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Dose Conversion Factor Evaluation and IMPACTS Analysis of Low Level Radioactive Waste

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Dose Conversion Factor Evaluation and IMPACTS Analysis of Low Level Radioactive Waste

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ABSTRACT

This report examines the evolution of dose conversion factors and uses the dose computation methods of the IMPACTS computer program to calculate the effect revision of these factors has on the radionuclide concentration limits in 10 CFR 61.55, part of the NRC standard for low level wastes. Changes in these limits have implications for low level radwaste disposal in the United States.

The original analysis for 10 CFR 61was completed in 1981. Since then, models of human anatomy and the biological behavior of radionuclides have been updated as additional data and improved techniques have advanced knowledge in this area. Revised dose conversion factors for the radionuclides of interest in 10 CFR 61 are included in the updates to these biological models. It is reasonable to conclude that changes in the dose conversion factors will have an effect on the results of evaluations that use methodologies that depend on dose conversion factors.

This paper examines the properties of the radionuclides of interest, changes to the dose conversion factors since 1981, and the magnitude of change to the doses in the scenarios that result from changes to dose conversion factors when modeled using the IMPACTS program.

Output from the IMPACTS program using dose conversion factors from International Commission on Radiological Protection-2 (ICRP-2), corresponding to the development of 10 CFR 61, were compared to IMPACTS program output using dose conversion factors from ICRP 26/30 and ICRP 60/72. Use of the more recent dose conversion factors with the IMPACTS program results in changes to the computed doses from the radionuclides used for waste classification. The doses have increased for some radionuclides; but for others, including many of those important to waste classification, the doses have decreased. The magnitude of the changes indicates that it is appropriate to modify the concentration limits in 10 CFR 61.55 Tables 1 and 2 to reflect the changes in the dose conversion factor (DCF) for each radionuclide.

If changes are implemented as discussed in this report, the overall effect on utility waste generation would cause a negligible change in Class A dry active waste (DAW), a reduction in Class B resins, and a potential increase in Class C cartridge filters (especially in plants with high reported C-14 activity or significant fuel defects). Improvements to the accuracy with which C-14 and transuranic radionuclide activities are developed would likely mitigate any detrimental effects on waste classification.

Keywords
Low level waste
10 CFR Part 61
Low level waste classification
Low level waste disposal

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
SUMMARY

Title 10 Code of Federal Regulations Part 61 established requirements and limits for the disposal of low level radioactive waste in shallow land disposal facilities in the United States. These limits were developed from studies of disposal site performance and theoretical radiation exposure documented in NUREG-0782, *Draft Environmental Impact Statement on 10 CFR 61 "Licensing Requirements for Land Disposal of Radioactive Waste"* and NUREG/CR-1759, *Data Base for Radioactive Waste Management*. These documents analyzed the limits for radionuclides in radioactive waste using theoretical models and the understanding of radiation dose as it was known at the time. NUREG/CR-1759, Volume 3 specifically discusses the IMPACTS methodology. The IMPACTS assessment included a comparison of the radionuclides' behavior in the disposal site environment and the resulting dose rates in specific exposure scenarios. Since this analysis was completed in 1981, the models of human anatomy and the biological behavior of radionuclides have been updated. Revised dose conversion factors for the radionuclides of interest in 10 CFR 61 are included in the updates to these biological models. The analysis that is discussed within this paper examines the properties of the radionuclides of interest, the changes to the dose conversion factors, and the magnitude of change to the doses in the scenarios modeled using the IMPACTS program due to the changes to dose conversion factors.

Output from the IMPACTS program using dose conversion factors from ICRP-2, corresponding to the development of 10 CFR 61, were compared to IMPACTS program output using dose conversion factors from ICRP 26/30 and ICRP 60/72. Use of the more recent dose conversion factors with the IMPACTS program results in changes to the computed doses from the radionuclides used for waste classification. For some radionuclides the doses have increased. Other radionuclides, including many of those important to waste classification, show a decrease in computed dose. The magnitude of the changes indicates that it is appropriate to modify the concentration limits in 10 CFR 61.55 Tables 1 and 2 to reflect the changes in the dose conversion factor (DCF) for each radionuclide.

The overall effect on utility waste generation, if changes were implemented as discussed in this report, would cause a negligible change in Class A dry active waste (DAW), a reduction in Class B resins and a potential increase in Class C Cartridge filters (especially in plants with high reported C-14 activity or significant fuel defects). Improvements to the accuracy with which C-14 and transuranic radionuclide activities are developed would likely mitigate any detrimental effects on waste classification.

2
CHARACTERISTICS OF RADIONUCLIDES IMPORTANT TO DISPOSAL

This analysis was completed to evaluate the effect of changes to radionuclide concentrations specified in Tables 1 and 2 of 10 CFR 61.55 when dose conversion factors (DCFs) used in the original analysis are compared to new research from the International Commission on Radiation Protection (ICRP). This analysis is based on the original IMPACTS calculations and methodology. The current study only modified the DCFs for the key radionuclides that affect classification, keeping all other variables constant. This approach was used, instead of trying to develop actual dose rate estimates, so that other variables, not specifically related to changes in DCFs, would not affect the comparison. Some background information on the key radionuclides and their importance in the disposal environment is provided below.

The following is a summary of the properties for the radionuclides with limits in Tables 1 and 2 of the Code of Federal Regulations Title 10, Part 61, Licensing Requirements for Land Disposal of Radioactive Waste (10 CFR 61). (1) The physical and chemical properties are presented below for the radionuclides listed in 10 CFR 61 and the commonly reported transuranics. (2) (3) The chemical properties of each element will determine the behavior of the radionuclide in the waste material, at the disposal facility, and within the environment. The physical properties determine the persistence and energy emission characteristics of the radionuclide.

H-3

In the waste matrix, hydrogen-3 (or tritium) exchanges with hydrogen in water or hydrocarbons and is expected to be principally tritiated water (HTO). Transport of tritium in the burial site environment is similarly governed. There is little to impede the exchange of tritiated water contained in the waste with groundwater. The transport is limited by the infiltration rate of rainfall into the burial site. Although hydrogen is in the alkali metal family of the periodic table, its element category is a nonmetal.

Tritium has a relatively short half-life compared to the institutional control period of the radioactive waste disposal facility. The emissions from tritium are also of low energy. The radioactive properties of tritium are summarized in Table 2-1.

Table 2-1
Hydrogen-3 Properties

Property	Value
Half-Life (years)	12.3
Emission Type	Beta
Total Frequency	1.000000
Average Energy (MeV)	0.00569
Maximum Energy (MeV)	0.01861

C-14

The carbon -14 content of solid radioactive waste is expected to be in non-volatile forms of carbon because volatile species, such as carbon dioxide (CO_2) or methane (CH_4), would be released at the point of formation. It is suspected that anion species of carbon, such as carbonates or bicarbonates, may form and be associated with metal cations in radioactive waste. It is also possible for C-14 to exchange with the carbon atoms in hydrocarbons. In the burial site, the major consideration relative to C-14 is associated with decomposition of organic materials. The basic decomposition reactions result in the formation of CO_2 under aerobic conditions and the formation of CH_4 under anaerobic conditions. The complex chemical behavior of carbon makes its content and behavior in the radioactive waste environment the subject of controversy. Although carbon is in the metalloid family of the periodic table, it is considered a nonmetal.

Carbon-14 has a long half-life relative to the institutional control period for a disposal facility, although the emission strength is low. The radioactive properties of C-14 are summarized in Table 2-2.

Table 2-2
Carbon-14 Properties

Property	Value
Half-Life (years)	5730
Emission Type	Beta
Total Frequency	1.000000
Average Energy (MeV)	0.04947
Maximum Energy (MeV)	0.1565

Co-60

Cobalt is a ferrous metal that forms bivalent ions. Transition metals in radioactive waste are expected to behave chemically as a metal oxide. As such, Co-60 is expected to be contained within waste with nuclear plant crud or similar radwaste. These materials are nickel – iron – cobalt spinels. Cobalt is a family VIII transition metal.

The half-life of cobalt-60 is relatively short in relation to the radioactive waste disposal facility institutional control period. The decay of cobalt-60 is distinguished by gamma emissions of significant energy.

Table 2-3
Cobalt-60 Properties

Property	Value			
Half-Life (years)	5.27			
Emission Type	Beta		Gamma	
Total Frequency	0.9988	0.0012	0.9985	0.9998
Average Energy (MeV)	0.09577	0.6259	1.25	
Maximum Energy (MeV)	0.3182	1.4914	1.1732	1.3325

Ni-59 and Ni-63

The behavior of nickel-59 and nickel-63 is based on their occurrence as ferrous metals of the VIII transition metal family. These radionuclides are present as bivalent ions in oxide compounds in radioactive wastes.

The half-life of both nickel-59 and nickel-63 are significant compared to the institutional control period of a radioactive waste disposal facility. The emissions associated with the decay of these radionuclides are weak. The physical properties of these radionuclides are summarized in Table 2-4.

Table 2-4
Nickel-59 and Nickel-63 Properties

Property	Value (Ni-59)	Value (Ni-63)
Half-Life (years)	7.6E4	100
Emission Type	X-ray	Beta
Total Frequency	0.196	1.00
Average Energy (MeV)		0.0174
Maximum Energy (MeV)	0.00693	0.0669

Sr-90

The behavior of strontium-90 is reflective of the alkaline earth family. Strontium is highly reactive and will form metal oxides as a component of radioactive wastes. It will also form oxides with carbon ($SrCO_3$) and sulfur ($SrSO_4$). Strontium-90 is partially soluble in the disposal facility environment.

Strontium-90 has an intermediate length half-life. While the emissions associated with the decay of strontium-90 are not distinctive, the emissions of the daughter product, yttrium-90, are intense. All are summarized in Table 2-5.

Table 2-5
Strontium-90 Properties

Property	Value (Sr-90)	Value (Y-90)
Half-Life (years)	29	0.0073
Emission Type	Beta	Beta
Total Frequency	1.000000	0.99885
Average Energy (MeV)	0.1958	0.9337
Maximum Energy (MeV)	0.546	2.28

Nb-94

Niobium is a transition element with chemical behavior similar to tantalum. It is corrosion resistant and expected to occur as an oxide (Nb_2O_5) in the radioactive waste and disposal site environment. Although niobium occurs in the +3, +4 and +5 oxidation states, the +5 is the most common.

The half-life of Nb-94 is much greater than the institutional control period of the disposal facility. It decays with the emission of a significant gamma ray. The properties of niobium-94 are summarized in Table 2-6.

Table 2-6
Niobium-94 Properties

Property	Value	
Half-Life (years)	2.0E4	
Emission Type	Beta	Gamma
Total Frequency	1.00	0.99892
Average Energy (MeV)	0.1458	
Maximum Energy (MeV)	0.4715	0.8711

Tc-99

The chemical behavior of technetium is intermediate to rhenium and manganese. It is a transition metal with oxides occurring in both the +4 and +7 states. The hexavalent state is particularly water soluble.

The half-life of technetium-99 is much longer than the institution control period of the disposal facility. The decay of technetium-99 includes a beta emission. The properties of technetium-99 are summarized in Table 2-7.

Table 2-7
Technetium-99 Properties

Property	Value	
Half-Life (years)	2.13E5	
Emission Type	Beta	Gamma
Total Frequency	0.99998	0.00065
Average Energy (MeV)	0.0846	
Maximum Energy (MeV)	0.2935	0.0895

I-129

Iodine is a halogen most commonly present as an anion. It is also expected to occur as iodomethane (methyl iodide). Iodine is expected to be mobile in the disposal facility environment.

The half-life of iodine-129 is long compared to the institutional control period of the disposal facility. As with many long lived radionuclides, the emissions associated with the decay of iodine-129 are weak. The properties of iodine-129 are summarized in Table 2-8.

Table 2-8
Iodine-129 Properties

Property	Value	
Half-Life (years)	1.6E7	
Emission Type	Beta	Gamma
Total Frequency	1.000	0.0751
Average Energy (MeV)	0.0409	
Maximum Energy (MeV)	0.154	0.03958

Cs-137

Cesium is an alkali metal with common occurrence as a cation, similar to sodium or potassium. In the +1 oxidation state, cesium is expected to be soluble and mobile in the radioactive waste matrix and disposal site environment.

Cesium has an intermediate half-life and decay is associated with a gamma of intermediate energy. The properties of cesium-137 are summarized in Table 2-9.

Table 2-9
Cesium-137 Properties

Property	Value		
Half-Life (years)	30.17		
Emission Type	Beta		Gamma
Total Frequency	0.947	0.851	0.0751
Average Energy (MeV)	0.17432		
Maximum Energy (MeV)	0.51397	0.662	0.03958

Pu-238, Pu-293, and Pu-241

Plutonium is an actinide and a transuranic. Plutonium exhibits multiple oxidation states including III, IV, V and VI. Plutonium is reactive and will form PuO_2 when moisture is present.

The half-life of plutonium-239 is long compared to the period of institutional control of the burial site. The half-life of plutonium-241 is fairly short, and the half-life of plutonium-238 is intermediate to these radionuclides. Plutonium-238 and plutonium-239 are alpha emitters whereas decay of plutonium-241 occurs with beta emission. The properties of plutonium-238, plutonium-239, and plutonium-241 are summarized in Table 2-10.

Table 2-10
Plutonium-238, Putonium-239, and Plutonium-241 Properties

Property	Value (Pu-238)	Value (Pu-239)	Value (Pu-241)
Half-Life (years)	87.74	2.41E4	14.35
Emission Type	Alpha	Alpha	Beta
Total Frequency	1.000	1.000	0.9998
Average Energy (MeV)			0.00523
Maximum Energy (MeV)	5.499	5.156	0.02078

Am-241, Cm-242, and Cm-243

Americium and curium are actinides and transuranics. Americium exhibits valence states between +2 to +7 with the +3 state being most common. For curium, the most stable oxidation state is +3. Americium and curium exhibit similar chemical behavior and oxidize in moist conditions.

The half-life of americium-241 is long compared to the period of institutional control of the disposal facility. Curium-243 has an intermediate length half-life, and Curium-242 has a short half-life. All are alpha emitters. The properties of americium-241, curium-242, and curium-243 are summarized in Table 2-11.

Table 2-11
Americium-241, Curium-242, and Curium-243 Properties

Property	Value (Am-241)	Value (Cm-242)	Value (Cm-243)
Half-Life (years)	432	0.44	28.5
Emission Type	Alpha	Alpha	Alpha
Total Frequency	1.000	0.9938	0.9971
Maximum Energy (MeV)	5.5445	6.113	6.066

3
BIOLOGICAL MODELS

In order to assess the radiological consequences of scenarios involving a disposal facility, assumptions must be made regarding the source term and the behavior of the radionuclides (including the dispersal of the activity and the dose conversion factors (DCFs)). These considerations are combined in the exposure pathway analysis that was developed as part of the IMPACTS program method. A detailed discussion of many of these assumptions is beyond the scope of this report. For the purpose of this analysis, changes to any of these other assumptions would introduce other variables in the results beyond the effects of the DCF changes which are the focus of this report. However, a brief review of the biological models associated with the development of the dose conversion factors is appropriate to understand the context of the evolution of the DCFs.

The human model is used to compute a dose from an exposure to a radionuclide. These models are most complex for pathways that include inhalation of contaminated air or ingestion of contaminated water or food. For NUREG/CR-1759, the fundamental dose conversion factors were used for 50-year committed dose. (4) Doses were calculated for 23 radionuclides and compared against seven human organs: total body, bone, kidney, thyroid, liver, lung, and gastrointestinal tract. The dose calculations were performed from pathway dose conversion factors (PDCFs) that were developed with fundamental dose conversion factors (DCFs).

In NUREG/CR-1759, the respiratory tract model was developed using parameters of the International Commission on Radiological Protection (ICRP) in ICRP-2. (5) This lung model was used with DACRIN, a computer code developed by Battelle, to compute the inhalation dose conversion factors for the IMPACTS analysis. (6) These computation methods are updated from the soluble and insoluble categories and critical organ methodology used for ICRP-2. For the ingestion model, data were used from NUREG-0172, *Age Specific Radiation Dose Commitment Factors for a One Year Chronic Intake,* for the radiation dose commitment factors. (7)

An update to the IMPACTS analysis was documented in NUREG/CR-4370, *Update of Part 61 IMPACTS Analysis Methodology,* in 1986. (8) This update included dose computation for nine human organs: whole body, lung, kidney, liver, red bone marrow, bone surface, stomach wall, lower large intestine, and thyroid. A whole body effective dose equivalent was also computed. The list of radionuclides considered was increased to 53. The biological models were updated based on the internal dosimetry methodology of ICRP-26 and ICRP-30. (9) (10) For the inhalation model, particles are assumed to have an activity mean aerodynamic diameter (AMAD) of 1 micron. The lungs and gastro-intestinal tract are modeled as compartments with transfer of the radionuclides based on solubility. One notable effect of this model is the increase in computed doses (and higher associated DCFs) for the insoluble transuranics.

For this analysis, updated IMPACTS dose computations were performed based on dose conversion factors as used in the RESRAD model. (11) These DCFs are based on ICRP-60 models of inhalation and ingestion and ICRP-72 for external dose. (12) (13) These methods are

similar to the ICRP-30 approach. The DCF values are further detailed in EPA Federal Guidance Reports FGR No. 11 and FGR No. 12. (14) (15)

4
DOSE CONVERSION FACTORS

For this analysis, the computations using the IMPACTS computer code were performed using the version supporting the NUREG/CR-4370 update to the IMPACTS analysis. This version includes the set of 53 radionuclides and is based on ICRP-30 dose conversion factors and models. Radionuclides are characterized as D, W, or Y class based on the solubility and clearance from biological compartments. The ICRP-60-based models, which are the more recent at the time of this study, continue the use of the D, W, or Y clearance classes. For this analysis, the input files were developed using DCFs consistent with the oxide chemical form of the radionuclides.

This analysis was restricted to the sixteen radionuclides specifically listed in 10 CFR 61 along with a group of commonly reported transuranic radionuclides. These radionuclides are listed in Table 4-1 through Table 4-5. The whole body dose conversion factors were pulled from the respective IMPACTS analysis NUREG reports and were updated for this analysis (referred to as ICRP-60). The solubility class for each radionuclide is noted in Table 4-1. The DCFs for ingestion and inhalation whole-body dose are in Table 4-1 and Table 4-2, respectively. The whole-body ground-volume-contamination DCFs are summarized in Table 4-3. Table 4-4 summarizes the whole-body DCFs for ground surface contamination, and Table 4-5 summarizes DCFs for external dose from submersion in contaminated air.

Table 4-1
Whole Body DCFs- Ingestion (mrem per pCi)

Radionuclide	NUREG/CR-1759	NUREG/CR-4370	ICRP-60
H-3 (*)	1.05E-07	8.98E-08	6.40E-08
C-14 (*)	5.68E-07	1.54E-06	2.09E-06
Co-60 (Y)	4.72E-06	1.13E-05	2.69E-05
Ni-59 (W)	1.63E-06	2.10E-07	2.10E-07
Ni-63 (W)	4.36E-06	5.77E-07	5.77E-07
Sr-90 (D)	1.86E-03	8.75E-05	1.42E-04
Nb-94 (Y)	1.86E-09	7.14E-06	7.14E-06
Tc-99 (D)	5.02E-08	1.02E-06	1.02E-06
I-129 (D)	9.21E-06	2.34E-04	2.76E-04
Cs-137 (D)	7.14E-05	8.19E-05	5.00E-05
Pu-238 (Y)	1.71E-05	1.37E-04	4.96E-05

Table 4-1
Whole Body DCFs- Ingestion (mrem per pCi) (Continued)

Radionuclide	NUREG/CR-1759	NUREG/CR-4370	ICRP-60
Pu-239 (Y)	1.91E-05	1.57E-04	5.18E-05
Pu-241 (Y)	3.32E-07	2.79E-06	7.66E-07
Am-241 (W)	5.41E-05	4.59E-03	3.64E-03
Cm-242 (W)	1.18E-04	1.18E-04	1.15E-04
Cm-243 (W)	3.75E-05	2.92E-03	2.51E-03

Table 4-2
Whole Body DCFs- Inhalation (mrem per pCi)

Radionuclide	NUREG/CR-1759	NUREG/CR-4370	ICRP-60
H-3	1.50E-07	1.26E-07	6.40E-08
C-14	3.40E-07	1.09E-08	2.90E-09
Co-60	2.80E-06	2.41E-04	2.19E-04
Ni-59	1.40E-06	9.18E-07	9.18E-07
Ni-63	3.80E-06	2.30E-06	2.30E-06
Sr-90	3.00E-03	2.10E-04	1.30E-03
Nb-94	8.20E-08	4.14E-04	4.14E-04
Tc-99	5.20E-08	7.08E-07	1.48E-05
I-129	7.80E-06	1.50E-04	1.74E-04
Cs-137	2.60E-05	4.83E-05	3.19E-05
Pu-238	2.50E-02	4.89E-01	2.88E-01
Pu-239	2.80E-02	3.47E-01	3.08E-01
Pu-241	3.80E-04	5.38E-03	4.96E-03
Am-241	6.30E-02	5.63E-01	4.44E-01
Cm-242	1.76E-02	1.76E-02	1.73E-02
Cm-243	4.80E-02	3.60E-01	3.07E-01

Table 4-3
Whole Body DCFs- External Ground Volume Contamination (mrem/yr per pCi/ m^3)

Radionuclide	NUREG/CR-1759	NUREG/CR-4370	ICRP-60
H-3	0.00E+00	0.00E+00	0.00E+00
C-14	0.00E+00	0.00E+00	8.93E-12
Co-60	1.54E-05	1.55E-05	1.08E-05
Ni-59	6.20E-09	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00
Sr-90	3.06E-08	1.92E-13	1.64E-08
Nb-94	9.63E-06	9.50E-06	6.45E-06
Tc-99	0.00E+00	1.39E-14	8.40E-11
I-129	1.92E-08	1.61E-08	8.69E-09
Cs-137	3.50E-06	3.39E-06	2.27E-06
Pu-238	1.93E-11	1.09E-10	1.01E-10
Pu-239	9.39E-11	0.00E+00	1.97E-10
Pu-241	3.43E-13	1.37E-12	1.26E-11
Am-241	7.71E-08	7.65E-08	2.91E-08
Cm-242	4.81E-10	4.81E-10	1.07E-10
Cm-243	3.82E-07	5.55E-07	3.87E-07

Table 4-4
Whole Body DCFs- External Ground Surface Contamination (mrem/yr per pCi/ m^2)

Radionuclide	NUREG/CR-1759	NUREG/CR-4370	ICRP-60
H-3	0.00E+00	0.00E+00	0.00E+00
C-14	0.00E+00	0.00E+00	1.88E-09
Co-60	3.84E-04	2.07E-04	2.74E-04
Ni-59	4.27E-06	1.45E-08	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00
Sr-90	2.74E-05	0.00E+00	3.32E-08
Nb-94	9.90E-05	1.44E-04	1.79E-04
Tc-99	0.00E+00	5.08E-11	9.11E-09
I-129	1.13E-05	1.47E-06	3.01E-06
Cs-137	3.99E-05	5.29E-05	3.33E-08
Pu-238	3.18E-06	3.94E-08	9.79E-08
Pu-239	1.22E-06	1.94E-08	4.29E-08
Pu-241	0.00E+00	0.00E+00	2.25E-10
Am-241	1.30E-05	2.21E-06	3.21E-06
Cm-242	4.41E-08	4.41E-08	1.12E-07
Cm-243	4.02E-05	1.23E-05	1.46E-05

Table 4-5
Whole Body DCFs- External Air Immersion (mrem/yr per pCi/ m^3)

Radionuclide	NUREG/CR-1759	NUREG/CR-4370	ICRP-60
H-3	5.19E-05	0.00E+00	3.78E-08
C-14	4.46E-04	0.00E+00	2.62E-08
Co-60	2.28E-02	1.19E-02	1.47E-02
Ni-59	5.98E-05	6.70E-08	0.00E+00
Ni-63	1.56E-04	0.00E+00	0.00E+00
Sr-90	1.76E-03	0.00E+00	8.80E-07
Nb-94	1.32E-02	7.43E-03	8.99E-03
Tc-99	7.60E-04	2.15E-09	1.89E-07
I-129	6.86E-04	2.80E-05	4.44E-05
Cs-137	1.53E-03	2.77E-03	9.04E-07
Pu-238	8.87E-05	2.33E-07	5.70E-07
Pu-239	5.17E-05	2.92E-07	4.95E-07
Pu-241	4.78E-05	0.00E+00	8.49E-09
Am-241	3.80E-04	7.29E-05	9.55E-05
Cm-242	2.59E-07	2.59E-07	6.65E-07
Cm-243	2.26E-03	5.42E-04	6.87E-04

5
IMPACTS MODEL

A copy of the updated IMPACTS code with associated input files conforming to the original 10 CFR 61 assessments, as specified in NUREG/CR-4370, was obtained. (8) The IMPACTS analysis methodology was developed to model the generic behavior of the disposal site system. Scenarios were developed as release, transport, and exposure pathway interactions involving complex models of waste and disposal site properties. This approach was designed as a generic method intended to serve as a basis for evaluation of the waste classification system. The IMPACTS analysis considers the operational and post operational period of the disposal site service life. The post operational period includes site closure and period of institutional control as well as the assumption of loss of passive control at later periods of passive institutional control. Scenarios consider exposure from direct contact with the waste as well as mobilization and exposure to contaminated air and water. (4)

The IMPACTS program computes doses from radioactive waste disposal for multiple exposure scenarios. These scenarios are considered either acute or chronic in duration. To compute a dose, the user provides a postulated source term. The model allows the translocation of the source term based on calculation of four parameters. These account for the time delay, disposal facility characteristics, waste form and package characteristics, and site environmental conditions. (4)

Once a fraction of the facility source term is trans-located, an exposure can be calculated. The scenario or pathway includes specific individual exposure sub-pathways. The fundamental dose conversion factors (DCFs) applicable to each exposure sub-pathway are combined to compute an overall pathway dose conversion factor (PDCF) for the specific scenario. The scenario dose is then computed as the sum of these sub-pathway exposures. (4) The general equation is as follows:

$$H = \Sigma C_i \times I_i \times PDCF_i$$

Where:
H = the dose to an individual in units of mrem/y
C = the concentration of the ith radionuclide (in Ci/m^3) in the particular waste stream
I = the transfer factor relating the concentration of the radionuclide in the waste to the concentration at the access location; and
PDCF = the pathway dose conversion factor for the *i*th radionuclide generally in units of mrem/y per Ci/m^3.

IMPACTS Model

To create a mathematical model of the radionuclide translocation, the scenario is modeled as a series of compartments through which radionuclides move. Transfer factors are used as functions or coefficients to compute the translocation. Two methods can be used to compute transfer between these postulated compartments. In the concentration factor (CF) method, time dependent behavior is ignored and the transfer is computed as a single factor. A more complex model can be developed using the systems analysis (SA) method in which differential equations are used to more accurately describe the behavior of the radionuclide in the system. The IMPACTS code uses the CF method. (4)

IMPACTS Model Assumptions

The IMPACTS model builds scenarios using individual DCFs combined into pathway dose conversion factors. Each scenario involves an access location with uptake pathways. The scenarios from NUREG/CR-1759 are summarized in Table 5-1 with the associated uptake pathways and PDCFs. (4)

Table 5-1
Uptake Pathways and PDCFs

Scenario	Access Location	Uptake Pathways	PDCF
Accident (acute)	Offsite Air	Inhalation (soil)	PDCF-1
		Direct Radiation (area)	
		Direct Radiation (air)	
		Inhalation (air)	
		Direct radiation (air)	
Intruder-Construction (acute)	Onsite soil	Inhalation (air)	PDCF-2
		Direct Radiation (air)	
		Food (air)	
		Direct radiation (volume)	PDCF-5
Intruder-Agriculture (Chronic)	Onsite Soil	Inhalation (air)	PDCF-3
		Direct Radiation (air)	
		Food (air)	
		Food (soil)	PDCF-4
		Direct Radiation (volume)	PDCF-5

Table 5-1
Uptake Pathways and PDCFs (continued)

Leaching & Migration (Chronic)	Well Water	Inhalation (soil)	PDCF-6
		Direct radiation (area)	
		Direct Radiation (air)	
		Food (water)	
Leaching & Migration (Chronic)	Open Water	Inhalation (soil)	PDCF-7
		Direct radiation (area)	
		Direct Radiation (air)	
		Food (water)	
		Ingestion (fish)	
Surface Water Runoff (Chronic)	Open Water	Inhalation (soil)	PDCF-7
		Direct Radiation (area)	
		Direct radiation (air)	
		Food (water)	
		Ingestion (fish)	
Atmospheric Transport (Chronic)	Offsite Air	Inhalation (soil)	PDCF-8
		Direct Radiation (area)	
		Direct Radiation (air)	
		Inhalation (air)	
		Direct Radiation (air)	
		Food (air)	

IMPACTS Model Pathways

The uptake pathways shown in Table 5-1 are defined using sub-pathways. In NUREG/CR-1759, these pathways are developed as shown in Table 5-2. A total of nine uptake pathways are defined from the sub-pathways. The sub-pathways include direct exposure and secondary exposures. As can be seen from the tabulated scenario information, for the direct exposure pathways, the fundamental dose conversion factors are used with the trans-located source. Additional transfer compartments are modeled for the uptake pathways involving inhalation and ingestion. For several of the internal dose sub-pathways, several transfers occur between compartments. This is

the case for the plant-animal-human sub-pathway, which is an example of these more complex routes of exposure. The radionuclide transfers first to the plant that is consumed by an animal which then results in an exposure from ingestion by the human in the scenario. (4)

Table 5-2
Uptake Pathway Definition

Uptake Pathway	Sub-pathway description
Food (soil)	Plant-human, plant-animal-human, plant-animal-product-human
Food (air)	Soil sub-pathways + fallout to plant surface + soil pathways from fallout
Food (water)	Soil sub-pathways + Irrigation to plant surface + water-human, water-animal-human, water-animal-product-human
Ingestion (fish)	consumption of fish living in contaminated water
Inhalation (air)	Air contaminated from soil suspended due to human activities
Inhalation (soil)	Air contaminated from soil due to natural processes
Direct Radiation (volume)	Exposure standing on contaminated ground (volume)
Direct Radiation (area)	Exposure standing on contaminated ground (surface)
Direct radiation (air)	Exposure standing in contaminated air

Disposal Site Environment Considerations

In NUREG/CR-1759 and NUREG/CR-4370, the IMPACTS program was used to model several types of environmental conditions for a disposal site. These settings were referred to as northeast, southeast, mid-west, and western. These reference sites include generic environmental conditions for these geographical regions. For example, the southeast environment has high temperature and precipitation while the western site has high temperature and high wind speed with low precipitation. The northeast and mid-west sites have moderate temperature. Generic soil and ground water characteristics also vary between the sites.

The input to the IMPACTS code included the waste characteristics file and the dose conversion factor file. The waste characteristics file includes the information on the waste streams and the radionuclide activity content. The dose conversion factor file specifies the DCFs in the format for use by the IMPACTS executable. The input to the IMPACTS code was kept constant with the exception of the dose conversion factors. As a result, this investigation serves as a sensitivity analysis of the changes in the DCFs. This was done to eliminate the need to further develop non-tangible factors that were used in the development of the actual 10 CFR 61.55 Table 1 and 2 concentrations but are not readily apparent or well documented in the existing literature.

To determine if the calculated dose changes with the DCFs in the same way for all burial site environments, the IMPACTS calculations were run with the parameters for the northeastern site, southeastern site, mid-western site, and western site. Cm-242 was not included in NUREG/CR-1759. The Cm-242 dose results are displayed similar to the other cases using the whole body dose from NUREG/CR-4370.

The DCFs from NUREG/CR-1759, NUREG/CR-4370, and the ICRP-60 were used to compute doses for the scenarios. The scenario dose for the later DCFs was divided by the corresponding scenario dose for the NUREG/CR-1759 DCFs case to develop a ratio for comparison. The results of these dose calculations are summarized in Table 5-3 with the limiting scenario indicated. From Table 5-1, "AG" is the intruder –agriculture scenario and "CO" is the intruder construction scenario.

Table 5-3
Uptake Pathways and PDCFs

Radionuclide		Dose as a Ratio to NUREG/CR-1759 Dose			
Limiting Scenario	Report	Northeast	Southeast	Mid-West	Western
H-3	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	8.53E-01	8.53E-01	8.53E-01	8.53E-01
	ICRP60	6.09E-01	6.09E-01	6.09E-01	6.09E-01
C-14	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	2.71E+00	2.71E+00	2.71E+00	2.71E+00
	ICRP60	3.68E+00	3.67E+00	3.68E+00	3.69E+00
Co-60	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	9.62E-01	9.62E-01	9.62E-01	9.62E-01
	ICRP60	7.01E-01	7.01E-01	7.01E-01	7.01E-01
Ni-59	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	2.88E-03	2.90E-03	2.90E-03	9.19E-02
	ICRP60	1.89E-03	1.91E-03	1.91E-03	6.51E-02
Ni-63	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	1.37E-01	1.38E-01	1.38E-01	1.43E-01
	ICRP60	1.37E-01	1.38E-01	1.38E-01	1.43E-01
Sr-90	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	4.01E-02	4.03E-02	4.02E-2	4.09E-02
	ICRP60	1.11E-01	1.11E-01	1.11E-01	1.11E-01
Nb-94	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00

Table 5-3
Uptake Pathways and PDCFs (continued)

Radionuclide		Dose as a Ratio to NUREG/CR-1759 Dose			
Limiting Scenario	Report	Northeast	Southeast	Mid-West	Western
AG	4370	9.56E-01	9.56E-01	9.56E-01	9.56E-01
	ICRP60	6.79E-01	6.79E-01	6.79E-01	6.79E-01
Tc-99	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	2.03E+01	2.03E+01	2.03E+01	2.03E+01
	ICRP60	2.03E+01	2.03E+01	2.03E+01	2.04E+01
I-129	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	1.83E+00	1.87E+00	1.89E+00	2.81E+00
	ICRP60	2.06E+00	2.11E+00	2.13E+00	3.22E+00
Cs-137	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
AG	4370	9.48E-01	9.48E-01	9.48E-01	9.48E-01
	ICRP60	6.42E-01	6.42E-01	6.42E-01	6.42E-01
Pu-238	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
CO	4370	1.22E+01	1.23E+01	1.22E+01	1.22E+01
	ICRP60	1.15E+01	1.15E+01	1.15E+01	1.15E+01
Pu-239	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
CO	4370	1.24E+01	1.24E+01	1.24E+01	1.24E+01
	ICRP60	1.10E+01	1.10E+01	1.10E+01	1.10E+01
Pu-241	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
CO	4370	3.23E+00	4.10E+00	4.32E+00	5.38E+00
	ICRP60	3.79E+00	5.02E+00	5.33E+00	6.84E+00
Am-241	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
CO	4370	4.96E+00	6.44E+00	6.84E+00	8.66E+00
	ICRP60	3.78E+00	4.99E+00	5.30E+00	6.82E+00
Cm-242	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00

Table 5-3
Uptake Pathways and PDCFs (continued)

Radionuclide		Dose as a Ratio to NUREG/CR-1759 Dose			
Limiting Scenario	Report	Northeast	Southeast	Mid-West	Western
CO	4370	1.00E+00	1.00E+00	1.00E+00	1.00E+00
	ICRP60	9.37E-01	9.38E-01	9.37E-01	9.40E-01
Cm-243	1759	1.00E+00	1.00E+00	1.00E+00	1.00E+00
CO	4370	2.09E+00	2.73E+00	2.96E+00	5.37E+00
	ICRP60	1.69E+00	2.25E+00	2.45E+00	4.59E+00

In the limiting case scenario, the ratio was identical for eleven of the sixteen radionuclides (H-3, C-14, Co-60, Ni-63, Sr-90, Nb-94, Tc-99, Cs-137, Pu-238, Pu239, and Cm-242). For five radionuclides the ratio of the doses was not identical (Ni-59, I-129, Pu-241, Am-241, and Cm-243). In all cases, the computed ratio was highest for the western site environment. In the humid site environment conditions, the magnitude of the increase was less for four radionuclides (I-129, Pu-241, Am-241, and Cm-243). In the case of one radionuclide, the magnitude of the decrease was greater (Ni-59). This establishes that the ratios computed for the western site are bounding. The ratios were lowest for the northeast site model. The calculated ratios for the southeast site model and mid-western site model were intermediate to those calculated for the western site and the northeastern site models. Use of the ratios for the western site was the most conservative assumption and would be uniformly applicable in all cases consistent with the intention of 10 CFR 61. (16)

6
IMPACTS MODEL RESULTS

This investigation of the dose conversion factors used with the IMPACTS program demonstrated that the parameters for a western semi-arid disposal site are bounding. The whole body dose output results for each case were converted to a ratio to the NUREG/CR-1759 whole body dose result. The results are displayed graphically for each radionuclide in Figure 6-1through Figure 6-16.

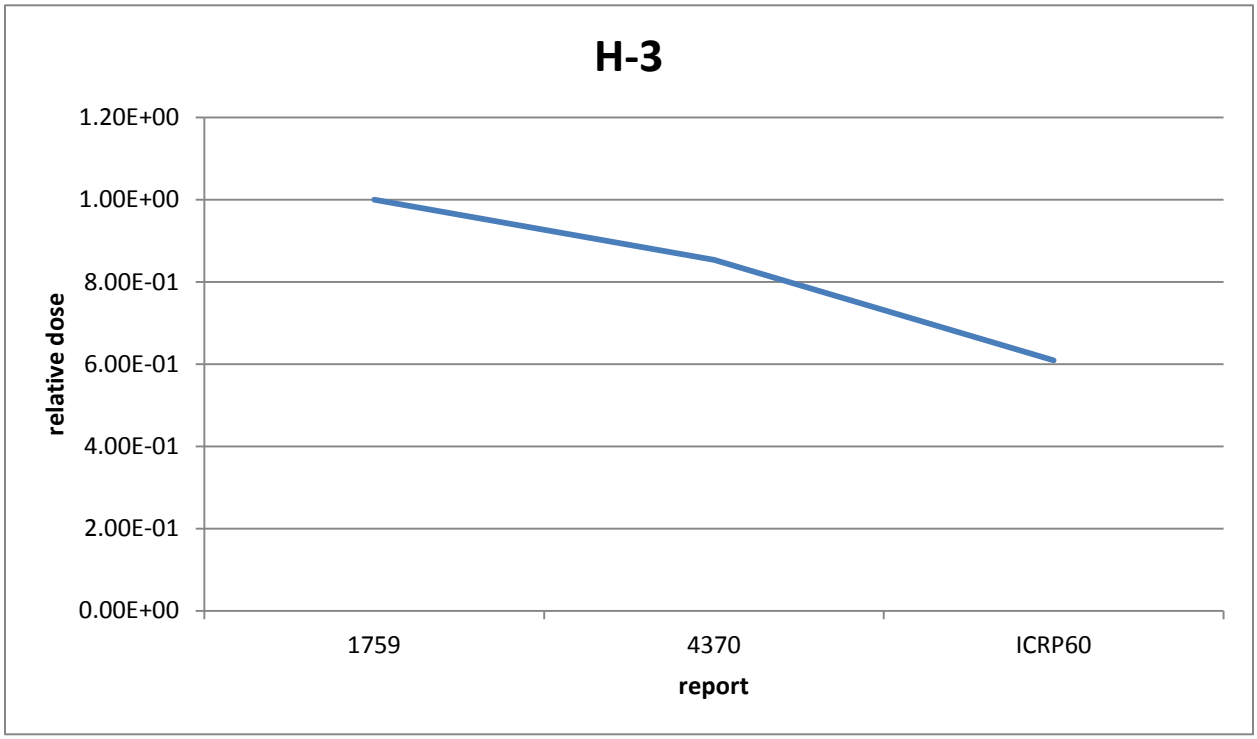

Figure 6-1
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for H-3

IMPACTS Model Results

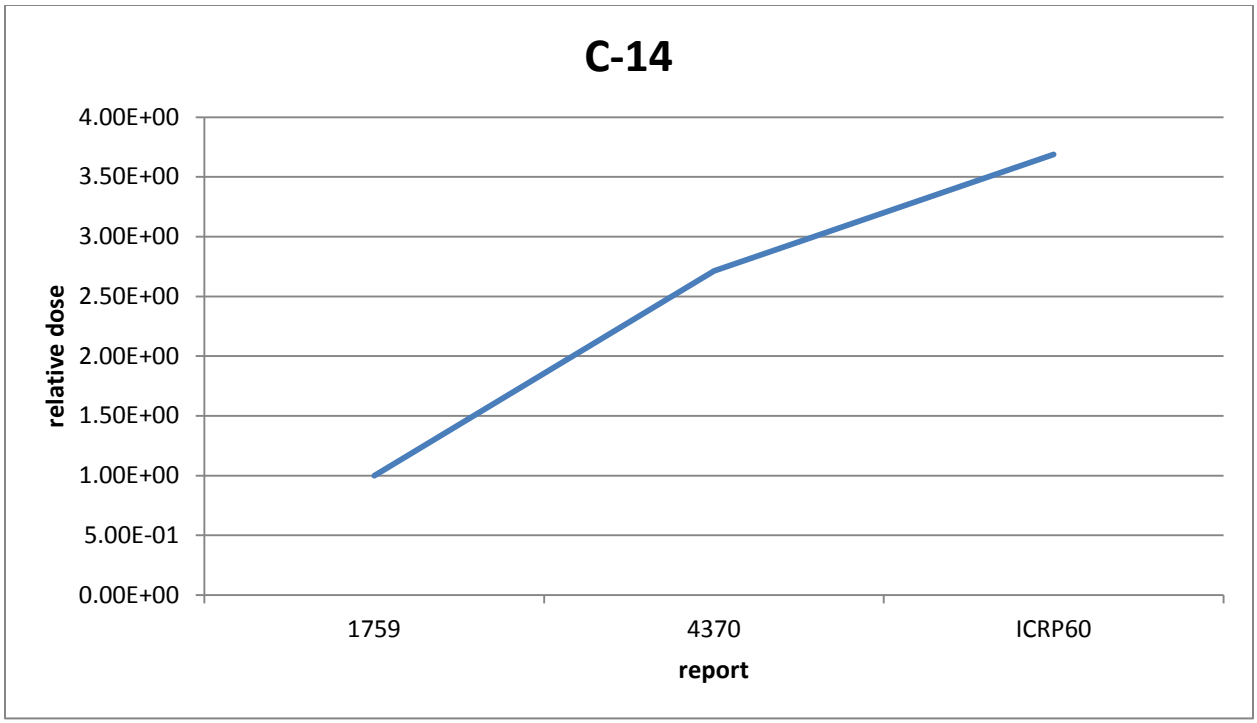

Figure 6-2
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for C-14

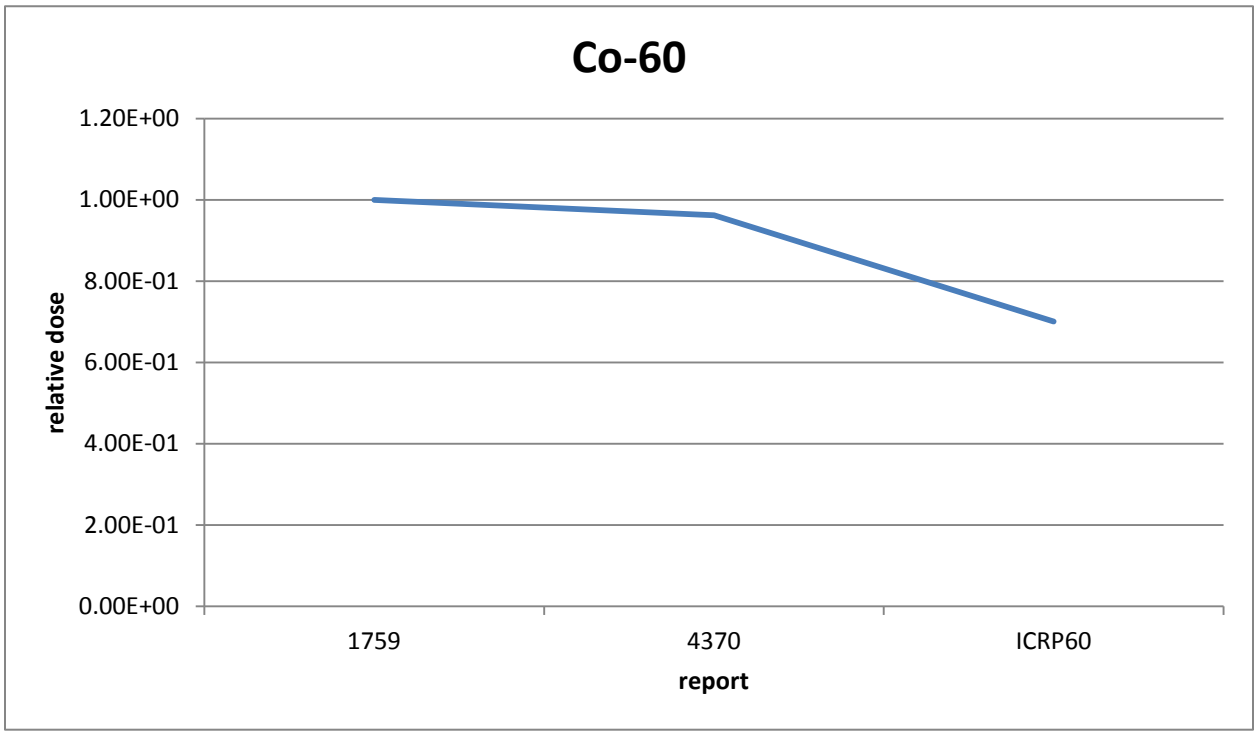

Figure 6-3
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Co-60

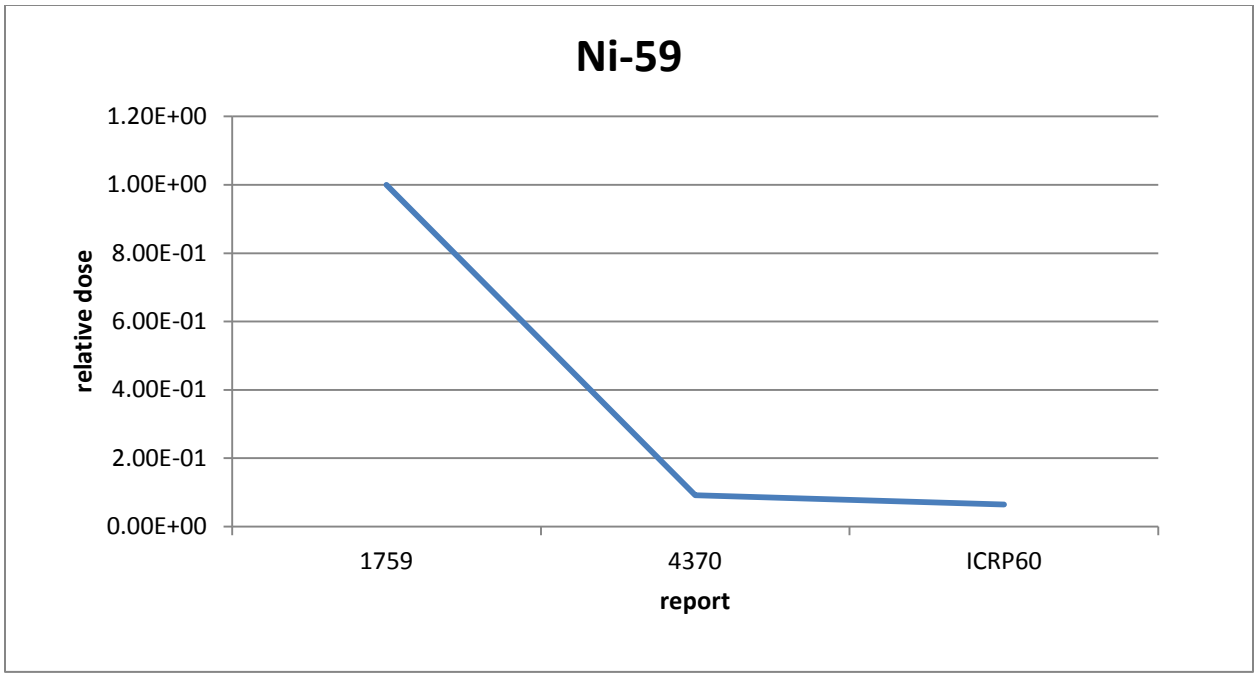

Figure 6-4
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Ni-59

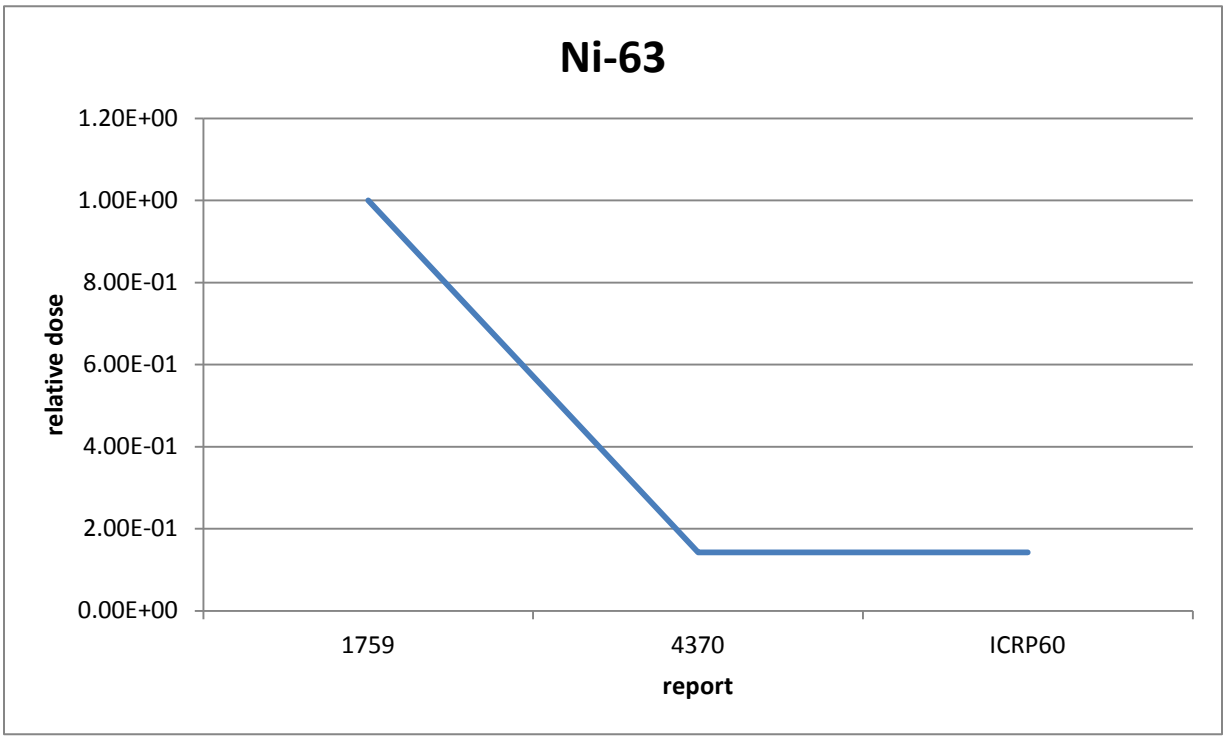

Figure 6-5
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Ni-63

IMPACTS Model Results

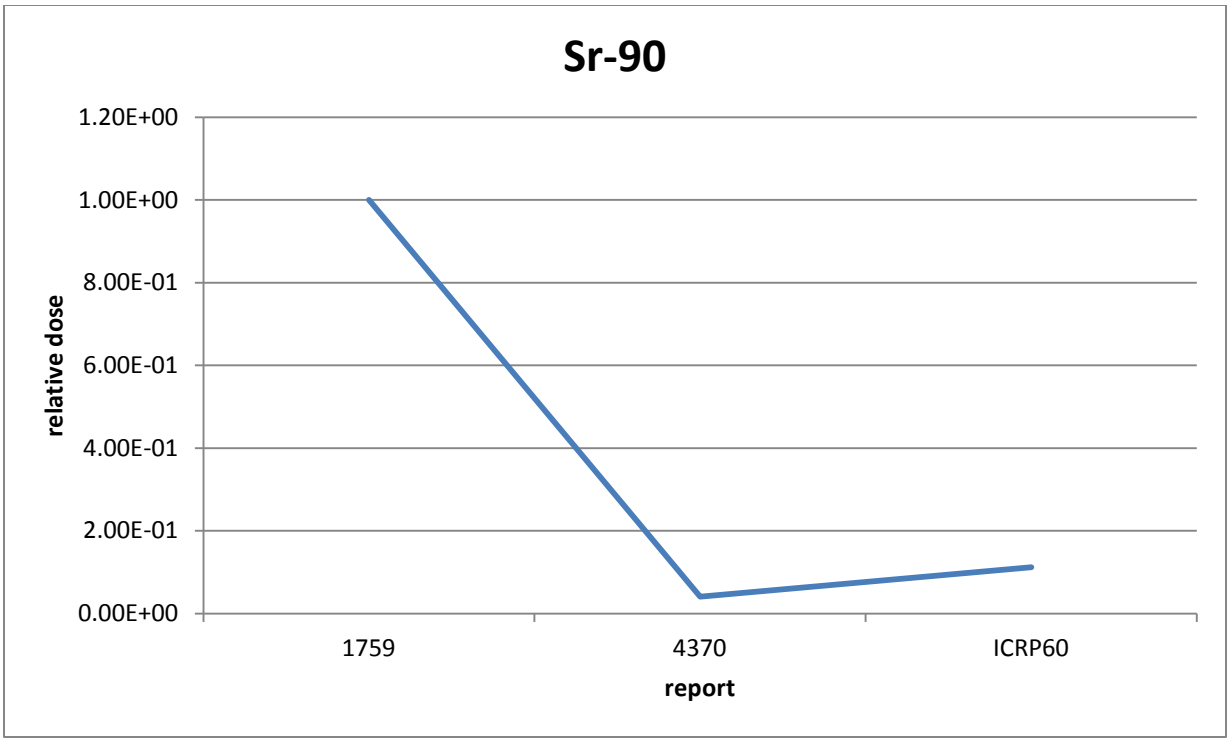

Figure 6-6
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Sr-90

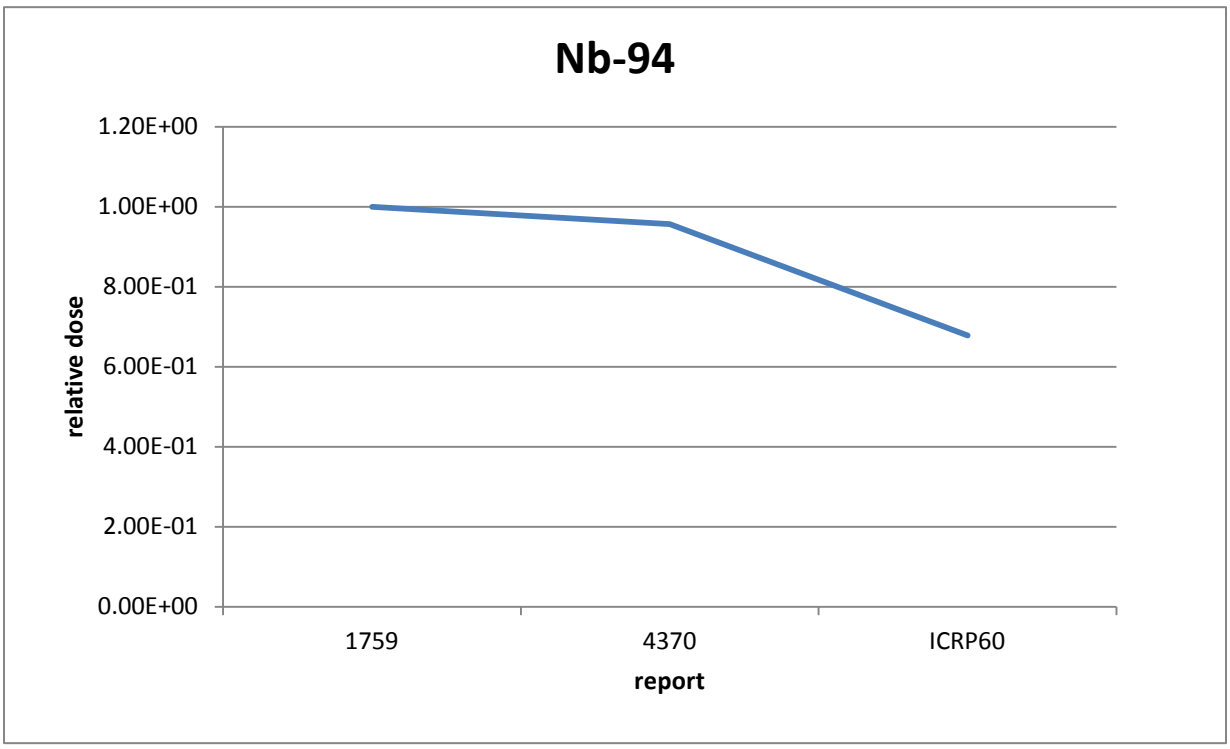

Figure 6-7
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Nb-94

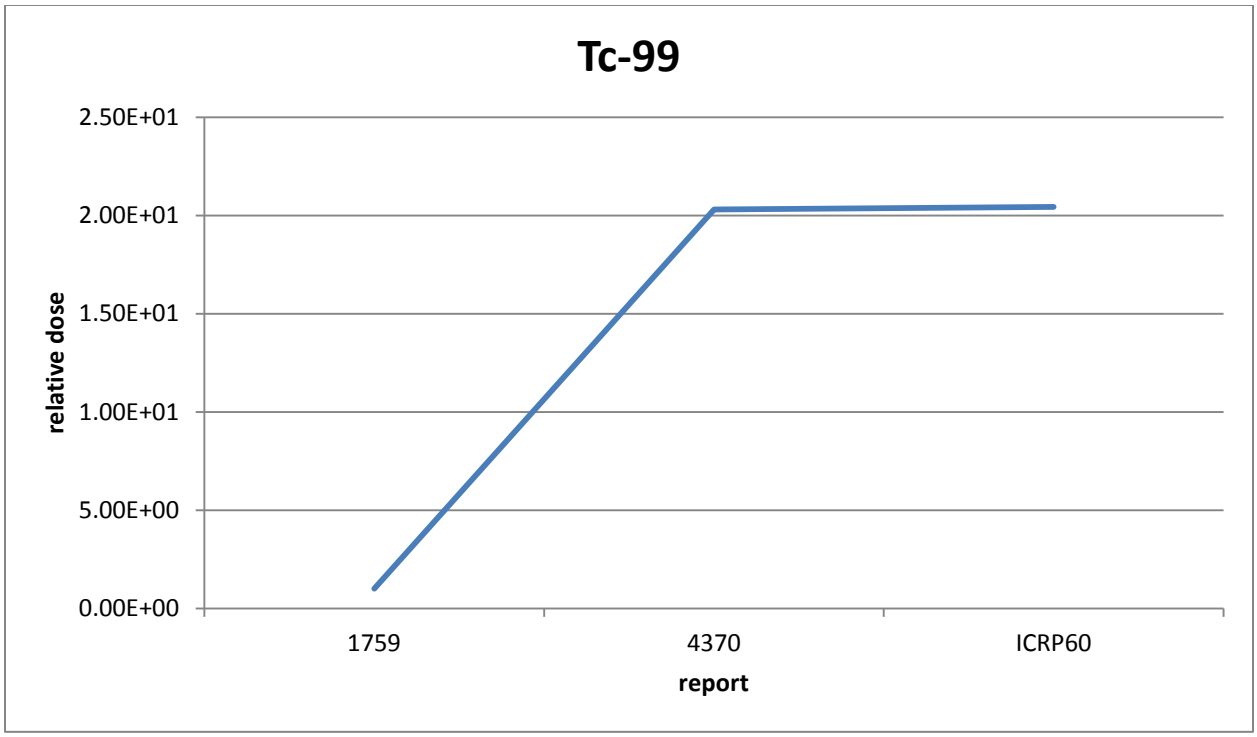

Figure 6-8
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Tc-99

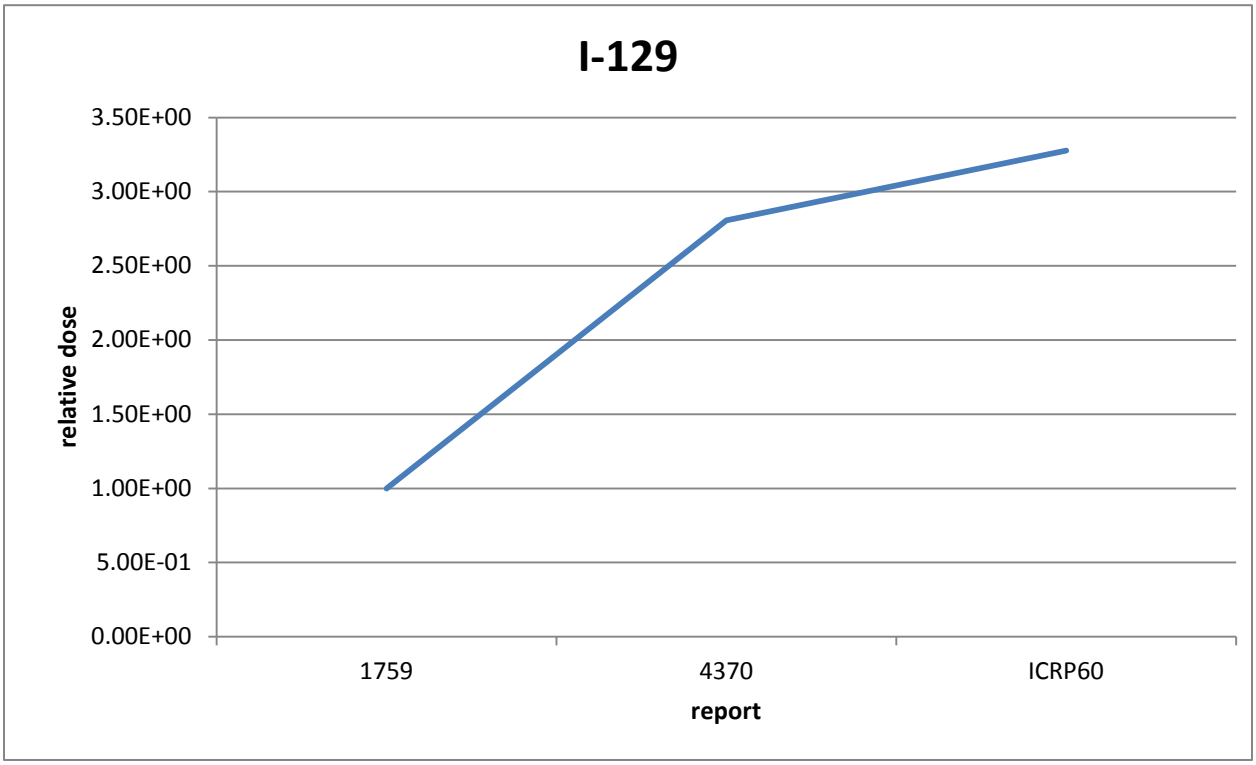

Figure 6-9
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for I-129

IMPACTS Model Results

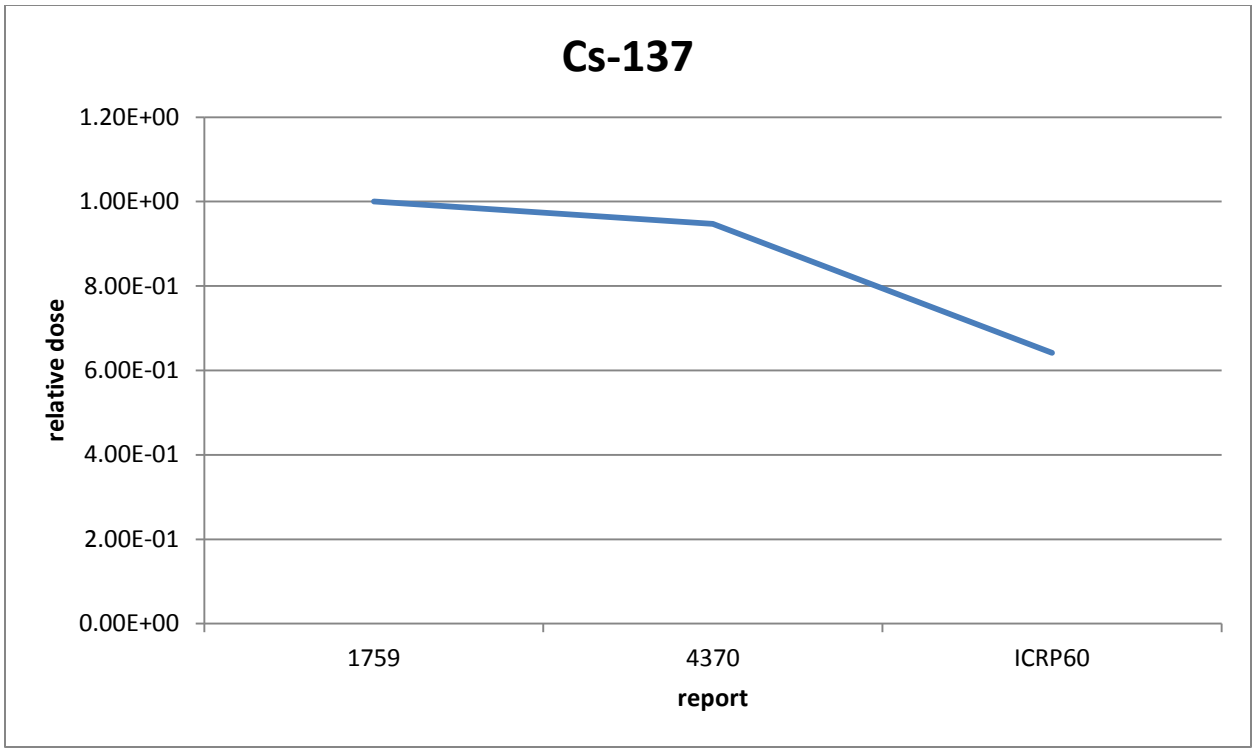

Figure 6-10
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Cs-137

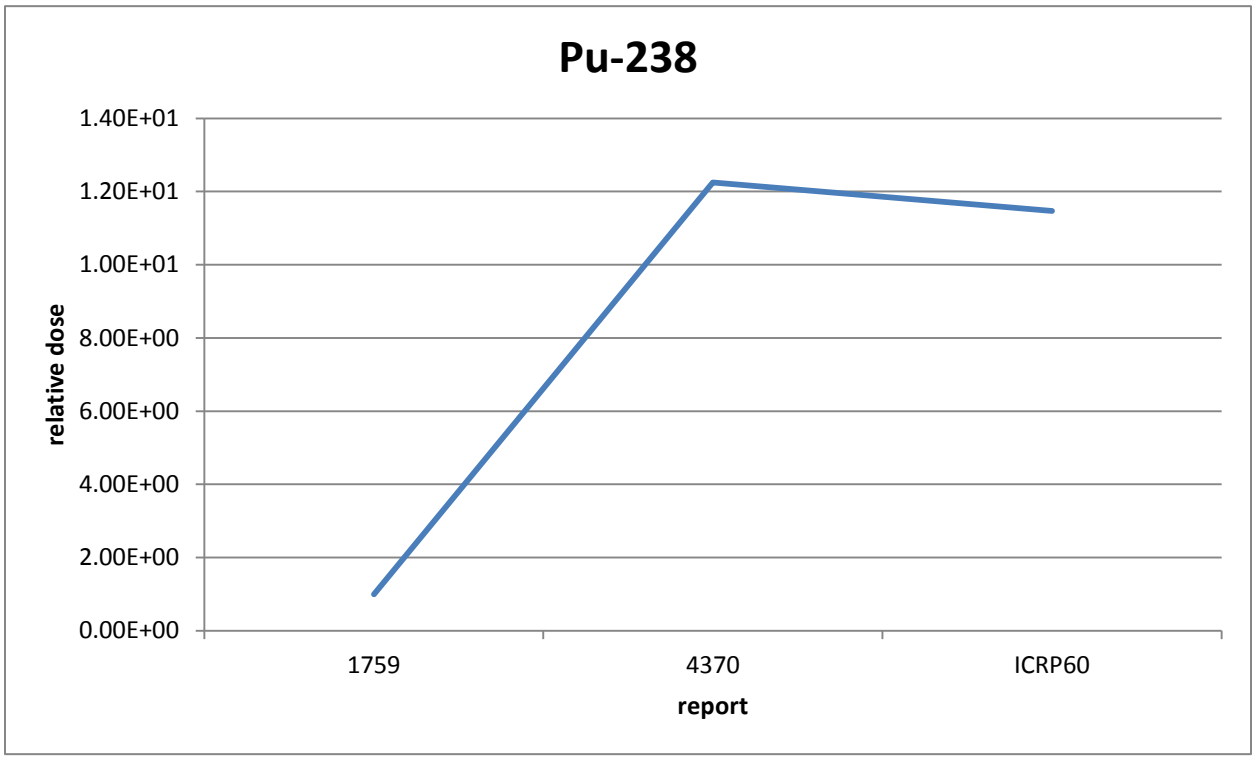

Figure 6-11
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Pu-238

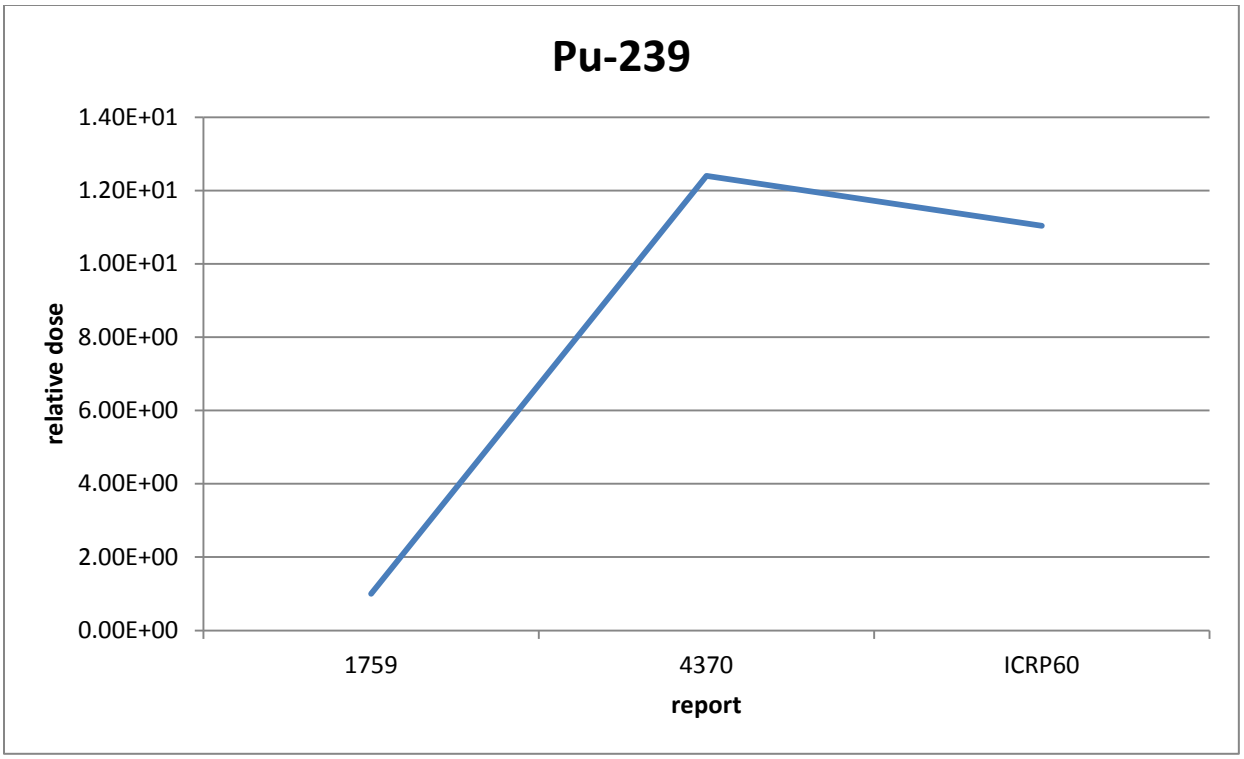

Figure 6-12
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Pu-239

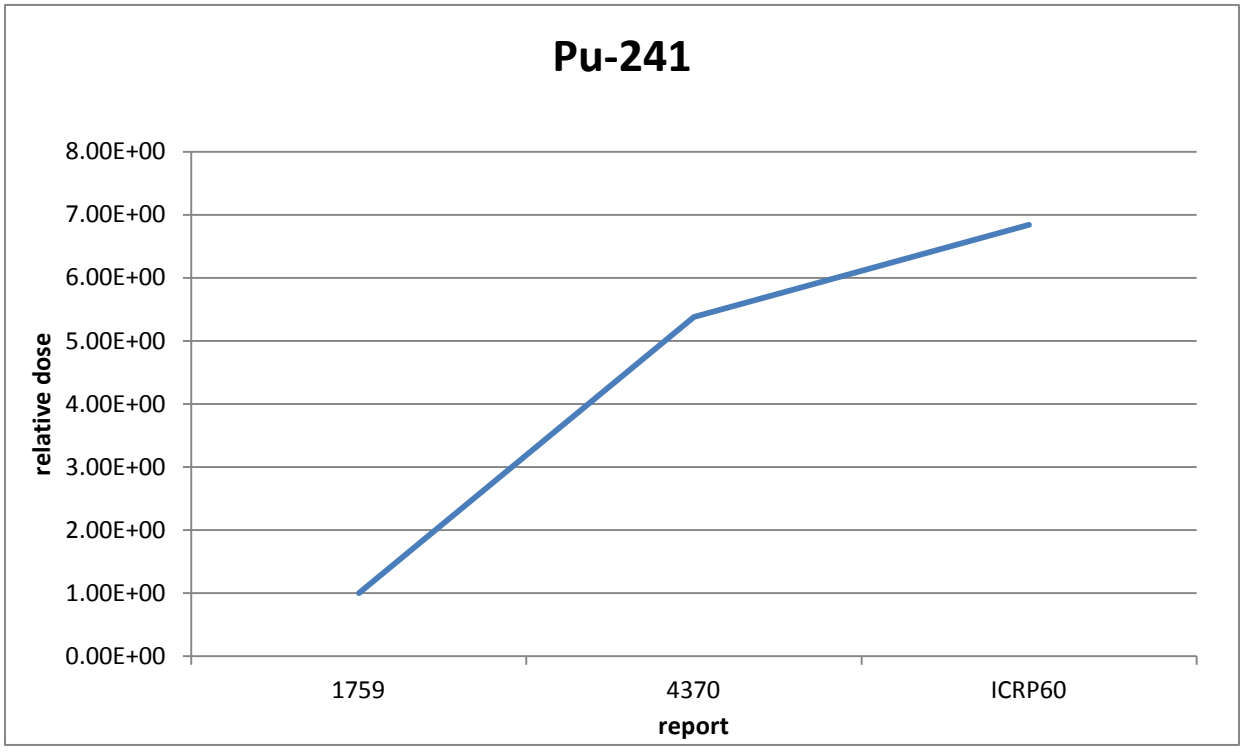

Figure 6-13
MPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Pu-241

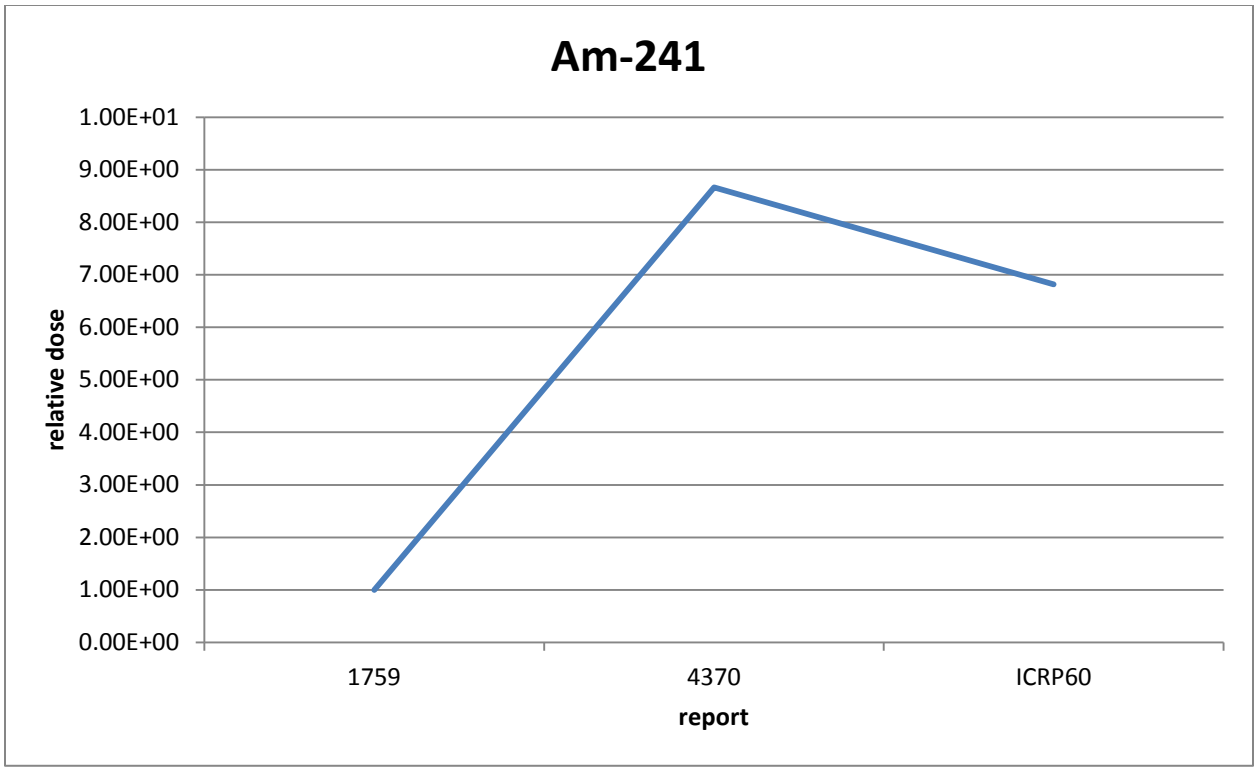

Figure 6-14
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Am-241

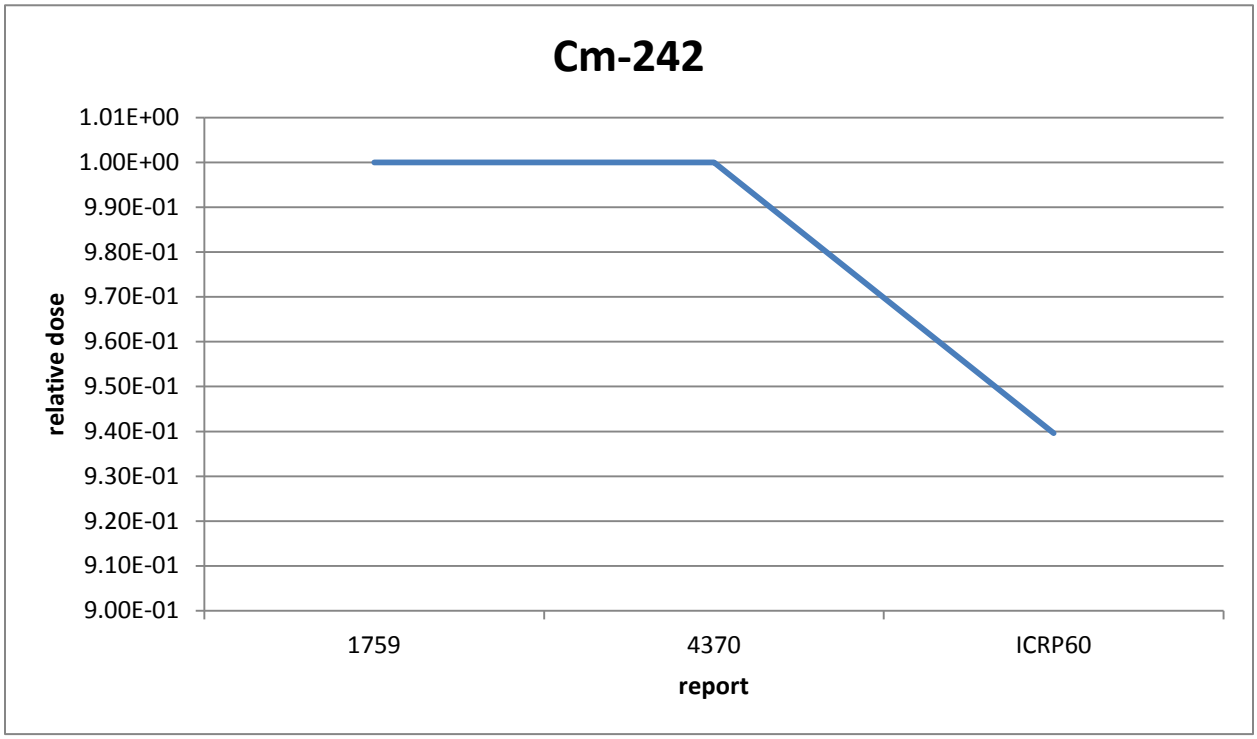

Figure 6-15
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Cm-242

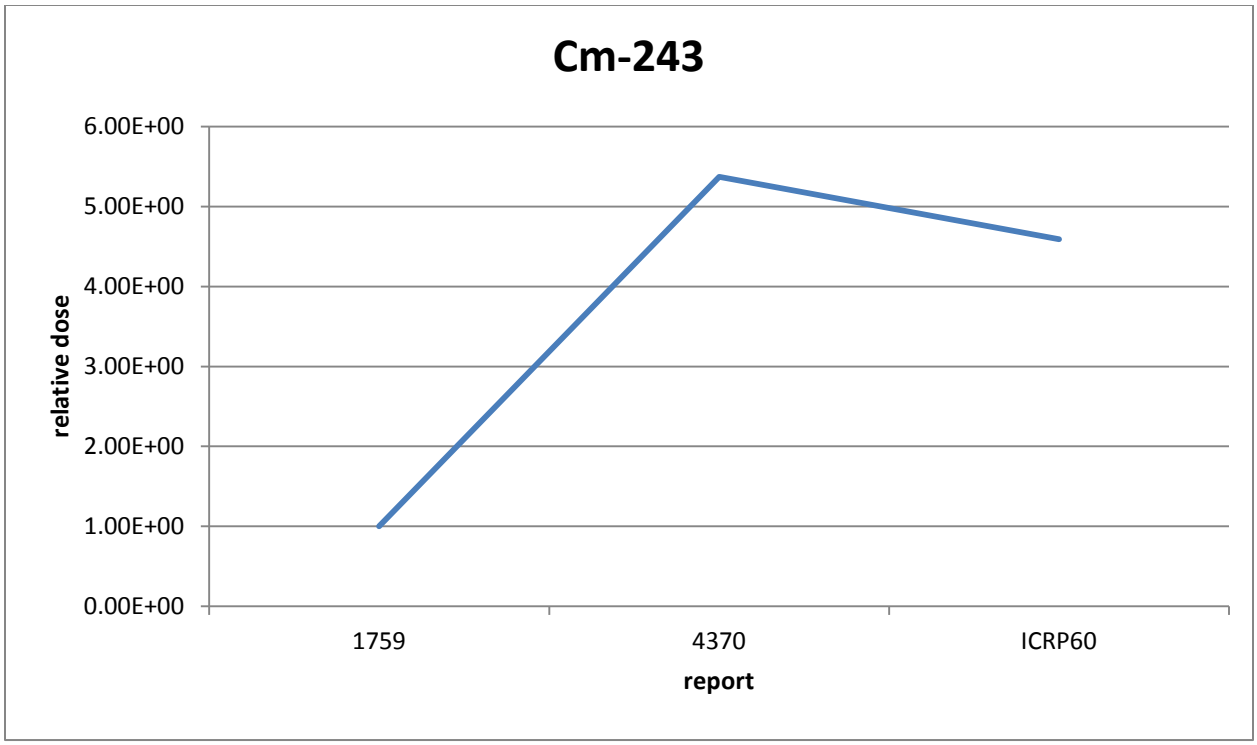

Figure 6-16
IMPACTS Model Results - Dose as a Ratio to NUREG/CR-1759 for Cm-243

The results of this analysis show that of the sixteen radionuclides considered, the dose projected by the IMPACTS scenarios decreases for eight radionuclides (H-3, Co-60, Ni-59, Ni-63, Sr-90, Nb-94, Cs-137, and Cm-242) and increases for eight radionuclides (C-14, Tc-99, I-129, Pu-238, Pu239, Pu-241, Am-241, and Cm-243). The radionuclides showing an increase include the transuranic radionuclide cases. The exception among the transuranics is curium-242, which was not included in NUREG/CR-1759. It is notable that doses projected for the transuranic radionuclides (with the exception of plutonium-241) decreased from the NUREG/CR-4370 model to the ICRP-60 model.

Of the radionuclides that show a decrease in projected dose, strontium-90 was unique. While the projected dose decreased from the NUREG/CR-1759 model to the NUREG/CR-4370 model, a slight increase was projected with the ICRP-60 model.

Of the phantom four radionuclides[1], namely H-3, C-14, Tc-99, and I-129, only tritium shows a downward trend in projected dose. The projected doses for C-14 and I-129 show an increase with both re-evaluations of the dose conversion factors. Tc-99 shows an increase from NUREG/CR-1759 to NUREG/CR-4370. The significance of the radionuclides for waste classification is discussed further below.

The projected doses for nickel-59 and nickel-63 show a sizable decrease from the NUREG/CR-1759 model to the NUREG/CR-4370 model. The projected dose for the ICRP-60 model is consistent with this lower dose projection from NUREG/CR-4370.

[1] So called because of the requirement in 10 CFR 20 Appendix G that they be manifested for disposal despite the fact that they are not typically seen in samples of commercial power plant waste above the detection limits at the laboratories.

IMPACTS Model Results

Plutonium-241 shows a fairly significant increase in projected dose. The limit for plutonium-241 is relatively high compared to the other transuranic radionuclides. Due to the short half-life of plutonium-241, it is much less persistent than the other plutonium isotopes in the disposal facility beyond the institutional control period.

Outside of the transuranic radionuclide category, seven radionuclides (H-3, Co-60, Ni-59, Ni-63, Sr-90, Nb-94, and Cs-137) show a reduction in projected dose and three (C-14, Tc-99, and I-129) show an increase in projected dose. As previously discussed, the projected dose increase is for C-14, Tc-99, and I-129. For H-3, Co-60, Nb-94. and Cs-137, there is a decrease in projected dose; but it is of a moderate magnitude, around 30 to 40 percent. For nickel-59 and nickel-63 the decrease is larger, however, with most of the decrease accounted for in the changes from NUREG/CR-1759 to NUREG/CR-4370. As noted above, while there was an overall decrease in projected dose for strontium-90, the projected dose increased slightly for the ICRP-60 model from the NUREG/CR-4370 case.

Changes to the projected dose are summarized in Table 6-1. The direction and size of the arrows depict the type of change in the dose projection and the relative magnitude of the change. In general terms, the trends are characterized as 24 decreasing versus 20 increasing. Three trends were rated as neutral. The increasing trends are dominated by those of the transuranic radionuclides, accounting for eleven of the 20. The observation for the transuranic radionuclides is due to the general increase in dose conversion factors for alpha emitting radionuclides with the changes to the methodology in ICRP-30 from ICRP-2. This was due in part to the increase in the relative biological effectiveness (RBE) attributed to alpha particles with this update. The projected doses for alpha emitters decreased from NUREG/CR-4370 to the more recent ICRP-60. It is worth noting that of the sixteen radionuclides only four increasing trends occur between NUREG/CR-4370 and ICRP-60.

Table 6-1
Projected Dose Trend Summary

Radionuclide	Trend Summery		
	NUREG/CR-1759 to NUREG/CR-4370	NUREG/CR-4370 to ICRP-60	NUREG/CR-1759 to ICRP-60
H-3	↓	↓	↓
C-14	↑	↑	↑
Co-60	↓	↓	↓
Ni-59	↓	→	↓
Ni-63	↓	→	↓
Sr-90	↓	↑	↓
Nb-94	↓	↓	↓
Tc-99	↑	→	↑
I-129	↑	↑	↑
Cs-137	↓	↓	↓
Pu-238	↑	↓	↑

Table 6-1
Projected Dose Trend Summary (continued)

Radionuclide	Trend Summery		
	NUREG/CR-1759 to NUREG/CR-4370	NUREG/CR-4370 to ICRP-60	NUREG/CR-1759 to ICRP-60
Pu-239	↑	↓	↑
Pu-241	↑	↑	↑
Am-241	↑	↓	↑
Cm-242	NA	↓	↓
Cm-243	↑	↓	↑

This investigation has demonstrated that using updated DCFs with the IMPACTS computer code results in changes to the dose computed in the exposure scenarios for some radionuclides. It is therefore possible that the doses for postulated scenarios would also change. This suggests that a reexamination of the concentration limits for the radionuclide content of radioactive waste is appropriate.

The ICRP has proposed updated biological models as described in ICRP-103. (17) Their current effort is to revise dose conversion factors for calculation of external and internal dose. These updated DCFs will be available within the next several years. The effect of these changes may be further justification for updating the radionuclide concentration limits in 10 CFR 61.

7
AFFECT ON WASTE CLASSIFICATION TABLES

The radionuclide concentrations in the waste classification tables in 10 CFR 61.55 would be expected to change based on the adjustments in the dose due to the differences in the DCFs. It should be noted, however, that the radionuclide concentration limits published in 10 CFR 61 did not completely correspond to values resulting in doses at the performance objectives. For some of the scenarios considered, doses from the original published concentrations were an order of magnitude or more below the dose performance objectives. In addition, conservative assumptions were made in some cases that were not supported by facts and significantly skewed results. As an example, for the western site, it was recognized that while water infiltration may in fact never occur; the site was modeled with an assigned percolation rate with the result that radionuclide concentrations calculated for this site become the limiting concentrations. These conservatisms provide weight to an argument against indiscriminate changes to the radionuclide concentration limits. (16)

The ratios of the dose computed using ICRP-60 based DCFs to the dose computed using the NUREG/CR-1759 DCFs were used to compute new values for the limits in 10 CFR 61. Changes to 10 CFR 61.55 Table 1 regulatory limits are shown in Table 7-1, and changes to 10 CFR 61.55 Table 2 are shown in Table 7-2.

Table 7-1
Code of Federal Regulations Title 10 Part 61 Table 1

Radionuclide	Value (Ci/m^3)	New Value (Ci/m^3)
C-14	8	2
C-14 in activated metal	80	20
Ni-59 in activated metal	220	3300
Nb-94 in activated metal	0.2	0.29
Tc-99	3	0.14
I-129	0.08	0.024
Transuranics w/ $T_{1/2}$ > 5 yr	100	8.7
Pu-241	3500	500
Cm-242	20000	21000

Affect On Waste Classification Tables

Table 7-2
Code of Federal Regulations Title 10 Part 61 Table 2

Radionuclide	Value (Ci/m^3)			New Value (Ci/m^3)		
	Class A	Class B	Class C	Class A	Class B	Class C
T1/2 < 5 yr	700	*	*	NC	*	*
H-3	40	*	*	65	*	*
Co-60	700	*	*	1000	*	*
Ni-63	3.5	70	700	24	490	4900
Ni-63 in activated metal	35	700	7000	240	4900	49000
Sr-90	0.4	150	7000	3.5	1300	61000
Cs-137	1	44	4600	1.5	65	7100

* No value for these radionuclides, NC = No calculation performed for T1/2 < 5 yr radionuclides

No limit was computed for the radionuclides with half-lives less than 5 years. The concern for these radionuclides is primarily an external radiation exposure for which the DCF change is minimal and does not typically control waste classification. The limit for transuranic radionuclides with half-lives greater than five years was computed based on the radionuclide with the largest calculated increase in dose. The new limit would decrease less if computed individually for the other transuranic nuclides or if the calculation were based on the average change of all of the transuranic radionuclides included in this group.

8
AFFECT ON CURRENT WASTE STREAMS

In developing the source term for power plant process wastes, EPRI collected shipping records from its members. About 65% of US plants participated by providing data to the effort. The data used covered a 4-year period, 2003 through 2006. (18) A review of the average DAW radionuclide concentrations presented in this EPRI report concludes that DAW would likely not be significantly affected by 10 CFR 61.55 classification table changes as identified in this report. However, the effects of changes to the classification tables on filter and resin waste streams are of some interest.

In general, the 10 CFR 61.55 Table 2 limits increased and the 10 CFR 61.55 Table 1 limits decreased. This has the effect of decreasing the importance of Cs-137, Sr-90, and Ni-63 in the classification of wastes. The importance to waste classification of C-14 and Tc-99 is increased significantly along with the transuranic radionuclides.

Filter wastes tend to be low volume, but they make up a large portion of the Class C waste generated. For BWRs, the filter waste stream is dominated by the transuranic actinides (TRU) fraction with significant contributions from C-14 and Tc-99. Future waste classification could be significantly affected by the changes suggested here with more filters with a waste classification of C or greater. (18)

For PWR filters, the importance of Ni-63 and Cs-137 for waste classification would be diminished significantly by the higher limits for Table 2 radionuclides. While the transuranic radionuclides would remain significant, the waste classification would be dominated by C-14 and Tc-99 to the point that PWR filters would potentially be, on average, Class C waste.

Table 8-1
Filter Waste 10 CFR 61.55 Table 1 Classification Summary

BWR Filters (Class A)		
Radionuclide	**10 CFR 61 Average Fraction**	**New Value Fraction**
TRU	0.048	0.55
Pu-241	0.011	0.076
Tc-99	0.0063	0.135
C-14	0.025	0.1
Table 1 sum of fractions	0.09	0.86
PWR Filters (Class A)		
Radionuclide	**10 CFR 61 Average Fraction**	**New Value Fraction**
TRU	0.085	0.98
Pu-241	0.036	0.25
Tc-99	0.23	5.02
C-14	0.36	1.42
Table 1 sum of fractions	0.71	7.67

For BWR resins, on average, the waste is Class A with 10 CFR 61.55 Table 2 being the most significant to waste classification. (18) With these proposed changes the average classification fraction for 10 CFR 61.55 Table 2 drops to less than half of the previous fraction of the Class A limit. The 10 CFR 61.55 Table 1 limit sum changes from an insignificant fraction of Class A to over fifty percent of the Class A fraction.

For PWR resins, the effect of raising the 10 CFR 61.55 Table 2 limits is dramatic with the waste dropping below the Class A limit on average. Although the Cs-137 concentration remains as a significant contributor to the waste classification fraction, the drop in Ni-63 and Sr-90 brings the average activity to Class A. For the 10 CFR 61.55 Table 1 radionuclides, the initial average fraction is quite low. After adjustment of the sum of fractions for the increased 10 CFR 61.55 Table 1 limits, the waste is just over 60% of the Class A limit on average. (18)

In general these changes facilitate the disposal of significant quantities of ion exchange resin as Class A versus Class B without altering the disposal site dose hazard.

Table 8-2
Resin Waste 10 CFR 61.55 Classification Summary

BWR Resins (Class A)		
Radionuclide	**10 CFR 61 Average Fraction**	**New Value Fraction**
Cs-137	0.25	0.166
Sr-90	0.10	0.012
Table 2 Sum of Fractions	0.39	0.18
TRU	0.029	0.33
Pu-241	0.007	0.05
Tc-99	0.0048	0.103
C-14	0.019	0.077
Table 1 sum of fractions	0.06	0.56
PWR Resins (Class A)		
Radionuclide	**10 CFR 61 Average Fraction**	**New Value Fraction**
Cs-137	1.2	0.80
Sr-90	0.76	0.086
Ni-63	0.15	0.021
Table 2 sum of Fractions	2.1	0.906
TRU	0.018	0.20
Pu-241	0.008	0.056
Tc-99	0.007	0.15
C-14	0.047	0.19
Table 1 sum of fractions	0.08	0.60

While this analysis shows a moderate impact for the changes to the 10 CFR 61.55 Table 1 limits, this conclusion should be viewed with caution. This analysis considered average activity levels; higher activity resin and filter wastes are expected to be more significantly affected. In addition,

classification is often controlled by the radionuclides with the most suspect analytical data that are also the radionuclides with the most affected limits. Tc-99 and C-14 are often reported at lower limits of detection (LLDs), and these LLD values may then be used in waste characterization as real values. In other cases, the activity of these radionuclides may be calculated as ratios to gamma emitting radionuclides without an adequate validation of the correlation within the assigned radionuclide pair. If this occurs, it may be more accurate to quantify these radionuclides as a constant concentration at the LLD level. In many situations, this would significantly lower the reported activity of these radionuclides.

9
CONCLUSION

This report examined the evolution of dose conversion factors and the affect that these have on the radionuclide concentration limits in 10 CFR 61.55 using the dose computation methods of the IMPACTS computer program. Dose conversion factors from ICRP-2 corresponding to the development of 10 CFR 61 were compared to dose conversion factors from ICRP 26/30 and ICRP 60/72.

Use of the more recent dose conversion factors with the IMPACTS program results in changes to the computed doses from the radionuclides used for waste classification. For some radionuclides the doses have increased. More radionuclides, including many of those important to waste classification, indicate a decrease in computed dose. The magnitude of the changes indicates that it is appropriate to modify the concentration limits in 10 CFR 61.55 Tables 1 and 2 to reflect the changes in the DCF for each radionuclide.

The overall effect on utility waste generation, if changes are implemented as discussed in this report, would cause a negligible change in Class A DAW, a reduction in Class B resins, and a potential increase in Class C Cartridge filters (especially in plants with high reported C-14 activity or significant fuel defects). Improvements to the accuracy with which C-14 and transuranic radionuclide activities are developed would likely mitigate any detrimental effects on waste classification.

10
REFERENCES AND BIBLIOGRAPHIES

References

1. **U.S. Nuclear Regulatory Commission.** Licensing Requirements for Land Disposal of Radioactive Waste. *Code of Federal Regulations, Title 10 Part 61.*
2. **Brookhaven National Laboratory.** Chart of the Nuclides. *National Nuclear Data Center.* [Online] 2013. http://www.nndc.bnl.gov/chart.
3. webelements. *Periodic Table.* [Online] 2013. Http://www.webelements.com.
4. **Oztunali, O.I. et. al.** Data Base For Radioactive Waste Management IMPACTS Analysis Methodology Report. *NUREG/CR-1759.* 1981. Vol. 3.
5. **ICRP.** Report of Committee II on Permissible Dose From Internal Radiation. *ICRP-2.* 1959.
6. **Houston, J.R. et.al.** DACRIN - A Computer Program for Calculating Organ Dose From Acute or Chronic Radionuclide Inhalation. 1974.
7. **US Nuclear Regulatory Commission.** Age Specific Radiation Dose Commitment Factors for a One Year Chronic Intake. *NUREG-0172.* 1977.
8. **Oztunali, O.I.** Update of Part 61 IMPACTS Analysis Methodology. *NUREG/CR-4370.* 1986. Vol. 1.
9. **ICRP.** Recommendations of the International Commission on Radiological Protection. *ICRP Publication 26.* 1977.
10. **ICRP**. Limits for Intakes of Radionuclides by Workers. *ICRP Publication 30.* 1979.
11. **Yu, C. et.al.** ANL/EAD-4. *User's Manual for RESRAD Version 6.* 2001.
12. **ICRP.** 1990 Recommendations of the International Commission on Radiological Protection. *ICRP Publication 60.* 1991.
13. **ICRP**. Age-Dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients. *ICRP Publication 72.* 1995.
14. **Eckerman, K.F. et.al.** Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion. *Federal Guidance Report No. 11.* 1988.
15. **Eckerman, K.F. and Ryman, J.C.** External Exposure to Radionuclides in Air, Water, and Soil. *Federal Guidance Report No. 12.* 1993.
16. **U.S Nuclear Regulatory Commission.** Draft Environmental Impact Statement on 10 CFR 61 "licensing Requirements for Land Disposal of radioactive Waste." *NUREG-0782.* September 1981.
17. **ICRP.** Recommendations of the International Commission on Radiological Protection. *ICRP-103.* 2008.
18. **EPRI.** An Evaluation of Alternative Classification Methods for Routine Low Level Waste from the Nuclear Power Industry. *Report 1016120.* November 19, 2007.

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