TableCalculator: a Transparent Public Tool to Replicate US NRC LLW Classification Table Calculations – 19395

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ABSTRACT

Classification of Low-Level Waste (LLW) as Class A, B, C, or Greater than Class C (GTCC) is based on tables provided in Section 61.55 of Title 10 of the *Code of Federal Regulations* (CFR). Those tables were developed from model projections of dose to an inadvertent intruder in agricultural and construction scenarios at different times after closure of a LLW land disposal site. The calculations were performed with two FORTRAN codes, which are documented in US NRC guidance documents published in the early 1980s. Although the equations and parameter values used in the codes are publicly available, no modern, user-friendly implementation of the codes is known to US NRC staff.

Because Very Low-Level Waste (VLLW) and GTCC waste disposal are related to the low end and high end of the existing LLW waste classifications, respectively, recent interest in options for disposal of VLLW and GTCC waste have generated public interest in the original assumptions made during the development of the LLW classification tables. Certain stakeholder analyses have recommended alternatives to the existing LLW concentration limits by calculating a projected intruder dose under different conditions than were evaluated in the original development of 10 CFR Part 61 (e.g., using more modern dosimetry or assuming deeper disposal) and comparing the radionuclide concentrations that result in a projected annual dose of 5 milliSieverts (mSv) (500 millirem (mrem)) total effective dose equivalent (TEDE) to the concentrations in the waste classification tables. However, beginning with the 10 CFR Part 61 LLW classification limits and modifying only one or two assumptions to generate a proposed concentration limit could lead to misleading results without a thorough analysis of whether other assumptions made in the original development of the waste classification tables remain valid. In particular, the US NRC made adjustments to the 10 CFR 61.55 table values during the rulemaking process based on qualitative considerations. Those adjustments mean that many of the values in the final tables cannot simply be assumed to quantitatively represent a 5 mSv (500 mrem) projected inadvertent intruder dose without an assessment of whether the technical bases used to develop the adjustments are applicable to the new analysis. Furthermore, the waste classification limits were based on the limiting critical organ dose rather than a TEDE. Therefore, any calculation based on the assumption that the waste classification limits correspond to 5 mSv (500 mrem) TEDE could benefit from consideration of how differences in exposure pathways could affect the limiting critical organ dose differently from the TEDE.

To facilitate a more comprehensive understanding of the calculations used to develop the waste classification tables, the US NRC staff has developed a user-friendly tool to replicate the original calculations. Results were verified against output from the FORTRAN codes and the classification table values. The tool, TableCalculator, is expected to be made publicly available and will allow the user to trace the original calculations and to observe the effects of changes in disposal assumptions and other parameter values.

INTRODUCTION

Purpose

The TableCalculator tool replicates the calculations of the FORTRAN codes that were used to support the development of the 10 CFR 61.55 tables for classifying LLW as Class A, B, C, or GTCC. The US NRC staff used those FORTRAN codes to perform a generic technical analysis in the context of rule development. The FORTRAN codes were not intended to be used to perform site-specific analyses. TableCalculator enhances the transparency of the original calculations and assumptions of the FORTRAN codes in several ways. First, implementing TableCalculator in a modern visual software tool allows users to see the relationships between steps of the calculations easily. Second, having a working implementation, as compared to a print-out of the code, allows users to quickly and efficiently test the risk significance of various assumptions made during the initial rule development in the early 1980s. Although the necessary parameters and equations are documented in US NRC guidance documents [1-4], retracing all of the effects of changing a parameter without a working implementation of the code would be impractical because identifying all of the parameter values and equations that were used, identifying which calculations were performed under various code input options, and calculating multiple matrix transformations by hand would be time-consuming and would introduce multiple opportunities for miscalculations. Finally, transparency has also been improved by documenting the meaning of the parameters used in the original FORTRAN codes in the TableCalculator tool itself, rather than in a series of separate documents, as is currently the case. The transparency developed from having a modern, object-oriented, working implementation with internal documentation is expected to be useful if the waste classification table values are used as benchmarks in discussions related to LLW classification, such as consideration of VLLW, GTCC Waste, or potential consideration of changes to the LLW classification limits themselves.

Background

The US NRC licensing requirements for land disposal of LLW are provided in 10 CFR Part 61. The analyses used to support the development of 10 CFR Part 61 in the early 1980s relied on six FORTRAN computer codes, which are documented in NUREG-0782, “Draft Environmental Impact Statement on 10 CFR Part 61 Licensing Requirements for Land Disposal of Radioactive Waste,” (DEIS) Appendix H [1]; NUREG-0945, “Final Environmental Impact Statement on 10 CFR Part 61 Licensing Requirements for Land Disposal of Radioactive Waste,” (FEIS) [2] Appendix D; NUREG/CR-1759, Vol. 3, “Data Base for Radioactive Waste Management – Impacts Analyses Methodology Report,” Section 6 and Appendix D [3]; and NUREG-0959, “User’s Guide for 10 CFR 61 Impact Analysis Codes,” [4] Appendix 1. Two of the six codes, called “DOSE” and “INVERSI,” were used to develop the radionuclide concentrations used as the class limits for Class A, B, and C LLW, which are given in Tables 1 and 2 of 10 CFR 61.55. These two codes were used sequentially. DOSE was run first to generate pathway dose conversion factors (PDCFs) that each converted radionuclide concentrations in a single contaminated medium to critical organ doses for eight sets of exposure pathways (Table I, *infra*). After DOSE was run, INVERSI was run using the PDCFs generated by DOSE with a number of assumptions about radionuclide transport and exposure scenarios to project inadvertent intruder doses in 20 hypothetical scenarios.

Out of the 20 hypothetical scenarios, the results of five were considered as potential concentration limits for Class A, B, or C waste prior to adjustments made during the development of the waste classification tables. Characteristics of those five scenarios are given in Table II (*infra*). The remaining 15 scenarios were discussed in the DEIS but the outputs calculated by INVERSI were not considered as potential waste class limits. Those remaining 15 scenarios included accident scenarios evaluated at the time of disposal (i.e., zero years of decay), scenarios based on a concrete-reinforced disposal facility evaluated various times up to 1,002 years after disposal (i.e., 1,000 years of facility performance after a 2-year post-operational period), and groundwater and surface water contamination scenarios evaluated at various times up to thousands of years after disposal.

The US NRC staff considered the results of five scenarios as potential waste class limits because, based on the disposal requirements for each waste class, two scenarios were considered to be applicable to Class A waste, one was considered to be applicable to Class B waste, and two were considered be applicable to

Class C waste. To set the Class A limits, US NRC staff assumed that the waste was unstabilized and no intruder barrier was present. Because no intruder barrier was assumed to be present, the scenarios considered for Class A waste assumed intrusion occurred 102 years after disposal to account for a 2-year post-operational care period and 100 years of institutional controls. Two scenarios were considered: (1) acute exposure during construction and (2) chronic exposure during agriculture (i.e., the UNSI-CON and UNSI-AGR scenarios, respectively, in Table II).

TABLE I. Description of Pathway Dose Conversion Factors Generated by the DOSE Code (Adapted from NUREG-0782, Vol. 4, Figure G.3) [1].

PDCF	Contaminated Medium	Description
1	Air	Inhalation, direct radiation from submersion in air, and direct radiation from radionuclides deposited on the ground
2	Air	Inhalation, direct radiation from contaminated air, and ingestion of food contaminated by non-equilibrium deposition of airborne particles
3	Air	Inhalation, direct radiation from contaminated air, and ingestion of food contaminated by equilibrium deposition of airborne particles
4	Soil	Ingestion of food contaminated by uptake from contaminated soil (including animal pathways)
5	Soil	Direct radiation from a volumetric soil source
6	Well Water	Ingestion of contaminated well water, ingestion of food contaminated through irrigation, inhalation, direct radiation from an area source, and direct radiation from submersion in contaminated air
7	Surface Water	The exposure pathways are the same as the exposure pathways for PDCF 6 except fish and seafood ingestion are included
8	Air	Inhalation, direct radiation from radionuclides deposited on the ground, direct radiation from submersion in air, and ingestion of food contaminated by deposition from air

For Class B waste, intrusion was also assumed to occur at 102 years after disposal. However, because Class B waste was assumed to be stabilized, the intruder was assumed to recognize the waste and therefore to be exposed for only 6 hours. This scenario is therefore also referred to as a “discovery” scenario (i.e., the STAI-CON scenario in Table II) because the US NRC assumed the intruder would only be exposed until he “discovered” the waste. Agricultural scenarios were assumed to be inapplicable for Class B waste because the intruder was assumed to recognize the waste before agriculture could occur. Class B limits were developed for only three radionuclides (i.e., Ni-63, Sr-90, Cs-137) because, for most radionuclides, the Class C limits were more limiting due to the longer assumed exposure time (see Table 7.1 of Vol. 2 of the DEIS [1]).

For Class C waste, intrusion was assumed to occur 502 years after disposal to account for a 2-year post-operational period and the 10 CFR 61.52(a)(2) requirement that Class C waste be disposed of either with an intrusion barrier that would deter intruders for 500 years or at sufficient depth to make an excavation scenario very unlikely. In addition, any waste stabilization was assumed to have deteriorated by the end of the 502-year period. Therefore, for Class C waste, the two scenarios considered (i.e., GEN5-CON and

GEN5-AGR scenarios in Table II) were the same as the scenarios considered for Class A waste except for the later intrusion time.

TABLE II. Key features of the 5 INVERSI scenarios for which the results were considered as potential initial values (i.e., prior to adjustments) for the concentration limits in the 10 CFR 61.55 waste classification tables.

Scenario and INVERSI designation	Credit for Waste Stabilization	Credit for Layered Disposal	Credit for Intrusion Barrier or 5 meters or deeper disposal depth	PDCFs Used (media)	Decay Time (years) (includes 2-year post-operational period)	Applicable Waste Class and radionuclides
Agriculture UNSI-AGR	No	No	No	3 (air) 4 (soil) 5 (soil)	102	Class A H-3, C-14, Fe-55, Ni-59, Co-60, Ni-63, Nb-94, Sr-90, Tc-99, I-129, Cs-135, and Cs-137
Construction UNSI-CON	No	No	No	2 (air) 5 (soil)	102	Class A U-235, U-238, Np-237, Pu-238, Pu-239/240, Pu-241, Pu-242, Am-241, Am-243, Cm-243, Cm-244
Construction (Discovery) STAI-CON	Yes	No	No	2 (air) 5 (soil)	102	Class B Ni-63, Sr-90, Cs-137
Agriculture GEN5-AGR	No (fails prior to intrusion)	No	Yes	3 (air) 4 (soil) 5 (soil)	502	Class C H-3, C-14, Fe-55, Ni-59, Co-60, Ni-63, Nb-94, Sr-90, Tc-99, I-129, Cs-135, and Cs-137
Construction GEN5-CON	No (fails prior to intrusion)	No	Yes	2 (air) 5 (soil)	502	Class C U-235, U-238, Np-237, Pu-238, Pu-239/240, Pu-241, Pu-242, Am-241, Am-243, Cm-243, Cm-244

As explained in the DEIS [1] and FEIS [2], the concentrations generated by DOSE and INVERSI underwent several modifications before being used as the concentrations in the waste classification tables. Those adjustments are explained in Table III.

TABLE III. Adjustments made to the concentration limits calculated by INVERSI during the original 10 CFR 61 rulemaking process.

Adjustment	Reason	Reference
Class A Cs-137 increased by a factor of 22	Cs-137 in Class A waste was expected to be mixed with waste with a lower Cs-137 concentration. This effect was expected to be greater for Class A waste than for Class B or C waste.	NUREG-0782 [1] Vol. 2 page 7-13
Class B Cs-137 increased by a factor of 10	Class B waste contaminated with Cs-137 was expected to be mixed with waste with a lower Cs-137 concentration.	NUREG-0782 [1] Vol. 2 page 7-13
Class C Cs-137 increased by a factor of 10	Class C waste contaminated with Cs-137 was expected to be mixed with waste with a lower Cs-137 concentration.	NUREG-0782 [1] Vol. 2 page 7-13
Class C limits other than Cs-137 all raised by a factor of 10	Three reasons were given: 1) low probability of intrusion, 2) inaccessibility of Class C waste, and 3) mixing of waste at the Class C limit with Class C waste below the Class C limit.	NUREG-0945 [2] Vol. 1 page 5-33 and NUREG-0945 Vol. 2 page S-21
All limits for C-14, Ni-59, Ni-63, and Nb-94 in metals raised by a factor of 10	Limits were increased to account for inaccessibility of the radionuclides in metallic waste.	NUREG-0782 [1] Vol. 2 page 7-9
Class A and C limits for alpha-emitting transuranic radionuclides with half-lives greater than 5 years	Additional calculations accounted for progeny ingrowth and additional radionuclides. After consideration of the additional results, the US NRC determined that a combined limit for all alpha-emitting transuranic radionuclides with a half-life greater than five years would be protective and simpler to implement than individual limits.	NUREG-0945 [2] Vol. 4 pages C-134 to C-138
Class A and C limits for Pu-241	Rather than using the limit calculated based on Pu-241, the limit was chosen based on ingrowth of Am-241 to 10 nCi/g (Class A) and 100 nCi/g (Class C).	NUREG-0782 [1] Vol. 2 page 7-16 and NUREG-0945 Vol. 3 page D-5
Class A and C limits for Cm-242	Limits for Cm-242 were not calculated during the development of the DEIS. Limits were calculated during the development of the FEIS based on ingrowth of Pu-238 to 10 nCi/g (Class A) and 100 nCi/g (Class C).	NUREG-0945 [2] Vol. 3 Appendix F page 43

Unlike DOSE, which was run with one set of input values, INVERSI accepted user input to specify certain assumed characteristics of the wasteform, disposal facility, and site. The “base case” set of those input values was used in INVERSI as the first step in generating the values underlying the concentrations in the waste classification tables (Table IV).

TABLE IV. INVERSI user inputs and base case values (based on page 22 of NUREG-0959 [4])

Parameter	Valid Values	Base Case
Region	1 = northeast, 2 = southeast, 3 = midwest, 4 = southwest, 5 = southeast with clay, 6 = southeast with sandy soil	2
Design	1 = "regular" shallow trench, 2 = concrete-walled trenches	1
Cover	1 = regular, 2 = thick, 3 = intruder barrier	1
Stabilization	1 = no special procedures, 2 = moderate, 3 = extensive	1
Emplacement	1 = random, 2 = stacked, 3 = decontainerized, 4 = random with sand backfill, 5 = stacked with sand backfill	1
Segregation	0 = no segregation, 1 = segregation	0
Layering	0 = false, 1 = true	0
Grouting between packages	0 = false, 1 = true	0
Hot waste facility	0 = false, 1 = true	0
Closure and post-operational care level	11 = 2 year modest closure with low care, 12 = 2 year modest closure with modest care, 13 = 2 year modest closure with high care, 21 = 4 year complete site re-stabilization with low care, 22 = 4 year complete site re-stabilization with moderate care, 23 = 4 year complete site re-stabilization with high care	13
Post-operational period	number of years between cessation of disposal of waste and transfer of title to site owner ranging from either 2 or 4 years at a minimum to 99 years as a maximum (minimum depends on post-operational care level)	2
Institutional control period	number of years between transfer of title to site owner and the assumed loss of institutional controls, ranging from 0 to 999 years	100
Credit for wasteform	0 = no credit, 1 = credit	0
Flammability	0 = non-flammable, 1 = low flammability, 2 = burns if heat supplied, 3 = flammable	3
Dispersibility	0 = near zero, 1 = light to moderate, 2 = moderate, 3 = severe	2
Leachability	1 = unsolidified, 2 = type A solidification, 3 = type B solidification, 4 = type C solidification	1
Chemical content	0 = no chelating agents or organic chemicals, 1 = chelating agents or organic chemicals	0
Stability	0 = unstable, 1 = stable	0
Accessibility	1 = readily accessible, 2 = moderately accessible, 3 = accessible with difficulty	1

DESCRIPTION OF TOOL

Overview

TableCalculator is implemented as a "Player" file created with the GoldSim®[a] modeling platform [5]. The file is expected to be made publicly available and can be run with a free GoldSim® player application. Figure 1 shows the introductory screen and main menu of the TableCalculator tool.

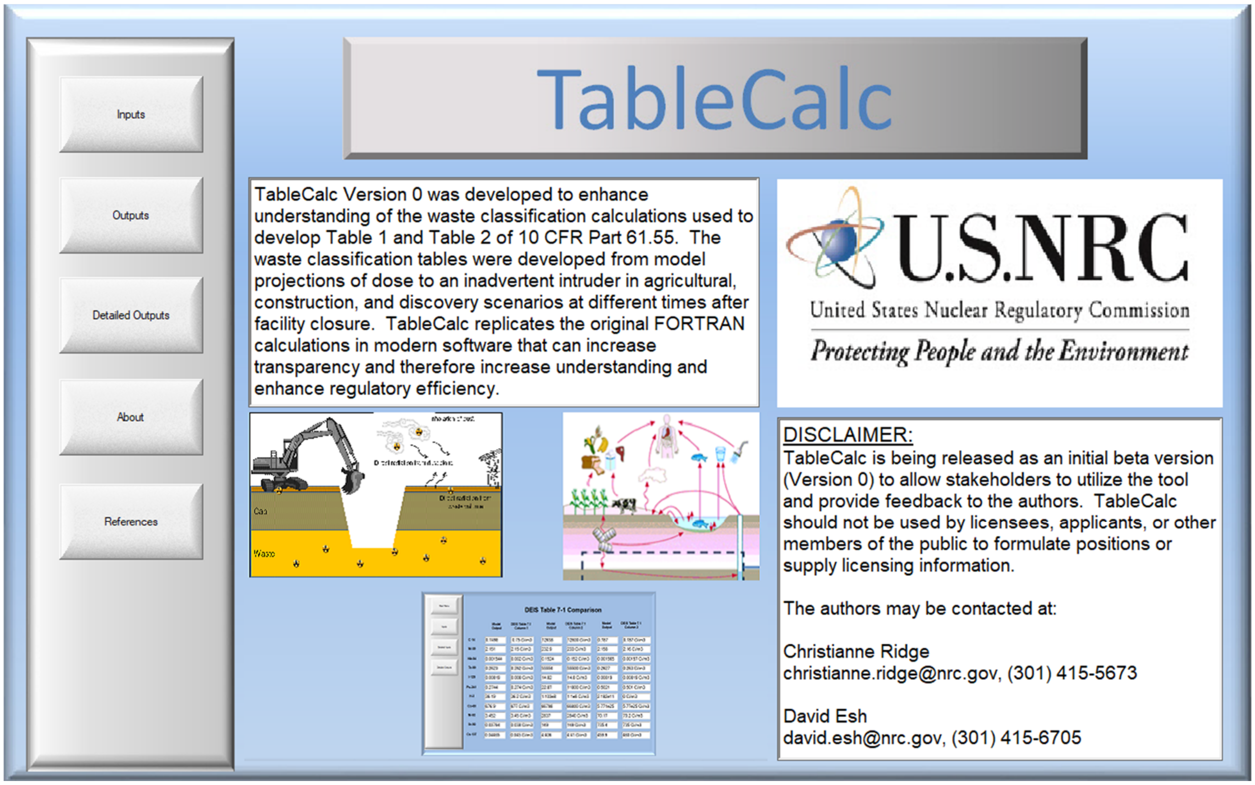

Figure 1. Introductory screen and main menu of the TableCalculator tool

Figure 2 shows an overview of a calculation of dose contributions for a construction scenario. As in the original FORTRAN codes, the PDCFs generated by the DOSE calculations are used by the implementation of the INVERSI calculations to calculate concentrations that would limit the dose to critical organs to their respective dose limiting criteria for each radionuclide in 20 hypothesized exposure scenarios.

The original DOSE code used dose conversion factors (DCFs) for inhalation, ingestion, and external exposure with a number of assumptions about consumption factors to generate the PDCFs. The DCFs used in the original DOSE and INVERSI calculations were based on the recommendations in International Commission on Radiological Protection Publication 2 (ICRP-2). Therefore, each of the resulting 8 PDCFs was a matrix of values for 39 radionuclides and the seven ICRP-2 organs (i.e., total body, bone, liver, thyroid, kidney, lung, gastrointestinal tract/lower large intestine (GI-LLI)).

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[a] GoldSim is a registered trademark of GoldSim Technology Group LLC in the United States and/or other countries.

TableCalculator offers simplified and detailed outputs. The simplified output provides the concentration results based on the most limiting critical organ dose and limiting scenario for the subset of scenarios originally considered as the bases for the Class A, B, and C limits. For the base case parameter values, the tool output matches the DEIS values (Figure 3). The detailed output dashboard provides options to view outputs for additional radionuclides, additional scenarios, and additional organs.

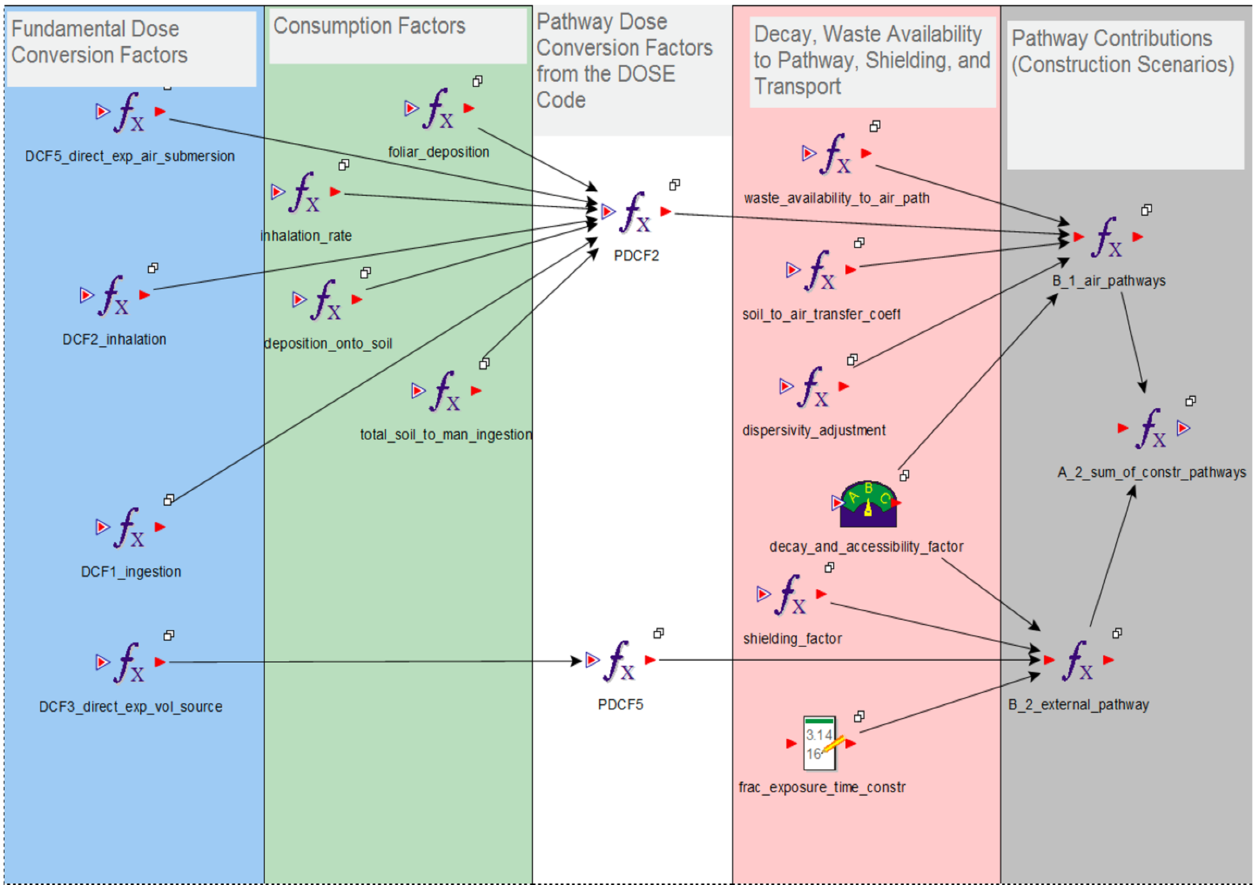

Figure 2. Example of a screen within the TableCalculator tool showing the calculation of dose contributions for a construction scenario

Tool Features

As described in the purpose statement, one of the goals of TableCalculator is to allow users to quickly and efficiently evaluate the significance of various assumptions made during the initial rule development in the early 1980s. That goal is accomplished by allowing the user to edit many of the parameter values used in the code and evaluate the effect on the resulting limiting concentrations. In addition to allowing users to test the effects of different assumptions about other wasteform, facility, and site characteristics in the framework of the original calculations, the tool provides for two other types of comparisons: (1) demonstrating the effects of using more modern dosimetry and (2) demonstrating the effects of discrepancies found in the original code.

Allowing the user to easily see the effects of choosing alternative dosimetry was one of the original goals of re-implementing the codes because it has been an area of interest for stakeholders. The calculations underlying the waste classification tables and the performance objectives in Subpart C of 10 CFR Part 61 are based on ICRP-2 recommendations, which includes dose limits for certain critical organs but does not provide weighting factors to combine the organ doses. Such weighting factors were developed as part of the ICRP Publication 26 (ICRP-26) methodology, as was the concept of the effective dose equivalent (EDE). Later, the US NRC created the term, "Total Effective Dose Equivalent" (TEDE), which adds the external dose to the weighted sum of organ doses (i.e., EDE).

DEIS Table 7-1 Comparison

	Model Output	DEIS Table 7.1 Column 1	Model Output	DEIS Table 7.1 Column 2	Model Output	DEIS Table 7.1 Column 3
C-14	0.7498	0.75 Ci/m3	12638	12600 Ci/m	0.787	0.787 Ci/m
Ni-59	2.151	2.15 Ci/m3	232.9	233 Ci/m3	2.158	2.16 Ci/m3
Nb-94	0.001544	0.002 Ci/m	0.1524	0.152 Ci/m	0.001565	0.00157 Ci
Tc-99	0.2623	0.262 Ci/m	55554	55500 Ci/m	0.2627	0.263 Ci/m
I-129	0.00819	0.008 Ci/m	14.82	14.8 Ci/m3	0.00819	0.00819 Ci
Pu-241	0.2744	0.274 Ci/m	22.87	11800 Ci/m	0.5021	0.501 Ci/m
H-3	36.19	36.2 Ci/m3	1.103e8	1.1e8 Ci/m	2.182e11	0 Ci/m3
Co-60	676.9	677 Ci/m3	66798	66800 Ci/m	5.771e25	5.77e25 Ci
Ni-63	3.452	3.45 Ci/m3	2837	2840 Ci/m3	70.17	70.2 Ci/m3
Sr-90	0.03764	0.038 Ci/m	149	149 Ci/m3	735.4	735 Ci/m3
Cs-137	0.04465	0.045 Ci/m	4.406	4.41 Ci/m3	459.9	460 Ci/m3

Figure 3. Example TableCalculator output screen. Additional detailed output screens provide results for additional radionuclides, additional scenarios, and additional organs.

Proposals to update the waste classification tables have been, at least partly, based on the suggested use of more modern DCFs and associated dose limits [6, 7]. The US NRC updated its radiation protection regulations in 10 CFR Part 20 to align more closely with the recommendations of ICRP-26 in 1991 (*Volume 56 of the Federal Register, page 23360* (56 FR 23360; May 21, 1991)). In Staff Requirements Memorandum, SECY-05-0073, "Implementation of New US NRC Responsibilities Under the National Defense Authorization Act of 2005 in Reviewing Waste Determinations for the US DOE," (SRM-SECY-05-0073) [8], the Commission directed the staff to allow the use of ICRP-26 (consistent with current 10 CFR Part 20 methodology) and imposed a 0.25 mSv (25 mrem) TEDE dose limit for a member of the public (i.e., instead of the organ doses listed in 10 CFR 61.41) in US NRC staff reviews of disposal of waste incidental to reprocessing.[b] In that SRM, the Commission also instructed the staff to allow the US DOE to use more modern dosimetry methodologies for calculating TEDE. More recently, that flexibility

[b] "Waste incidental to reprocessing" is US DOE waste that is managed as LLW. Under the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA) Section 3116(b), the US NRC, in conjunction with the appropriate state authority, monitors certain disposal actions related to waste incidental to reprocessing to assess compliance with the performance objectives in 10 CFR Part 61.

and the change of the dose limit for the 10 CFR 61.41 performance objective have been incorporated into the proposed rule for 10 CFR Part 61.

TableCalculator is expected to allow the user to view the effect of changing dosimetry by selecting the original dosimetry, which was based on ICRP-2 recommendations, or more modern dosimetry, based on Federal Guidance Reports (FGRs) 11 through 13 and 15 [9-12]. The original dosimetry used dose limiting criteria of 5 mSv (500 mrem) for the total body or bone, 15 mSv (1500 mrem) for the liver, kidney, lung, or gastrointestinal tract/lower large intestine, and 30 mSv (3000 mrem) for the thyroid. To calculate limiting concentrations from projected doses using more modern dosimetry, TableCalculator assumes a dose limiting criterion of 5 mSv (500 mrem) TEDE.

TableCalculator also addresses discrepancies discovered between the documentation of the original calculations and the FORTRAN codes, as well as apparent discrepancies within the codes themselves. The majority of the discrepancies involved differences between the equations as implemented in the original FORTRAN codes and the corresponding documentation. For example, Table B-12 of NUREG/CR-1759 Vol. 3 indicates that PDCF 1 is the sum of intermediate equations 6 and 9 in that table. However, the INVERSI code implements PDCF 1 as the sum of intermediate equation 5 and 9 in that table. PDCF 1 is only used in the single container accident and fire scenarios, which did not directly affect the waste classification tables. However, if the tool is used to benchmark how alternative scenarios would have been considered at the time the tables were developed, the difference between the version of the equation in Table B-12 of NUREG/CR-1759 Vol. 3 [3] and the implementation in INVERSI may be of interest.

In other cases, there appeared to be discrepancies in the original code itself. For example, the calculations of the soil-to-plant-to-man and total-plant-to-man transfer factors in the DOSE code appeared to sum factors that were given on a per year and per day basis without adjusting the units to match. TableCalculator provides the user the option to use values corrected for the unit mismatch or to use the calculations as originally programed. Allowing the user to switch between the corrected and uncorrected version quickly demonstrates the effects of this discrepancy. Internal documentation of the tool (e.g., embedded comments and programming element descriptions) notes any areas where the equations or parameter used appear to be internally inconsistent or where the FORTRAN code did not exactly match the corresponding description in the documentation.

Tool Verification

References existed to verify outputs of both the DOSE and INVERSI codes [1-4]. The DOSE code was originally run with one set of input values and output eight PDCFs. Each of those PDCFs was a matrix of results for 7 organs and 39 radionuclides. Of those 39 radionuclides, 23 were included in the INVERSI code. The US NRC staff verified the PDCF values generated by TableCalculator for those 23 radionuclides by comparing them to the data file (called "NUCS") that was used as input to the INVERSI code. For those radionuclides, the PDCF values calculated by TableCalculator match the values in the NUCS data file[c] listed in both NUREG-0782, Vol. 4, Appendix H [1] and NUREG/CR-1759, Vol. 3, Appendix D [3]. As explained in the FIES [2] (NUREG-0945, Vol. 3, Appendix C, Section 5.4 and

[c] PDCF values for some radionuclides included in the NUCS data file are different from the values reported in NUREG/CR-1759, Vol. 3, Tables 2-4 through 2-11 [3] and the NUREG-0782, Vol. 4, Tables G.3 through G.10 [1] because of updates to the calculations after those tables were created. The values reported in the NUCS data file in NUREG-0784, Vol. 4 and NUREG/CR-1759, Vol. 3 reflect the updated values and are consistent with the PDCFs reported in the FEIS [2] (NUREG-0945, Vol. 3, Tables C-48 to C-53), with the exception of the PDCF 1 value for the bone dose for Am-243, which appears to be a typographical error in Table C.48 of the FEIS [2]. PDCF 1 did not directly affect the 10 CFR 61.55 waste classification limits.

Appendix D), additional PDCFs were calculated after the DEIS [1] was issued for 13 radionuclides that are part of heavy metal decay chains. Although concentration outputs for those radionuclides did not directly affect the 10 CFR 61.55 waste classification tables, TableCalculator will include PDCF values for those radionuclides. Those PDCF values will be verified by comparison to FEIS [2] (NUREG-0945, Vol. 3) Tables C.48 through C.55.

TableCalculator radionuclide concentration outputs, which corresponded to outputs of the INVERSI code, were verified by comparison to the base case outputs for all 20 scenarios considered in the INVERSI code, as provided in NUREG-0959, Appendix 2 [4]. Outputs for the most limiting of the organ values for each radionuclide were further checked by comparison to Table 7.1 of NUREG-0782, Vol. 2 [1]. Historical references were not available to verify INVERSI outputs for values of the input parameters that differed from the base case. Because independent verification with a historical reference was not available, the implementation of input flags different from the base case was checked by a staff member who was not involved with the original implementation of the tool. Unit conversions are automatically accounted for in the GoldSim® modeling platform.

DISCUSSION

Recent interest in options for the disposal of VLLW and GTCC waste has led to discussions of the original assumptions underlying the development of the US NRC regulations for near-surface LLW disposal and the applicability of those assumptions to modern disposal facilities and potential alternative types of sites. The classification limits for Class A, B, and C waste are often used as benchmarks in those discussions.

Both the US NRC staff and stakeholders sometimes refer to the concentration limits in the waste classification tables as representing a 5 mSv (500 mrem) dose (see, e.g., NUREG-1854, Appendix B [13] and 59 FR 17052; April 11, 1994 [14]). Having a working implementation of the code helps clarify some of the complexities of that simplified characterization. In particular, a working implementation of the code clarifies exactly what the calculated concentration limits were and where adjustments were made during the original development of the waste classification tables (Table III, *supra*). To use the waste classification limits as benchmarks of intruder risk in certain stylized scenarios, it is necessary to understand the bases for those adjustments, evaluate whether they are applicable, and determine whether they have already been credited to avoid double-counting. For example, the Class C limits were raised by a factor of 10 based on stakeholder comments after the draft proposed rule was published in the early 1980s. Based on the description of that adjustment in the FEIS [2] (see pages S-21 and 5-33), another way to conceive of the Class C limits in 10 CFR 61.55 is that the concentrations would result in critical organ doses that were a factor of 10 greater than the original dose limiting criteria (e.g., 50 mSv (5 rem) bone or whole body dose) with a 10 percent chance of occurrence.

For doses that are in the range of stochastic effects, an argument can be made for the similarity of a 5 mSv (500 mrem) dose and a 50 mSv (5 rem) dose with a 10 percent chance of occurrence. That similarity may be assumed in “inverse” or “back” calculations in which adjustments to the classification limits are proposed based on a comparison of the radionuclide concentrations that result in a projected annual dose of 5 mSv (500 mrem) TEDE in a more modern assessment (e.g., using more modern dosimetry or assuming deeper disposal) with the concentrations in the waste classification tables. However, in that type of inverse calculation, may not be appropriate to assume that the waste classification concentration limits correspond to a dose of 5 mSv (500 mrem) if the assumptions underlying the development of the class limits are not applicable to the situation under consideration. For example, it would be conceptually inconsistent to assume that the Part 61 Class A limit for Cs-137 corresponds to 5 mSv (500 mrem) whole body dose if a large volume of waste is likely to be present at the Class A limit because the assumption that the waste would be mixed with lower activity waste was one of the reasons for applying a factor of

22 to the calculated concentration value (Table III). Similarly, it would be conceptually inconsistent to assume the Part 61 Class C limits correspond to a TEDE of 5 mSv (500 mrem) if the more modern analysis takes credit for the inaccessibility of the waste or low probability of intrusion because that would effectively double-count the credit. One of the goals of re-implementing the codes used in the original development of the waste classification tables is to improve the transparency of all of the calculations, assumptions, and qualitative considerations underlying the 10 CFR 61.55 waste classification table limits for US NRC staff and stakeholders so that any inapplicable assumptions can be avoided in future calculations based on those limits

In addition, because the calculations supporting the classification limits were performed with dosimetry that was based on ICRP-2 recommendations, the concentration limits were set based on the most limiting critical organ dose. In the *Federal Register* (FR) Notice for the Proposed Rule for Disposal of High-Level Radioactive Wastes in a Proposed Geological Repository at Yucca Mountain, Nevada (64 FR 8640; Feb. 22, 1999), the US NRC states:

> "As a matter of policy, [the US] NRC considers 0.25 mSv (25 mrem) TEDE as the appropriate dose limit within the range of potential doses represented by the current 10 CFR 72.104 limit of 0.25 mSv (25 mrem) (whole body), 0.75 mSv (75 mrem) (thyroid dose), and 0.25 mSv (25 mrem) (to any other critical organ)."

Although the Commission policy, as expressed in 64 FR 8640, was to treat a TEDE dose as roughly equivalent to the same dose to the whole body using the older dosimetry, to evaluate the sensitivity of the waste classification calculations to changes in dosimetry it is useful to consider which organ dose was limiting in the original calculation. For most radionuclides in most of the scenarios that were considered, the limiting criterion was 5 mSv (500 mrem) to the bone. Doses of 15 mSv (1500 mrem) to the lung were the next most frequently limiting constraint, followed by 5 mSv (500 mrem) to the total body. Having a working implementation of the code clarifies which organ doses were limiting for each radionuclide in each scenario. This working implementation also simplifies the process of determining how the identity of the limiting organ and the value of the limiting organ dose could change if other parameters in the calculation change.

Transparency has also been improved by documenting the meaning of the parameters used in the original FORTRAN codes in the TableCalculator tool itself rather than a separate document. One important aspect of this documentation was to clarify the link between the parameter values used in the code and the conceptual discussions in the existing documentation. For example, NUREG-0782 [1] describes that the exposure duration for construction scenarios is 500 hours unless the waste is stabilized, in which case the US NRC assumed the intruder would be exposed for only 6 hours before the intruder recognized the waste and ended the exposure (i.e., also called a "discovery" scenario [1-2]). The original FORTRAN code implements that discovery scenario by including a factor of 0.012 (i.e., 6 hours / 500 hours) for stabilized waste construction scenarios in one of the intermediate parameters used to calculate the projected dose in that scenario. However, no comment in the original code explains the purpose of the factor of 0.012, and no description in the text explains which intermediate parameter implements the adjustment for the change in duration. The reader would need to map the factors in each intermediate parameter and be thoroughly familiar with both scenarios to understand the origin of that factor of 0.012 in the FORTRAN code. The same is true of multiple parameters and factors applied in the code. TableCalculator improves transparency by explaining the meaning of each parameter in the code itself and supplying references to the original documentation.

In some cases, explicit assignments of the meanings of parameters were not provided in the documentation and the staff has made its best judgement in documenting the meaning of parameter values. For example, comparison of the descriptions of PDCF 2 and PDCF 3 in the DEIS and supporting references show that the only difference between the modeled pathways are that PDCF 2 is based on an acute scenario in which deposition of radionuclides from air onto plants and soil is not expected to reach equilibrium, whereas PDCF 3 is based on a chronic scenario in which deposition is assumed to reach equilibrium. The description of PDCF 3 indicates that a factor was applied to the plant and soil uptake pathways to account for non-equilibrium deposition but does not document what value was used for that factor. However, comparison of the equations used to calculate PDCF 2 and PDCF 3 indicate that the factor appears to be a factor of 0.242, which is applied only to pathways affected by deposition from air in the calculation of PDCF 3. Although this type of assignment does create the potential for errors, confidence is provided by the ultimate match of the TableCalculator output with the test output provided in NUREG-0959 [4] for all 20 scenarios evaluated by INVERSI. In addition, in those cases, references are given to specific sections of the DEIS or other associated documents that informed the staff's description of the parameter value so that the user is alerted when the staff has applied judgement in assigning meaning to a parameter value and user can make an independent conclusion. Transparency was greatly improved by this effort because this documentation has been provided directly in the TableCalculator tool itself in the equation objects where the parameter values are used, instead of in a separate document. Therefore, users of TableCalculator would not need to map parameter values to text descriptions in supporting references as is currently necessary for the DOSE and INVERSI codes.

Documenting the meaning of parameter values directly in the code is also useful because it helps the user more clearly see only the calculations that were used to support the development of the waste classification tables rather than the much larger set of assumptions and calculations used to support the entire set of issues considered in the DEIS and FEIS for 10 CFR 61 (e.g., cost-benefit analyses). For example, Section 3.5 of Appendix G of NUREG-0782 [1] describes ground-water scenarios and Figure G.6 in that section provides locations of the individual well, boundary well, population well, and surface water access location. Those well locations were considered in some of the analyses used to support the DEIS; however, the groundwater scenarios were not used directly in the development of the concentration limits in 10 CFR 61.55. In some cases, an incomplete reading of the documentation could lead to incorrect conclusions. For example, although a "well-water" PDCF is calculated by DOSE, that PDCF is not used by INVERSI and was not used directly in the development of the waste classification limits in 10 CFR 61.55. That result is clearer in the TableCalculator tool than it was in the original FORTRAN code because TableCalculator was developed with a modern object-oriented modeling platform which makes it visually clear that the well-water PDCF does not connect to other objects in the code.

CONCLUSIONS

The FORTRAN codes that were used to support the development of the 10 CFR Part 61 waste classification tables were created to perform a generic technical analysis in the context of rule development and were not intended to be used to perform site-specific analyses. Furthermore, the computational resources available to conduct inadvertent intruder analyses have advanced considerably since the DOSE and INVERSI codes were first implemented, and more modern resources are now available to develop more sophisticated intrusion analyses. However, the waste classification limits for Class A, B, and C LLW are still used as benchmarks in discussions related to LLW classification, such as consideration of VLLW, GTCC, or potential consideration of changes to the LLW classification limits themselves. To facilitate a more comprehensive understanding of the calculations used to develop the waste classification tables and the assumptions underlying the LLW classification limits in 10 CFR Part 61, the US NRC staff developed a user-friendly tool to replicate the original calculations.

The goal of re-implementing the original codes is to make the original calculations and underlying assumptions transparent and to provide a tool that would let the user easily test the effects of alternative assumptions. By allowing users to alter parameter values, TableCalculator allows users to quickly and efficiently test the risk significance of various assumptions made during the initial rule development in the early 1980s. In addition to allowing users to test the effects of different assumptions about other wasteform, facility, and site characteristics in the framework of the original calculations, the tool illustrates the effects of discrepancies found in the original code and demonstrates the effects of using more modern dosimetry on the calculated limiting radionuclide concentrations. Transparency was developed from having a modern, object-oriented, working implementation with internal documentation.

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