the site and to preclude potential theft of site tools or radioactive materials. The four-man security force is under the control of a security chief and performs such functions as checking personnel and visitors into and out of the disposal site, conducting periodic patrols of the grounds and the site perimeter, and maintaining communications with law enforcement and other offsite emergency personnel. Like the site RSO, the security chief has direct lines of communication with corporate management, particularly the senior radiation safety officer.

5.1.6 Administration Division

This division is responsible for routine office work under the supervision of the office manager, including coordinating shipments, maintaining records, and billing customers. As shown in Figure E.12, this division can be conceptually divided into three basic sections: records, customer service, and contracts.

Records are kept by a site librarian who maintains files and performs other functions including document reproduction, data recall, and coordination of routine reports. The 4 secretary/receptionists function as typists, file clerks, bookkeepers, and receptionists as needed by the various departments.

The customer service section coordinates the delivery of radioactive material to the site, schedules shipments, assesses charges for disposal services, and bills customers. The customer service section also informs customers of current disposal requirements and facility services which can be provided. Payment and accounting for routine site expenses is also handled by this section. The contracts section consists of a contract coordinator who works with corporate management and other site operational divisions to obtain needed outside services such as laboratory analyses, heavy equipment rental, transportation services, and utilities. The contract coordinator also arranges the use, as necessary, of outside consultants such as a registered surveyor.

5.1.7 Quality Assurance Division

The Quality Assurance (QA) program at the site is run by a QA supervisor who has three technicians under his supervision. The function of this division is to maintain compliance with applicable regulations, license conditions, and approved operational procedures, and has stop-work authority over site operations. Some of the site operations which are monitored by QA technicians include: trench construction, closure, site maintainance, waste disposal, equipment maintenance, and legal and procedural compliance by waste shippers and site personnel. Safety inspections, reviews of maintenance records, and training of site personnel are also included in their duties.

5.2 Site Operations

Site operations discussed in this section include: waste receipt, inspection, handling, storage, and disposal; radiation and contamination control; site groundskeeping and maintenance; environmental monitoring; security; record-keeping and reporting; and quality assurance.

5.2.1 Waste Receipt and Inspection

Shipments of radioactive waste arrive by truck (generally as sole use shipments but occasionally via common carriers) and are processed onto the site on a first come, first served basis. Accompanying the shipments are manifest documents--termed radioactive shipment records (RSRS)--which describe the content of the shipment. An example of an RSR used at one disposal site is included as Figure E.13. Arriving shipments are inspected for compliance with applicable federal regulations and waste acceptance criteria established as conditions in the disposal facility license.

Applicable federal regulations include those promulated by NRC in 10 CFR Parts 20 and 71, as well as those promulated by the Department of Transportation (DOT) in 49 CFR 170-179. DOT regulations contained in 49 CFR 170-179 have been recently incorporated into 10 CFR Part 71 by reference (Ref. 19). These regulations include, for example, waste packaging requirements, labelling requirements, vehicle placarding requirements, and allowable direct radiation and removable contamination levels at accessible surfaces of transport vehicles. Summaries of allowable direct radiation and removable contamination limits are included in Tables E.5 and E.6.

Waste acceptance criteria at existing disposal facilities vary somewhat from site-to-site. For purposes of this appendix, however, those waste acceptance criteria which are assumed for the reference disposal facility are provided in Table E.7. These reference criteria, which have been assumed considering license conditions at existing disposal facilities, include packaging criteria for liquid scintillation vials, absorbed liquids, and animal carcasses, as well as a limit on the amount of free standing liquid allowed in waste packages (Refs. 20-22). Other reference criteria included limits on the quantities of radioactivity that may be received and possessed onsite at any one time prior to disposal as well as package and shipment quantity limits for special nuclear material (Refs. 20-22).

The results of these inspections are recorded on radiation survey forms and summarized on the RSRs accompanying the waste shipments. Shipments found to be in compliance with federal regulations and license conditions proceed into the disposal area for unloading. Violations of transportation regulations are reported to federal and state authorities in compliance with federal and state regulations and license conditions. Damaged or leaking waste packages are identified and appropriate protective or remedial action is taken. Depending upon license conditions, damaged or leaking waste containers may be overpacked or repackaged, and either accepted for disposal or returned to the sender. Free-standing liquids detected are removed and solidified. Activities such as overpacking and solidification are performed at the waste activities facility.

SHIPPER: ____________________

ADDRESS: ____________________

PHONE: ____________________

SHIPMENT NO.: ____________________

DATE OF SHIPMENT: ____________________

CARRIER: ____________________

NO. 4064 PAGE ____ OF ____

☐ ____________________

TOTAL QUANTITY	PROPER SHIPPING NAME & HAZARD CLASS (PER 49 CFR 172.101)		TOTAL WEIGHT IN POUNDS
	Radioactive Device, N.O.S.	— Radioactive Material	
	Radioactive Material, Fissile, N.O.S.	— Radioactive Material	
	Radioactive Material, Low Specific Activity, N.O.S.	— Radioactive Material	
	Radioactive Material, N.O.S.	— Radioactive Material	
	Radioactive Material, Limited Quantity, N.O.S.	— Radioactive Material	
	Radioactive Material, Special Form, N.O.S.	— Radioactive Material	

(1) Item No.	(2) Cubic Feet	(3) Weight (Pounds)	(4) Physical Form	(5) Chemical Form	(6) Radionuclide	(7) Special Nuclear Material (Grams)	(8) Source Material (Kilograms)	(9) Activity [ ] Curies [ ] Millicuries	(10) Radiation Levels MR/HR Surface	3 Feet	(11) Transport Group	(12) Transport Index	(13) Label	(14) Fissile Class	(15) Type of Container
													Radioactive —		
													Radioactive —		
													Radioactive —		
													Radioactive —		
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													Radioactive —		
													Radioactive —		
													Radioactive —		
			TOTALS												

THIS IS TO CERTIFY THAT THE ABOVE-NAMED MATERIALS ARE PROPERLY CLASSIFIED, DESCRIBED, PACKAGED, MARKED AND LABELED AND ARE IN PROPER CONDITION FOR TRANSPORTATION ACCORDING TO APPLICABLE REGULATIONS OF THE DEPARTMENT OF TRANSPORTATION.

____________________ ____________________
Authorized Signature *Title*

THIS IS TO CERTIFY THAT ARTICLES ARE IN COMPLIANCE WITH ALL REGULATIONS APPLICABLE AT THE DESIGNATED DISPOSAL SITE.

____________________ ____________________
Authorized Signature *Title*

Figure E. 13 Example Radioactive Shipment Record

Table E.5 Radioactive Materials Maximum Radiation Level Limitations

Radiation level (dose) rate at any point on an external surface of any package of radioactive material may not exceed:

- 200 millirem per hour.
- 10 millirem per hour at three feet (transport index may not exceed 10).

Unless the packages are consigned to a "sole use" or "exclusive use" closed transport vehicle (except aircraft). Then the maximum radiation levels may be:

- 1,000 millirem per hour at 3 feet from external package surface.
- 200 millirem per hour at external surface of the vehicle.
- 10 millirem per hour at 6 feet from external surface of the vehicle.
- 2 millirem per hour in any position of the vehicle which is occupied by a person.

Source: 49 CFR 173.393 (i) and (j).

Table E.6 Radioactive Material Contamination Limits

Removable (nonfixed) radioactive contamination is considered significant if the level of contamination exceeds any of the following when averaged over any area of 300 cm^2 of any part of the package surface:

Contaminant	Maximum Permissible Level	
	uCi/cm^2	dis/min/cm^2
Natural or depleted uranium and natural thorium		
Beta-gamma	10^{-3}	2,200
Alpha	10^{-4}	200
All other beta-gamma emitting radionuclides	10^{-4}	200
All other alpha-emitting radionuclides	10^{-5}	22

Source: 49 CFR 173.397

Table E.7 Waste Acceptance Criteria for the Reference Disposal Facility

Basic Criteria
1. Receipt of waste containing transuranic radionuclides is restricted to waste streams containing less than 10 nanocuries total transuranic nuclides per gram of waste, provided that the transuranic radionuclides are essentially evenly distributed within a homogeneous waste form. Household smoke detectors containing Am-241 foils which may exceed the transuranic limit of 10 nanocuries per gram of material may be accepted for disposal provided that the entire detector is disposed.
2. Absorbed liquids may be received for disposal at the disposal facility provided that sufficient absorbent is used to absorb twice the volume of liquid. The container in which the absorbed liquid is shipped must be lined with a sealed plastic liner (minimum 4 mil thickness).
3. With the exception of liquid scintillation vials, other liquid-containing vials used for in vitro clinical or laboratory testing, and animal carcasses, no liquids may be received which have not been absorbed or solidified. Solidified and absorbed liquids shall contain less than 0.5% or one gallon of free-standing liquids per container, whichever is less.
4. Liquid scintillation vials and fluids, other liquid organics with similar chemical properties, and radioactive materials in individual units or vials (not to exceed 50 ml) used for in vitro clinical or laboratory testing may be received for disposal provided that the waste material is packaged in sufficient absorbent material to absorb twice the total volume of liquid. The container in which the waste material and absorbent is shipped must be lined with a sealed plastic liner (minimum 4 mil thickness).
5. Animal carcasses or other biological material must be layered with absorbent and lime and place within a sealed inner container which is then placed within a larger container having a capacity at least 40% greater than the inner container (e.g., a 30-gallon drum within a 55-gallon drum). The inner container must be completely surrounded by additional absorbent material and the outer container must be sealed.
6. Use of cardboard, fiberboard, and other paper packages for delivery of radioactive waste to the disposal facility is prohibited.
7. Chemically explosive radioactive material that might react violently with water or moisture may not be accepted for disposal at the site.
8. Gaseous Kr-85 and Xe-133 may be received for disposal provided that the disposal containers are either sealed sources or DOT specification cylinders. The internal pressure within a container may not exceed 1.0 atmosphere and the total activity contained within each container may not exceed 100 curies.

Table E.7 (continued)

Undisposed Possession Limits

The licensee may not possess (undisposed) at any time more than the following quantities:

1. 60,000 curies of byproduct material;
2. 80,000 pounds (36,000 kg) of source material; or
3. 5,000 grams of special nuclear material (SNM).

SNM Packaging and Shipment Limits

1. No single package shall contain more than 100 grams of uranium-235, or 60 grams of uranium-233, or any combination thereof, such that the sum of the ratios of the quantity of each special nuclear material to the quantities specified does not exceed unity--i.e.;

$$\frac{\text{grams contained U-235}}{100} + \frac{\text{grams contained U-233}}{60} \leq 1.$$

2. No single package may contain more than 15 grams of any combined uranium-235 or uranium-233 per cubic foot of total volume.

3. Each accumulation of packages (a shipment) shall contain not more than 500 grams of uranium-235 or 300 grams of uranium-233, or any combination thereof, such that the sum of the ratios of the quantity of each special nuclear material to the quantities therein does not exceed unity--i.e.,

$$\frac{\text{grams contained U-235}}{500} + \frac{\text{grams contained U-233}}{300} \leq 1.$$

4. Each accumulation of packages shall be stored at least 12 feet from any other package containing special nuclear material.

5.2.2 Waste Storage

Generally, waste received at the site is disposed of within a few days. Waste that must be temporarily stored is generally left in transport vehicles. There may be a reason, however, to temporarily store a few packages in a designated storage area, as when waste packages arriving by common carriers are stored temporarily. As it often takes considerable time to process a waste transport vehicle into and out of a disposal site, it is sometimes more convenient to drop off waste packages (and accompanying paperwork) received from common carriers at the site storage area. The waste can then be disposed at a later time.

An added storage requirement exists for wastes containing special nuclear material. (At the reference facility, special nuclear material is limited to uranium-233 and enriched uranium-235; no plutonium is accepted for disposal.) License conditions require that any single shipment of special nuclear material must be stored at least 12 feet from any other package containing special nuclear material.

5.2.3 <u>Waste Disposal</u>

Waste is randomly emplaced in the trench using cranes and forklifts, and backfilled with dirt removed during trench excavation. Random waste emplacement results in a trench volume use efficiency of about 50%. License conditions prohibit uncovered waste from extending more than 100 feet beyond the backfilled portion of the trench. License conditions also require that backfill operations commence immediately if radiation readings greater than 100 mr/hr are recorded at the trench boundary, and continue until radiation levels are reduced below 100 mr/hr. License conditions prohibit waste packages from being placed or standing in water, so waste disposal commences at the high end of the trench and works down towards the lower end. Rainwater falling within the open trench and contacting the uncovered waste packages drains away to the lower end of the trench. Rainwater collecting in the lower end of the trench is then removed as necessary and treated by such methods as solar evaporation or solidification.

Waste is emplaced to within one meter of the top of the trench. Earthen fill is then backfilled into the trench. A one meter thick cap composed of soil is then placed upon the backfill and is mounded. No special compaction is performed on the backfill and cap other than that provided by trucks and heavy earth moving equipment driven over the top of the cap. The cap is then covered with natural overburden material as necessary to provide good drainage characteristics and according to the final contours planned for the site surface. The overburden is then reseeded to promote growth of a short-rooted grass cover.

Similar to the storage requirements discussed above, an additional requirement exists for disposal of wastes containing special nuclear material. License conditions require that each package of waste containing special nuclear material be disposed of in such a manner as to have a minimum of eight inches of earth (or wastes not containing special nuclear materal) in all directions from any other package containing special nuclear material.

Following trench capping, the disposal trenches are each marked with a monument which is inscribed with the following information:

- o A trench identification number;

- Total trench activity of radioactive material in curies, excluding source and special nuclear material; mass of source material in kilograms; and mass of special nuclear material in grams;

- Date of completion of waste disposal into the trench; and

- Volume of waste in the trench.

In addition, each of the four top corners of the disposal trench are marked with a marker stone.

During waste handling and disposal, operations are monitored to ensure radiation safety. After the transport vehicle is unloaded it is again surveyed for contamination and decontaminated, as necessary, prior to leaving the restricted area. The results of the survey are recorded on the accompanying RSR.

5.2.4 Site Groundskeeping and Maintenance

Groundskeeping includes both the upkeep of grounds and the maintenance of external building surfaces. The purpose of groundskeeping is to promote site integrity by maintaining proper contour and soil conservation practices, by properly maintaining external structures and site systems, and by overseeing closed burial trenches in an efficient manner. Groundskeeping activities include contouring of the ground surface, emplacement of a soil cover material such as grass, fertilizing, mowing, etc.

A site maintenance program entails routine inspection of site surfaces and fences for trench settlement, gullying, damage, debris, etc. Repairs are made as necessary.

An important part of the reference facility site groundskeeping and maintenance program is surface water management. A surface water management program is site-specific (i.e., is dependent on each site's topography, amount of rainfall, etc.), but its overall purpose is to divert surface water resulting from precipitation away from open trenches and to allow the surface water to flow offsite in a manner which will minimize erosion. The reference disposal facility is assumed to utilize low berms around open trenches to help accomplish this.

5.2.5 Site Safety, Radiation, and Contamination Control

This section describes licensee programs, operations, and procedures at the reference disposal facility to ensure site safety and to minimize potential offsite releases of contaminants. Included in this discussion are methods used at the reference facility to:

- maintain personnel exposures to levels in compliance with 10 CFR Part 20, and furthermore to levels as low as reasonably achievable (ALARA);

- o maintain releases of radioactive materials to unrestricted areas to levels in compliance with 10 CFR Part 20, and furthermore to levels ALARA;
- o monitor compliance with transportation regulations promulgated by the Department of Transportation (DOT) in 49 CFR 170-179; and
- o ensure industrial (nonradiological) safety at the site.

Many of the site procedures described in this section are utilized for a combination of reasons. For example, strict monitoring for compliance with DOT transportation regulations serves to help reduce site personnel exposures and site contamination levels in addition to reducing potential transportation impacts. Controlling site contamination to low levels reduces personnel exposures as well as minimizes potential offsite releases through liquid or airborne pathways.

The remainder of this section describes licensee methods to maintain site safety and to control radioactive materials at the disposal facility. To do so, this section has been divided into five subsections as follows:

- o personnel radiation monitoring;
- o site radiation and contamination control;
- o industrial safety;
- o abnormal or emergency situations; and
- o training.

5.2.5.1 Personnel Radiation Monitoring

Personnel radiation monitoring at the reference facility includes use of personnel monitoring devices, periodic internal monitoring, and administrative controls to ensure radiological safety.

Monitoring devices are worn by all site personnel who may become occupationally exposed to ionizing radiation. A long-term record of cumulative personnel exposures is maintained through the use of film or thermoluminescent dosimeter (TLD) badges. These are replaced, analyzed, and the resulting exposures reviewed and recorded on a periodic basis (usually on a monthly or quarterly schedule). In addition, monitoring badges are replaced and analyzed whenever there is reason to believe that an employee may have received an unusually high radiation dose. Pocket dosimeters are also worn by site personnel and are used to provide an indication of radiation exposures over shorter time periods. These basic monitoring devices may, depending upon the circumstances, be supplemented by additional equipment such as electronic dose ratemeters, finger or wrist monitoring badges, and/or continuous air samplers.

A periodic internal monitoring program is maintained for exposed individuals as a supplement to use of personnel monitoring devices (film badges, TLDs, and dosimeters). The internal monitoring program consists of an annual gamma scan for the lungs and thyroid in addition to a semiannual comprehensive bioassay. An immediate gamma scan and bioassay collection are performed if there is reason to believe that a site worker may have inhaled or ingested contaminated material. The gamma scan and bioassay is normally carried out at a nearby diagnostic laboratory. If through a site accident, a worker may receive an open wound and the wound is suspected of having become contaminated, a direct gamma scan is performed. Backup blood or wound swab samples are also collected and analyzed.

Administrative controls are used to maintain exposures to levels as low as reasonably achievable (ALARA). A baseline is established for each new site employee, which includes that employee's previous radiation exposure history. This baseline, quantified by an initial gamma scan and bioassay, is used to establish the employee's body burden prior to working at the site, and allows an evaluation of additional exposures received at the site. Records of subsequent occupational exposures are maintained, and an employee's functions are typically rotated to preclude individual employees from receiving a disproportionate share of exposure. Table E.8 provides an illustration of typical employee quarterly exposure levels at an existing disposal facility (Ref. 23).

5.2.5.2 Site Radiation and Contamination Control

The licensee conducts routine radiological surveys to detect removable contamination and fixed radioactivity, and to minimize the potential for spread of contamination or unnecessary exposure to radiation.

As discussed in Appendix E, Section 5.2.1, waste transport vehicles and waste packages arriving at the disposal facility are routinely inspected by health physics technicians for compliance with federal regulations and license conditions

Table E.8 Example Quarterly Exposures at an Existing Disposal Facility

Job Description	No. Personnel Monitored	Total Exp.* (rem)	Av. Exp. (rem)
Health Physics	10	3.312	0.331
Offloaders	26	11.745	0.452
Truck Drivers	8	0.221	0.028
Technical Services	5	0.066	0.013
Equipment Operators	6	3.128	0.521
Maintenance	12	0	0
Administrative Personnel	40	1.405	0.035
Contract Personnel	5	0	0
Total:	112	19.877	

Total Activity Disposed: 98,905.4 Ci

Total Volume Disposed: 12,500 m^3

*First quarter of 1979.

Shipments found to be in compliance with transportation regulations and license conditions proceed into the disposal area for unloading. Violations of transportation regulations are reported to federal and state authorities. Damaged or leaking waste packages are identified and appropriate protective or remedial action is taken. Vehicle offloading operations are monitored by a health physics technician(s) equipped with portable radiation survey equipment. Radiation levels at the edge of the active trench are controlled to levels less than 100 mr/hr. Should radiation levels exceed 100 mr/hr, the trench is immediately backfilled with earth or low-activity waste until radiation levels drop below 100 mr/hr. Waste transport vehicles leaving the disposal area are again inspected, surveyed, and decontaminated as necessary to comply with transportation regulations.

Routine housekeeping activities carried out at the site to minimize and control the spread of contamination include periodic surveys of site grounds, buildings, and equipment. Table E.9 summarizes an operational contamination monitoring program, including survey frequencies and contamination limits, currently used at an existing disposal facility (Ref. 21). This survey program is supplemented by the environmental monitoring program discussed in Appendix E, Section 5.6. Surveys or contamination control are also carried out whenever a site area or piece of equipment is used in a controlled area known to be contaminated or suspected of contamination through such possible events as a small spill.

Personnel procedures to control contamination and minimize exposures also include the use of anticontamination clothing and personnel surveys. At the reference disposal facility, waste handlers and other site personnel which may come into contact with radioactive materials are required to wear anticontamination coveralls, gloves, and other items as necessary. These are replaced when contaminated, and the used items are disposed as radioactive waste or sent offsite to a radioactive laundry service for decontamination. Site protective clothing may be supplemented by additional equipment such as additional anticontamination clothing, controlled air suits, or respirators if the situation indicates their use. All persons are required to conduct personal surveys ("frisking") for contamination upon leaving the restricted area as well as any other time the person has reason to suspect that he has become contaminated. Safety decontamination showers are provided for use if needed, and personnel decontamination is supervised by the site RSO if needed.

5.2.5.3 Industrial Safety

Radioactive waste disposal facility operators in the past have generally concentrated on radiation safety to the exclusion of a separate comprehensive industrial safety program. The radiation safety officer at the reference disposal facility doubles as the safety officer, and has one radiation safety technician assigned specifically to inspection of equipment and job safety practices and hazards safety control. A program of industrial safety paralleling the radiation program does not, however, exist at the reference facility. Rather, aspects of personnel safety such as use of protective clothing are generally meant to meet both radiation and industrial safety standards. For example, all radiological workers or personnel working with overhead equipment wear anticontamination coveralls, anticontamination gloves, protective hard hats, and safety-toe shoes. Workers are also trained in standard signals and alarms used on site equipment and by supervisory personnel, and follow specific work rules.

Table E.9 Survey Program and Operational Contamination Limits

Frequencies		Removable Contamination	Fixed Radioactivity
Radiation-Controlled (Restricted) Facilities or Buildings		Daily	Daily
Operational Trench		NA	Continuously (operational phase)
Site Grounds Outside--Operational Trench Area		NA	Weekly
Site Equipment		Weekly	Weekly
Nonradiation-Controlled (Nonrestricted) Facilities or Buildings		Monthly	Monthly
Waste Transport Vehicles		Arrival/Departure	Arrival/Departure
<u>Limits</u>			
Skin and Personal Clothing	alpha beta-gamma	0* 0	
Protective Clothing	alpha beta-gamma	0 1,000 dpm	
All Items for Unconditional Release	alpha beta-gamma	22 dpm/100 cm^2 220 dpm/100 cm^2	0.1 mrem/hr**
Sole Use Vehicles	alpha beta-gamma	220 dpm/100 cm^2 2,200 dpm/100 cm^2	0.5 mrem/hr**
All Site Areas, Facilities Equipment, Outside Restricted Areas	alpha beta-gamma	22 dpm/100 cm^2 220 dpm/100 cm^2	0.1 mrem/hr
All Site Areas, Facilities, Equipment, or Tools Inside Restricted Areas	alpha beta-gamma	220 dpm/100 cm^2 1,000 dpm/100 cm^2	0.5 mrem/hr

*Not detectable using survey instrumentation.
**At any accessible surface.

5.2.5.4 Abnormal or Emergency Situations

Procedures and specific actions are established at the reference facility to aid in quickly and safely handling abnormal occurrences or site emergencies. Abnormal occurrences may include events such as a minor injury or a minor spill of radioactive material. A minor injury may be addressed through use of first aid equipment contained in site vehicles and in the health physics offices. In the event of a minor spill, the radioactive material is recovered and disposed, and the area in which the spill took place is decontaminated.

Site emergencies are expected to occur much more infrequently than abnormal occurrences, but are also expected to be potentially more serious. Specific actions contained in site procedures for emergency situations may include efforts to minimize exposures and control the potential spread of contamination, use of additional anticontamination or respiratory equipment, communication with emergency or law enforcement agencies, notification of regulatory authorities, and filing follow-up reports.

Overall control of an emergency situation is the responsibility of the site RSO, who directs actions of radiation safety technicians and other site workers in addition to coordinating with site security. Site security personnel maintain communications with site personnel responding to an emergency as well as with offsite emergency organizations. A central communications control point is maintained in the site security office and from this point, site personnel can be directed in their actions via loudspeakers located in the administration and operational areas and by radio communications with site security vehicles. These are radio-equipped four-wheel drive vehicles containing emergency equipment such as respirators and anticontamination clothing. The radios can also be used to communicate with local offsite emergency services such as police, fire, and ambulance. A call tree is established at the facility for telephone communication with corporate and site management, site personnel, local offsite emergency services (police, fire, ambulance), federal emergency services (e.g., DOE regional coordinating offices for radiological assistance), and federal and state regulatory agencies.

In addition, existing federal regulations require timely notification of federal authorities for a number of types of abnormal occurrences or emergency situations, as well as follow-up reports. Specific notification and reporting requirements depend upon the severity of the incident and some of these requirements are set out in the following federal regulations:

10 CFR 19.13(d)	Notices, instructions, and reports to workers
10 CFR 20.402	Theft or loss of licensed material
10 CFR 20.403	Notification of incidents
10 CFR 20.405	Reports of overexposures and excessive levels and concentrations
10 CFR 70.52	Accidental criticality/theft/loss of special nuclear material
29 CFR 1904	Recording and reporting occupational injuries and illness

49 CFR 171.15	Immediate notice of certain hazardous materials incidents
49 CFR 171.16	Hazardous materials incident reports
49 CFR 177.861	Accidents involving radioactive materials

At the reference facility, a checklist is used to ensure that initial notification, follow-up reporting, and follow-up action implementation are completed within time limitations specified in the regulations. Data from these incident reports are used to evaluate and improve the site quality assurance and industrial safety programs.

The historical record does not contain evidence of accidents resulting in acute releases of radionuclides which would present a hazard to the public health and safety (Ref. 6). Nonetheless, specific site procedures addressing a number of different types of radiological and nonradiological emergencies are developed at the reference facility and drilled at least annually. These site procedures include planning for such potential events as major spills; treatment of irradiated, contaminated, injured, or contaminated and injured personnel; fires; bomb threats; and civil disorders.

Incidents such as a major spill would generally be expected to involve a transport vehicle or possibly a waste container accidently dropped from a crane. In this case, steps are taken to rope off and contain the contamination to a small area. The vehicle can then be decontaminated in a manner which minimizes personnel exposure.

Generally speaking, treatment for trauma, shock and hemorrhage takes precedence over personnel decontamination procedures and treatment of possible symptoms from irradiation. If an injured worker is in a high radiation environment, he is immediately removed from this environment concurrently with any other immediate life-saving actions that may be needed. The site is equipped with safety decontamination showers and first aid equipment, and some of the radiation safety technicians have additional training in emergency medical care. Prior arrangements have been made with a local hospital to receive injured personnel. If necessary, a site health physics technician may accompany ambulances to assist hospital personnel in further decontamination of injured site personnel.

For potential onsite fires, the main concern is the possibility of generating airborne radioactive material and the spread of contamination. A number of hand-held fire extinguishers are located on site vehicles and at a number of (stationary) site locations. Generally, a fire in a trench would be quickly extinguished by backfilling with soil. Personnel involved in the emergency use respiratory equipment and anticontamination clothing as appropriate. Local offsite fire fighting agencies may be called upon to assist. Arrangements are made by the site RSO to periodically review elements of basic radiation safety with these agencies.

5.2.5.5 Training

Pursuant to 10 CFR Part 19 of the Commission's regulations, each disposal site employee receives instruction in the hazards and controls of radioactive materials commensurate with the worker's duties and responsibilities for handling materials, and with the extent of anticipated worker exposure. This is combined with training in operational procedures to provide a solid basis for safe onsite work. Supplementary training to deal with site emergency conditions is also carried out. The worker is instructed at initial orientation, in the classroom, and under actual working conditions in a variety of subject areas. Each employee is certified upon the sucessful completion of each training subject area, and training records documenting the type of training received and the resulting scores are kept for a two-year period at the site. Periodic refresher training and recertification is required biannually after initial qualification. Example subject areas which have been covered in radiological worker training programs at existing disposal facilities include: (Refs. 24, 25)

- Company and Site Organization
- Principles of Radioactive Waste Disposal
- Site Planning, Design, Security, Maintenance, and Operation
- Interaction with Radiological Safety Staff
- Site Radiation Work Rules
- Waste Handling Procedures
- Federal, State, and Local Regulations
- Facility License and Possession Limits
- Responsibilities of Employees and the Company
- Forbidden Practices
- Site Security
- Warning Signs and Alarms
- Basic Radiochemistry
- Nuclear Interactions with Matter
- Background Radiation
- Modes of Exposure
- Estimation of Dose Equivalent
- Radiation Dose Limits
- Biological Effects of Chemicals, Radioactivity, and Radiation
- Basic Protective Measures
- Anticontamination Clothing
- Surveys
- Radiation Exposure and Contamination Control
- Emergency Procedures
- Monitoring

5.2.6 Environmental Monitoring Program

An environmental monitoring program is carried out at the referenced disposal facility to monitor and control potential releases of radioactivity during site operations, to detect movement of radionuclides from the disposal trenches to the environment, and to provide information as to the long-term containment of radioactive waste disposed at the site. This is accomplished through an environmental sampling program in which samples are collected on the disposal site in addition to samples collected at a number of offsite locations. Potential exposure pathways to and possible impacts on individuals or local populations are also evaluated as part of the program.

Monitoring for potential long-term environmental releases is principally accomplished through well water samples obtained from both onsite and offsite wells, and from monitoring for the presence of water, if any, in trench sumps.

Monitoring for potential short-term operational releases of radioactivity is principally accomplished through collection of soil and vegetation samples, air samples, and samples collected to monitor direct gamma radiation levels. This portion of the environmental monitoring program is performed in conjunction and coordinated with the site survey program discussed in Appendix E, Section 5.2.5. (As discussed earlier, the survey program is a housekeeping activity involving periodic surveys of site grounds, buildings, and equipment for removable contamination and fixed radioactivity levels.) Information obtained from the environmental monitoring program is used to improve the effectiveness of the survey program and vice versa.

Potential short-term releases are expected to be minimal since site operations mainly involve handling of packaged wastes. However, some minor airborne releases may occur from pumping precipitation out of operational trenches followed by subsequent solar evaporation. Some minor airborne releases may also occur through operations (e.g., vehicle washdown, waste repackaging, liquid solidification) at the waste activities facility. These operations, however, are monitored by airborne sampling equipment. Experience has shown, however, that operational releases can be minimized through strict contamination control practices.

A summary of the operational monitoring program at the reference facility is included as Table E.10. This program includes collection of well water samples, soil and vegetation samples, and air samples, as well as monitoring for direct gamma radiation levels. Results from individual measurements recorded in the environmental monitoring program are retained for the life of the site along with information on sampling location and date, sample size (e.g., wet/dry weight), sampling and analytical procedures, units of data, and precision and accuracy associated with individual measurements. Additional information on the types of samples collected is presented below.

5.2.6.1 Well Water

Water samples are routinely collected from onsite monitoring wells, as well as offsite wells used by private residences. Onsite monitoring wells include 10 wells located along the perimeter of the restricted area as well as 15 wells scattered throughout the disposal area. The sample frequencies are semiannually for the boundary wells and quarterly for the disposal area wells. The samples are analyzed for gross alpha activity, gamma-emitting isotopes, and tritium as HTO.

In addition, the water level in each of the onsite wells is measured on a monthly basis to monitor fluctuations in the ground-water table. A total of five offsite wells used by private residents are also monitored on a semiannual basis. These wells are located both upstream and downstream of the ground-water flow beneath the site and are analyzed in a similar manner as the onsite monitoring wells.

Table E.10 Reference Facility Operational Monitoring Program

Sample Description	No. of Locations	Type	Media	Frequency of Analysis	Type of Analysis
External Gamma	50	Continous	TLD	Quarterly	Exposure
Atmosphere	3	Continous	Particulate Filter	Daily	Gross Beta-Gamma
			Particulate Filter	Weekly	Gamma Isotopic
			Charcoal Cartridge	Weekly	I-131
Soil & Vegetation	10	Grab	-	Quarterly	Gross Beta-Gamma Gross Alpha Tritium
Offsite Wells	5	Grab	H_2O	Semiannual	Gamma Isotopic Gross Alpha Tritium
Site Boundary Wells	10	Grab	H_2O	Semiannual	Gamma Isotopic Gross Alpha Tritium
Disposal Area Wells	15	Grab	H_2O	Quarterly	Gamma Isotopic Gross Alpha Tritium
Filled Disposal Trench Sumps	58	Grab	H_2O	Monthly	Gamma Isotopic Gross Alpha Tritium

*Trench sumps are checked on a monthly basis. Analysis would only take place if water was determined to be present in a sump

Filled and capped disposal trench sumps are checked on a monthly basis to determine if any water has collected. If any has collected, the water sample is analyzed for gross alpha activity, gamma-emitting isotopes, and HTO. The cause for any water collection is also immediately investigated and steps are taken to remove the collected water and prevent its reoccurrence. The number of disposal trench sumps monitored corresponds to the number of trenches constructed. By the time the site is closed, the facility is projected to contain 58 disposal trenches.

5.2.6.2 Soil and Vegetation

Soil and vegetation samples are collected at preselected locations in the disposal area on a quarterly basis. Analysis is performed on gross alpha activity, gross beta-gamma activity, and HTO. An annual gamma isotopic analysis is also performed. If the samples indicate significant levels of activity, additional samples are immediately obtained and analyzed. The cause of the elevated contamination levels are determined and the situation corrected.

5.2.6.3 Air

One low-volume, constant flow air sampler is operated continuously during disposal operations at a location nearby and downwind of the operating disposal trench. The sampler consists of a particulate filter which is analyzed daily for gross beta-gamma activity as well as a charcoal cartridge which is analyzed weekly for I-131. Additional grab samples are obtained and analyzed during abnormal occurrences such as a small spill. Two more air samplers are located in the waste activities building in the solidification area.

5.2.6.4 Direct Radiation

Direct radiation levels at the site are monitored through use of 50 TLD monitoring devices. Thirty-two TLDs are located along the boundary of the restricted areas. The remaining 18 TLDs are located in different parts of the administration and operational areas. One TLD is located in the administration building, 2 in the garage, 5 in the delivery vehicle parking area, 7 in the waste activities building, and 3 in the health physics/security building. The TLDs along the monitoring fences are replaced and analyzed on a quarterly basis. The remaining TLDs are replaced and analyzed on a monthly basis.

5.2.7 Security

The site security program is needed both for radiation health and safety considerations as well as to protect the many thousands of dollars worth of equipment, buildings, and facilities located onsite. The security program at the case facility is assumed to include the following:

- Full-time security personnel and a security training program.

- o Controlled access and exit from site areas including fencing and lighting, material gate passes, badge control, personnel and vehicle search procedures, lock and key control, etc.
- o Radio and telephone communication ability with emergency and law enforcement agencies.
- o Identification badges and dosimetry for site employees and visitors.
- o Procedures for notifying site personnel and local authorities in the event of an emergency in compliance with federal and state regulations and conditions.

Security personnel are assumed to interact closely with health physics personnel and carry out a number of functions which include checking people and vehicles into and out of the site, periodic patrols of site areas and fences, helping to respond to emergencies, and maintaining communications. Access to the restricted area is limited to employees, authorized unescorted visitors and contractors, visitors with escorts, and federal and state inspectors who require access to perform their duties. Site security equipment includes a few four-wheel drive vehicles which can be used to proceed to potential trouble spots if necessary. These vehicles are equipped with radios to communicate with each other and with a central security control point, and also contain emergency equipment such as anticontamination clothing.

5.2.8 Recordkeeping and Reporting

A number of records are assumed to be maintained at the site to cover the areas required by law, operational control, and for future use. Records which are assumed to be maintained at the facility include:

- o Personnel exposures
- o Waste receipt and disposal records
- o Personnel training records
- o Records for the QA program
- o Environmental monitoring data
- o Operating procedures
- o Records of site surveillance, and monitoring

Personnel exposures - Records are kept in compliance with NRC regulations contained in 10 CFR Part 20.

Waste receipt and disposal records - Records of waste disposal activities are generally retained permanently. These include the radioactive shipment records (RSRs) prepared by the shipper describing the name of the customer, waste package contents, radiation readings, results of shipment inspection for compliance with DOT transportation regulations, the dates of waste shipment receipt and disposal, and the disposal trench location (see Figure E.13). Some waste requires additional documentation because of more restrictive conditions placed on it.

Personnel training records - At the completion of each training program, the worker is certified and a record of the training course contents and results is kept. This information includes employee's name, social security number, expiration date, qualification date, contents of training program, final examination grade, date taken, and the instructor's signature as certification of successful course completion.

Environmental and personnel monitoring data - These records include offsite effluent and control station measurements, well water and stream water measurements, and extra measurements performed to more closely define a possible problem. Onsite workplace monitoring records for airborne, radiation field, and radioactive contamination hazards are maintained.

Records from the QA program - These include results of inspections, tests, audits, calibration records, records of nonconformance and their resolution, deviations, operating logs, and incident reports.

Records of site surveillance and monitoring - Surveillance and monitoring records are kept permanently, since the past history and trends indicated by these records are needed to verify the performance of the disposal facility.

In general, administrative records such as personnel files, internal office memos, preliminary designs and budgets, and other records of this type are not permanent and are assumed not to be retained longer than three years.

Reporting requirements include reporting periodic site inventory data, notices of shipper noncompliance, notices of abnormal events or license violations, personnel exposures, and environmental monitoring results to the appropriate regulatory agency or agencies. The licensee also complies with the reporting requirements of 10 CFR 70.54 (Nuclear Material Transfer Reports) for special nuclear material.

5.2.9 Quality Assurance

The quality assurance (QA) program at the site functions as a parallel department which provides quality control and training support to disposal operations. The QA personnel are not only familiar with the operating procedures, maintenance requirements, safety rules and basic radiation work procedures, but also have the responsibility to recommend improvements and coordinate the site training program. QA documentation is intended to provide adequate information to identify and correct substandard items, but is streamlined to the minimum required to achieve the objective. The QA program includes the following areas:

- personnel monitoring
- emergency drills and equipment
- contamination control
- working procedures
- site maintenance
- site groundskeeping
- waste receipt, inspection, storage, and disposal
- radiation instrument care and calibration

- o environmental monitoring
- o security
- o construction of disposal trenches
- o closure and stabilization
- o recordkeeping

In addition, a management audit program is carried out at least quarterly to maintain high standards of radiological control and safety and to ensure compliance with federal, state, local, and site license requirements. The program includes a review of operating procedures and past exposure records, facility inspections, and surveillance of work being performed. The senior RSO is directly responsible for the implementation of the audit program. The following areas are included in the management audit plans of a currently operating facility (Ref. 24):

- o Dosimetry Program
- o Radiological Control and Safety Program
- o Emergency Drills and Equipment
- o Operational Procedures and Performance
- o Personnel Decontamination
- o Radiological Survey and Posting
- o Radiation Instrumentation
- o Environmental Monitoring
- o Site Security

5.3 Facility Closure and Long-Term Site Control

This section briefly describes the assumed actions taken by the licensee to close the reference disposal facility and to prepare the facility for long-term care by the site owner. Following closure, long-term care activities by the site owner are also described. As discussed below, these activities are costly, and are principally a result of the compressible and degradable nature of much of the waste, and the practice at the reference facility of randomly and indiscriminately mixing this compressible waste with the other waste disposed into the facility. In addition, no special attention is paid to reducing the void volumes within the disposal trench and within the disposed waste packages through waste emplacement and trench cover compaction techniques.

The extensive long-term maintenance activities and high long-term care costs form a base case against which the costs and benefits of alternative waste forms and disposal facility design and operating practices are compared. In this way, the costs of alternative measures carried out during disposal facility operation to improve the stability of the facility may be compared against corresponding reductions in long-term care costs. Additional information is provided in Appendix Q, which develops cost estimates for facility closure activities as well as costs for various levels of long-term maintenance activity.

5.3.1 Reference Disposal Facility Closure

Final closure of the reference disposal facility is assumed to require approximately one year and mainly involves dismantling and decontaminating site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring. Initial closure activities are assumed to last approximately one year, which is followed by a somewhat indefinite period of time prior to license termination during which the grass cover over the final disposal trenches are established, the site is inspected prior to transfer to the site owner, etc.

Of the six buildings on the reference disposal facility, three of them--the administration building, the health physics/security building, and the site warehouse -- are located in the administrative area of the site and should be 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. The site shed is decontaminated as necessary and is also left standing onsite for further potential use by the licensee and the site owner. To accommodate the waste produced during dismantlement and decontamination operations, either an additional small trench is excavated, or space is left in the last of the fifty-eight (58) large disposal trenches. The volume of waste produced during these operations is estimated to be relatively small--about 1130 m^3 (40,000 ft^3) (Ref. 26).

For the reference facility, there is assumed to be no efforts to recontour the disposal site land. The trench covers are left mounted. 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 few hotter spots are observed but these are filled with overburden as necessary to reduce the radiation levels to background.

5.3.2 Institutional Controls

At this point, the disposal license is terminated and control of the site is transferred to the site owner. For this appendix, the site owner is assumed to be a state agency. Activities which take place during the institutional control period include site inspection and maintenance and site monitoring. Considerable maintenance activities are required during this time period, and mainly involve repair of slumping, subsidence and other disposal trench instability problems. Site maintenance is expected to be significant for 5 to 10 years after which the disposal areas begin to stabilize. During this phase, environmental monitoring of the disposal facility continues.

6. REFERENCE DISPOSAL FACILITY COSTS

This section presents a very brief summary of the cost assumed in this environmental impact statement for siting, designing, constructing, operating, and closing the reference disposal facility, as well as costs for 100 years of institutional control. The costs are summarized from the calculations in Appendix Q and may be presented 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. The costs are then each multiplied by parameters which account for additional indirect costs, cost of money, contingenity and profit.

Postoperational costs are broken up into closure costs and institutional control care costs. Closure costs are calculated assuming that 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 provide adequate assurance for site closure. These 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.

6.1 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.

6.1.1 Direct Capital Costs

For the reference disposal facility, the following items are included as direct capital costs, in 1980 dollars:

Capital Outlay		1980 $ (X1000)
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.

In the analysis, the required direct labor costs are assumed to be included as part of construction operations. 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. 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.

Building costs, which include the costs of labor required for construction, are assumed to vary depending upon the complexity of the activities taking place within the particular building. These costs are 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

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. 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. Legal fees during facility siting, licensing, and construction are assumed to average approximately $200,000 per year for each of the five years.

6.1.2 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.

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.

6.1.3 Annual Fixed Capital Charge

The annual fixed capital charge includes such items as interest on borrowed money, return on equity, depreciation, taxes, and insurance. Calculation of annual fixed charges for an actual 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 (25%) of the initial total investment cost, carried out over the 20-year operating life of the facility.

6.1.4 Total Capital Costs

Total capital costs are estimated as the product of the total capital investment times the annual fixed change rate over a period of 20 years, times a profit margin. For the purposes of this appendix, 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 reference disposal facility,

Total capital cost = 10.38 ($7,452,050)
= $77,352,300.

6.2 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 costs for environmental 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.

6.2.1 Direct Operational Costs

A summary of the direct operational costs over the 20-year life of the disposal facility are 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

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.

Disposal cell construction takes place continuously during facility operation. 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.

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 life. Operators of an actual facility will actually 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.

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. The assumed payroll costs per job function are listed in Table E.4. A 10% fringe is added to the base personnel costs; a 50% overhead is then calculated from the 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 in Table E.10. All gamma-isotopic, HTO, and I-131 sample analyses are assumed to be performed using offsite services.

Regulatory costs include costs associated with license renewals, inspection fees, and amendments.

Consumables (utilities, fuel, supplies, etc.) are estimated at $200,000 per year.

6.2.2 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 as well as a 20% profit.

6.2.3 Total Operational Costs

Total operational costs are estimated as the following:

$$\text{Total operational costs} = (1.2)(1.3)(\text{direct costs}) = 1.56\ (\text{direct costs})$$

For the reference disposal facility, total capital and operational costs equal the following:

$$\begin{aligned}\text{Total Costs} &= 10.38\ (\text{direct capital costs}) \\ &\quad + 1.56\ (\text{direct operational costs}) \\ &= 10.38\ (7{,}452{,}100) + 1.56\ (\$68{,}875{,}000) \\ &= \$184{,}797{,}000 \\ &= \$185./m^3 \\ &= \$5.23/ft^3\end{aligned}$$

6.3 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. However, to ensure that funds will be available to implement closure should for some reason the site is closed earlier than scheduled, the projected costs for closure are assumed to be covered by a surety mechanism obtained by the licensee. Funds for institutional control costs, however, 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.

6.3.1 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. As an illustration in Appendix Q, two levels of closure costs are estimated: low and high. The low scenario is summarized below.

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. A summary of the estimated costs are as follows:

Summary of estimated closure costs ($x1000)	
1. Building demolition	300.0
2. Waste disposal materials and survey	1.3
3. Personnel	503.3
4. Consumables	30.5
5. Equipment	120.6
6. Environmental monitoring	53.4
	$1,009.

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. 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 for the reference facility (assuming a low level of closure activities) are estimated at about $1 million in 1980 dollars. However, to estimate the closure costs at the end of the 20-year operating life, the costs are increased to account for inflation during that period. In addition, the licensee is assumed to accrue funds for closure through the operating life of the disposal facility through use of a surcharge ($ per m^3 of waste) on the waste received at the disposal facility. Monies collected through this surcharge mechanism are assumed to be set aside and invested into an interest-bearing fund. To assure the availability of funds for closure should the disposal facility close earlier than expected, the closure costs are also assumed to be protected by a surety mechanism. In Appendix Q, the total unit closure costs to the disposal facility customer are estimated as follows:

$$UCC = \frac{IT_o \ (1+j)^{IT_o}}{V_w} \left\{ f + \frac{i}{[(1+i)^{IT_o}-1]} \right\}$$

IT_o = site operational life (years)

V_w = volume of waste

C_{80} = closure cost in 1980 dollars

i = average interest rate

j = average inflation rate

f = annual fee for assuring availability of closure funds.

For the reference facility, IT_o is 20 years, V_w is one million m^3, i is assumed to be 10%, j is assumed to be 9% and f is assumed to be 1.5%. This results in a total inflated closure cost (at year 2000) of $5.6 million and a unit cost to disposal facility customers of $3.64/m³ (10¢/ft³).

6.3.2 Institutional Control

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 long-term care of the facility. The level of effort expended by the state is assumed to be a function of the degree of stability at the facility, and the level of surveillance, maintenance, and monitoring activities required 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. An approximate figure of $50,000 per man-year is assumed for a state employee.

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:

- 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 long-term care 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.

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.

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.

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 contractor's fee is presented as Table E.11. 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 stabilize over time. This is similar to the approach taken by Battelle-Pacific Northwest Laboratories (PNL) in NUREG/CR-0570 (Ref. 10).

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. 27). However the estimated costs may be conservatively high. As long as there is assurance that the facility is in a stable condition, it may be possible to get by with considerably less expenditures.

The estimated costs for the high level of maintenance, however, may be too low and contingency is assumed for unforeseen events. Unforeseen events could include water management problems ranging from periodic withdrawal of water

Table E.11 Estimated Annual Institutional Control Base Costs

Level of Effort	Adm	Contractor Costs ($k, per year)					Total
		Personnel	Supplies	Equipment	Monitoring	Fee	
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 (low)	8.4 (mod)	9.06	149.6
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

from disposal trenches and solidification, to large scale dewatering activities brought about by an extensive occurrence of the bathtub effect.

Three levels of additional (contingency) costs are developed in Appendix Q and are estimated to 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 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).

To determine institutional control costs over 100 years, the effects of inflation and interest must be considered. These effects are considered in Appendix Q and a formula is derived to estimated total long-term care costs. These may be converted to unit costs (\$/m) simply by dividing by the volume of waste disposed. In Appendix Q, the long-term care costs are given as follows, where:

$$\text{Costs} = \frac{IT_o\ PV_{80}\ (1+j)^m}{[(1=i)^{IT_o} -1]\ (1+i)^{IT_c}}, \text{ where}$$

IT_o = site operational life (years)

IT_c = closure period (years)

$m = IT_o + IT_c$

C_{80} = closure costs (1980 dollars)

i = nominal interest rate (expressed as decimal - e.g., 9% = 0.09)

j = inflation rate (expressed as decimal)

PV_{80} = present value of institutional control in 1980 dollars

$$= C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+j)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n}, \text{ where}$$

For the reference facility, total institutional control care costs are calculated assuming a high level of long-term care costs and a moderate contingency level. Assuming that IT_o is 20 years, IT_c is 2 years, i is 10%, j i=s 9%, the values for C_a, C_b, and C_c are as given in Table E-11, and the contingency is $367,000 per year for ten years, then the total institutional control cost is $34.6 million, or $34.6/m³ (98¢/ft³). Higher costs would be expected for disposal facility sites where there is a potential for a severe bathtubbing problem.

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APPENDIX F

ALTERNATIVE DISPOSAL TECHNOLOGIES

1. INTRODUCTION

A description of a reference near-surface disposal facility located in a humid environment in the eastern United States is provided in Appendix E. The reference facility is used to determine base case costs and impacts against which the costs and impacts of alternative waste forms as well as alternative disposal facility designs and operating practices can be assessed. Alternative waste forms considered in this environmental impact statement are addressed in Appendix D. Alternative disposal facility design and operating practices are addressed in this appendix. Costs for these alternative design and operating practices are developed as incremental costs to those associated with the design and operating of the reference facility as described in Appendices E and Q. Postoperational costs are not addressed in this appendix but are considered as part of the analyses in Chapter 5 of this EIS.

A number of variations in near-surface disposal techniques are discussed in Section 2. The discussion in Section 2.1 serves to provide a frame of reference to the later sections by reviewing ways in which designs may vary depending upon specific site characteristics. The remainder of Section 2 is devoted to discussion of alternative near-surface disposal technologies which can be used to improve long-term site stability and to reduce potential long-term impacts from: (1) potential inadvertent intrusion by humans, plants, or animals, and (2) long-term environmental releases and impacts. Many of the alternatives considered also have potential resultant impacts upon site operational safety--principally radiation exposures to site personnel--and these potential impacts are also discussed when appropriate.

Section 3 addresses land disposal alternatives to near-surface disposal, including intermediate depth disposal and mined cavity disposal. Section 4 reviews disposal technology options other than land disposal, including ocean disposal, and extraterrestrial (space) disposal. In Section 5, differential costs for the disposal technology options considered in this appendix are presented. These costs are calculated in a similar manner and consistent to the cost analysis for the reference disposal facility presented in Appendix Q. Finally, Section 6 provides a list of references to this appendix.

2. ALTERNATIVE NEAR-SURFACE DISPOSAL TECHNOLOGIES

2.1 Design Variations Related to Specific Site Characteristics

A reference disposal facility having a conceptual site design (e.g., trench size, facility layout) that is representative of existing disposal facilities has been described in Appendix E. The actual design of a particular disposal facility, however, can be influenced by site-specific conditions. Three design elements of disposal trenches which can be influenced by the characteristics of a particular site are trench dimensions, slopes of excavations, and final grades. Additionally, variations in dimensions and slopes can influence the overall disposal costs.

Trench Dimensions

As the dimensions of an excavation increase, the land use efficiency of using the excavation for waste disposal increases. For example, if the base case trench planar dimensions (180 m x 30 m) are doubled (to 360 m by 60 m), the land use efficiency is raised by about 6% (from 9.45 ft^3/ft^2 to about 10 ft^3/ft^2). If the planar dimensions are tripled, an increase in land use efficiency of nearly 8% can be realized. (The land use efficiency is defined as the volume of waste that is disposed per unit land area, including the area separating the individual disposal cells. Only land suitable for disposal is considered in this calculation. Land area set aside for administrative functions, borrow areas, and other areas not specifically used for placement of waste in near-surface excavati(are excluded from this calculation.)

Expansion of trench planar dimensions will require additional expenditures of money for excavation, but the increased land use efficiency results in a decrease in the land area commited for waste disposal. If gentle side slopes are required for safe construction and operation of the facility (as indicated by the nature of the existing soils), the positive effect on land use efficiency achieved by increasing trench dimensions becomes even greater. However, when a trench width is increased substantially, a major asset of trench disposal is diminished in strength--i.e., the direct radiation shielding provided by the walls of the trench and the waste packages within the trench. The narrower the trench, the greater the radiation shielding to facility workers that can be generally achieved. As the width of a trench becomes a large multiple of the depth, radiation "shine" from waste packages can become a problem. In addition, as the trench width is increased, the ease of waste emplacement from outside of the trench is diminished. Eventually, as the trench width increases it becomes first impractical and then impossible to emplace waste from outside of the trench. Waste emplacement activities must then be carried out from inside the trench, resulting in increased occupational exposures. When waste emplacement is performed within the trench, trench design, trench construction, and waste emplacement operations are also affected. For example, at the reference disposal facility described in Appendix E, each trench is equipped with a ramp which is occasionally used to facilitate placement of waste packages by forklifts. For a very wide trench, two or more ramps may be required to accommodate a steady flow of waste emplacement vehicles (e.g., forklifts) through the trench. These ramps would be used routinely, as opposed to intermittently as they presently are at most commercial disposal sites.

The mode of trench construction would also be generally modified as the size of the excavation is increased. For example, a silt trench can be excavated using a small backhoe. For the reference disposal trench described in Appendix E, the excavation work can be performed using large backhoes, draglines, or pan-scrapers. For very large trenches, pan scrapers and draglines become more practical tools for excavation.

The use of emplacement vehicles within disposal trenches introduces several logistics problems including the potential hazard of trench wall collapse, increased labor hours spent in higher radiation fields, and maintaining trafficability within the excavation. The hazard of potential wall collapse is particularly enchanced when long unsupported vertical walls are employed and vehicles operate close to these unsupported walls.

Precipitation management is another consideration. Dewatering of large excavations and maintenance of good drainage in large area excavations can be difficult. If the bottom of the excavation is not properly designed for drainage, the ability to move vehicles within the trench can be diminished. For very large excavations, it is prudent to employ both an active dewatering system (sumps and/or well points) and a full area drain (a layer of granular soil over the bottom of the entire excavation).

Increasing the depth dimension of a disposal trench can have an effect on both land use efficiency and disposal costs. For example, assume that the depth of the reference facility disposal trench is doubled from 8 m to 16 m, while the planar dimensions of the trench (180 m x 30 m), the side slopes (1 horizontal: 4 vertical), and the 1 m backfill thickness between the waste and the original ground surface all remain the same. The additional depth afforded in this example results in a 75 to 80% increase in land use efficiency (from 9.45 ft^3/ft^2 to between 16.5 and 17 ft^3/ft^2). Based upon a total volume of waste disposed of one million m^3, this increased land use efficiency results in a requirement for only 30 disposal trenches as opposed to the base case total of 58 trenches. This also results in a need for only 19.3 ha (45 acres) of land committed for waste disposal as opposed to the 34.7 ha (87 acres) requirement for the reference facility. The cost differential for this example (shown in Table F.4) is estimated to be about $\$3.99/m^3$ ($0.11/ft^3$). (Table F.4 and the other cost analysis tables are presented in Section 5.)

It should be emphasized that this estimate is provided as an illustration and does not consider the operational problems that would be associated with the above example of very deep trench disposal. For instance, the above example does not consider such potential operation problems as ease of trench construction or emplacement of waste. In addition, the above example assumes a very large depth to ground water (greater than 18 m), which may be a very restrictive requirement for humid eastern sites. Another consideration is the assumption that steep (1:4) slopes can be safely employed.

In eastern as well as western states, many substrata are characterized by granular soils that cannot necessarily be successfully excavated at 1:4 slopes. One option would be to greatly reduce the steepness of the site slopes, which could reduce the increased land use benefit of deep burial to an overall land use efficiency of only 40 to 50% higher than that realized by the reference disposal facility. Another more expensive option is trench wall shoring. If trench wall shoring was required in the above example deep disposal trenches, costs would be increased by about $\$24.65/m^3$ ($\$0.75/ft^3$).

<u>Slopes of Excavations</u>

As alluded to above, the existing characteristics of the soil profile at a disposal site can influence the land use efficiency through the need to maintain safe side slopes. Recommended safe side slopes for different soils are outlined in standards published by the Occupational Safety and Health Administration (OSHA). The OSHA standards with respect to excavations (Ref. 1) state that banks more than 5 feet high should be shored, laid back to a stable slope (angle of repose), or that some other equivalent means of protection should be provided where employees may be exposed to moving ground or cave-ins. The recommended excavation slopes for trenches based on soil types are summarized below.

Soil or Ground Type	Slope (H:V)	Angle of Repose
1. Solid rock, shale, or cemented sand and gravels	Vertical	90°
2. Completed angular gravels	1/2:1 (1:2)	63°26'
3. Recommended slope for average soils	1:1	45°
4. Compacted sharp sand	1 1/2:1	33°41'
5. Well-rounded loose sand	2:1	26°34'

The OSHA trenching requirements also state minimum shoring requirements for vertical walled excavations under various ground conditions. In general, gentle slopes result in reduced land use efficiency.

Final Grades

The existing topography of a disposal site can influence the designs employed. For example, construction of disposal trenches on steep slopes can be difficult. Construction equipment is typically difficult to operate on slopes greater than 25%. In addition to construction difficulties and the potential for erosion, operational activities such as waste emplacement can prove to be difficult on steep slopes. Irregular topography can also limit the size of trenches within a tract of disposal facility land.

Hydrogeologic Considerations

The depth of a disposal trench is generally limited by the local depth to ground water. Other hydrogeological factors which impact facility design include depth to bedrock, depth to heterogeneous horizons, and distance to ravines and gullies. These factors can limit the sizes and locations of disposal trenches.

2.2 Control of Potential Intrusion by Humans, Plants, or Animals

This section discusses potential methods which may be used at near-surface disposal facilities to reduce the impacts of potential inadvertent intrusion into disposed waste by humans, plants, or animals. Inadvertent human intrusion into disposed waste can result from such potential human activities as construction of a house or operation of a small garden upon the disposal facility. Intrusion into disposed waste by burrowing animals or deep-rooted plants may also occur and could result in increased exposures to humans through: (1) surfacing radioactive material which could then be dispersed by wind or water, (2) human consumption of contaminated plants and animals, or (3) increasing rainwater percolation into the disposed waste and thereby potentially increasing radionuclide migration through ground water. The immediate impacts of plant and animal intrusion, however, would be considerably less significant than potential direct human intrusion.

Many of the methods described in this section which may be used to reduce or eliminate the impacts of potential intrusion have been either used in the past at existing disposal facilities or require only minor development. Some potential methods, however, such as use of biological barriers to plant or animal intrusion, appear to require additional research and development. In addition, some of the methods discussed in this section have an additional positive effect in that the methods may help reduce potential ground-water migration. Potential operational health and safety considerations are also addressed.

2.2.1 Thicker Trench Covers

One method which may be used to reduce the potential for intrusion (and also minimize intrusion impacts) is simply to increase the thickness of the cover (the trench cap) over the disposal trench. Before analyzing the increased costs that could result from an increased disposal cap thickness, however, it is useful to briefly consider the nature of potential intrusion, and the nature of existing and future disposal facilities. A more extensive discussion is provided in Chapter 4 of this EIS.

The actions of future potential inadvertent intruders are impossible to precisely predict. Nonetheless, it is possible to conservatively postulate two scenarios which could lead to potential significant exposures. One scenario would be the construction of a house on the disposal facility and the second would be persons living in the constructed house and potentially consuming food grown in a small garden located in contaminated soil. In order to postulate that potential significant exposures to intruders can occur under these scenarios, it is necessary to assume that the scenarios involve activities that penetrate the surface of the ground for significant depths. As discussed below, this assumption may be problematical in some cases.

Typically, a near-surface disposal facility would be sited in areas which are flat to gently rolling. The practical reasons for this include ease of construction and promotion of rainwater runoff, while at the same time minimizing erosion. The disposal facility would not be located at a site having significant topographic relief. This implies that major earthmoving activities may not be required for construction of roads, buildings, etc. In many areas of the country, both in eastern and western regions, houses are constructed without basements and with few excavations. Emplacement of water mains, sewage connections and other utilities would, however, typically, involve excavations down to a few meters. Somewhat deeper excavations would result if basements were constructed. A lower range of excavation depth for typical basements for a housing development is believed to be about 3 to 3.5 m (10-11.5 ft) (Ref. 2).

Farming and gardening are surface activities. Plowing, harvesting, and other agricultural activities generally do not involve disturbing the soil for more than a few feet below the ground surface, and many typical root crops have relatively shallow root systems.

In any case, scenarios such as housing construction, or gardening activities at a disposal location require an assumption that persons performing such activities do not know that a potential hazard exists. Although it is difficult to predict with certainty the structural integrity of disposed waste after a few hundred years--particularly wastes such as miscellaneous low-activity trash--objects such as corroded equipment and monolithic blocks of solidified material would probably remain. It is likely, that persons potentially contacting the waste material would recognize that something was out of the ordinary and cease activities. Gardening is not an activity that can profitably be undertaken in a field full of half-buried 55-gallon drums filled with concrete.

At the reference disposal facility, the waste is assumed to be emplaced to a level approximately one meter below the top of the trench. This one meter space is filled with overburden, and a cap is then emplaced which is also assumed to be one meter thick. This results in approximately two meters (6.6 ft) of earth between the top of the waste and the surface of the ground. This thickness of cover would probably preclude contact of the waste through most potential agricultural activities, but may still allow partial contact through such activities as construction of a basement.

An additional 3 meters of overburden would raise the distance between the waste and the ground surface to about 5 meters (16.4 ft). The thickness would place the top of the disposed waste about 1.5-2 meters (5-6.6 ft) below the lower level that typical basements would be expected to be constructed. An earthen thickness of 3 to 5 meters would also be expected to place the waste below typical burrowing depths of many burrowing insects and animals, as well as below the root depths of many plant species--particularly many food crops.

At existing disposal facilities, disposal trenches are excavated, filled with waste, covered over with previously excavated soils, and capped. There is usually considerable excess dirt from trench excavation and this dirt is generally applied as additional overburden over the trench cap. Existing disposal facilities often have as much as 8 to 12 feet (2.4 to 3.7 m) of earth separating the top of the disposed waste and the surface of the earth. An upper bound estimate of the costs of increasing the disposal cell cover thickness can be made by using standard construction cost estimation guides (Ref. 3). At a rate of $0.75/yd^3 ($0.98/m^3) to excavate, haul (assume a 1,500 ft haul distance), and spread earth using scrapers, increasing the earthen thickness over the disposal cells by 3 meters would cost an approximate additional $1.59/m^3 ($0.05/ft^3) (See Table F.5).

In a similar vein, an increased distance between the ground surface and the top of the disposed waste could be achieved by increasing the thickness of earthen material between the top of the waste and the top of the trench. This is assumed to be equal to one meter at the reference disposal facility, which results in a thickness of earthen material between the waste and the top of the trench cap equal to about 2 meters. If only the bottom 4 m out of the 8 m excavation were used for waste disposal, the thickness of earthen material between the waste and the top of the trench cap would be increased to 5 m (16.4 ft). The reduction in potential intruder impacts would be equivalent to the case described above regarding increased overburden thickness, but would be brought about through decreased land use efficiency. If at the reference disposal facility only the bottom 4 m (instead of the bottom 7 m) of all disposal trenches were used for waste disposal, then the land use efficiency would be dropped from about 2.9 m^3/m^2 to approximately 1.6 m^3/m^2. The land area committed to waste disposal would be raised from about 87 acres to about 157 acres, and the number of disposal trenches constructed raised from 58 to 105. Due to the additional amount of trench construction, filling, grading, seeding, and other groundskeeping activities that would be performed, costs would be proportionately raised (by about \$4.7/m^3 or \$0.13/ft^3) (See Table F.6).

At existing disposal facilities, the thickness of earthen material emplaced between the top of the waste and the top of the trench typically ranges from about one to eight feet. For example, at the Barnwell, SC disposal facility, this distance for most disposal trenches typically ranges from about one to three feet. (After backfilling, installing the cap, and covering with overburden, however, the distance between the top of the waste to the ground surface usually ranges from 2 to 3 meters.) In addition, slit trenches have been used in the past at the Barnwell facility for disposal of wastes having high surface activity levels. Typically, a fill thickness of 10-12 feet was used for shielding purposes (Ref. 4). These trenches, however, involved disposal of only a small volume of waste.

At the commercial disposal facility located in the Hanford Reservation near Richland, Washington, license conditions require a minimum earth thickness of eight feet between the top of the waste and the original ground surface (Ref. 5). The site is located in an extremely arid area (about 6 inches of rain per year), and the depth to the ground-water table is on the order of 100 m (Ref. 6). Therefore, disposal trenches can be dug to greater depths than at the reference facility located in the humid eastern U.S. (Typically, trenches are excavated at the Richland commercial disposal facility to depths of about 12 meters, as opposed to the assumed 8 m at the reference facility, resulting in no significant loss in land use efficiency (Ref. 7).

2.2.2 Disposal of Wastes Having High Radiation Levels

It is expected that the majority of the waste streams that would require disposal by methods that provide protection against inadvertent intrusion would also be characterized by high surface radiation levels. Other wastes having high surface radiation levels may be dominated by short-lived isotopes, and therefore may not be of significant concern to a potential future inadvertent intruder. However, the temporary high radiation levels associated with such wastes would still require additional care during waste handling and disposal operations. It is useful, therefore, to consider a number of potential waste disposal concepts which may offer increased protection against the actions of a potential inadvertent intruder, while at the same time offering increased worker radiation protection during waste handling and disposal operations.

Typically, only a small fraction (about 10%) of the packages received at commercial radioactive waste disposal facilities would be characterized by elevated exposure rates (e.g., greater than about 5 R/hr). These wastes pose some restrictions on operations at disposal facilities. At the present time, most high exposure rate ("hot") waste is dealt with on a case-by-case basis. For example, optimal locations for shielding in trenches are often reserved for high exposure rate waste packages. Optimal locations in trenches can include corner locations and positions between waste packages having low activity levels. Additionally, rapid partial backfilling of high exposure rate packages may be employed to reduce radiation levels to acceptable working levels.

Special "hot" waste disposal cells have been employed from time to time at some of the commercial disposal facilities, as well as at some of the U.S. Department of Energy radioactive waste disposal facilities--e.g., Oak Ridge National Laboratory, (Ref. 8) the Hanford Reservation, (Ref. 9) and Los Alamos Scientific Laboratory) (Ref. 10). The types of disposal cells that have been employed for disposal of high-exposure-rate waste packages have included slit trenches, caissons, reinforced concrete culvert pipes, auger holes, and toner tubes (a specific type of caisson with a basket funnel for introducing waste packages).

The following subsections discuss four potential disposal methods which can be used to reduce or eliminate potential inadvertent intruder impacts while at the same time reduce potential worker exposures during site operations. These methods include layered disposal, slit trenches, caisson disposal, and walled trenches. Caissons and walled trenches are two examples of possible use of "engineered structures" for waste disposal. Following these subsections are two sections which investigate additional methods by which potential inadvertent intruder exposures may be reduced or eliminated. These include grouting interstitial voids between disposed waste packages with cement grout and installation of engineered human intruder barriers.

2.2.2.1 Layered Waste Disposal

Protection against inadvertent intrusion may be accomplished by layering of the waste according to the relative hazard of the waste. The concept of trench layering involves placement of wastes having a higher potential hazard along the bottom of the trench with wastes having a lower potential hazard emplaced on top. Typically, higher potential hazard waste would include waste packages characterized by high surface radiation levels or wastes that could pose a significant airborne hazard if disturbed by excavation.

For illustrative purposes, the example case of layered waste disposal employs the same trenches described in the reference disposal facility (Appendix E). In the reference facility trench, only the bottom 7 m out of the 8 m excavated is used for disposal of waste. In layered waste disposal, the bottom 2 m of the excavation is assumed to be reserved for disposal of higher potential hazard waste material. Any remaining space in the bottom 2 m is used for disposal of lower activity waste. The 5 m of space available above the bottom 2 meters is also used for disposal of lower potential hazard waste material (see Figure F.1). Thus, the inadvertent intruder would have to dig through 2 m of backfill and 5 m of lower hazard waste before encountering waste that could result in a significant potential exposure. Excavation work that uncovered boxes and drums of low activity waste would probably discourage further excavation long before the more hazardous material was reached. Layered waste disposal would also help to reduce personnel exposures during disposal operations by providing additional shielding for wastes having high gamma radiation levels.

The option of layered waste disposal would not appreciably alter facility design, operations or labor requirements. However, there would have to be an adequate mix of lower hazard to higher hazard waste on hand to allow for successful implementation of the option (i.e., a lower hazard waste to higher hazard waste volume ratio of about 2.5 to 1 or greater). Maintaining an input of waste at this ratio would require either careful scheduling of input from waste generators, and/or implementing greater storage capability at the site. For example, if higher activity waste were to be received at the site at a rate equivalent to that of the lower activity waste, a fraction of it would be buried as it was received, while the remainder would be stored for future disposal (when sufficient lower hazard waste became available). It would also be necessary to have the capability of transporting the waste from the site waste storage area. Therefore, operational changes at the disposal facility could involve temporary storage of waste, additional coordination of waste receipt and emplacement, and transport of stored waste from the storage area to the disposal trench. Significant cost differences are estimated to include construction of an inexpensive moderate-sized waste storage facility (e.g., an open-sided roofed structure intended to provide some weather protection for the stored wastes, and perhaps a storage pad with tarpolins for large packages), and hiring of some additional personnel. The estimated cost differential for this option (shown in Table F.7) is about \$37.73 per m^3 for waste requiring layered disposal (\$1.07/ft^3). No additional land would be committed to waste disposal.

2.2.2.2 Slit Trench Disposal

A slit trench typically has a length dimension which is more than 5 times the width dimension (the width dimension is generally less than 5 meters). The depth of slit trenches used in the past at disposal facilities (e.g., at Oak Ridge National Laboratory (Ref. 8) and the Barnwell, S. C. commercial disposal facility (Ref. 11)) have been generally equivalent to the excavation depths of the larger disposal trenches employed at the facilities. For the assessment performed in this appendix, the assumed dimensions of vertical walled slit trenches are assumed to be 20 m in length, 3 m in width and 8 m in depth. The minimum spacing employed between slit trenches is assumed to be 2 m. The assumed disposal efficiency is 50%, which means that only 50% of the total available void space is eventually occupied by waste packages.

For the cost analysis provided in Section 5 of this appendix (see Table F.8), it is assumed that 10% of the waste volume received at the facility requires

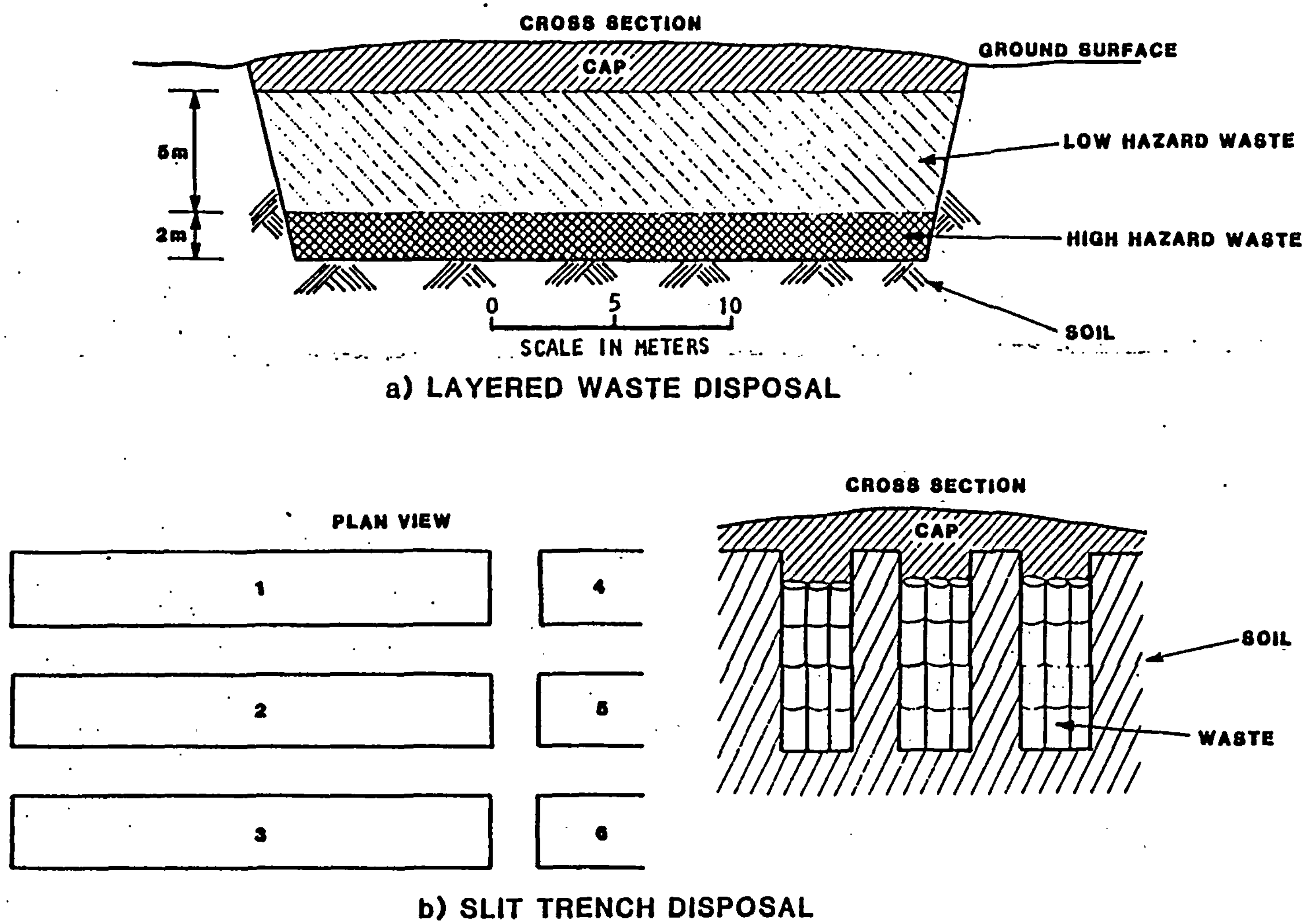


Figure F.1 Layered Waste and Slit Trench Disposal

disposal using slit trenches. The assumed slit trench dimensions and spacing imply that the land use efficiency of slit trench disposal is approximately half the efficiency of the reference trenches (180 m x 30 m x 8 m) described in Appendix E (or about 4.7 ft^3/ft^2). The unit cost differential between the base case unit disposal cost for the "hot" waste requiring slit trench disposal, shown in Table F.8, is $91.49 per m^3 of waste disposed into slit trenches ($2.59/$ft^3$).

This cost is calculated assuming that no shoring is used during slit trench construction and waste emplacement, which raises difficulties regarding emplacement of standpipes and French drains. That is, for the reference disposal facility, after initial construction of the disposal facility trenches, some additional construction work inside the trenches is needed to smooth the disposal trench floor and to provide a gentle slope to the gravel-filled French drain which runs along one side of the trench. The French drain also slopes toward one end of the trench where a gravel-filled sump is excavated. Standpipes are then placed into the sump and at other locations in the French drain. Performing such activities within a deep, narrow slit trench, however, raises operational safety questions. Since a smooth trench bottom cannot be assumed, the usefulness of standpipes and French drains were considered questionable and were therefore assumed not to be installed in the slit trenches. If shoring were used--either to allow construction work inside the slit trenches or to maintain side walls during waste emplacement--then unit costs for slit trench operations would be considerably higher.

The slit trench option results in an additional 1.6 ha (4 acres) committed to waste disposal. The overall land use efficiency for this option is estimated to be 8.75 ft^3/ft^2 (mixture of regular and slit trenches). The major anticipated benefit of employing this option is a reduction in the occupational exposures received by the waste emplacement labor force at the disposal facility. It is estimated that the use of slit trenches can possibly reduce occupational exposures by between 10 and 20%. Use of slit trenches for high activity wastes would be expected to reduce potential intruder exposures by a factor of about two. Some drawbacks to the use of slit trenches include the added expense and moderate slope failure hazards existing for vertical walled trenches. Additional drawbacks include the difficulty in installation of reliable monitoring devices within the trenches. The restricted width dimensions of slit trenches may preclude the burial of very large waste packages.

2.2.2.3 Caisson Disposal

To represent the estimated costs and anticipated benefits of use of caissons, tubes, or reinforced concrete pipes for disposal of high activity waste, an example case employing reinforced concrete pipes is evaluated. In the illustration provided here, each "hot" waste disposal cell is assumed to consist of a 30 in (0.6 m) inside diameter reinforced concrete culvert pipe which is 24 ft (7.3 m) in length. These culvert pipes are inserted vertically into a slit trench which is 15 m (50 ft) in length, 1.5 m (5 ft) in width and 8 m (26 ft) in depth. After waste emplacement, the culvert pipes are assumed to be capped with a 0.6 m (2 ft) thick layer of concrete. Earthen overburden is then applied, graded for drainage, and seeded. Void spaces between the caissons are assumed to be backfilled with earth (see Figure F.2).

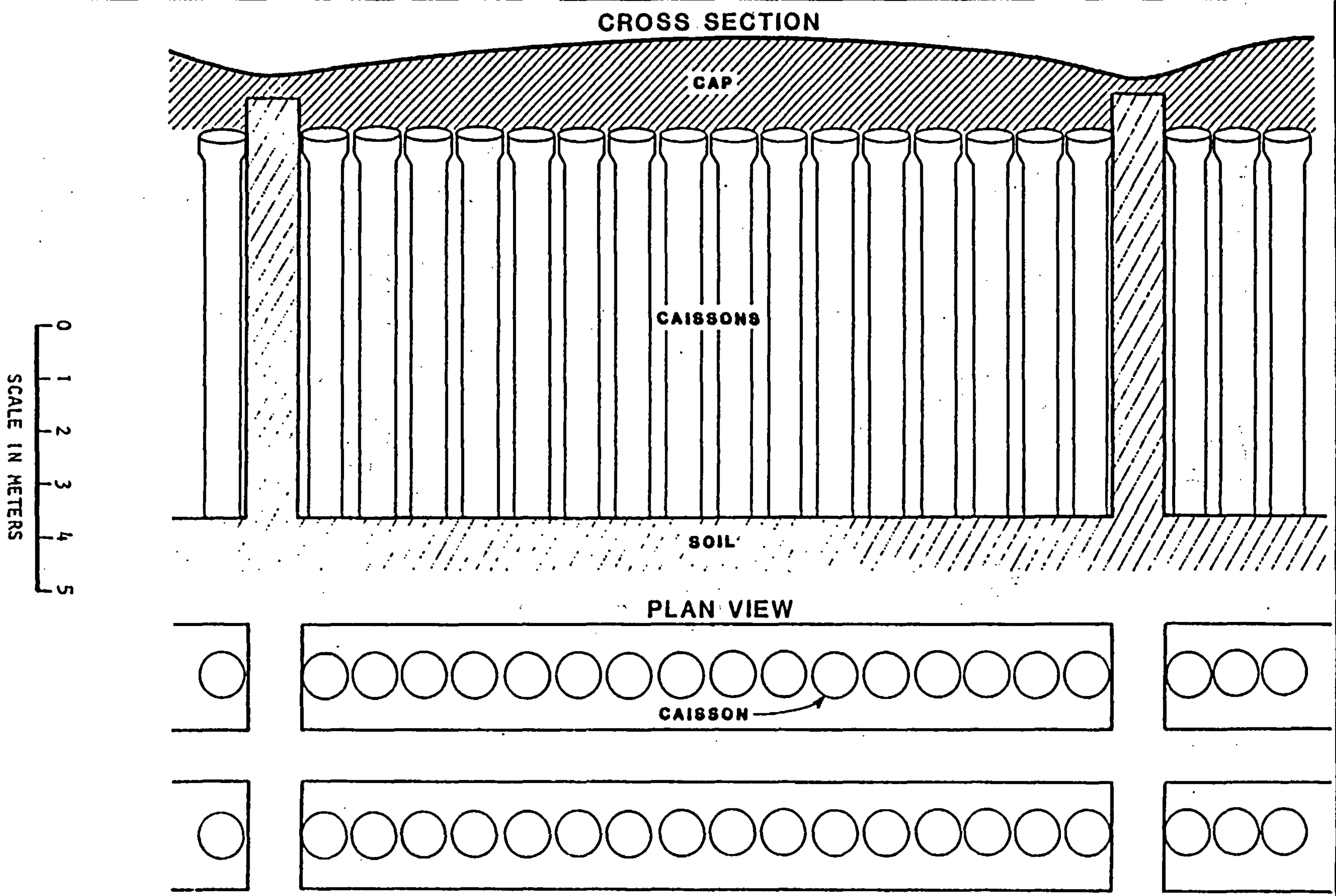


Figure F.2 Caisson Trench Disposal

Each slit trench can accommodate 16 of the reinforced concrete culvert pipes, which can accommodate either 55- or 83-gallon drums. Larger diameter pipes could be used for larger waste packages. As a result of the lower potential for slope failure resulting from the lateral structural support provided by the culvert pipes and the shielding provided by the concrete, the inter-trench spacing can be reduced. Therefore, each slit trench is assumed to be separated from adjacent trenches by a minimum of 1 m (3.3 ft). This results in an overall land use efficiency which is about 60 to 65% of the efficiency attained for the reference trenches (180 m x 30 m x 8 m) described in Appendix E. The reduction in occupational exposures provided by this option is probably similar to that estimated for the slit trench case described earlier (10 to 20%).

As an illustration, costs are estimated for an example in which 10% of the waste received at the disposal facility is disposed using caisson trenches. The estimated cost differential above the reference case for this example (shown in Table F.9) is \$216.45 per m^3 of waste disposed into the caisson trenches (\$6.13/ft^3). Again, these costs were calculated assuming that no shoring is used to construct the caisson trenches and consequently no gravel drains or monitoring standpipes are installed. Similarly to the previous case, if such shoring were required, unit differential costs would be considerably higher.

2.2.2.4 Concrete Walled Trench Disposal

A third type of "hot waste" disposal cell which has been employed for selected wastes in foreign countres (e.g., Chalk River, Canada) (Ref. 12) is a walled trench. For illustrative purposes, the concrete walled trench is assumed to be constructed of reinforced concrete and having 0.3 m (1 ft) thick walls and floor. The depth of the trench from the top of the trench walls to the floor of the trench is assumed to be 8.3 m, while the inside planar dimensions are assumed to be 12 m by 3 m. A 0.3 m gravel base is then assumed to be emplaced in the bottom of the trench prior to waste emplacement. A monitoring standpipe is also emplaced into one corner of the trench. The waste is then assumed to be stacked into the trench to a height of 7 m. Interstitial voids may be filled with earth or, for increased stability and intruder protection, by a cement grout. Filled trenches are then covered by a one meter thick concrete cap followed by a layer of overburden graded for drainage. The walled trenches described here are capable of handling 55- and 83-gallon drums, as well as steel liners up to 1.8 m (6 ft) in diameter. The dimensions of the walled trenches can also be increased to be able to handle larger sized waste packages, at a decrease in radiation shielding to facility workers.

The spacing between walled trenches is assumed to be a minimum of 3 m as a result of the requirements for concrete forming work. Due to the larger spacing required for this type of disposal cell and the volume lost by the wall displacement, the land use efficiency is calculated to be less than 25% of that for the reference trench. The anticipated reduction in occupational exposure for waste emplacement workers should be roughly equivalent to that estimated for the other "hot" waste disposal options (about 10 to 20%).

Differential costs are estimated for (1) an example in which 10% of the waste volume delivered to the disposal facility is assumed to be disposed in concrete

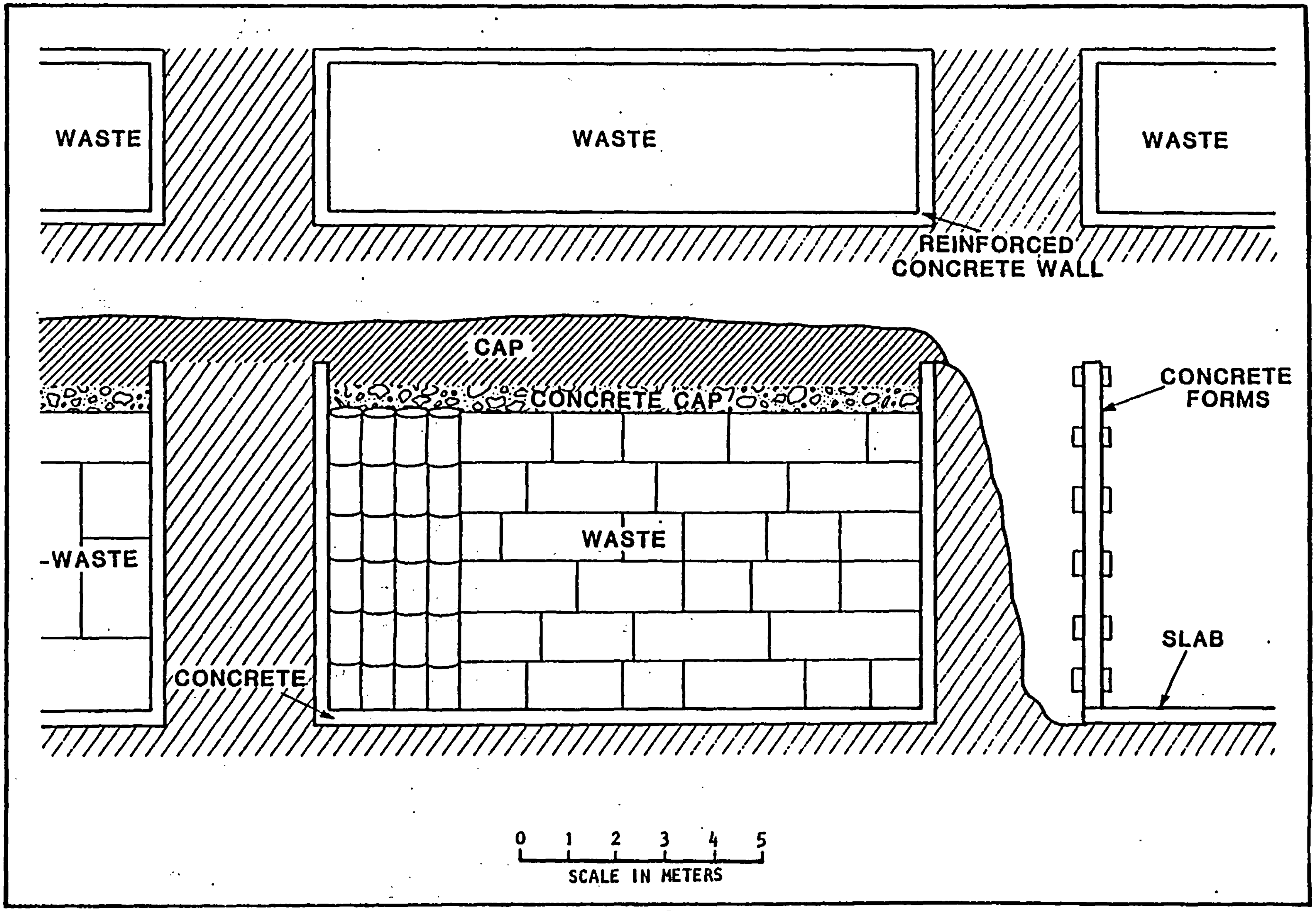


Figure F.3 Concrete Walled Trench

walled trenches, and (2) an example in which 100% of the waste is disposed in concrete walled trenches. These differential costs are presented in Tables F.10 and F.11, and are $256/m^3$ ($7.25/ft^3$) for the former example and $161/m^3$ (84.56/ft^3) for the latter example. The effects of economics of scale are apparent. Additional land use for the two examples are, respectively, 4.1 acres and 39.5 acres. Costs (for 10% of waste disposed) are seen to be higher than either slit trenches on caisson trenches. The additional land use, however, is less than these two cases.

Based on the relatively higher cost, this option may not be warranted to achieve lower occupational doses. On the other hand, this option affords a greater degree of protection for the inadvertent intruder.

2.2.3 Grouting

Another available method which could be used to reduce intruder impacts would be to fill void spaces between waste packages with a cement grout. The grout would greatly increase the difficulty of excavating into the disposed waste. The cement fill would also provide greater radiation shielding than ordinary dirt backfill. In addition, since the grout would also reduce trench cover subsidence and subsequent infiltration of rainwater into the disposed waste, decomposition of the disposed waste would be reduced. This reduces the potential for airborne dispersion and increases the likelihood that an intruder would recognize that something was out of the ordinary and investigate.

For illustrative purposes, the waste packages are assumed to be stacked into the reference disposal trenches prior to grouting. As discussed in Section 2.3.3.1, this is more costly than random emplacement and increases occupational exposures. The relative cost of cement grouting is high, however, and the less void volume requiring filling, the lower the overall costs will be.

In this example, the waste is emplaced in layers. After each layer is completed, tremie pipes are lowered to the base of the trench through void spaces between the waste packages at perhaps 6 to 8 separate locations. The grout is pumped through the tremie pipes until the grout level reaches the top of the first waste layer. The pumping activities generally would be carried out in stages (grouting each layer in areal sections). After the first waste layer is grouted, additional waste emplacement could proceed. Each layer of waste would be similarly grouted.

The grouting operation for each layer would probably consume at least one to two weeks of time. In order that waste disposal operations not be halted during grouting, it would be necessary to operate with two or more trenches open concurrently. The labor force would also have to be augmented. Additional supplies and equipment would include grouting equipment (pumps, hose, and tremie pipes), and cement. An increase in the storage area would also be needed for warehousing the cement prior to use.

The estimated differential cost for this disposal option, excluding the cost for waste stacking, is about $38 per m^3 of disposed waste ($1.08/ft^3$), or about $115 per m^3 of grout (see Table F.12).

A less expensive alternative could involve use of controlled density fill in place of the cement grout. In this example, the controlled density fill is assumed to be a commercially available lower strength concrete. The material is emplaced in layers using tremie pipes in a similar manner as the grout fill and is identical to the grouting case with respect to operational, equipment, and manpower requirements. The principal difference is cost because the low density concrete is considerably less expensive than the cement grout. The estimated differential cost for the controlled density fill (excluding the cost for waste stacking) is about \$24 per m^3 of disposed waste (\$0.70/ft^3) or about \$74 per m^3 of grout. Other than cost, the only appreciable difference in the final trench status is the overall strength of the fill. Controlled density fill will provide additional support to the trench cap but is more capable of being excavated. Therefore, the controlled density fill provides slightly less intruder protection. The benefits to trench cap integrity and leach resistance are assumed to be equivalent to that for grout cement.

2.2.4 Bio-barriers

As discussed above, potential intrusion of burrowing animals and deep-rooted plants into disposed waste at a near-surface disposal facility can potentially impact humans in three ways.

- 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.
- 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.

Some typical burrowing depths of certain animals are provided below (Ref. 13).

Species	Maximum Typical Burrow and Tunnel Depth
Harvester Ant	3.0 m
Moles	1.2 m
Pocket Gopher	0.6 m
Pocket Mouse	1.6 m
Deer Mouse	0.6 m
Field Mouse	0.6 m
Earthworms	0.5 m

Root depths of plants can, depending upon the species, range from fairly shallow depths to very deep depths. Some plants native to arid regions, for example, have root depths that can range up to 100 feet.

Occasional cases of plant and animal intrusion have been documented at disposal facilities operated by the Department of Energy (DOE). For example, at the Hanford Reservation, cribs have been extensively used in the past for disposal of liquid waste, and are still occasionally used at the present time. (A crib is a shallow disposal trench, occasionally gravel-lined, into which liquids are piped and allowed to percolate into the sandy soils.) Burrowing animals such as jackrabbits have, on occasion, burrowed into the cribs in an effort to obtain salts deposited by the percolating liquids. Radioactive salts thus consumed were then dispersed by the burrowing animals and their predators. On other occasions at the Hanford Reservation, swallows have been known to obtain radioactive mud from settling basins for use in constructing nests (Ref. 14).

Other incidents have been noted at the Hanford Resrvation in which plants growing over disposal trenches and cribs have accumulated fission products and transuranic elements in shoot tissues (Ref. 15).

At the Oak Ridge National Laboratory (ORNL), a tree has been reported to have been removed from the disposal area after it was noticed to have accumulated radiocontaminants (Ref. 16). Mud-dauber wasps have also been observed at this facility to have built nests from contaminated mud obtained from waste seeps (Ref. 14).

Uptake and dispersion of radiocontaminants by plants and animals has not been reported at commercial disposal facilities. However, at the Sheffield disposal facility, a small animal burrow was reported in a study by Heim and Machalinski. The authors pointed out that the burrow, which was about 20 inches in depth, was a potential concentrated source of rainwater infiltration (Ref. 17).

Actual potential impacts of plant and animal intrusion into disposal wastes are site-specific and are, furthermore, difficult to predict. 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).

The impacts that have resulted from documented cases of plant and animal intrusion have not been cause for a significant public health and safety problem. Nontheless, the fact that plant and animal intrusion has occurred in the past makes it worth considering during development of regulations for near-surface disposal of waste. It would probably be most advantageous to consider ways in which the occurrence of plant and animal intrusion can be minimized or eliminated. This is believed to be probably of most significance in helping to reduce potential migration of ground water to levels as low as reasonably achievable.

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:

- Increasing the thickness of earthen fill between the top of the disposed waste and the facility surface.
- Placing higher activity material farther below the surface (layering the waste).
- Reducing the potential for leaching and dispersion of waste forms, particularly higher activity wastes.

Barriers against intrusion may also be used. One barrier which has been used with success (Ref. 14) 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 (Refs. 5 and 9).

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., (Refs. 15 and 18). The study was limited to an arid area (annual precipitation of about 6.25 in) and involved use of a large test trench in addition to 16 small lysimeters. The barrier consisted of a .6 to 1.2 m layer of cobble stones (2.54 to 5.1 cm in diameter) over which was emplaced a .32 to 1.05 m layer of soil. Between the cobbles and the soil was emplaced different additional barriers: (a) nothing, (b) a 25 mm layer of small (0.3 to 0.6 cm in diameter) stones, (c) a 25 mm layer of small stones covered by 175 cm of 10% asphalt emulsion in water, and (d) 25 mm layer of stones covered by the asphalt emulsion mixed with root toxin.

Use of the cobbles alone appeared to be effective against intrusion by harvester ants and pocket mice, but ineffective against intrusion by russian thistle (tumbleweed) roots. Russian thistles are common in the western United States and are aggressive water seekers. Fine soil particles sifted down into the cobbles, creating a path followed by the roots. The layer of small stones prevented soil from sifting down into the cobbles and slowed down, but did not prevent, penetration of russian thistle roots through the cobbles. (It was theorized by the authors of the study that air spaces between the cobbles helped to slow root growth.) In the study, the asphalt layer and the asphalt/root toxin layers were 100% effective in preventing the penetration of roots through the cobbles. In addition to providing a physical barrier to plant roots, the asphalt layer would be expected to reduce percolation of water into the cobbles, thus creating a dessicated zone beneath the asphalt layer which plant roots would be less likely to enter. The root toxin killed plants whose roots contacted the toxin.

It is possible that a layer of herbicide placed at an appropriate distance below the ground surface over a disposal trench could be used to prevent intrusion of deep-rooted plants. Deep-rooted plants would be killed when their roots contacted the toxin, while shallow-rooted plants would survive to provide a ground cover. Herbicides are also available that are nontoxic to the plant but inhibit root growth.

A disadvantage is that herbicides tend to degrade in soils, sometimes fairly rapidly. Measures would need to be developed to ensure the effectiveness of the herbicide over extended time periods--i.e., up to 100 years. It has been suggested that controlled release of herbicides could be accomplished by encapsulating the herbicides within a polymer membrane. The membrane would act both as a reservoir for storage of a herbicide and as a sustained and controlled delivery vehicle to release herbicide to the soil (Ref. 19). Controlled release of chemicals through membranes has been frequently used in the past for such applications as home pesticide dispensers and pet flea collars (Ref. 20) and is under study for use in applications such as interuterine birth control devices (Ref. 21).

To summarize, the use of cobbles or asphalt layers would appear to be straight-forward 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 problems were in evidence at a disposal facility. Subsidence problems 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.

2.2.5 Engineered Human Intrusion Barriers

Just as it may be feasible to construct biological barriers against intrusion into disposed waste by animals and plant roots, it may also be feasible to construct engineered barriers against intrusion into disposed waste by humans. The barrier function could be combined with other functions such as control of potential erosion and eliminating potential intrusion by plants and animals.

An inadvertent future intruder could be a small construction company digging excavations for foundations for a small housing development or a gardener tilling the land. An effective intruder barrier would therefore include some component which would discourage the intruder from digging into the buried waste. That is, once a barrier component is encountered, the intruder would then either be permanently discouraged or would seek more information about the land being worked upon before proceeding with work again. This component may be a large thickness of cobbles, a layer of boulders, a concrete mat, or any equivalent means of deterring excavation.

In general, an intruder barrier constitutes a thick trench cover and can therefore reduce the possibility of erosion resulting in uncovering of buried waste. The protection against significant erosional events provided by the intruder barrier should be capable of lasting for several hundred years.

A third important function of an intruder barrier is to prevent transfer of radiocontaminants into the food chain. The principal concerns of food chain uptake include burrowing animals (e.g., rabbits, mice, ants) and deep-rooted plants.

For illustrative purposes, the conceptual intruder barrier which will be evaluated consists of multiple layers of sand, clay, gravel, cobbles, and boulders. Viewing the intruder barrier from the final ground surface down to the buried waste (as an intruder would encounter it, see Figure F.4), the barrier consists of 0.5 m (1.6 ft) of topsoil with shallow rooted vegetation, 0.75 m (2.4 ft) of sand, 0.25 m (0.8 ft) clayey soil layer, 0.5 m (1.6 ft) of sand, 0.1 m (0.33 ft) of asphaltic concrete, 0.9 m (3 ft) of gravel, 1 m (3.3 ft) of cobbles (7.5 to 15 cm diameter), 1.0 m (3.3 ft) of boulders and 0.5 m (1.6 ft) of sand. The total thickness of this intruder barrier is 5.5 m (18 ft). This intruder barrier is installed on top of the existing 2 m (6.6 ft) of backfill and trench cover.

The resulting distance between any potential inadvertent intruder and the buried waste is 7.5 m (25 ft). This represents a depth far in excess of most small construction activities (e.g., housing developments) and farming activities. The principal potential threats to intrusion for depths greater than 7.5 m are well drilling and deep foundation construction. The 2 m (6.6 ft) of cobbles and boulders coupled with the 0.1 m (0.33 ft) of asphaltic concrete should help to alert any drilling or heavy construction labor forces to the prospect that they should not be working at that location. The required costs to remove the asphaltic concrete, cobbles, gravel, and boulders should also aid in discouraging the attempted construction activities.

Of the near-surface design options, the construction of an intruder barrier represents one of the larger cost additions. For example, the estimated cost differential for a disposal facility with an intruder barrier such as the one described above installed over all of the reference disposal trenches is about \$59/m^3 (\$1.68/ft^3). (See Table F.13.)

As discussed earlier in Section 2.2.4 regarding biological barriers, installation of an engineered intruder barrier such as the one described above would tend to become an extremely expensive enterprise unless subsidence of the disposal trench cap had been eliminated. The whole point of an engineered intruder barrier is that once it is installed, it is difficult to remove. Any repairs or trench restabilization work required after barrier installation would be both expensive and difficult.

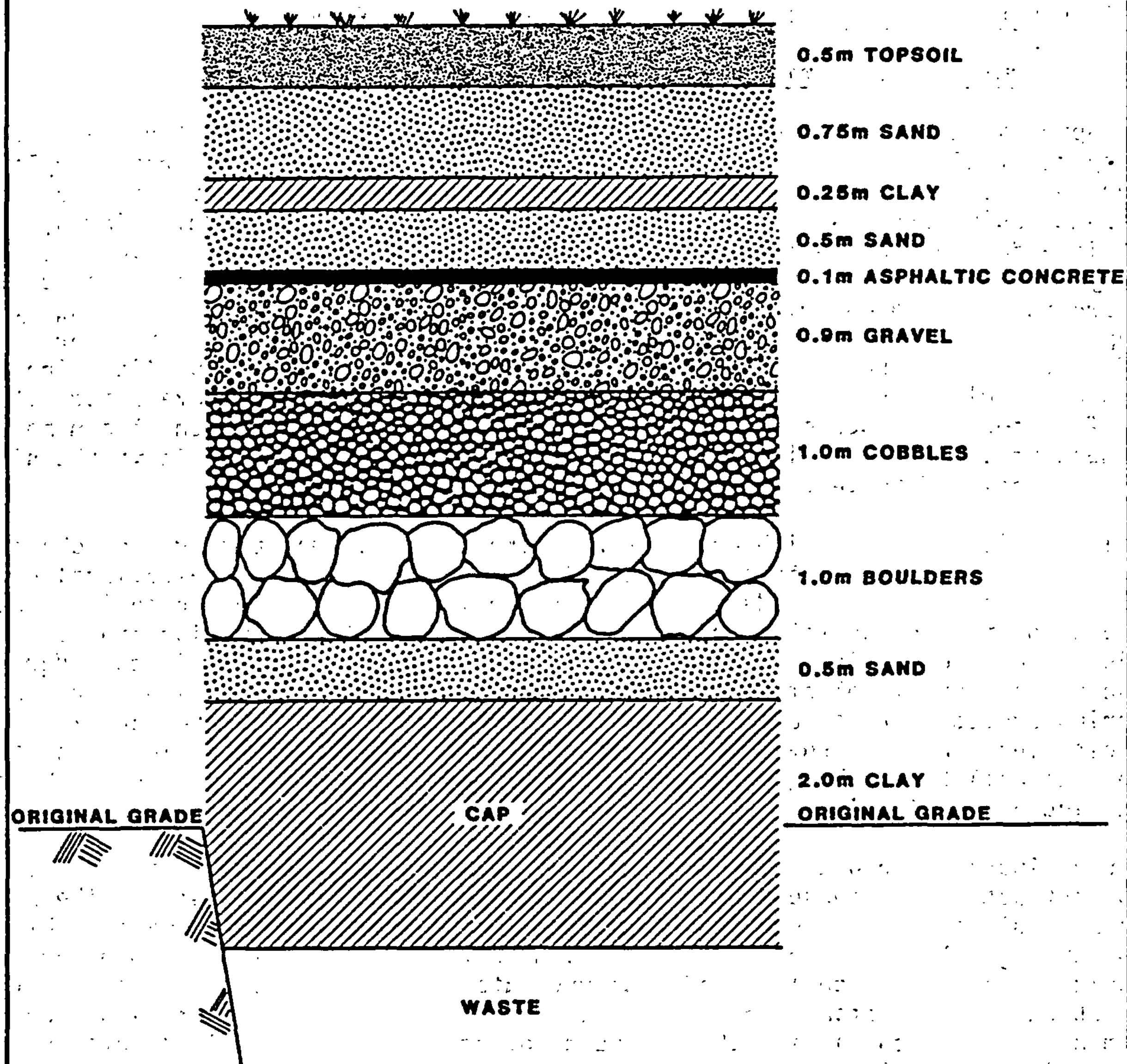


Figure F.4 Engineered Intruder Barrier

2.3 Control of Potential Long-Term Environmental Releases

2.3.1 Improved Monitoring

In Appendix E, an environmental monitoring program is described for the reference disposal facility. As part of this environmental monitoring program, samples for analysis are obtained from monitoring wells, air samplers, and thermoluminescent dosimeters, as well as from soil and vegetation. The monitoring system is intended to provide information on the potential movement of radionuclides away from active disposal trench areas, completed trenches, and other areas where radioactive materials are handled. In the long run, the monitoring system supplies information regarding performance of the site with respect to protection of ground water and protection of the health and safety of the public. The system should therefore be designed so that performance can be evaluated with confidence. Confidence in the monitoring system is provided when it can be demonstrated analytically that no significant contamination can leave the site without being detected.

This EIS is concerned with determining appropriate overall performance objectives and technical criteria for LLW disposal and, therefore, operational details such as recommended methods of installing monitoring wells or the optimum locations for monitoring wells are beyond its scope. Such information can be obtained elsewhere (e.g., Refs. 22, 23). It is useful, however, to briefly consider the approximate level of costs that would be associated with an improved monitoring system. Areas considered in this appendix in which environmental monitoring can be improved relative to the reference facility include increasing the reliability of the ground-water and surface water monitoring, and airborne particulate monitoring.

For an improved ground-water monitoring system, the site operator is assumed to contract with a consulting hydrologist to help design the system. The hydrologist would collect enough data to ascertain the gradient of the water table, the average flow rate, and the dispersion characteristics of the subsurface media. The confidence level of a ground-water monitoring system is a direct function of the distance between the wells and the potential sources of contamination (trenches), and the frequency of sampling. Statistical methods to determine the optimal well locations, spacing, and sampling frequency have been described in the literature (Ref. 24).

For illustrative purposes, the improved ground-water monitoring system includes a total of 20 perimeter wells along the restricted area fence (as compared to 10 for the reference facility). Each of these perimeter wells extend several feet into the saturated zone (minimum depth of 19 m). The perimeter wells are sampled quarterly, as opposed to semiannually as in the reference facility. The number of monitoring wells within the trench areas is raised from 15 to 30, and these wells are also sampled on a quarterly basis. The locations of these wells are selected based on the analysis performed by the consulting hydrologist.

In the reference facility monitoring system, surface runoff is not routinely monitored. The improved monitoring system employs a flow activated automatic runoff monitoring system used in conjunction with a discharge channel located at the northeast corner of the site. Flow composite samples are collected on a weekly basis and sent to an offsite laboratory for radiochemical analysis. This monitoring system is operated during the 20-year operational period.

The final component of the improved monitoring system is an expansion of airborne particulate monitoring. The three-location airborne particulate monitoring system is upgraded to include ten additional air sampling units, which are situated at various locations within the restricted area. The samplers are located near areas where radioactive materials are handled routinely as well as along the site boundary. Particulate filter samples are collected on a daily level and sampled for gross beta-gamma contamination. In addition, samples are sent offsite on a weekly basis for more detailed analysis such as a gamma spectrum analysis.

The benefit of the improved monitoring system is a greater level of confidence in evaluating the performance of the site and an ability to initiate remedial action when indicated in a timely fashion. The estimated differential cost for the improved monitoring system shown in Table F.14 is $1.86/m^3 ($0.05 ft^3).

2.3.2 Control of Infiltration and Erosion

2.3.2.1 Improved Trench Covers

Installation and maintenance of an adequate cover (cap) over the disposed waste is one of the more important (if not one of the most important) considerations at a near-surface disposal facility. The trench cap provides radiation shielding and an infiltration barrier to moisture. A properly designed and constructed trench cover is also important in helping to minimize erosion.

The role of the trench cap as an infiltration barrier is especially important. If significant quantities of water are allowed to infiltrate through the trench cap and contact the disposed waste, then some of the radioactivity contained in the waste may be leached from the waste and released into the environment. Optimal conditions at a disposal facility would exclude the contact of significant quantities of water with the disposed waste. Minimizing water movement into disposed waste also helps to reduce the rate of anaerobic waste degradation (Refs. 24 and 25).

In the reference facility discussed in Appendix E, the trench caps are assumed to consist of one meter of backfill to original grade, plus an additional one meter of soil added above the original grade. In this section, some example alternatives to the reference case are briefly investigated and their costs quantified. These alternatives include improved compaction techniques, thicker trench covers, and possible use of multiple moisture barriers.

Before these alternatives are discussed, however, a brief background review is presented regarding a number of potential different types of trench covers which have been investigated by EPA and others (Refs. 24-28). Some considerations regarding placement of a final ground cover (i.e., grass) are also briefly discussed. Space does not allow a more detailed discussion of the different types of potential trench caps or the considerations leading to placement and maintenance of a final ground cover; however, the interested reader may find additional information in the references cited.

2.3.2.1.1 Background on Potential Trench Covers

Within the last few years, considerable information has been collected and published regarding the design and installation of covers for disposal facilities. Much of this information, (References 24 and 26, for example) has been publishe by EPA in connection with solid and hazardous waste disposal. Another referenc which was prepared by SCS Engineers under contract to the EPA Office of Radiati Programs, is entitled "Study of Engineering and Water Management Practices that Will Minimize the Infiltration of Precipitation Into Trenches Containing Radioactive Waste" (Ref. 27). Some of the potential trench covers analyzed by EPA and others (e.g., Ref. 28) include clay, soil additives, asphalt, plastic membranes, and concrete.

A widely recommended cover for disposal areas is a cover composed of natural clay minerals--e.g., montmorillonite, illite, kaolinite, etc. Natural clay deposits are widespread in the United States. Chemically, all clay minerals consist of hydrous aluminum silicates, but incorporate differing amounts of water and accessory ions such as calcium and magnesium. As stated by EPA (Ref. 24):

> "The ability of clay aggregates to swell and expand derives from the existence of ionic charges that attract surficial layers of molecular water, as well as the tendency of some clays, particularly montmorillonite, to absorb additional interlayer water molecules. Therefore, when clay particules contact water, the effective diameter of the particles is increased and concurrently available pore space is diminished, resulting in decreased permeability rates. Maintaining moisture content is therefore relevant to ensuring low permeability and liner effectiveness in containing leachate. Moisture content is also important to the degree to which clays can be compacted in order to achieve the lowest permeability possible. Some clays such as montmorillonite have a greater tendency to absorb water than other types. For each type, an optimum moisture level exists for maximum compaction."

Clay covers can be very effective as a moisture barrier. For example, Hawkins and Hart (Ref. 29) have reported that in tests at Oak Ridge National Laboratory, a cap of dry bentonite clay 2 inches (5 cm) thick placed under a 0.61 m (2 ft) soil cover was completely effective in preventing rainfall at an annual rate of 50 inches from entering disposal cells. Another advantage is that clay has a self-healing property and can tolerate some settling without a significant loss in effectiveness. However, some care is required in the cover application. A clay cap can be penetrated by insects, animals, and plant roots. In addition, dried clay has a tendency to crack, and efforts should be made to retain its moisture content. In addition, clay covers need to be protected from freeze-thaw cycles. It was recommended by EPA (Ref. 27) that covers having high clay contents be protected from freezing temperatures and from drying out by an additional layer of more permeable soil (e.g., a few feet thick) over the clay cap.

Natural clay deposits can contain substantial nonclay components such as sand and silt. These components reduce the sealant properties, but if in proper proportions, can improve the workability and ease of application of the cover and reduce the susceptiblity of cracking due to freeze-thaw cycles or from drying out. Nonuniform mixtures of clay and other material can result in locations of concentrated infiltration. Commercially available clay mixtures such as bentonite or volclay add to the expense of the clay but help to provide a more uniform quality. This does not mean that natural clay deposits cannot be used, but it does indicate the need for quality control during obtaining, mixing, and applying moisture resistant trench covers.

Soil additives (soil sealants) may be applied as liquids to disposal trench covers. Upon drying, the soil additives polymerize, and the resultant swelling forms a sheet around soil particles, thus forming a seal. Development of soil additives has been relatively recent, and they have been used to help stabilize mine tailings. Soil additives are expected to be low in cost, but their long-term effectiveness is currently questionable. Apparently, there is a problem regarding control of the polymerization process, resulting in some cases in incomplete seals. There is also an apparent problem regarding long-term stability to chemical and biological attack. Use of soil additives would therefore appear not to be presently viable as a primary moisture barrier. Soil additives could be used, however, as an inexpensive backup to a primary barrier such as a clay cap.

Asphalt (e.g., asphalt concrete, hydraulic asphalt concrete, soil concrete, hot liquid asphalt) could also be used as a trench cover, but would be more difficult and expensive to apply than, for example, clay. Asphalt is also subject to degradation when exposed to air and sunlight, and so an asphalt cover would need to be covered with a layer of soil. An asphalt cover (underneath a soil layer) would be more water-resistant than clay, as long as the asphalt layer is intact, and would also act as a barrier to intrusion by humans, plant roots, and animals. A potential problem, however, is that while asphalt is more self-healing than concrete, for example, it is less self-healing than a clay cover. Therefore, asphalt could crack severely under subsidence, losing some or all of its effectiveness. Minor cracking, however, would probably have only a negligible effect upon asphalt effectiveness.

Another potential problem is that if subsidence problems require repairs to trench covers, then the asphalt layer would make this task more difficult and expensive. Assuming that subsidence problems at a particular trench could be eliminated (e.g., from disposing in that trench only wastes having structural integrity), an asphalt layer in conjunction with a compacted clay layer could prove to be effective.

Plastic membranes include such materials as polyethlene, polyesters, polyvinyl chloride, butyl rubber, or nylon, and are frequently used as liners in holding ponds or at hazardous waste disposal facilities. Membranes are generally installed in sections, with one section heat sealed or cemented to an adjacent section. As long as the membrane is not punctured, permeability of water through the membrane is essentially nil.

Plastic membranes tend to degrade in sunlight, so they would require a protective soil cover if used as a trench cover. More importantly, some question exists as to the long-term resistance to degradation at a disposal facility. In any case, special care would have to be taken during installation of a membrane as a trench cover to prevent tears or holes from occurring during installation.

Finally, concrete could be used as a trench cover material. Concrete is brittle, however, and would tend to crack over time--particularly under settling conditions. The effectiveness of a concrete trench cover by itself as a moisture barrier would be problematical. If properly supported, however, concrete could be effective as a moisture barrier, in addition to a barrier to plants, animals, and human intruders. An example of added support could be the use of grouting to fill the interstitial spaces between (stacked) waste packages.

2.3.2.1.2 Final Covers

After a cover (cap) has been placed over a disposal trench, it is important that the cap be stabilized by a final cover (Refs. 24 and 25). A lack of such a final cover leads to uncontrolled water and wind erosion of the trench caps. Two types of final covers are in general use today: natural vegetation (e.g., grass), and a hard surface cover such as cobbles or rip-rap.

A natural vegetation cover at a disposal facility can serve several functions, such as physically stabilizing earth materials, reducing erosion and infiltration of precipitation infiltration into the disposed waste, and enhancing the appearance of a site. A thick grass cover, for example, breaks the impact of falling water droplets on the earth surface, and reduces the run-off rate from the site, thereby reducing the potential for water erosion. By the same token, the plant roots help to hold the soil in place, thereby minimizing wind erosion. Reducing the rate of run-off, of course, also has the effect of increasing the amount of water infiltrating into the trench caps. However, some of the precipitating water will be caught upon leaves and other plant surfaces and will tend to evaporate rather than infiltrate into the soil. In addition, some of the water infiltrating into the trench caps will evaporate out of the soil surface. Water absorbed into plant roots may also be transpired through the plant leaves.

These processes of evaporation and transpiration--termed evapotranspiration--can result in a substantial amount of water being removed from soils. Evapotranspiration is enhanced by vegetation with dense root systems and a dense soil cover. It is important, however, that the root systems of cover grasses be of shallow depth to preclude contact with and uptake of radionuclides from the disposed waste. Examples of vegetation having shallow but dense root systems include hay, meadow grasses, and rye. Vegetation species native to the general area of the disposal site are preferable, as these species are more likely to be acclimated to the site climate.

Care needs to be taken when preparing the site for the final covering of vegetation--e.g., grading, spreading fertilizer, and mulching. If top soil removed from initial excavations is stock-piled, then this can be replaced on the completed trench cover to help promote plant growth. It has been observed that in the past at some facilities, miscellaneous fill has been used to repair cracks and sinkholes caused from trench subsidence. The fill is often devoid of essential plant nutrients. Growth of a soil cover is naturally retarded in these spots, leaving bare spots which can persist for some time. This can result in areas showing localized signs of erosion, or result in areas having concentrated point sources of infiltration.

Soil fertility is also desired in that it helps to promote evapotranspiration. First, fertile soil produces a lusher plant growth for a given crop. Second, fertile soil leads to healthier plants, which photosynthesize more rapidly and increase the water demand on the soil system.

While not as aesthetic as a vegetation cover, a layer of rip-rap or cobbles can also be effective as a final soil cover. This technique is particularly useful in arid climates, where it is more difficult to establish a vegetative cover. Such a hardened layer, in addition to preventing wind erosion, is also effective in eliminating intrusion by burrowing animals.

2.3.2.1.3 Example Alternative Trench Cover Designs

There are three principal design options which are discussed below to provide added assurance aginst infiltration of water into disposal trenches. These options are: (1) use of more densely compacted trench caps, (2) use of thicker compacted trench caps composed of low permeable clay soil, and (3) use of additional moisture barriers within a thicker trench cap. These options were selected based upon the above review of potential alternatives and improved trench covers. A number of other alternative designs could be envisioned. However, these are adequate for the purposes of this environmental impact statement.

Compaction

Improvements in trench cap performance can be obtained through increased attention to waste and cover compaction. Until fairly recently, little attention has been paid to compaction of disposed wastes other than the compaction that can be achieved by application of several feet of trench cover, plus driving over trench covers with waste transport and other site vehicles. This is the case assumed at the reference disposal facility. Decreased infiltration and percolation through a trench cover (by reducing porosity and thus permeability) can be inexpensively achieved, however, through use of improved compaction techniques using commercially available compacting equipment such as vibratory compactors. Within the last few years, for example, the operators of a disposal facility located in a humid environment have employed a mechanical vibratory compactor to provide additional compression of disposed waste and compaction of filled trench caps. The disposal site operators have reported that use of the vibratory compactor has greatly reduced subsequent maintenance of filled and capped trenches (Ref. 31).

Soil compaction is a standard construction technique and for a particular type of soil, a particular relationship can be developed which relates the moisture content of the soil to the amount of compaction (the dry density of the soil). These relationships can be determined and graphed using laboratory techniques. For a particular soil, an optimum moisture content can be determined which results in maximum compaction (greatest dry density). In standard construction practice, specifications for compaction require the soil to be compacted near the optimum moisture content and to a dry density specified as a percent of the standard determined in the laboratory--e.g., 90% of the standard (ASTM 1557) laboratory maximum density.

In practice, a variety of equipment types may be potentially used depending upon the type of soil. Some of these are listed in Reference 32 and include sheepsfoot rollers, rubbertire rollers, smoothwheel rollers, vibrating baseplate compactors, and crawler tractors (D8 or greater size). Soil to be compacted would be applied in 6- to 12-inch lifts and several passes made to compact each lift to the desired density. The depth of compaction available using such equipment is on the order of zero to six feet (Ref. 32).

For an example calculation of differential costs, the reference disposal facility operators are assumed to lease a vibratory compactor and employ an additional heavy equipment operator to operate the compactor. The compactor would be originally used to compact the 1 m of earthern fill down to the approximate level of the original site grade. Then, the 1 m soil cap would be applied in reasonably uniform 20 to 31 cm (8-12 in) layers and compacted to a minimum 95% of the maximum compactible density test.

Unit differential costs for this option are calculated (see Table F.15) to be about $\$1.90/m^3$ ($\$0.05/ft^3$). The resulting benefit is expected to be a decrease in trench subsidence and maintenance requirements. However, as stated above, the depth of compaction only extends for a few feet below the surface. Therefore, the potential long-term trench cap subsidence would be reduced but would not be eliminated.

Thicker Clay Cap

Another option would be to utilize low-permeability soil materials (clay) for the cap. For example, an additional 2 meters of high-grade clay soil would cost an additional $\$8.40/m^3$ ($\$0.24/ft^3$), assuming that the additional clay soil would be imported at a cost of $\$3.50/yard^3$ from a borrow pit located approximately 10 miles from the disposal facility (see Table F.16). The additional 2 m soil thicknesses would be applied in 8-12 in layers and compacted using mechanical compaction techniques. A three meter thick compacted clay cap would cost an approximate additional $\$10.90/m^3$ ($\$0.31/ft^3$). After installation and compaction, the cap would be covered with overburden and graded prior to seeding.

Moisture Barriers

Other methods may be potentially used to reduce percolation through trench caps. These include, for example, installation of single or multiple "moisture barriers" within a thicker trench cap. In this section, unit differential costs for four moisture barrier cases are briefly examined. The cases examined are shown in Figure F.5. For moisture barrier Case A, a single natural material barrier

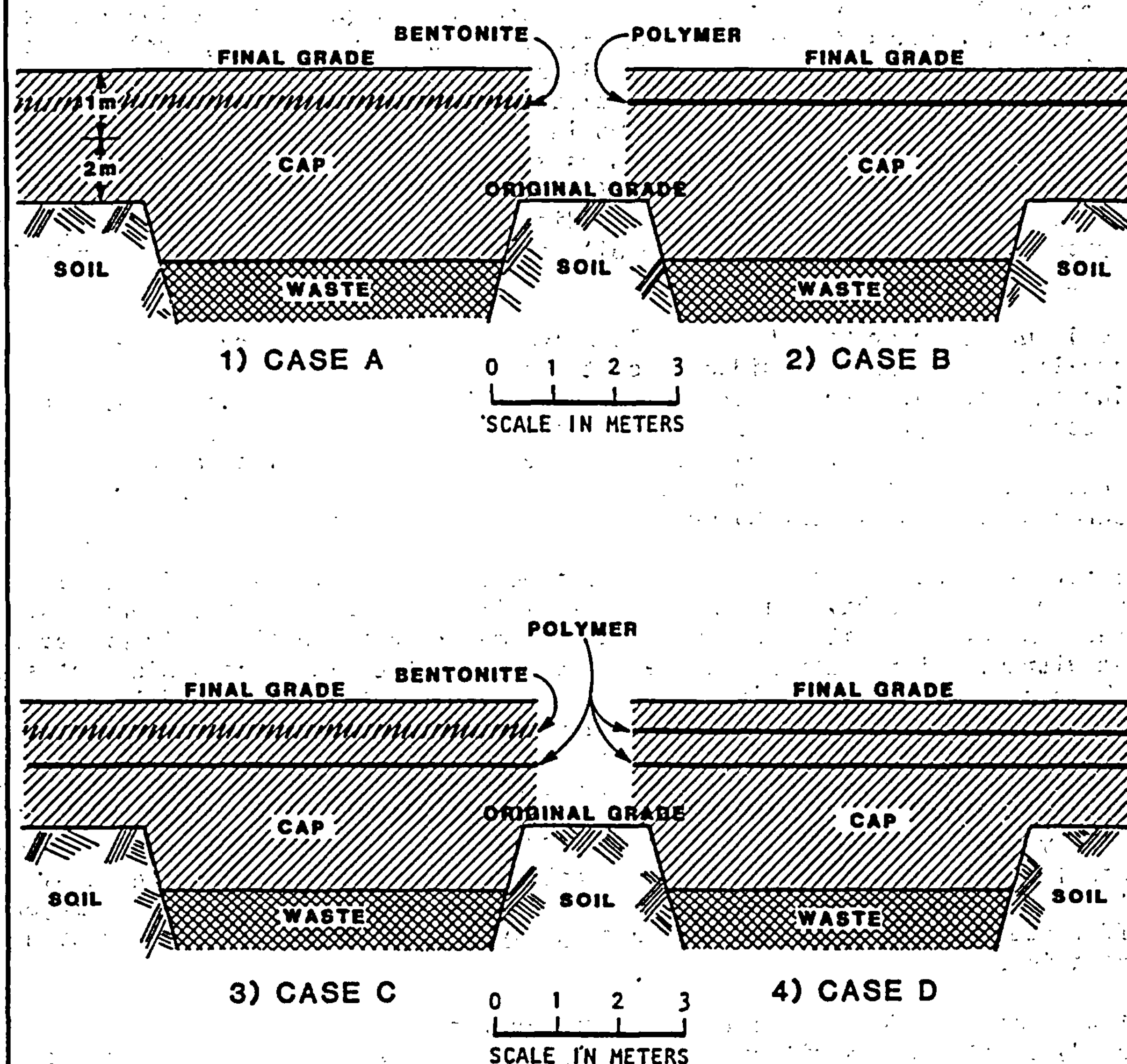


Figure F.5 Moisture Barriers

consisting of 4 pounds of bentonite per square foot is added to the above 2 meters of compacted clay soil. The bentonite layer is mixed at a depth approximately 0.5 m below the top of the compacted cap. This option results in additional costs due to the bentonite (or equivalent) layer, installation of the bentonite, import of offsite clayey soils, and grading and compacting the additional soil volumes. The estimated cost differential for application of the moisture barrier Case A (shown in Table F.20) is $14.80/m^3 ($0.42 ft^3). This option affords the same attributes as the thicker lower permeability cap with some additional assurance of infiltration protection afforded by the inclusion of bentonite in the cap. Additional erosional protection could also be provided by revegetation in topsoil (greater chance of long-term survival of vegetation).

In moisture barrier Case B, a single polymer membrane moisture barrier is installed at roughly the midpoint of the additional soil thickness. The principal cost difference between Case B and Case A is the cost difference between the polymer membrane and the bentonite. The polymer membrane is assumed to be a 36 mil reinforced hypalon membrane which is installed on top of a mounded surface to promote drainage. The polymer membrane is assumed to have a permeability equivalent to or lower than the bentonite.

Polymer membrane have been shown to last up to twenty-five years (Ref. 33). (Polymer membranes have only been commercially available for this length of time.) However, if it is assumed that the membrane is sufficiently protected from ultraviolet radiation and thermal stresses, then it is possible that such membranes could retain their integrity for much greater lengths of time--e.g., perhaps up to 100 years. It should be noted that in the event of significant subsidence, a bentonite (or equivalent) moisture barrier has a higher probabilty of maintaining its integrity (clays can self-anneal under certain circumstances). The estimated cost differential between moisture barrier Case B and the reference facility (Appendix E) is $15.30/m^3 ($0.43/ft^3). This option affords the same general attributes that Case A does (namely, infiltration prevention, additional intruder protection, and additional erosion protection), with the only major difference being cost and perhaps a slightly greater degree of infiltration protection.

Moisture barrier Case C consists of two barriers: (1) a bentonite barrier, and (2) a polymer (36 mil reinforced hypalon) barrier. The polymer membrane is installed at the midpoint depth of the additional 2 m soil thickness, and the clay barrier is installed at or near the original ground surface. The polymer membrane is installed deeper to provide added protection against thermal and ultraviolet stress. The membranes are installed on mounded surfaces to promote drainage. The costs of Case C are identical to Case B with the addition of the cost of a polymer membrane. The estimated cost differential between moisture barrier Case C and the reference facility described in Appendix E is approximately $18.30/m^3 ($0.52/ft^3). This option affords the same positive attributes as Cases A and B, with the added assurance afforded by a redundant barrier system.

Moisture barrier Case D consists of two polymer membranes (both 36 mil reinforced hypalon). The membranes are similarly (to Case C) installed at a depth of 1.5 m

(4.9 ft) and 3.0 m from the final grade on mounded surfaces to promote drainage. The only cost difference between Case D and Case C is assumed to be the cost differential between the bentonite barrier and the polymer membrane barrier. The estimated cost differential between moisture barrier Case D and the reference facility is approximately $18.80 m^3/($0.53/ft^3). Case D offers the same positive attributes as Case C, including the redundant barrier protection.

The differential costs of the thicker clay cap and moisture barrier options are summarized below:

Case	Cost $/m^3
Thicker, denser cap (2 m)	$ 8.41
Thicker, denser cap (3 m)	$10.89
Moisture barrier Case A	$14.83
Moisture barrier Case B	$15.30
Moisture barrier Case C	$18.34
Moisture barrier Case D	$18.81

As illustrated above, a number of alternative trench cap designs could be used at near-surface disposal facilities. These designs cover a range of costs, but none involves a significant increase in overall operational costs. The problem is that the benefits (at additional time and expense) from constructing the caps will be significantly reduced as long as potential subsidence problems exist at the site. Increased attention to compaction, using the mechanical compacting equipment, is expected to reduce the degree of subsidence. Further significant improvements in trench stablity are discussed in Section 2.3.3.

2.3.2.2 Infiltration Contact Time

The quantity of radioactivity that is leached from a given waste form is a function of the degree to which water is allowed to contact the waste form. The function of the improved disposal trench covers discussed in the preceding section is to minimize the amount of water that can infiltrate into the disposal trenches and contact the disposed waste. This reduces the amount of radioactivity that could be leached from the waste. A further reduction in the amount leached can be obtained through minimizing the time that infiltrating water is allowed to contact the waste. This can be accomplished by using highly permeable material (e.g., sand) as a backfill.

As discussed in Appendix G, the contact time with disposed waste for water percolating down through trench backfill would be greater for backfill composed of lower permeable soils than for backfill composed of higher permeable soils. This is because the speed of the percolating water is higher for materials with higher porosity than for materials with lower porosity. Use of a sandy backfill, then, would allow percolating water to quickly flow past disposed waste to the bottom of the trench, thus reducing the contact time and the potential for leaching. Use of a sand backfill would also be expected to readily sift down into the interstitial spaces between waste packages and therefore help reduce the presence of voids in a disposal trench.

A layer of sand--perhaps 6 inches to a foot thick--could also be placed at the bottom of the disposal trench prior to waste package emplacement. This would reduce the possibility of rainwater falling on an open trench, or water percolating through a closed trench cap, from collecting and standing around the bottom waste packages. This is especially important when one considers that at existing disposal facilities higher activity waste packages are frequently emplaced on or near the bottom of the disposal trenches to reduce radiation exposure to facility personnel. Water percolating to the bottom of the trench will percolate below the bottom waste packages into the sand layer, and flow into the French drain along one side of the trench. The French drain then directs the water to a sump at the low end of the trench before the percolating water has a chance to contact the lowest waste packages for extended periods of time. The sand layer also provides a smooth trafficable foundation for operation of vehicles such as fork lifts in the trench.

To implement this option, the disposal trench is assumed to be excavated an additional 0.15 m (6 in), and after the French drain, sumps, and standpipes are installed, a layer of sand 0.15 m thick is spread smoothly across the floor of the trench. Thus, the trench volume utilized for waste disposal remains the same as for the reference facility, as well as the height of the waste above the water table. The remainder of the disposal operations remain the same as before, with the exception that the sand backfill is utilized instead of backfill composed of previously excavated site soils. The 1 m space between the top of the waste and the top of the trench is also filled with the sand backfill. The backfill is obtained from a local borrow pit.

Assuming one million m^3 of randomly disposed waste at the facility, approximately 65,000 m^3 of sand would be required annually, or approximately 1.3 million m^3 over the 20 years operating life of the facility. This would result in an additional operational expense of approximately \$6.70/m^3 (\$0.19/ft^3) above that for the reference facility (see Table F.18). The added expense, however, is believed to be justifiable considering the overall gain--i.e., the overall reduction in potential infiltration contact time with the waste. In fact, use of a sandy layer on trench floors in addition to use of a sandy backfill is presently part of standard operating practice at the Barnwell, SC disposal facility (Refs. 11, 34).

2.3.2.3 Surface Water Drainage

Surface water management at the reference facility consists of drainage control through grading of the site. Temporarily installed earth berms are used to direct flowing water away from open trenches which are being actively used for waste disposal. Table E.1 in Appendix E shows the annual run-off to be 151 mm out of a total annual precipitation of 1168 mm. Thus, only about 13% of the rainfall is expected to be carried off as surface flow, considering the flat to gently sloping character of the site and the clayey sand soils. The relatively low run-off is not likely to cause an erosion problem assuming that the soil is stabilized by such means as use of a good vegetative cover or a rip-rap layer.

Surface drainage improvement through the use of ditching and channelization can be useful in reducing the quantity of water which percolates into the soil. This is accomplished by transporting the runoff water from the site before significant volumes can infiltrate into the soil.

The following presents an example of one method which may be used to improve drainage from the site. The costs and effectiveness of similar types of drainage systems at a real disposal facility would be site-specific. However, the following example illustrates the magnitude of the costs involved.

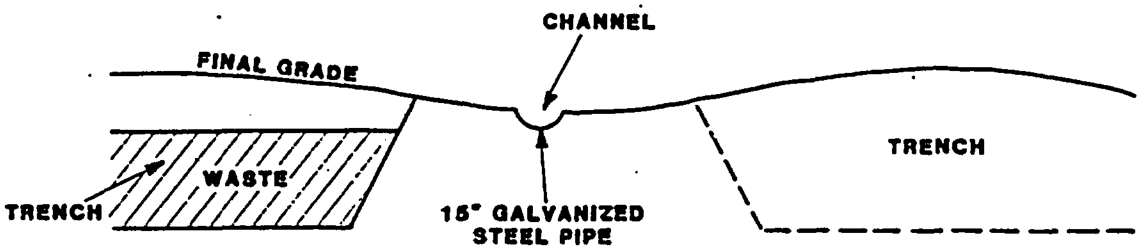
An improved drainage network for the site is assumed to include a secondary system, a primary system, and a main discharge channel to carry runoff from the site (see Figure F.6). The secondary system runs along the spaces between the trenches and collects water flowing off of the sloped trench caps. The collected surface water is directed to the primary system which runs along the facility perimeter as well as along the two main access roads into the restricted area (the north-south roads bisecting the facility as shown in Figure E.11). The secondary system consists of shallow trenches with liners of corrugated metal (1/3 of a pipe section). The primary drainage system is a larger capacity lined ditch system which collects the flow from the secondary system and carries it to the main discharge channel. The primary system runs entirely around the perimeter of the site. Again, corrugated metal liners are used, although larger radius sections are used to provide greater capacity.

The primary drainage system discharges at several points into the main discharge channel which carries the discharge offsite to another drainage channel which ultimately drains into a stream. The discharged water would then flow into a river. The discharge channel is assumed to be 500 m long and consists of a trapezoidal channel with gravel lining. A flow-activated automatic run-off monitoring system is installed onsite in the discharge channel.

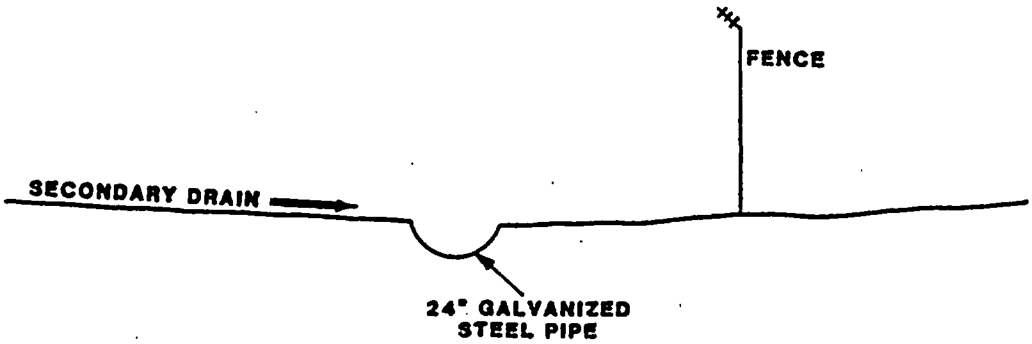
The estimated cost differential for installation of a surface drainage system (shown in Table F.19) is $7.47/m^3 ($0.21/ft^3). The anticipated benefit is an overall reduction in the amount of water which percolates into the site soils.

2.3.2.4 Weather Shielding

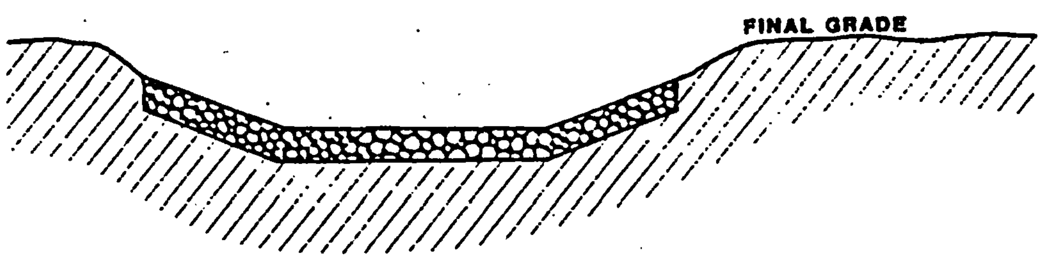
To reduce or eliminate the amount of rainwater falling into an open trench during disposal operations, a temporary structure such as a weather shield may be potentially employed. At some disposal sites (i.e., Oak Ridge), (Ref. 35) corrugated metal arch sections are used to cover narrow trenches which are left open for long periods of time. At other sites (i.e., INEL), (Ref. 36) tension structures or air-supported buildings with large clearspans are used to provide weather shielding.



a) SECONDARY DRAINAGE CHANNEL



b) PRIMARY DRAINAGE CHANNEL



c) DISCHARGE CHANNEL

Figure F.6 Surface Drainage System

Use of weather shielding can result in additional waste handling problems. Even the largest weather shields have limited headroom. A tension structure with a clearspan of about 36 m can provide about 12 m of headroom at the center of the arch. This provides a serious limitation on emplacement of wastes from cranes located at relatively shielded positions at the ground surface. Most waste emplacement would therefore have to be performed by transporting the wastes directly into the trenches, and locating them by means of forklifts or small "cherry picker" cranes which operate directly on the trench floor. The use of weather shielding necessarily implies that the waste emplacement work force spends more time in relative proximity to the waste, and therefore higher occupational doses are anticipated. It is estimated that occupational doses will increase by about 15% with the use of weather shielding.

The weather shield assumed to be used at the disposal facility is a tension type structure in which a fabric is stretched over a series of arches to produce a completely enclosed free-standing structure. A shield having dimensions of 36.5 m x 190 m would be sufficient to enclose the entire surface of a standard trench. Access into the structure would be via standard hinged and large overhead doors located in the sides or ends of the structure. Once the trench is filled and capped, the structure would be dismantled and reassembled at another trench.

The estimated cost differential for the use of a weather shield in the disposal operations (shown in Table F.20) is $26.77/m³ ($0.76/ft³). The structure would greatly reduce or eliminate direct entry of precipitation in the open trenches. However, higher personnel radiation exposures would be expected to be experienced by the site staff as a result of the required in-trench handling operations. In addition, the cost estimate does not include costs for additional personnel or waste handling equipment that may have to be acquired to operate and emplace waste from within the disposal trench.

2.3.3 Control of Subsidence and Trench Instability

The major problem that has been experienced to date at near-surface disposal facilities has been subsidence of disposal trench covers. Subsidence problems observed at disposal facilities have ranged from minor settling and trench cap cracking to extensive cap collapse and creation of large-scale sinkholes. Subsidence is basically caused by the existence of void spaces within disposal trenches, including void spaces created by degradation of compressible material such as paper or other combustible trash. Problems which have been observed in the past at disposal facilities have included:

- Increased percolation of water into the disposed waste, resulting in potentially increased ground-water migration.
- Creation of leachate accumulation problems.
- Greatly increased site maintenance costs which were not expected when the waste was disposed.

- At an arid western disposal facility, exposure of disposed waste which was then dispersed by wind.

- A reduction in the ability to predict the long-term impacts of disposed wastes.

It is apparent that control of subsidence and assurance of site stability is of major importance in design and operation of a near-surface disposal facility. The following subsections discuss a number of possible facility designs and operating practices which may be used to help control, and possibly even eliminate, subsidence. These designs and practices all involve ways in which voids can be reduced in disposal cells and include waste emplacement techniques; waste segregation; use of caissons and walled trenches; more extreme compaction techniques; use of grouting and controlled density fills; decontainerized disposal; and increased volume reduction through onsite waste processing.

2.3.3.1 Waste Emplacement

In general, waste emplacement at existing disposal facilities is accomplished by either random disposal (including dumping or rolling containers into the disposal trenches, and placement of heavier items in a random fashion), or by stacked placement of items in some orderly or interlocking fashion. Stacked emplacement is used to either maximize trench space utilization or provide waste-shielded "pockets" in which higher activity containers may be placed. Past practices at commercial disposal facilities have ranged from completely random to entirely stacked disposal, with current techniques generally characterized by a mixture of random and stacked emplacement. Variations of stacked emplacement have been used, including individual placement of stacked boxes, large right cylinders, and some individual smaller (200 liter) drums in specific spots. In cavities formed by these first-layer containers, higher-activity waste may be placed. Lower activity waste may be then randomly stacked or rolled, depending on the mode of off-loading that is most efficient, on top of the first-layer containers. The stacking height is dependent on the types of containers received, the capabilities of the waste handling equipment, and the backfill required to maintain desirable radiation levels.

Waste stacking necessarily requires a segregation of waste according to characteristics such as geometric shape, stability, radiation levels, handling methods required for safe emplacement, and integrity of the package. For example, large boxes (containing low specific activity material) might be stacked in the trench less easily than setting the boxes on a trench edge and rolling the boxes in, but stacking is preferable since the box may rupture, and a stacked wall of boxed waste may be useful in controlling backfill spill-over down the working face. Drums, on the other hand, generally do not rupture as easily when rolled down the face of the trench and are typically stacked only when containing high levels of activity dictating individual handling. High activity waste may even be emplaced in separate preshielded disposal columns (e.g., toner tubes) to provide for additional radiation shielding to site personnel while further minimizing use of backfill. Excessive use of backfill reduces trench utilization efficiency. Other miscellaneous waste packages are either stacked or randomly dumped, depending on the time factor and the probability of container rupture.

An advantage of stacked rather than random placement of waste containers is that it enhances stability of the disposed waste, resulting from a reduction in trench void space and an associated decrease in the potential for subsidence. This promotes the integrity of the trench cover and reduces the infiltration of rainwater, thus reducing maintenance requirements as well as the potential for ground-water migration. Stacked emplacement is also estimated to improve the excavated volume use efficiency from about 50% to about 75%, resulting in an approximate 50% increase in trench capacity. Additional attractive features of stacked emplacement include a reduction of stresses on the integrity of waste containers, more control over high activity containers, and use of other waste (instead of backfill) for shielding. Where trench space is at a premium and a sufficient fraction of the incoming waste packages have uniform configurations for stacking, it may be to the operator's advantage to use this method.

There are also disadvantages to stacking of waste containers. Stacking is a more labor-intensive effort compared with random placement. For containers requiring individual attachment to offloading devices, such as large (170 ft^3) liners or high activity drums, a reasonably conservative increase in manpower (or decrease in waste emplacement rate) of about 20% over random placement requirements is estimated to occur. For smaller containers such as drums, which are often rolled off of transport vehicles into the trenches, the labor requirements are multiplied by a factor of about 4. This translates into an overall estimated increased labor requirement for waste handlers of about 1.5, compared with random emplacement of all container types. This not only increases the labor cost per unit volume, but raises worker radiation exposure levels proportionately. Where segregation of high activity waste is not performed, trench radiation levels may at times prohibit workers from assisting in the desired positioning of containers.

The anticipated impacts on operational costs are reviewed in Table F.21. As shown, use of stacked disposal is estimated to result in an increased cost differential of \$22.24/m^3 (\$0.63/ft^3). Overall radiation doses among waste handlers would also rise. These additional exposures could be reduced if stacked disposal was carried out concurrently with a program to segregate wastes having higher surface radiation levels.

2.3.3.2 Waste Segregation

Waste segregation is separation of waste materials at the disposal facility in accordance with specific characteristics. This may be according to isotopic content, chemical content, activity, container size, shape, or structural stability. Some forms of waste segregation are in use already at both government and commercial disposal facilities. Existing packaging, handling, and disposal restrictions on waste packages containing special nuclear material are one example. In addition, differing site acceptance criteria have forced some segregation of waste among the commercial facilities still in operation. Other practices have been used with less consistency, such as separate disposal of high-activity wastes in "hot wells".

Most existing waste segregation practices are based on the radiation hazard of waste packages. For wastes having high surface radiation levels which could require use of extensive backfill if mixed with the main body of waste, it may be more cost effective to use specially placed caissons or slit trenches which afford improved shielding with little backfill volume required. Use of this segregation technique may also reduce radiation exposures received by facility personnel from high-activity waste by 20% or more. This is because less direct exposure time is incurred while transferring high activity waste to a deep excavation with vertical sides than to an open area where it must be covered to reduce lateral exposure rates.

Two examples of wastes which are prime candidates for segregation are wastes having high concentrations of organic chemicals and chelating agents and wastes such as compressible low activity trash for which long-term stability cannot be assured. Segregation of such wastes from other wastes will result in overall improvements to the potential for ground-water migration. With unsegregated waste disposal, nuclide migration from a trench would be based on limiting isotopes and worse case conditions. With segregation, the most innocuous wastes having limited activity and short half-lives could be disposed of in trenches engineered to contain that waste over its hazardous lifetime with a high confidence level. More hazardous and longer half-life wastes could concurrently be disposed in appropriately engineered (more expensive) disposal areas allowing greater controls to be utilized in a cost-effective manner on that small fraction of the more hazardous waste. Although this concept is not a radical departure from current techniques, it will require that wastes requiring segregation from other wastes be identified on shipment manifest documents.

A summary of the overall costs of waste segregation is included in Table F.22. These additional costs are expected to be relatively minor--i.e., an additional $6.08/m^3$ ($0.17/ft^3$) in unit disposal costs. An additional benefit could be in overall dose reductions to site crews from segregated disposal of high activity wastes. These overall reductions in workers' exposures could be as much as 20%.

Proper segregation of wastes is dependent on cooperation from the waste generator. The waste generator must provide sufficient information in radioactive shipment records regarding the package contents to enable the disposal facility operator to properly classify the waste. This administrative tool, properly applied, and coupled with a few minor modifications in operations, can result in overall improvements in waste disposal.

2.3.3.3 Decontainerized Disposal

Decontainerized disposal refers to emplacement of low activity wastes divested of any external shipping container. Presently, wastes such as bulk low activity material (e.g., low activity thorium wastes, zirconium sands, calcium fluoride wastes) or large pieces of machinery are occasionally disposed at disposal facilities without external shipping containers. Considered in this section is the potential option of extending this disposal technique to other low activity wastes such as dry trash and biological wastes. The key factor is the absence of a container which would temporarily isolate the waste from the soil backfill. A major question is how to effect waste removal from a shipping container in a safe, efficient (economical) manner and dispose of the waste in an equally safe, efficient manner.

For decontainerized disposal, waste streams are assumed to be disposed of by methods similar to that employed at a sanitary land fill. Waste would be emptied from containers onto the ground and covered over periodically with a soil layer using heavy equipment. The waste containers could then be decontaminated and reused.

Benefits would be realized both during and after disposal operations. The absence of containers will reduce the waste volume somewhat, with additional savings occurring through container reconditioning and reuse. However, the major advantage is anticipated to come from accelerated stabilization of disposal trenches by allowing soil chemical action and equilibrium to occur within the waste without the time lag from container degradation.

A major disadvantage is the current lack of some prerequisite conditions and techniques. The current nonsegregation of radioactive forms does not allow wholesale utilization of decontainerized disposal. Additionally, decontainerization of medium-to-high activity wastes would not be advantageous because of the accompanying hazards of direct gamma radiation and potential airborne contamination to the waste emplacement labor force. A minor fraction of this concentrated waste becoming airborne could constitute a large hazard to the disposal crew, and affect the local offsite environment.

Another difficulty for decontainerized disposal is development of viable emplacement techniques. A significant industry-wide change would evolve from the concept of reconditioning transport containers. This would also indicate need for additional decontamination and waste treatment facilities with additional manpower requirements at the site itself.

Actual empirical data is not available on the increase in manpower and equipment requirements for decontainerized waste emplacement. Based on an assumption of 50-60% of all waste received as being disposed of by decontainerized methods, the increase in labor is estimated to be a factor of 4-5 times that needed for random placement of containerized wastes. In addition, a means for opening a container and exposing the contents, transferring the contents to the trench, emptying the containers, and compacting a protective fill on the waste without excess exposure risk to persons, both offsite and onsite, will need to be developed. Performing this operation will require close proximity to many potential exposure hazards including direct radiation and airborne contamination. Increased requirements for monitoring of personnel (both internal and external) and equipment will be a prerequisite to licensing this type of operation. Possible use of clothing such as controlled-air anticontamination suits may also be required. A presorting operation would be needed to ensure that small pieces of high activity material are not contained in otherwise low activity waste material. The occasional presence of such high activity material could result in significant additional (accidental) exposures to site workers. A weather shield would be required in humid or windy areas. Increased trench and site perimeter airborne monitoring would also be needed.

Assuming that a method of emplacement is approved for decontainerized waste, a separate disposal area would be required, segregating this waste from other waste streams disposed of at the facility. An increase in crew size would be needed to offset the lowered efficiency per unit volume expected in this type of emplacement, and additional handling equipment would be required. Increased unit costs are shown in Table F.23, and are estimated to run in the range of $93.50 per cubic meter of waste disposed in a decontainerized manner ($2.65/ft^3) or higher.

Radiation worker exposures would be expected to rise proportionately to the increase in work force. As discussed above, the potential for additional accidental exposures would also be expected to be greater than for the reference case.

2.3.3.4 Compaction to Greater Depths

Section 2.3.2.1.3 discussed use of standard construction techniques using heavy machinery (vibratory compactors, sheepsfoot rollers, etc.) to compact backfill into disposal trenches followed by compaction of the disposal trench cap. This compaction is expected to help compress disposed wastes and reduce voids, thus reducing settlement and subsidence problems, infiltration of water, and potential migration of radionuclides. Maintenance requirements would also be reduced. The depth of compaction achieved by these standard construction techniques is only a few feet, however. Thus, shallow compaction would not be expected to completely eliminate potential subsidence as long as a significant amount of compressible waste is disposed in the disposal trench.

Additional construction techniques, which have never been used at LLW disposal facilities but which could be considered as expensive means to achieve very deep compaction (e.g., down to the bottom of a disposal trench), include pile driving and dynamic consolidation. Both methods have been considered for potential application at the Sheffield, Illinois disposal facility (Ref. 33).

Pile driving as a means to densify deep soil deposits--particularly loose cohesionless soils--has been practiced for several years. In this technique, wood piles would be driven in a close grid pattern through the disposal trench cap and into the disposed waste. Compaction would be achieved through displacement of the soil/waste mixture by the piles as well as by vibrations generated through driving the pile. After driving, the piles could be potentially removed and holes filled with low compressive material such as cement or backfill. The piles could then be reused in another location. A problem with this would be that the piles would become contaminated as a result of contact with the waste materials. This contamination would then be available for transfer to workers or equipment or become dispersed into the air, thus becoming an occupational as well as an offsite radiation hazard. The removed piles would eventually have to be disposed as radioactive waste. As an alternative, the driven piles could be cut off at ground level and covered with a compacted cap. This would result in significantly increased expenses, however.

Dynamic consolidation (or dynamic compaction) is a relatively new (25 years) construction technique which, while not previously used at radioactive waste disposal facilities, has been used to reduce settlement problems at landfills. The technique has been developed by Menard (Refs. 37, 38) and has principally been used in Europe. In practice, a large (5-40 ton) weight is dropped from a significant height (e.g., 20-100 ft) several times over a limited area. For an area such as a disposal trench, an optimum weight and drop height would first be determined. Then, a crane would drop the weight a number of times at several locations in a pattern across the trench cover surface. Depressions left by the weight would be filled in and additional passes over the trench surface may be made as desired and depending upon site-specific conditions.

The impact of the dropped weight is believed to cause partial liquefaction of granular and nonsaturated soil, which allows the soil mass to settle into a denser state. For saturated cohesive soils, it has been hypothesized that the shock waves and high stresses caused by repeated high energy impacts result in gradual liquefaction and consolidation of the soil. The method is reported to be effective to depths of 15 m (50 ft) and can achieve surface settlements of 5 to 15% of the deposit thickness (Ref. 33).

Other than the expense, the principal drawback to this compaction technique is the potential for expulsion of contaminated soil and waste. Depending upon the characteristics of the soil, the weight employed, and the drop height, depressions having depths of up to several feet may be produced. Care would have to be taken so that the dropped mass did not penetrate the cover material to the point that the waste is contacted and/or expelled into the air. As in the case of the piles, this would cause a contamination problem for personnel and equipment, not to mention an airborne hazard both onsite and offsite.

One way to reduce the potential for airborne spread of contamination would be to restrict the mass of the weight and the dropping height. However, this would also diminish the effectiveness of the compaction technique in that the depth of compaction would be reduced.

In any case, an example economic calculation is performed in Table F.24 for dynamic compaction of the 58 disposal trenches. As shown in Table F.24, this is estimated to result in an additional $\$18.61/m^2$ ($\$0.51/ft^3$).

2.3.3.5 Engineered Supports for Disposal Trench Covers

As discussed in the previous sections, waste stacking, waste segregation, and deep compaction all appear to offer improvements in the ability to reduce voids and to control (and possibly eliminate) subsidence. Decontainerized disposal could also be used to help reduce trench subsidence, and would be useful for such wastes as low activity bulk solids, contaminated building rubble, or occasional large pieces of machinery, provided that disposal of such wastes was carried out in an operationally safe manner. However, decontainerized disposal currently appears to be a nonviable option for general extension to all wastes.

This section discusses optional disposal methods involving construction of engineering supports for trench caps. The types of engineering supports addressed include caisson disposal, walled trench disposal, and grouting and controlled density fill. These disposal concepts were previously introduced in Section 2.2 regarding their potential use as barriers to the potential inadvertent intruder.

2.3.3.5.1 Caisson Disposal

Caisson disposal was discussed in Section 2.2.2.3 as a means of reducing exposures to site personnel during waste disposal operations as well as reducing potential impacts to a future inadvertent intruder. Caissons may also be used as a means of providing support against subsidence and of reducing potential ground-water impacts particularly for an occasional high activity waste stream. It does not appear, however, that caisson disposal would be suitable for disposal of all of the waste delivered to the disposal facility. In Section 2.2.2.3, differential costs were calculated for an example in which 10% of the waste delivered to the reference disposal facility (about 100,00 m^3) were disposed in caissons. These differential costs were estimated to be about $216/$m^3$ ($6.13/$ft^3$). In the calculations, the number of caisson trenches constructed was 2,585, replacing 6 reference trenches, and about 17 additional acres of land was committed to waste disposal. If caissons were used to dispose of all of the waste, then 25,000 such caisson trenches would be constructed and the additional land area raised to about 170 acres. Costs would also be high.

In addition, much of the wastes which would be thus emplaced in caissons would be of very low activity, and use of this more elaborate disposal method may not be necessary to ensure protection of public health and safety. Another problem would be that caisson disposal would be unwieldly and inefficient for odd-shaped waste such as contaminated machinery or disposal of wastes shipped in large boxes.

2.3.3.5.2 Walled Trench Disposal

Walled trenches were previously discussed (in Section 2.2.2.4) as a method of reducing exposures to site workers and to a potential inadvertent intruder. Walled trenches may also be used as a means of providing structural support for trench covers. The cost and land use differential for walled trench used for 10% of the waste received at the site was estimated in Section 2.2.2.4 to be $256/$m^3$ ($7.25/$ft^3$) and 4 acres, respectively. If walled trenches were used for all wastes at the facility, the unit differential cost would be $161/$m^3$ ($4.50/$ft^3$) and the additional land use 39.5 acres.

2.3.3.5.3 Grouting and Controlled Density Fill

Another method available to reduce subsidence is to fill the void spaces between waste packages with a material that will help support the trench cap before emplacement of the trench cap. The types of agents available for void space filling include clay (bentonite) slurries, grout, and controlled density fill. The use of slurries may not be practical since it involves introducing quantities of liquids over time. Conversely, grouts and controlled density fills generally set into solid form with little or no residual liquids.

For illustrative purposes, two cases of void space minimization are considered in this appendix. As discussed in Section 2.2.2.5, the first case involves the use of grout which is pumped into the void spaces between stacked waste containers before backfilling. The estimated differential cost for this disposal option is $38.22/$m^3$ ($1.08/$ft^3$). The resultant benefits include greater trench cap integrity, additional intruder protection, and increased resistance of the waste to leaching.

The second case involves use of controlled density fill in place of the cement grout. In this example, the controlled density fill is assumed to be a commercially available lower strength concrete (e.g., K-crete, Mearlcrete). The estimated differential cost for the controlled density fill is \$24.62/m^3 (\$0.70/ft^3). Other than cost, the only appreciable difference in the final trench status is the overall strength of the fill. Controlled density fill will adequately support the trench cap but is more capable of being excavated. The benefits to trench cap integrity and leach resistance are assumed to be equivalent to that for grout cement.

2.3.3.6 Centralized Waste Processing

One distinct disposal technology option available is additional volume reduction of waste in a centralized location. Of the 50,000 m^3 (1.77 million ft^3) of waste that arrives annually at the reference disposal facility, approximately 20% (or 10,000 m^3) could be significantly reduced in volume at a regional processing facility by either compaction or incineration. It should be noted that a larger fraction of all potential waste volumes destined for disposal sites can be significantly reduced in volume. However, it is believed that large volume generators can probably perform volume reduction at the point of waste generation. It will generally be the low volume generators such as hospitals, academic institutions, and various industrial facilities which may not have the facilities or the economic means to perform volume reduction at the point of generation. The types of waste streams that appear most amenable to centralized or disposal site processing include contaminated trash from institutions (e.g., hospitals and universities), source material and special nuclear material trash, and low-activity trash from industrial radioactive material licensees. (See Appendix D for a discussion of these waste streams.)

In this appendix, three centralized waste processing options are considered:

1. Compaction of institutional compactible trash and industrial low activity trash is performed using a compactor/shredder capable of achieving a volume reduction factor of between three and four. Compaction not only increases the available volume capacity of the reference disposal facility but also increases the overall stability of the disposal trenches. Assuming a fixed annual volume input to the reference disposal facility, compaction of 10,000 m^3 of compressible wastes to a volume of approximately 2,500 m^3 results in a reduction of the land area which must be committed to waste disposal from about 35 ha (87 acres) to about 30 ha (73 acres).

   The compaction facility includes the compactor/shredders, the compactor building, and a small storage area. The compaction facility requires two full time personnel for operation. This compaction facility is assumed to be situated on the 52-acre parcel of land owned by the site operator immediately adjacent to the leased disposal site property. The estimated cost for compaction of waste at the compaction facility is \$503/m^3 (\$14.25/ft^3).

2. The above waste streams are incinerated using a fluidized bed incinerator. Depending upon the waste streams incinerated, a volume reduction factor of between 40 and 80 is achieved prior to solidifying the resultant ash in a suitable binder. It is likely that the principal wastes processed by the fluidized bed incinerator at the regional facility will be contaminated trash from small institutions and industry. Of the annual waste input of 50,000 m^3 (1.77 million ft^3) to the reference disposal facility, approximately 5,100 m^3 (roughly 10% by volume) is combustible waste from small waste generators, and therefore amenable to incineration at a centralized location. The estimated differential cost for incineration at this facility is $1,039/$m^3$ ($29.43/$ft^3$). More detailed descriptions of incineration can be found in Appendix D and Reference 39. The benefits of incineration include decreased land use and greater trench stability.

3. The above waste streams are incinerated as in option no. 2. In addition, an industrial hydraulic press is installed which is capable of achieving an overall volume reduction factor of 6.0. Waste streams which are assumed to be compacted via the hydraulic press include PWR noncombustible trash, BWR noncombustible trash, and fuel fabrication plant noncombustible trash. The estimated unit cost for compaction of these three waste streams is $1,006 per m^3 of input waste ($28.49/$ft^3$).

Centralized waste processing operations may take place at any suitable location within a region. For convenience, however, processing activities are assumed to take place upon a parcel of land immediately adjacent to the reference disposal facility. The three centralized waste processing options correspond to the assumptions of waste spectra 2, 3, and 4 as described in Appendix D, and are derived from information obtained from References 39 and 40.

3. LAND DISPOSAL ALTERNATIVES TO NEAR-SURFACE DISPOSAL

The disposal options reviewed in Section 2 of this appendix represent variations in near-surface disposal technology. In this section, land disposal alternatives to near-surface disposal are discussed. The two principal disposal alternatives addressed in this section are disposal in intermediate depth excavations (greater than 15 m depth) and disposal in deep-mined cavities.

3.1 Intermediate Depth Disposal

Intermediate depth disposal is assumed in this appendix to mean disposal of waste at depths greater than 15 m (49 ft). (In Section 2.1.1, deeper burial was briefly considered--but was restricted to depths on the order of 16 m (52 ft).) While five meters represents the maximum expected depth for small construction and farming activities (excluding well drilling), the maximum expected depth for heavy construction activities (excluding surface mining) is probably less than 15 m. Deep burial at some localities (especially many areas in the humid eastern United States) may be difficult as a result of relatively shallow depth to ground water and heterogenous subsurface media (e.g., fractured rock). However, it is believed that intermediate depth disposal could easily be practiced in a number of areas in the western and southwestern U.S. Perhaps a suitable location could be located in the eastern U.S.

The use of deep trenches appears to have limited applicability. As previously stated, in the humid eastern U.S., the number of locations amenable to a deep excavation (35 to 50 m) without encountering either ground water or fractured media is probably quite small. Additionally, the practicality of construction of a deep trench may be questionable from both a side slope requirement and an operational requirement. The large depth excavation would require (if excavation as a trench were feasible) either substantial shoring to keep the excavation open or would would require terracing or gentle slopes. Once the slopes are terraced or gently sloped, the excavation then begins to resemble an open-pit mine or strip-mine geometry. Another drawback to using very deep trench excavations is the potential difficulty in waste emplacement. Existing conventional lifting equipment would not be adequate. Either modified mine hoists or dumping would be required. Use of hoists could significantly increase the labor requirements in elevated radiation fields while dumping wastes into deep excavations would probably rupture many waste containers.

Application of strip-mine or open-pit mine technologies appears to be more viable options. Surface mining technologies can be applied to either existing mines that have not been fully reclaimed or to new sites where geologic conditions would permit such large excavations. (It should be noted that the principal goal of the application of intermediate depth disposal is to provide added protection for the inadvertent intruder. The majority of radioactive waste commercially generated will not require such extensive protection for the inadvertent intruder.) For purposes of analyses, an average annual waste input of 50,000 m^3 (1.77 million ft^3) over 20 years duration is assumed.

The example intermediate depth disposal facility can be accommodated on a leased tract of land equivalent to that described for the reference disposal facility (approximately 60 ha (148 acres)), including the excavation itself, the administrative area, overburden storage areas, and waste activities buildings and staging areas.

Both the design and operation of the intermediate depth disposal facility differ significantly from the reference disposal facility described in Appendix E. The excavation is assumed to be a circular open-pit with a spiral access road leading down into the excavation. The excavation is roughly circular with a 410 m diameter at the base of the excavation and a 480 m diameter at ground surface. The maximum depth of the excavation is 34 m. The disposal cell consists of three layers of waste each 5 m thick. Each layer of waste is emplaced by forklifts and boom cranes within the excavation. Random emplacement is assumed throughout the operations with a void space utilization of 50% assumed.

After the final waste layer is emplaced, a final disposal cap of 15 meters of overburden is added, which results in a minimum thickness of 15 m between the waste and the final grade. The equipment needs for the intermediate depth disposal are similar to the reference disposal facility, with the addition of 3 forklifts for waste emplacement activities, 2 pan scrapers to handle the extra overburden volumes, 4 dump trucks to supplement earth moving activities, and 2 extra cranes for waste emplacement. The building and structure requirements are assumed to be similar to those required for the reference near-surface disposal facility described in Appendix E.

The labor requirements for the intermediate depth disposal facility are increased as a result of the need for additional heavy equipment operators, dump truck drivers, semiskilled labor, and unskilled labor. The overall unit disposal (design and operation only) costs for intermediate depth disposal are $238/m^3$ ($6.75/ft^3$) for disposal in an existing mine site (not fully reclaimed), and $344/m^3$ ($9.75/ft^3$) for a new site. This results in an increase over the design and operating costs of the reference facility of $53/m^3$ ($1.50/ft^3$) and $159/m^3$ ($4.50/ft^3$), respectively. It is assumed that the site for either option is located in a semiarid or arid portion of the U.S., precluding large dewatering requirements. The major benefits of intermediate depth disposal include significant protection for the inadvertent intruder as well as some increased ground-water protection. The major disadvantages are higher costs.

3.2 Mined Cavity Disposal

The two basic options available for mined cavity disposal are: (1) creation of a new mined cavity for disposal, and (2) rehabilitation of an existing mine for disposal. Construction of a new mined cavity can be accomplished either in salt media or in hard rock media (e.g., granite or basalt). One significant variation from a near-surface disposal facility is the land requirement. To control access to the mine and prevent intrusion (especially in the form of well drilling), between 1,000 and 1,400 acres of surface property are assumed to be acquired for a mined cavity capable of handling one million m^3.

The disposal horizons for the example newly constructed salt-mined cavity is assumed to be 549 m (1,800 ft) below the ground. The example rehabilitated salt mine is assumed to be 325 m (1,066 ft) below the ground. The room and pillar design is the geometry assumed for both new mined cavity disposal sites and for rehabilitated sites. The initial capital outlay for a mined cavity disposal is considerably higher than that for a near-surface disposal facility ($40 to 60 million as opposed to $7.5 million). The significant components of capital investment include underground equipment (e.g., continuous mining machines and trucks), surface equipment (e.g., waste handling equipment), surface facilities, and the construction of four shafts (i.e., waste, worker, air intake, and air exhaust).

Compared to a near-surface disposal facility, a number of additional surface buildings and facilities are required for a mined cavity disposal facility. The additional surface facilities include: a waste receiving building, cap and powder magazines (for hand-rock mining only), a hoist building, and an electrical substation for underground power requirements. A significant area (10 ha or 25 acres) would have to be set aside at each mined cavity disposal site for mined material storage (new mines only).

Disposal operations require relatively close contact with the waste packages. Waste is handled, in effect, twice: once at the receiving building, and once within the mined cavity. As a result of the double handling and the confined working areas, it is estimated that the occupational exposures for mined cavity operation for one million m^3 of waste are about four times higher than those experienced at a near-surface disposal facility. A large mined cavity disposal facility will require between 150 and 175 persons on the payroll (over twice the requirement for a near-surface disposal facility). While a near-surface disposal facility will require approximately 40 people to work directly with the waste (intermittent or continuous work), a mined cavity facility will require between 80 and 100 persons working directly with the waste.

The estimated cost for mine cavity disposal, assuming disposal in salt, ranges from \$512/m^3 (\$14.50/ft^3) to \$839/m^3 (\$23.80/ft^3). These costs are design and operating costs only and represent an additional \$327/m^3 (\$9.26/ft^3) and \$654/m^3 (\$18.52), respectively, over design and operating costs of the reference disposal facility. The lower range of costs is representative of the costs for a rehabilitated mine.

4. ALTERNATIVES TO LAND DISPOSAL

The two alternatives to land disposal discussed in this section are ocean disposal and space disposal.

4.1 Ocean Disposal

The United States Atomic Energy Commission (AEC) previously licensed disposal of low-level radioactive waste at a number of Atlantic and Pacific Ocean sites. The disposal site locations varied greatly in terms of distance from shore and depth to disposal area. In the early 1960s, the AEC began to phase out ocean disposal of radioactive waste, and by the end of 1970, all the U.S. ocean-related disposal activities had ceased. Ocean dumping up to this time had been conducted at 5 different locations in the Pacific Ocean, one location in the Gulf of Mexico, and 11 locations in the Atlantic Ocean. The waste was not evenly distributed among the 17 disposal sites, as two Atlantic sites and one Pacific site received about 90% of the low-level radioactive volume disposed at sea (the Pacific site actually consists of two subsites). The locations and waste volumes disposed of at the four principal disposal sites are shown in Table F.1 (Ref. 29).

Although not currently practiced in the United States, ocean disposal of radioactive waste is practiced by several foreign countries. The Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) developed a program which, in 1967, led to the first international disposal operation involving five countries. Additional international organizations were carried out from 1969 through 1976, utilizing the International Atomic Energy Agency's (IAEA) guidelines to regulate operations of sea disposal of

Table F.1 Summary of Past Ocean Disposal Practices

Site	Location (Lat/Long)	Depth (m)	Distance from Land (km)	Approximate No. of 55 gal Drums Dumped	Approximate Total Volume (m^3)
Atlantic Site "A"	38°30'N 72°06'W	2,800	190	14,300	2,970
Atlantic Site "B"	37°50'N 70°35'W	3,800	320	14,500	3,020
Pacific Site "A"	37°50'N 123°08'W	900	60	3,500	728
Pacific Site "B"	37°37'N	1,700	77	44,000	9,150

radioactive waste. The regulations encompassed site selection, packaging and container design, ship design, health physics, recordkeeping, and supervision of dumping operations.

In 1972, the International Ocean Dumping Convention (IODC) made specific recommendations which were adopted in 1974 by the IAEA. Not all radioactive-waste producing countries have adopted the IODC recommendations or those standards developed by the IAEA. Thus, international agreement on regulating ocean disposal activities for radioactive wastes is presently lacking.

In the United States, the EPA has the responsibility of developing a permit program for ocean dumping of all wastes, including radioactive waste as well as solid and hazardous wastes. EPA was provided with this regulatory responsibility by the Ocean Dumping Act of 1974 (PL 92-532) and since this law was passed, EPA has instituted a domestic criteria and standards development program.

There are two major concepts for sea disposal--ocean dumping of packaged wastes and sediment penetration using free falling projectiles containing several waste packages. The costs (including transportation costs) have been calculated by Reference 29 to be $710/m³ ($20.10/ft³) and $2,200/m³ ($62.30/ft³) respectively. However, many technical, legal and social issues regarding ocean disposal will require resolution in its use as a disposal technique.

4.2 <u>Extraterrestrial (Space) Disposal</u>

The concept of space disposal of radioactive waste has been under investigation for a number of years. Studies have focused almost entirely on high-level waste (HLW) disposal since the tremendous costs involved render this alternative nonviable for all but the most hazardous materials (i.e., highly concentrated fission products and transuranics). Currently this method is not considered cost-effective or technically feasible for HLW disposal, although studies are continuing. Advanced concepts in such technologies as isotope separation and low-cost heavy-lift launch vehicles (HLLV) may result in future application of this method for HLW.

The key to utilization of space as a waste disposal option is cost reduction. The largest cost item is the launching cost, which is dependent on both the capabilities of the launch vehicle and the destination of the payload. Eight potential methods (destinations), some of which isolate the waste within the solar system (e.g., high earth orbit, solar orbit) and others which can be considered as permanent disposal methods (e.g., solar impact or solar system escape), are shown Table F.2 (Ref. 41). The costs associated with each destination is also given in Table F.2 in terms of dollars per pound of gross payload. These costs are 1972 estimates using the space shuttle for payload delivery to low-earth orbit (LEO) and an advanced centaur rocket to boost the payload to high-earth orbit (HEO), or to escape velocity. These costs must be considered nonconservative since the cost per pound listed is for the gross payload and does not consider the waste containers. In addition, the cost of shuttle launches has significantly increased since the 1972 study.

Table F.2 Cost Estimates for Space Disposal of LLW*

Destination	Launch Costs**				
	Shuttle		HLLV		
	$/lb	$/m³	$/lb	$/m³	10⁹ $/year†
High Earth Orbit	628	2,200,000	27	94,000	24
Solar Orbit					
Single-Burn Earth Escape	628	2,200,000	27	94,000	24
via Mars or Venus	794	2,800,000	34	120,000	30
Double-Burn Circular Orbit	800	2,800,000	34	120,000	30
Solar System Escape					
via Jupiter	3,500	12,300,000	150	520,000	130
Direct	4,420	15,500,000	190	660,000	170
Solar Impact					
via Jupiter	4,700	16,400,000	200	700,000	175
Direct	Payload zero with existing vehicles		--	--	--

*Source: Reference 41.

**Based on cost estimates for 1972 dollars.

†Based on annual disposal volume of $250,000 m³.

Use of an advanced shuttle configuration or a totally new low-cost HLLV could greatly reduce the launch cost. A conceptual vehicle capable of placing a 500,000 pound payload into LEO (the shuttle capacity is 65,000 pounds) for 5 million (1977) dollars, equivalent to about 9 dollars per pound, would yield a factor of 23.5 in cost reduction over the standard shuttle vehicle (Ref. 41). Applying this factor for LEO injection to the eight destinations listed in Table F-2 (not strictly accurate, but adequate for the purpose of this discussion) yields a rough minimum value for the cost per pound of space disposal based on advanced technology. For comparison with other LLW disposal methods, launch costs are also entered in Table F.2 in terms of the cost per cubic meter of waste (assuming an average waste density of 1.6 g/cm^3, or 3,500 lbs/m^3).

The amount of LLW expected to be generated in the U.S. between 1980 and 2000 is roughly 250,000 m^3/y averaged over the next 20 years. At a waste density of approximately 1,600 kg/m^3, this would equal 875 million pounds of waste to be disposed of per year. The annual launch costs would therefore range from 24 billion to 17 billion dollars. Also, at 500,000 pounds (143 m^3) per launch, this would require almost five HLLV launches per day.

The costs shown in Table F.2 do not account for cost-saving measures aimed at reducing the quantities of LLW to be launched (e.g., advanced radioisotope separation and concentration, increased hold-up time before launch, and exclusion of very low activity wastes. Hence, the total annual costs could undoubtedly be reduced. Conversely, the launch costs for the HLLV are based on a launch vehicle that currently exists only on paper. The estimated unit costs (per m^3) are based on the assumption that the entire payload is LLW. In actuality, the payload includes the waste container, which could be a large fraction of the payload for wastes requiring sustantial gamma shielding, or for protection against atmospheric burn-up following an aborted launch.

Although there is uncertainty in HLLV launch costs, they are sufficiently accurate for the purpose of comparing space disposal with other methods discussed in this report. For reference purposes, the estimated design and operation unit costs for land disposal range from \$185/m^3 (\$5.24/ft^3) for the reference near-surface disposal facility to \$839/m^3 (\$23.80/ft^3) for a mined cavity. The cost of the least expensive space disposal method (launch costs only) is thus seen to be three orders of magnitude greater than for land-based disposal. (As noted previously, this estimate is based on an advanced HLLV yet to be developed.) In conclusion, it can be seen that space disposal is not currently feasible economically or technically for LLW disposal. The development of a HLLV would render this option technically feasible, but it would still not be cost effective. However, space disposal remains of interest for the disposal of HLW.

5. COSTS

In this section, estimated costs for implementation of the disposal options considered in this appendix are presented. The cost analyses presented in this section are calculated based on the approach set out in Appendix Q and represent incremental cost changes from those calculated in Appendix Q for the reference disposal facility.

The cost analyses are broken down into (1) capital costs, and (2) operational costs. Postoperational costs for the optional disposal technologies or for various combinations of optional disposal technologies are generally considered as part of the analyses performed in Chapters 4 and 5 of the EIS. Unit costs for equipment and material were obtained from standard construction guides (e.g., Refs. 3, 42 and 43) and from information obtained from a consultant (the firm of Dames and Moore of White Plains, NY).

Additional capital costs are calculated based upon the postulated need to (1) purchase additional equipment and material during the preoperational period of the disposal facility, and (2) enlarge the size of disposal facility buildings to accommodate increases in the number of personnel and construction equipment, and the amount of material used during operations. In the disposal options, additional purchased equipment and material frequently consisted of monitoring equipment such as air samplers. (Additional air samples were assumed to be installed when a particular disposal option was likely to result in additional disposal cells under operation simultaneously or when a particular disposal option had a potential for release of airborne contamination.) Similar to Appendix Q, additional heavy construction equipment was not assumed to be purchased but was assumed to be leased during the operational period.

Costs for enlargement of disposal facility buildings for the disposal options were estimated through use of Table F.3. Each disposal option was assessed regarding three considerations: (1) the relative number of additional personnel required, (2) the relative number of additional construction equipment required and (3) the relative amount of additional perishable supplies required (i.e., supplies that would have to be protected from weather). For each consideration, a low, medium, or high level of increase was assigned. The sizes of the health physics building ($45/ft^2), garage (25/ft^2), and warehouse (25/ft^2) were then increased as follows:

	Building size increase (ft^2)		
Level of increase	Health physics (personnel)	Garage (equipment)	Warehouse (consumables & supplies)
Low	0	0	0
Medium	4,000	1,000	1,000
High	8,000	2,000	5,000

To assign the increase levels for the health physics building and garage, the following numerical guide was used:

Table F.3 Relative Level of Increase in Personnel, Equipment, and Storage for Disposal Options

Disposal Options	Relative # of Additional Personnel	Relative # of Additional Equipment	Relative Increase in Storage	Additional Construction
Deeper trench (no shore)	low	low	low	
Deeper trench (shoring)	mod	low	mod	
Increased distance	low	low	low	Additional lan
Thicker trench cover	low	low	low	
Layered waste disposal	low	low	low	1-storage bldg
Slit trench (10% of vol.)	low	low	low	
Caisson disposal (10% of vol.)	mod	mod	mod	
Concrete walled trench (10% of vol.)	mod	mod	mod	
Concrete walled trench (100% of vol.)	high	high	high	
Grouting	low	mod	mod	
Engineered intruder barrier	mod	high	mod	
Improved monitoring	low	low	low	
Improved thicker trench covers	low	low	low	
Moisture barriers	low	low	low	
Sand backfill	low	low	low	
Surface water drainage	low	low	mod	
Weather shielding	low	low	low	
Stacked emplacement	mod	mod	low	
Waste segregation	low	low	low	
Improved compaction	low	low	low	
Decontainerized disposal	high	mod	mod	1-storage bldg. + increase wast activities bldg
Dynamic compaction	low	low	low	

Level of increase	Health physics building (# of additional personnel)	Garage (# of additional pieces of equipment)
Low	0-10	0-3
Medium	11-30	4-9
High	31+	10+

To assign increase levels for the warehouse, a judgment was made considering the relative amount of material (e.g., cement) that would need to be purchased during operations as well as the relative number of additional personnel. For some disposal options, additional building space was required as shown in Table F.3. Additional operational costs are grouped into five main areas:

- o additional trench construction materials;
- o additional personnel;
- o additional consumables;
- o additional equipment; and
- o additional monitoring charges.

Additional trench construction materials include such items as standpipes, gravel, cornermarkers, cement, etc. Surveying charges (to bench mark disposal cells) were also included as part of materials costs. Surveying costs were estimated by assuming that the disposal facility operators subcontract with a surveyor as a consultant and that each disposal cell requires 8 hours at $60/hr. However, an upper limit on surveying charges was established at $120,000/yr. As the number of disposal cells to be surveyed increase, it will eventually be cheaper to retain a surveyor full time rather than as a part time consultant.

Personnel costs were estimated in the same manner as personnel costs in Appendix Q. A base level of costs are first estimated and then a ten percent fringe is calculated. A 50% overhead is then calculated from the sum of the base and the fringe costs. Finally, the base, fringe, and overhead costs are summed. Similarly to Appendix Q, costs for consumables were then estimated as 10% of the base personnel costs.

Additional heavy equipment costs were estimated by assuming that all such additional equipment is leased.

Additional monitoring charges were estimated by assuming a number of offsite analyses (e.g., gamma spectrum I-131) are performed at an average charge of $50 per sample analysis.

The cost analyses presented in this section for disposal options representing variations on near-surface disposal include the following:

Disposal Option	Table
Deeper trench	F.4
Thicker trench covers	F.5
Increased distance below top of trench	F.6
Layered waste disposal	F.7
Slit trench (10% of waste volume)	F.8
Caisson disposal (10% of waste volume)	F.9
Concrete walled trench (10% of waste volume)	F.10
Concrete Walled trench (entire waste volume)	F.11
Grouting	F.12
Engineered human intrusion barrier	F.13
Improved monitoring	F.14
Improved compaction	F.15
Improved thicker cap	F.16
Moisture barriers	F.17
Sand backfill	F.18
Surface water drainage system	F.19
Weather shielding	F.20
Stacked waste emplacement	F.21
Waste segregation	F.22
Decontainerized disposal	F.23
Dynamic compaction	F.24

Table F.4 Differential Costs for Deep Trench Disposal

Assumptions:

- Total volume input of 1 million m^3/20 years, or 50,000 m^3/year
- 30 deep trenches (approximate dimensions: 180 m x 30 m x 16m) replace 58 reference trenches
- Random disposal of waste
- Waste volume capacity of deeper trench = 33,600 m^3
- Costs are calculated with and without shoring

ADDITIONAL CAPITAL COSTS

A. Without Shoring	$ 0
B. With Shoring	
(1) Increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$	$180,000
(2) Increase warehouse by 10,000 ft^2 @ $42/$ft^2$	250,000
	$430,000
Engineering and Design:	43,000
	$473,000

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Construction Materials

(1) Standpipes and Casings	
58 reference trenches @ $670.50/trench	$ 38,889
30 deep trenches	
56 ft of 6" pvc standpipe @ $2.45/ft	
3 standpipes/trench = $411.60/trench	
3 standpipe casings @ $150/standpipe = $450/trench	
30 trenches @ $861.60/trench	$ 25,848
	–$ 13,041
(2) French Drain	
58 reference trenches @ $425/trench	$ 24,650
30 deep trenches @ $425/trench	$ 12,750
	–$ 11,900

Table F.4 (continued)

(3) Seed and Mulch		
1.5 acres/trench @ \$295/acre		
58 reference trenches		\$ 25,665
30 deep trenches		\$ 13,275
		-\$ 12,390
(4) Corner Markers and Monuments		
6.7 ft^2 of granite corner markers and monuments per trench @ \$18.30/ft^2 = \$122/trench		
58 reference trenches		\$ 7,076
30 deep trenches		\$ 3,662
		-\$ 3,414
(5) Surveyor		
\$60/hr and 8 hrs/trench		
58 reference trenches		\$ 27,840
30 deep trenches		\$ 14,400
		-\$ 13,440
(6) Shoring (optional)		
58 reference trenches		\$ 0
30 deep trenches		
wall area/trench = 6720 m^2 = 72,334 ft^2		
material charge = \$2.40/ft^2		\$5,208,050
30 trenches x 72,334 ft^2 x \$2.40		+ \$5,208,050
B. Additional Personnel		
(1) With No Shoring		
1 heavy equipment operator @ \$21,000		\$ 21,000
	Fringe:	2,100
	Overhead:	\$ 11,550
		\$ 34,650
	x 20 yrs	\$ 693,000
(2) With Shoring		
1 heavy equipment operator @ 21,000		21,000
5 semiskilled laborers @ \$15,000		75,000
10 unskilled laborers @\$10,000		100,000
		\$ 196,000
	Fringe:	19,600
	Overhead:	107,800
		\$ 323,400
	x 20 yrs	\$6,468,000

Table F.4 (continued)

C.	Additional Consumables	
	With no shoring	$ 42,000
	With shoring	$ 392,000
D.	Additional Equipment	
	1 - drag-line excavator for 240 months @ $8,000/mo	$ 1,920,000
E.	Additional Monitoring	0
	Total additional operational charges	
	With shoring:	$13,933,865
	Without shoring:	$ 2,555,807

Unit Differential Costs:

With shoring: $\frac{10.38(473,000)+1.56(13,933,865)}{1,000,000\ m^3} = \frac{26,646,569/m^3}{1,000,000}$

$= \$26.65/m^3\ (\$0.75/ft^3)$

Without shoring: $\frac{1.56(2,555,807)}{1,000,000\ m^3} = \$3.99/m^3\ (\$0.11/ft^3)$

Table F.5 Differential Costs for Thicker Trench Covers

Assumptions:

- Costs are estimated based upon the equivalent construction costs of \$0.75/yd^3 to excavate, haul, and spread earth using scrapers at an average haul distance of 1,500 ft and an average rate of 5,500 yd^3/day
- Fill required = disposal area x cover thickness, where the disposal area = vol/(EMP x EFF x SEFF), Vol = waste volume (m^3); EMP = emplacement efficiency; EFF = volumetric disposal efficiency (m^3/m^2); SEFF = surface use efficiency
- Example calculations are developed for Vol = 1,000,000 m^3; EMP = 0.5 (random disposal); EFF= 6.4 m^3/m^2 (reference trench); SEFF = 0.9 (reference trench); and a cover thickness = 3m.

ADDITIONAL CAPITAL COSTS	\$ 0
ADDITIONAL OPERATIONAL COSTS	
Excavation, haul, and spread of fill volume required = 1,000,000/(.5 x 6.4 x .9) = 347,222 m^3/m^2 of cover 3 meters cover: 1,041,667 m^3 = 1,362,500 yd^3	
Costs = 1,362,500 yd^3 @ \$0.75/yd^3	\$1,021,875
Total additional operational costs	\$1,021,875

Unit Differential costs

$$\frac{1.56(1,021,875)}{1,000,000} = \frac{1,594,125}{1,000,000} = \$1.59/m^3 \ (\$0.05/ft^3)$$

Costs per unit disposal area = \$0.55/m^2

Table F.6 Differential Costs for Increasing the Distance Between the Waste and the Top of the Disposal Cell

Assumptions:

- o Costs are calculated on the basis of 1,000,000 m^3 of waste randomly disposed into reference disposal trenches.
- o The bottom 4 m (rather than the bottom 7 meters) is used for waste disposal, resulting in a reduction in trench waste capacity (50% disposal efficiency) from about 17,230 m^3 to about 9,524 m^3. The number of trenches required is increased from 58 to 105, and the number of disposal trenches that need to be constructed per year is raised from about 3 to 5-6.
- o The land area commited for disposal is raised from about 87 acres to about 157 acres, or an additional 70 acres.
- o Additional costs involve additional material costs such as standpipes and markers, as well as additional land. Also, since the number of trenches that must be excavated is increased, additional machinery and personnel are assumed to be required.

ADDITIONAL CAPITAL COSTS

Purchase 40 additional acres of land @ $1200/acre	$ 48,000

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Construction Materials

1. Standpipes and Casing

58 reference trenches @ $670.50/trench	$ 38,889
105 reference trenches @ 670.50/trench	- 70,403
	+ $ 31,514

2. Gravel Drain

58 reference trenches @ $425/trench	$ 24,650
105 reference trenches @ $425/trench	44,625
	+ $ 19,975

3. Seed and Mulch

87 acres @ $295/acre	$ 25,665
157 acres @ $295/acre	46,315
	+ $ 20,650

Table F.6 (Continued)

4.	Corner markers and monuments			
	58 reference trenches @ $122/trench		$	7,076
	105 reference trenches @ $122/trench			12,810
			+ $	5,734
5.	Surveyor			
	58 reference trenches @ $480/trench		$	27,840
	105 reference trenches @ $480/trench			50,400
			+ $	22,560
B.	Additional Personnel			
	1-heavy equipment operator @ $21,000		$	21,000
		Fringe:		2,100
		Overhead:		11,550
		x 20 yr	$	693,000
C.	Additional Consumables		$	42,000
D.	Additional Equipment			
	1 - panscraper for 24 mo. @ $8,000/mo		$	1,920,000
E.	Additional Monitoring			0
	Total additional operational costs		$	2,713,433

Unit Differential Costs

$$\frac{10.38\ (48{,}000) + 1.56\ (2{,}713{,}433)}{1{,}000{,}000} = \frac{4{,}731{,}194}{1{,}000{,}000}$$

$$= \$4.73/m^3\ (0.13/ft^3)$$

Table F.7 Differential Costs for Layering Operations

Assumptions:

- 10% of the one million m^3 (100,000 m^3) requires layering
- Layering requires a waste storage building and additional labor

ADDITIONAL CAPITOL COSTS

Building Construction-add 6,000 ft^2 storage building @ $20/$ft^2$		$ 120,000
	Engineering and Design	$ 12,000
		$ 132,000

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Construction Materials		$ 0
B. Additional Personnel		
1 Radiation safety technician @$15,000		$ 15,000
1 Semiskilled laborer @ $15,000		$ 15,000
1 Quality assurance technician @$14,000		$ 14,000
		$ 44,000
	Fringe:	$ 4,400
	Overhead:	$ 24,200
		72,600
	x 20 yrs	$1,452,000
C. Additional Consumables		$ 88,000
D. Additional Equipment		0
E. Additional monitoring		0
Total additional operational costs:		$1,540,000

Unit differential costs (per m^3 of layered waste)

$$\frac{10.38(132,000) + 1.56(1,540,000)}{100,000} = \frac{1,370,160 + 2,402,400}{100,000}$$

$$= \frac{3,772,560}{100,000} = \$37.73/m^3 \ (\$1.07/ft^3)$$

Table F.8 Differential Costs for Slit Trench Operations
(Ten Percent of Waste Volume)

Assumptions:

- About ten percent of 1,000,000 m^3 of waste is disposed in slit trenches, which replace an equivalent volume of randomly disposed waste in reference trenches.
- Slit trench dimensions: 20m x 3m x 8m, of which the bottom 7m is used for waste disposal. Spacing between trenches = 2m. Disposal efficiency = 50%.
- Slit trench waste capacity = 210 m^3, reference trench waste capacity = 17,230 m^3. Therefore, 492 slit trenches (disposal volume = 100,320 m^3) replace 6 reference trenches.
- Unit area of slit trench = (22m x 5m) = 110m^2 = 1184 ft^2. Surface area of 492 slit trenches = 582,528 ft^2. Surface area of 6 reference trenches = 6 x (183m x 33m) = 36,234 m^2 = 390,057 ft^2 = 8.95 acres.
- Use of slit trenches for 10% of waste requires additional 517,518 ft^2 = 11.88 acres. Existing licensed acreage sufficient.
- Construct approximately 25 trenches/yr, or one every 2 weeks
- Assume deletion of standpipe and gravel drain. Emplacement would otherwise require trench shoring at considerable additional expense.

ADDITIONAL CAPITAL COSTS

Add atmospheric sampler @ $900	$	900
Engineering and Design		90
	$	990

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

(1) Standpipes

6 reference trenches @ $670.50/trench	$	4,023
492 slit trenches assume no stand pipes		0
	-$	4,023

(2) French Drain

6 reference trenches @ $425/trench	$	2,550
492 slit trenches assume no installed drain		0
	-$	2,550

(3) Seed and mulch

6 reference trenches x 1.5 acres/trench x $295/acre	$	2,655
492 slit trenches require 12 acres		
12 acres x $295/acre		3,540
	+$	885

Table F.8 (continued)

(4) Corner Markers and Monuments		
6.7 ft^2 of granite corner markers and monuments per trench @ $18.30/$ft^2$		
6 reference trenches		$ 732
492 slit trenches		60,054
		+$ 59,322
(5) Surveyor		
$60/hr and 8 hrs/trench		
6 reference trenches		$ 2,880
492 slit trenches		236,160
		+$ 233,280
B. Additional Personnel		
1-heavy equipment operator @ $21,000		$ 21,000
2-semiskilled laborers @ $15,000		30,000
2-unskilled laborers @ $10,000		20,000
1-radiation safety technician @ $15,000		15,000
1-quality assurance technician @ $14,000		14,000
		$ 100,000
	Fringe:	10,000
	Overhead:	55,000
		$ 165,000
	x 20 yrs	$3,300,000
C. Additional Consumables		$ 200,000
D. Additional Equipment		
1-backhoe for 240 mo @ $4,000/mo		960,000
1-40 ton crane for 240 mo @ $4,500/mo		1,080,000
		$2,040,000
E. Additional Monitoring		
50 offsite sample analyses/yr @ average $50/sample x 20 years		$ 50,000
Total additional operational costs		$5,876,914

Unit differential costs

$$\frac{10.38(990) + 1.56(5,876,914)}{100,320} = \frac{9,178,262}{100,320} = \$91.49/m^3 = \$2.59/ft^3$$

Table F.9 Differential Costs for Caisson Disposal
(Ten Percent of Waste Volume)

Assumptions:

- About ten percent of 1,000,000 m^3 of waste is disposed in caissons, which replace an equivalent volume of randomly disposed waste in reference trenches
- Assume caissons consist of 30" concrete culvert pipes 24 ft in length, placed in slit trenches constructed 15m x 1.5m x 8m, 16 caissons per trench. Average spacing between trench = 1m.
- Assume deletion of standpipes and gravel drain. Emplacement would otherwise require trench shoring at considerable additional expense.
- Disposal capacity is $40m^3$/trench, assuming stacked disposal at 75% efficiency. Reference trench waste capacity = $17,230m^3$. Therefore, 2,585 caisson trenches (disposal volume = 103,400) replace 6 reference trenches.
- Unit area of caisson trench = (16m x 2.5m) = 40 m^2 = 430.6 ft^2. Surface area of 2,585 caisson trenches = 1,113,100 ft^2. Surface area of 6 reference trenches = 390,060 ft^2
- Use of slit trenches for 10% of waste requires additional 723,040 ft^2 = 16.6 acres
- Construct approximately 129 caisson trenches, or 2.5/week.
- After waste placement, backfill with concrete (0.6 m thick concrete cap) plus overburden.

ADDITIONAL CAPITAL COSTS

(1) 3-atmospheric samplers @ $900 each	$ 2,700
(2) increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$	180,000
(3) increase garage by 1000 ft^2 @ $25/$ft^2$	25,000
(4) increase warehouse by 1000 ft^2 @$25/$ft^2$	25,000
	$ 232,700
Engineering and Design:	23,270
	$ 255,970

ADDITIONAL OPERATIONAL COSTS

A. Additional Construction Materials

(1) Standpipes

6 reference trenches @ $670.50/trench	$ 4,023
2585 caisson trenches assume no standpipes	0
	-$ 4,023

Table F.9 (continued)

(2)	French Drain	
	6 reference trenches @ $425/trench	$ 2,550
	2,585 caisson trenches assume no gravel required	0
		–$ 2,550
(3)	Seed and Mulch	
	6 reference trenches x 1.5 acres/trench x $295/acre	$ 2,655
	2,585 caisson trenches require 24 acres	
	24 acres x $295/acre	7,080
		+$ 4,425
(4)	Corner Markers and Monuments	
	6 reference trenches @ $122/trench	$ 732
	2,585 caisson trenches @ $122/trench	315,528
		+$ 314,796
(5)	Surveyor	
	6 reference trenches @ $480/trench	$ 2,880
	Surveyor consulting fees @ $120,000/yr	240,000
		+$ 237,120
(6)	Concrete Backfill (cap)	
	fill/trench = (15m x 1.5m x 0.6m) = 13.50 m^3 = 17.7 yd^3	
	17.7 yd^3 @ $45/$yd^3$ x 2,585 trenches	+$2,054,067
B.	Additional Personnel	
	2-heavy equipment operators @ 21,000	$ 42,000
	4-semiskilled laborers @ 15,000	60,000
	2-unskilled laborers @ 10,000 =	20,000
	2-radiation safety technicians @ 15,000 =	30,000
	1-quality assurance technician @ $14,000 =	14,000
		$ 166,000
	Fringe:	16,600
	Overhead:	91,300
		$ 273,900
	x 20 yrs	$5,478,000
C.	Additional Consumables	$ 332,000

Table F.9 (continued)

D.	Additional Equipment	
	2-backhoes for 240 mo @ $4,000/mo	$ 1,920,000
	2-40 ton cranes for 240 mo @ $4500/mo	2,160,000
		+$ 4,080,000
E.	Additional Monitoring	
	150 offsite sample analyses/yr @ average $50/sample x 20 years	$ 150,000
	Total additional operational costs	$12,643,835

Unit Differential Costs

$$\frac{10.38\ (255{,}970) + 1.56\ (12{,}643{,}835)}{103{,}400} = \frac{\$22{,}381{,}351}{103{,}400}$$

$$= \$216.45/m^3\ (\$6.13/ft^3)$$

Table F.10 Differential Costs for Concrete Walled Trench (Ten Percent of Waste Volume)

Assumptions:

- About ten percent of 1,000,000 m^3 of waste is disposed in walled trenches, which replace an equivalent volume of waste randomly disposed in reference trenches

- Walled trench inside dimensions: 12 m x 3 m x 8.3 m, of which the bottom 7.3 m is used for waste disposal. The thickness of walls and slab = 0.3 m. A 0.3 m-thick gravel base is placed on the bottom of the trench. Spacing between trenches = 3 m. Disposal efficiency = 75% (stacked disposal).

- Concrete walled trench waste capacity = 189 m^3; reference trench waste capacity = 17,230 m^3. Therefore, 547 walled trenches replace 6 reference trenches (disposal volume = 103,400 m^3).

- Unit area of walled trench = (15.3 m x 6.3 m) = 96.4 m^2 = 1,038 ft^2. Surface area of 6 reference trenches = 390,060 ft^2 = 9 acres. Surface area of 547 walled trenches = 567,645 ft^2 = 13 acres.

- Use of concrete walled trenches for 10% of waste requires an additional 177,585 ft^2 = 4 acres

- Construct approximately 27 walled trenches/yr or about one every two weeks.

ADDITIONAL CAPITAL COSTS

(1)	add 1 atmospheric sampler @ $900	$ 900
(2)	increase health physic/security building by 4,000 ft^2 @ $45/$ft^2$	180,000
(3)	increase garage by 1,000 ft^2 @ $25/$ft^2$	25,000
(4)	increase warehouse by 1,000 ft^2 @$25/$ft^2$	25,000
		$ 230,900
	Design and Engineering:	23,090
		$ 253,990

ADDITIONAL OPERATIONAL COSTS

A. Additional Construction Materials

(1) Standpipes and Casings

6 reference trenches @ $670.50/trench	$ 4,023
547 walled trenches with one standpipe/trench	
547 trenches @ $223.50/trench	$ 122,255
	+$ 118,232

Table F.10 (continued)

(2)	Gravel Drain	
	reference trenches @ $425/trench	$ 2,550
	547 walled trenches. Gravel volume/trench	
	= (12m x 3m x 1.3m) = 10.8 m^3 = 14.13 yd^3	
	547 trenches x 14.13 yd^3/trench x $5/$yd^3$	$ 38,636
		+ $ 36,086
(3)	Seed and Mulch	
	6 reference trenches x 1.5 acres/trench x $295/acre	$ 2,655
	547 walled trenches require 13 acres	
	13 acres @ $295/acre	$ 2,835
		+$ 1,180
(4)	Corner Marker and Monuments	
	6 reference trenches @ $122/trench	$ 732
	547 walled trenches @ $122/trench	$ 66,734
		+$ 66,002
(5)	Surveyor	
	6 reference trenches $$480/trench	$ 2,880
	Surveyor consulting fees	$ 240,000
		+$ 237,120
(6)	Additional Material	
	Form work	
	30 m x 8.6m 258m^2 = 2777 ft^2/trench. Form	
	work = $0.68/$ft^2$ for 3 uses prior to replacement	
	2777 ft^2/trench x 547 trenches x $0.68/$ft^2$	$1,032,933
	Concrete	
	124.2m^3/trench = 162.45 yd^3 x 547 trenches @ $45/$yd^3$	$3,998,795
	Reinforcing Steel	
	0.74 tons/trench x 547 trenches @ $430/ton	$ 174,055
B.	Additional Personnel	
	4-semiskilled laborers @ 15,000	$ 60,000
	4-unskilled laborers @ $10,000	40,000
	1-heavy equipment operator @ $21,000	21,000
	1-radiation safety technician @ $15,000	15,000
	1-quality assurance technician @ $14,000	14,000
		$ 150,000
	Fringe:	$ 15,000
	Overhead:	82,500
		247,500
	x 20 yrs	$4,950,000

Table F.10 (continued)

C.	Additional Consumables	$ 300,000
D.	Additional Equipment	
	2-40 ton cranes for 240 mo @ $4,500/mo	$ 2,160,000
	1-concrete pump for 240 mo @ $5,000/mo	1,200,000
	1-backhoe for 240 mo @ $4,000/mo	960,000
		$ 4,320,000
E.	Additional Monitoring	
	50 offsite sample analyses/yr @ average $50/sample x 20 yrs	$ 50,000
	Total additional operational costs	$15,284,403

Unit Differential Costs

$$\frac{10.38\ (253{,}990) + 1.56(15{,}284{,}403)}{103{,}400} = \frac{26{,}480{,}085}{103{,}400}$$

$$= \$256.09\ m^3\ (\$7.25/ft^3)$$

Table F.11 Differential Costs for Concrete Walled Trench (Entire Waste Volume)

Assumptions:

- o Disposal of 1,000,000 m^3 of waste entirely in walled trenches.
- o Walled trench capacity = 189 m^3, requires 5,291 trenches.
- o Surface area of 5,291 trenches = 5,492,000 ft^2 = 126.08 acres. Surface area of 58 reference trenches = 3,770,000 ft^2 = 87 acres. Use of walled trenches requires additional 39.5 acres.
- o Construct 265 trenches/yr or about 5 trenches/week.

ADDITIONAL CAPITAL COSTS

(1) Add five atmospheric samplers @ \$900	\$ 4,500
(2) Increase health physics/security building by 8,000 ft^2 @ \$45/ft^2	360,000
(3) Increase garage by 2,000 ft^2 @ 25/ft^2	50,000
(4) Increase warehouse by 5,000 ft^2 @ \$25/ft^2	\$ 125,000
	539,500
Engineering and Design:	53,950
	\$ 593,450

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Constructional Materials

(1) Standpipes and Casings

58 reference trenches @ \$670.50/trench	\$ 38,889
5,291 walled trenches with one standpipe/trench 5,291 trenches @ \$223.50/trench	\$1,182,539
	+\$1,143,650

(2) Gravel Drain

58 reference trenches @ \$425/trench	\$ 24,650
5,291 walled trenches. 5,291 trenches x 14.13 yd^3/trench x \$5/yd^3	\$ 373,809
	+\$ 349,159

(3) Seed and Mulch

58 reference trenches x 1.5 acres/trench @ \$295/acre	\$ 25,665
5,291 walled trenches 126 acres @ \$295/acre	\$ 37,170
	+\$ 11,505

Table F.11 (continued)

(4)	Corner Markers and Monuments	
	58 reference trenches @ $122/trench	$ 7,076
	5,291 walled trenches @ $122/trench	$ 645,502
		+$ 638,426
(5)	Surveyor	
	58 reference trenches @ $480/trench	$ 27,840
	Surveying consultant costs @ $120,000/yr	$ 2,400,000
		+$ 2,372,160
(6)	Additional Material	
	Formwork - 2777 ft²/trench x 5291 trenches @ $0.68/ft²	$ 9,991,313
	Concrete - 162.45 yd³/trench x 5291 trenches @ $45/yd³	$38,678,533
	Reinforcing Steel - 0.74 tons/trench x 5291 trenches @ $430/ton	$ 1,683,596
B.	Additional Personnel	
	3-radiation safety technicians @ $15,000 =	$ 45,000
	30-semiskilled laborers @ $15,000	450,000
	30-unskilled laborers @ $10,000	300,000
	3-heavy equipment operators @ $21,000	63,000
	3-quality assurance technicans @ $14,000	42,000
	1-foreman @ $28,000	28,000
		$ 928,000
	Fringe:	92,800
	Overhead:	$ 510,400
		$ 1,531,200
	x 20 yrs	$30,624,000
C.	Additional Consumables	$ 1,856,000
D.	Additional Equipment	
	4-concrete pumps 240 mo @ $5,000/mo	$ 4,800,000
	3-backhoes for 240 mo @ $4,000/mo	2,880,000
	3-40 ton cranes for 200 mo @ $4,500/mo	3,240,000
	3-pickup trucks for 240 mo @ $750/mo	540,000
	1-farm tractor for 240 mo @ $800/mo	192,000
		$11,652,000

Table F.11 (continued)

E.	Additional Monitoring	
	200 offsite sample analyses/yr @ average \$50/sample x 20 yrs.	\$ 250,000
	Total additional operational costs:	\$99,250,342

Unit Differential Costs

$$\frac{10.38(593{,}450) + 1.56\ (99{,}250{,}342)}{1{,}000{,}000} = \frac{160{,}990{,}545}{1{,}000{,}000}$$

$$= 160.99/m^3\ (4.56/ft^3)$$

Table F.12 Differential Costs for Grouting

Assumption:

- o Costs based upon 1,000,000 m^3 of waste disposed by stacking into reference trenches. (75% efficiency). Available disposal volume per trench = 2 x 17,230 m^3 = 34,460 m^3. At 75% efficiency, have 25,845 m^3 of waste and 8,615 m^3 of void space per trench (not counting 1 m backfill between top of waste and trench). Disposal of 1,000,000 m^3 of waste by stacking therefore requires 1E+6/25,845 = 39 trenches having 333,000 m^3 of void space. Grout volume therefore equals waste volume x $\frac{(1-EFF)}{EFF}$
- o Differential costs for stacking included elsewhere (see Table F.21). Costs are for grouting alone.
- o Case A: cement
  Case B: low strength (200 psi) cement)

ADDITIONAL CAPITAL COSTS

(1) Increase garage by 1,000 ft^2 @ $25/$ft^2$		$ 25,000
(2) Increase warehouse by 1,000 ft^2 @ $25/$ft^2$		25,000
		$ 50,000
	Engineering and Design:	5,000
		$ 55,000

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

(1) Grout

Case A.	333,000 m^3 = 436,000 yd^3 @ $45/$yd^3$	$19,619,980
Case B.	436,000 yd^3 @ $25/$yd^3$	$10,900,000

B. Additional Personnel

1-semiskilled laborer @ $15,000		$ 15,000
2-unskilled laborers @ $10,000		20,000
1-quality assurance technician @ $14,000		14,000
		$ 49,000
	Fringe:	4,900
	Overhead:	26,950
		$ 80,850
	x 20 yrs	$ 1,617,000

C. Additional Consumables $ 98,000

Table F. 12 (continued)

D.	Additional Equipment	
	2-cement pumps for 240 mo @ $5,000/mo	$ 2,400,000
	2-tremie pipe and hose systems	400,000
		$ 2,800,000
E.	Additional Monitoring	$ 0
	Total additional operational costs	
	Case A	$24,134,980
	Case B	$15,415,000

Unit Differential Costs

Case A. Cement:

$$\frac{10.38(55{,}000) + 1.56\ (24{,}134{,}980)}{1{,}000{,}000} = \frac{38{,}221{,}469}{1{,}000{,}000}$$

$$= \$38.22/m^3\ (\$1.08/ft^3)$$

$$= \$114.66/m^3 \text{ of grout}$$

Case B. Low-Strength Cement:

$$\frac{10.38(55{,}000) + 1.56\ (15{,}415{,}000)}{1{,}000{,}000} = \frac{24{,}618{,}300}{1{,}000{,}000}$$

$$= \$24.62/m^3\ (\$0.70/ft^3)$$

$$= \$73.85/m^3 \text{ of grout}$$

Table F.13 Differential Costs for Installation of an Engineered Human Intruder Barrier

Assumptions:

- o Costs based upon 1,000,000 m^3 of waste randomly disposed into reference trenches. This results in a total disposal area = vol/(EMP X EFF X SEFF) = 347,000 m^2, where EMP = 0.5, EFF = 6.4, and SEFF = 0.9.
- o The engineered intruder barrier is 5.5 m thick and consists of layers of sand, clay, gravel, cobbles, bounders asphaltic concrete, and topsoil, and is installed on top of existing 1 m thick backfill and 1 m thick cap.
- o The engineered intruder barrier consists of 43,511 yd^3 of material per trench at an average cost of $6.00/$yd^3$

CAPITAL COSTS:

Increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$		$ 180,000
Increase garage by 2,000 ft^2 @ $25/$ft^2$		50,000
Increase warehouse by 1000 ft^2 @ $25/$ft^2$		25,000
		$ 255,000
	Engineering and Design:	25,500
		$ 280,500

OPERATIONAL COSTS

A. Additional Materials

(1) Standpipes add 20 ft to each standpipe. 58 trenches x 3 standpipes/trench x 20 ft @ $2.45/ft		$ 8,526
(2) Barrier material 43,511 yd^3/trench x 58 trenches @ $6/$yd^3$		$15,141,828

B. Additional Personnel

4-heavy equipment operators @ 21,000/yr		$ 84,000
4-semiskilled laborers @ $15,000/yr		60,000
2-unskilled laborers @ $10,000/yr		20,000
2-quality assurance technicians @ $14,000		28,000
		$ 192,000
	Fringe:	19,200
	Overhead:	105,600
		$316,800
	x 20 yrs	$ 6,336,000

Table F.13 (Continued)

C.	Consumables	$ 384,000
D.	Additional Equipment	
	2-pan scrapers for 240 months @ $8,000/mo	$ 3,840,000
	1-asphalt paver for 240 months @ $3,775/mo	906,000
	1-crawler tractor for 240 months @ $4,200/mo	1,008,000
	1-vibratory compactor for 240 months @ $6,000/mo	468,000
	5-dump trucks for 240 months @ $6,000/mo	7,200,000
	1-motor grader for 240 months @ $3,200/mo	768,000
		$14,190,000
E.	Additional Monitoring	0
	Total additional operational costs	$36,060,354

Unit Differential Costs

$$\frac{10.38(280,500) + 1.56(36,060,354)}{1,000,000} = \frac{59,165,742}{1,000,000}$$

$$= \$59.17/m^3 \ (\$1.68/ft^3)$$

Table F.14 Differential Costs for Improved Monitoring

Assumptions:

- Improved monitoring consists of 25 additional wells at an average depth of 60 ft, 10 particulate air samplers, and (optional) one automatic runoff sampler.
- Well construction: 1,500 total feet at $15/ft = $22,500.
- Cost of consulting services for well location selection = $20,000.
- Purchase and installation of 10 particulate air samplers @ $900/sampler = $9,000.
- Purchase and installation of automatic runoff sampler = $7,000.
- Construction of WEIR for sampler = $10,000.

CAPITAL COSTS			
Monitoring systems purchase and installation		$	48,500
Engineering and design fees			4,850
Consulting fees			20,000
		$	73,350
Without runoff sampler		$	54,650
OPERATIONAL COSTS			
A. Additional Trench Construction Materials			0
B. Additional Personnel			
1-radiation safety technician @ $15,000		$	15,000
	Fringe:		1,500
	Overhead:		8,250
			24,750
	x 20 yrs	$	495,000
C. Additional Consumables			30,000
D. Additional Equipment			0
E. Additional Monitoring			
Offsite sample analysis @ average $50/sample			
25 wells, quarterly samples			5,000
10 air samples, 50 each/yr			25,000
runoff samples, 50/yr			2,500
		$	32,500
	x 20 yrs	$	650,000
Total additional operational costs:		$	704,750
Without runoff samples		$	654,750

Table F.14 (continued)

Unit Differential Costs:

$$\frac{10.38(73,350) + 1.56(704,750)}{1,000,000} = \frac{1,860,783}{1,000,000}$$

$$= \$1.86/m^3 = \$0.05/ft^3$$

Without runoff samples: $1.59/m^3 = \$0.04/ft^3$

Table F.15 Differential Costs for Improved Compaction

Assumptions:

- The costs are a function of the area compacted, which is Vol/(EMP x EFF x SEFF). Costs are estimated based upon 1,000,000 m^3 of randomly disposed waste, where EMP = 0.5, EFF = 6.4 m, and SEFF = 0.9.

ADDITIONAL CAPITAL COSTS			$ 0
ADDITIONAL OPERATIONAL COSTS			
A.	Additional Materials		$ 0
B.	Additional personnel		
	1-heavy equipment operator @ $21,000		$ 21,000
		Fringe:	$ 2,100
		Overhead:	$ 11,550
			$ 34,650
		x 20 yrs	$ 693,000
C.	Additional Consumables		$ 42,000
D.	Additional Equipment		
	1-vibratory compactor for 240 mo @ $1,950/mo		$ 468,000
E.	Additional Monitoring		0
	Total additional operational costs		$1,203,000

Unit Differential Costs:

$$\frac{1.56(1,203,000)}{1,000,000} = \$1.88/m^3 \ (\$0.05/ft^3)$$

Cost per unit disposal area = $.065/$m^2$

Table F.16 Differential Costs for Improved Thicker Cap

Assumptions:

- o Thicker Cap Case A. Two meters of imported clay compacted to 95% of maximum density.
- o Thicker Cap Case B. Three meters of imported clay compacted to 95% of maximum density.
- o Fill required = disposal area x cover thickness, where the disposal area = Vol/(EMP x EFFx SEFF), and
  - Vol = waste volume (m^3)
  - EMP = emplacement efficiency
  - EFF = volumetric disposal efficiency (m^3/m^2)
  - SEFF = surface use efficiency
- o Example calculation for vol = 1 million m^3, EMP = 0.5 (random disposal), EFF = 6.4 m^3/m^2 (reference trench), and SEFF = 0.9 (reference trench)

ADDITIONAL CAPITAL COSTS		$ 0
ADDITIONAL OPERATIONAL COSTS		
A. Additional Trench Construction Materials		
Case A: 2 meter cap disposal area = 1,000,000/(.5 x 6.4 x .9) = 347,222 m^2. Fill required = 694,444 m^3 = 908,333 yd^3 Purchase and haul fill @ $3.50/$yd^3$		$ 3,179,165
Case B: 3 meter cap fill required = 1,041,666m^3 = 1,362,499 yd^3 Purchase and haul fill @ $3.50/$yd^3$		$ 4,768,747
B. Additional Personnel		
1-heavy equipment operator @ $21,000		$ 21,000
	Fringe:	$ 2,100
	Overhead:	11,550
		$ 34,650
	x 20	$ 693,000
C. Additional Consumables		$ 42,000
D. Additional Equipment		
1-crawler tractor for 240 mo @ $4200/mo		$ 1,008,000
1-vibratory compactor for 240 mo @ $1950/mo		$ 468,000
		$ 1,476,000

Table F. 16 (continued)

E. Additional Monitoring $ 0

Total additional operational costs:

Case A:	$ 5,390,165
Case B:	$ 6,979,747

Unit Differential Costs:

Case A: $\frac{1.56(5,390,165)}{1,000,000}$ = \$8.41/m^3 (\$0.24/ft^3)

= \$2.92/m^3 of disposal area

Case B: $\frac{1.56(6,979,747)}{1,000,000}$ = \$10.89/m^3 (\$0.31/ft^3)

= \$3.78/m^2 of disposal area

Table F.17 Differential Costs for Moisture Barriers

Assumptions:

0 Costs based upon random disposal of 1,000,000 m^3 of waste into 58 reference disposal trenches.

0 Barrier options: A = one bentonite layer
B = one polymer membrane layer
C = one polymer membrane layer plus one bentonite layer
D = two polymer membrane layers

o Bentonite is used as a rate of 4 lbs/ft^2

o Costs in addition to those for 2 m-thick compacted clay caps (Table F.16).

ADDITIONAL CAPITAL COSTS			$ 0
ADDITIONAL OPERATIONAL COSTS			
A. Additional Trench Construction Materials			
Two meter thick clay cap (from Table F.16)			$ 3,179,165
Case A	86 acres (3,746,160 ft^2) of bentonite 7,492 tons @ $260/ton		$ 1,948,003
Case B	3,746,160 ft^2 of 36 mil reinforced hypalon @ $0.60/$ft^2$		$ 2,247,696
Case C	Material Cost of Case A plus Case B.		$ 4,195,699
Case D	Twice additional material cost of Case B.		$ 4,495,392
B. Additional Personnel			
1-heavy equipment operator @ $21,000			$ 21,000
		Fringe:	2,100
		Overhead:	11,550
			$ 34,650
		x 20	$ 693,000
C. Additional Consumables			$ 42,000
D. Additional Equipment			
1-crawler tractor for $240 mo @ $4200/mo			$ 1,008,000
1-vibratory compactor for $240 mo @ $1950/mo			$ 468,000
			$ 1,476,000

Table F.17 (Continued)

E.	Additional Monitoring	$ 0
	Total additional operational costs:	
	Case A:	$ 7,338,168
	Case B:	$ 7,637,861
	Case C:	$ 9.585.864
	Case D:	$ 9,885,557

Unit Differential Costs

Case A $\frac{1.56(7,338,168)}{1,000,000} = \$11.45/m^3\ (\$0.32/ft^3)$

Case B $\frac{1.56(7,637,861)}{1,000,000} = \$11.92/m^3\ (\$0.34/ft^3)$

Case C $\frac{1.56(9,585,864)}{1,000,000} = \$14.95/m^3\ (\$0.42/ft^3)$

Case D $\frac{1.56(9,885,557)}{1,000,000} = \$15.42/m^3\ (\$0.44/ft^3)$

Table F.18 Differential Costs for Use of a Sand Backfill

Assumptions:

- Costs estimated based upon disposal of 1,000,000 m^3 of waste into reference disposal trenches.
- Sand backfill is assumed to be procured, trucked to the disposal facility, and stockpiled for use at an average cost of \$2.50/yd^3.
- Costs are calculated for both random and stacked disposal, and include an equivalent of a 1 m thick backfill between the waste and the top of the trench. For random disposal, required sand volume = 1,000,000 m^3 + 58 x (180 m x 30 m x 1 m) = 1,313,200 m^3. For stacked disposal, required sand volume = 333,333 m^3 + 39 x (180 m x 30 m x 1m) = 543,933 m^3.

ADDITIONAL CAPITAL COSTS	\$ 0
ADDITIONAL OPERATIONAL COSTS	
A. Additional Materials	
Random disposal: 1,313,200 m^3 = 1,717,666 yd^3 @ \$2.50/yd^3	\$ 4,294,164
Stacked disposal: 543,933 m^3 = 711,464 yd^3 @ \$2.50/yd^3	\$ 1,778,661
B. Additional Personnel	\$ 0
C. Additional Consumables	\$ 0
D. Additional Equipment	\$ 0
E. Additional Monitoring	\$ 0
Total additional operational costs:	
random disposal	\$ 4,294,164
stacked disposal	\$ 1,778,661

Unit Differential Costs

Random disposal: $\frac{1.56\ (4,294,164)}{1,000,000}$ = \$6.70/m^3 (\$0.19/ft^3)

Stacked disposal: $\frac{1.56\ (1,778,661)}{1,000,000}$ = \$2.77/m^3 (\$0.08/ft^3)

Cost per m^3 of sand = 5.11/m^3 (\$0.14/ft^3)

Table F.19 Differential Costs for a Surface Water Drainage System

Assumptions:

- Primary system, discharge channel, and run-off monitor installed during facility construction, secondary system installed in stages during facility operations.
- Primary system runs entirely around 60 ha state-owned land plus along 2 north-south site access roads. (See Figure E.11) (system 5200 m in total length)
- Secondary system runs between trenches (along lengths and ends) and carries discharge to primary system (system 10,900 m in total length).
- Drainage channel carries discharge from primary system to an offsite publicly owned drainage channel which empties into a nearby stream.
- Primary system consists of 1/3 section of 24" radius galvanized pipe; secondary system consists of 1/3 section of 15" radius galvanized pipe; discharge channel consists of trapezoidal sectioned gravel channel 500 m long. Gravel layer 3.5 m wide and 0.6 in thick.

CAPITAL COSTS

(1)	Primary system: 5200 m = 17,061 ft @ \$19.43 ft	\$ 331,499
(2)	Discharge channel: gravel (3.5 m x 500m) = 1050m^3 = 1,373 yd^3 @ \$10/yd^3	\$ 13,730
(3)	Purchase and install automatic runoff sampler	\$ 7,000
(4)	Construction of WEIR for sampler	\$ 25,000
(5)	Increase warehouse by 1,000 ft^2 @ \$25/ft^2	\$ 25,000
		\$ 387,229
	Engineering and Design	\$ 38,723
	Total additional capital costs	\$ 425,952

Table F. 19 (continued)

OPERATIONAL COSTS		
A. Additional Materials		
(1) Secondary System		
10,900 m = 35,763 ft @ $10.25/ft		$ 366,570
(2) System Maintenance Contingency		
5 maintenance operations @ $1.19/ft for 52,824 ft of system		$ 314,303
(3) Additional Personnel		
1-semiskilled laborer @ $15,000		$ 15,000
2-unskilled laborers @ $10,000		20,000
		$ 35,000
	Fringe:	$ 3,500
	Overhead	$ 19,250
		$ 57,750
	x 20 years	$1,155,000
C. Additional Consumables		$ 70,000
D. Additional Equipment		0
E. Additional Monitoring		
Offsite sample analysis @ average $50/sample, 50 samples/yr		$ 50,000
Total additional operational costs:		$ 1,955,873

Unit Differential Costs

$$\frac{10.38\ (425,952) + 1.56\ (1,955,873)}{1,000,000} = \frac{7,472,544}{1,000,000}$$

$$= \$7.47/m^3\ (\$0.21/ft^3)$$

Table F.20 Differential Costs for Weather Shielding

Assumptions:

- Tension structures employed.
- Purchase 3 tension structures having dimensions 36.6m x 190m @ $100/m^2 = $695,400 apiece
- Weather shield moves during operations cost 1.5% of total capital cost and include costs for temporary help, repairs, etc.
- Costs calculated on basis of 1,000,000 m^3 of waste.

CAPITAL COSTS

3 tension structures @ $695,400 apiece	$2,086,200
Engineering and Design	208,620
	$2,294,820

OPERATIONAL COSTS

Weather shield moves	
55 moves at 1.5% of $2,294,800	$1,893,210

Unit Differential Costs:

$$\frac{10.38(2,294,820) + 1.56(1,893,210)}{1,000,000} = \frac{26,773,639}{1,000,000}$$

$$= \$26.77/m^3 = \$0.76/ft^3$$

Table F.21 Differential Costs for Stacked Waste Emplacement

Assumptions:

- Costs based upon 1,000,000 m^3 of waste disposed by stacking into reference trenches at 75% efficiency. The available disposal volume per trench is 34,460 m^3. At 75% efficiency, can dispose of 25,845 m^3 per trench. The number of disposal trenches is reduced from 58 to 39.

ADDITIONAL CAPITAL COSTS

Increase health physics/security building by 4,000 ft^2 @ \$45/ft^2	\$ 180,000
Increase garage by 1,000 ft^2@ \$25/ft^2	\$ 25,000
	\$ 205,000
Engineering and Design:	20,500
	\$ 225,500

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

1. Standpipes	
58 trenches @\$670.50/trench	\$ 38,889
39 trenches @\$670.50/trench	\$ 26,150
	-\$ 12,739
2. French Drain	
58 trenches with 85 yd^3/trench @ \$5/yd	\$ 24,650
39 trenches with 85 yd^3/trench @ \$5/yd	\$ 16,575
	-\$ 8,075
3. Seed and Mulch	
58 trenches = 87 acres @ \$295/acre	\$ 25,665
39 trenches = 58.5 acres @ \$295/acre	\$ 17,258
	-\$ 8,407
4. Monuments and Markers	
58 trenches @ \$122/trench	\$ 7,076
39 trenches @ \$122/trench	\$ 4,758
	-\$ 2,318
5. Surveyor	
\$60/hr @ 8 hrs/trench	
58 trenches @ \$480/trench	\$ 27,840
39 trenches @ \$480/trench	\$ 18,720
	-\$ 9,120

Table F.21 (continued)

B.	Additional Personnel		
	4-Radiation safety technicians @ $15,000		$ 60,000
	4-Heavy equipment operators @ $21,000		84,000
	5-Semiskilled laborers @ $15,000		75,000
	6-Unskilled laborers @ $10,000		10,000
	1-Quality assurance technician @ $14,000		14,000
			$ 293,000
		Fringe:	$ 29,300
		Overhead:	$ 161,150
			$ 483,450
		x 20 yrs	$9,669,000
C.	Consumables		$ 586,000
D.	Additional Equipment		
	4-forklifts for 240 months @ $1,000/mo		$ 960,000
	1-40 ton crane for 240 months @ 4,500/mo		$ 1,080,000
	1-onsite transport vehicle 240 months @ $2,100/mo		$ 504,000
			$ 2,544,000
E.	Additional Monitoring		0
	Total additional operational costs:		$12,758,341

Unit Differential Costs

$$\frac{10.38\ (225{,}500) + 1.56\ (12{,}758{,}341)}{1{,}000{,}000} = \frac{22{,}243{,}702}{1{,}000{,}000}$$

$$= \$22.24/m^3\ (\$0.63/ft^3)$$

Table F.22 Differential Costs for Waste Segregation

Assumptions:

- o Waste segregation requires additional labor and additional equipment
- o Costs calculated based on 1,000,000 m³ of randomly disposal waste

ADDITIONAL CAPITAL COSTS

Add atmospheric sampler @ $900		$ 900
	Engineering and Design	90
		$ 990

ADDITIONAL OPERATIONAL COSTS

A.	Additional Trench Construction Materials		$ 0
B.	Additional Personnel		
	1-radiation safety technician @ $15,000		$ 15,000
	1-semiskilled laborer @ $15,000		$ 15,000
	3-unskilled laborers @ $10,000		$ 30,000
	1-quality assurance technician @ $14,000		$ 14,000
			$ 74,000
		Fringe:	7,400
		Overhead:	40,700
			$ 122,100
		x 20 yrs	$ 2,442,000
C.	Additional Consumables		$ 148,000
D.	Additional Equipment		
	1-40-ton boom crane for 240 mo. @ $4,500/mo.		$ 1,008,000
	1-forklift for 240 mo. @ $1,000/mo		240,000
			$ 1,248,000
E.	Additional Monitoring		
	50 offsite analyses/yr @ $50/sample x20 yrs		$ 50,000
	Total additional operational costs:		$ 3,888,000

Unit Differential Costs.

$$\frac{10,38(990) + 1.56(3,888,000)}{1,000,000} = \frac{6,075,556}{1,000,000} = \$6,08/m^3 \quad \$0.17/ft^3$$

Table F.23 Differential Costs for Decontainerized Disposal

Assumptions:

- Costs based upon decontainerized disposal of lower activity compressible unstable waste, assumed to be about 56% of 1,000,000 m^3, or 560,000 m^3 for waste spectrum 1 (50% disposal efficiency).
- Operations require additional personnel, increased storage space, increased facility building sizes and increased airborne sampling.
- Operations require segregated waste disposal and use of weather shielding; however, costs calculated here do not include costs for segregation. (Waste segregation alternative is automatically triggered and costs included when decontainerized alternative is implemented in computer programs).

CAPITAL COSTS:

1. Add 10 atmospheric samplers @ $900	$ 9,000
2. Increase health physics/security building by 8,000 ft² @ $45/ft²	$ 360,000
3. Increase garage by 1,000 ft² @ $25/ft²	$ 25,000
4. Increase warehouse by 1,000 ft² @ $25/ft²	$ 25,000
5. Construct additional storage area covering 6,000 ft² @ $20/ft²	$ 120,000
6. Increase waste activities building by 6,025 ft² @ $50/ft²	$ 301,250
	$ 840,250
Engineering and Design	$ 84,025
	$ 924,275

ADDITIONAL OPERATIONAL COSTS

A. Additional Construction Materials $ 0

B. Additional Personnel

6-Radiation safety technicians @ $15,000	$ 90,000
6-Heavy equipment operators @ $21,000	$ 126,000
12-Semiskilled laborers @ $15,000	$ 180,000
25-Unskilled laborers @ $10,000	$ 250,000
2-Quality assurance technicians @ $14,000	$ 28,000
	$ 679,000
Fringe:	$ 67,400
Overhead:	$ 370,700
	$ 1,112,100
x 20 yrs	$22,242,000

Table F.23 (continued)

C.	Additional Consumables	$ 1,348,000
D.	Additional Equipment	
	1-four wheel drive vehicle for 240 months @ $800/mo	$ 192,000
	1-pickup for 240 months @ $750/mo	180,000
	2-forklifts for 240 months @ $1,000/mo	480,000
	1-crawler tractor for 240 months @ $4,200/mo	1,008,000
	1-vibratory compactor for 240 months @ $1,950/mo	468,000
	1-farm tractor for 240 months @ $2,100/mo	504,000
	1-onsite transport vehicle 240 months @$2,100/mo	504,000
		$ 3,336,000
E.	Additional Monitoring	
	500 offsite sample analyses per year @ $50/analysis x 20 years	$ 500,000
	Total additional operational costs:	$27,426,000

Unit Differential Costs

$$\frac{10.38\ (974{,}275) + 1.56(27{,}426{,}000)}{560{,}000} \equiv \frac{52{,}378{,}535}{560{,}000}$$

$$= \$\ 93.53/m^3 = \$2.65/ft^3$$

Table F-24. Differential Costs for In-Situ Dynamic Compaction of Compressible Waste

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Assumptions:

- o Costs based upon dynamic consolidation of trenches containing unstable wastes, or 1,000,000 m^3, if no waste segregation is performed.
- o Dynamic consolidation costs calculated if performed by outside firm under contract.
- o Compacted area = Vol/(EMP x EFF) = 312,500 m^2, where EMP = 0.5 and EFF = 6.4.
- o Disposal area (347,222 m^2) requires additional clayey cover averaging 3 meters thick.

CAPITAL COSTS

Add 10 atmospheric samplers @ $900	$ 9,000
Engineering and Design:	$ 900
	$ 9,900

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

1. Additional Clay Soil 3m x 347, 222 m^2=1,041,666 m^3 = 1,362,499 yd^3 1,362,499 yd^3 @ $3.50/$yd^3$	$ 4,768,747
2. Standpipes Repair one standpipe/trench 58 trenches @ $223.5/trench	$ 12,963

B. Dynamic Compaction Costs

1. Dynamic consolidation @ $6.50/$m^2$ 312,500 m^2 x $6.50/$m^2$	$ 2,031,250
2. Install new fill and compact, move, spread, and backfill earth into trenches, plus compaction of 1,362,499 yd^3 at approximately $2.00/$yd^3$	$ 2,724,998

Table F-24 (continued)

C.	Additional Personnel		
	2-radiation safety technicians @ $15,000		$ 30,000
	1-quality assurance technician @ $14,000		14,000
			$ 44,000
		Fringe:	4,400
		Overhead:	24,200
			$ 72,600
		x 20 yrs	$ 1,452,000
D.	Additional Consumables		$ 88,000
E.	Additional Equipment		0
F.	Additional Monitoring		
	500 offsite sample analyses @ $50/analysis x 20 yrs		$ 500,000
	Total additional operational costs:		$11,577,958

Unit Differential Costs

$$\frac{10.38(9{,}900) + 1.56(11{,}577{,}958)}{1{,}000{,}000} = \frac{18{,}164{,}376}{1{,}000{,}000}$$

$$= \$18.16/m^3 \ (\$0.51/ft^3)$$

Cost per unit disposal area = $\$6.31/m^2$

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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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- inadvertent intrusion
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- waste form
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