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Proposed Modification to the NRC Branch Technical Position on Concentration Averaging and Encapsulation (BTP)

Technical Bases and Consequence Analysis

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REPORT SUMMARY

Disposal of low-level radioactive waste in the United States has changed significantly with the loss of Class B and C disposal access for ~85% of U.S. nuclear power plants. Waste processing and disposal methods and radiation exposure modeling methods as well as significantly different economic considerations exist that were not envisioned during the development of existing regulations and guidance documents. To promote increased disposal options, this report evaluates alternatives to current waste classification guidance.

Background

With the recent closure of the Barnwell disposal site to out-of-compact waste, the United States has gone from six operating, nationally accessible disposal sites in the 1970s to a single site in 2008. The one available site is restricted to the lowest-activity wastes. The majority of plants will be forced to store some of their low-level radioactive waste (LLRW). The Electric Power Research Institute (EPRI), as part of a broader set of initiatives to develop management options for Class B and C LLRW, is investigating potential regulatory changes that will help to more consistently classify LLRW on the basis of understood risks. These include changes to criteria for concentration averaging for packaging LLRW from various sources and concentration levels. In parallel, the Nuclear Regulatory Commission (NRC) has undergone a strategic reassessment of issues and priorities related to LLRW disposal. The reassessment identified revisiting the NRC Branch Technical Position (BTP) on concentration averaging and encapsulation as an early priority.

Objectives

To clarify issues related to the BTP position and develop recommendations for specific changes to the BTP.

Approach

Using data collected in 2007 in support of EPRI report 1016120, *An Evaluation of Alternative Classification Methods for Routine Low-Level Waste from the Nuclear Power Industry*, the project team further investigated potential changes in applying the NRC BTP on concentration averaging and encapsulation. Proposed changes in averaging criteria as they apply to homogeneous waste streams are investigated using the RESRAD computer program along with direct calculations using Microshield™. To address specific questions, data related to non-utility waste generation were collected from the Manifest Information Management System (MIMS) maintained by the Department of Energy. The impacts of non-utility wastes were evaluated by combining the streams in a common disposal environment and evaluating the resultant mixture

with additional RESRAD cases. A further review of regulatory requirements, positions, and operational commitments of operating disposal sites, their states, and other government agencies was made using public information to determine programmatic impacts. Information was collected from Internet sources.

Results

The proposed changes to the BTP include 1) establishing a more consistent overall basis for averaging following the original bases for 10 CFR Part 61, 2) relaxing 10 averaging restrictions on homogeneous wastes placed in containers, 3) averaging the volume of contained materials classified as cartridge filters and activated metals in a manner similar to dry active waster (DAW), and 4) eliminating 1.5 averaging constraints on Nb-94 in activated metals. These changes will provide a more flexible basis for classification, reduce disposal cost, and reduce or eliminate storage requirements on an industrywide basis while maintaining the level of risk of disposal within currently accepted standards.

EPRI Perspective

NRC adoption of the proposals described in this report will provide the nuclear industry with a disposal pathway for the majority of low-level waste that must currently be stored on-site. The analysis performed in this study proves that even with the modifications proposed, performance objectives for the disposal site would still be met. Future research efforts to expand the availability of disposal options will focus on using 10 CFR 61.58 to provide more risk-informed guidance for waste disposal.

This report will benefit persons actively involved in the processing, management, and disposal planning of LLRW in power plants. It also will benefit persons involved in design and licensing of new reactor facilities currently announced by a number of plant operating companies. Currently, it is envisioned that up to 90% of the activity in LLRW will need to be stored on-site. Reductions in the amounts of material and activity that would have to be stored would significantly extend the storage time frames of existing facilities.

Implementation of these proposals depends on a favorable NRC interpretation. This would provide a technical basis for state regulators to follow the lead of the NRC. Without NRC endorsement, state regulators would have to make an independent finding without benefit of a pre-established position. The NRC has indicated that they have limited internal resources to address LLRW issues. The NRC has further indicated, at the commissioner level, that they hope to leverage the work performed by the industry in these matters.

It is important for the industry to take a pro-active position in the resolution of LLW disposal to reduce or preclude storage of materials on-site and to reconstruct the regulatory framework to facilitate disposal in existing venues as well as to develop new disposal venues.

Keywords

Low-level radioactive waste
Branch technical position
Concentration averaging
10 CFR part 61
Waste disposal

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INTRODUCTION

The storage of Class B and C low level waste streams due to limited availability of disposal capabilities has been become a concern for both the nuclear power industry and material licensees. The absence of new low-level waste (LLW) disposal facilities and the closure of the Barnwell, SC disposal facility to out-of-compact waste have prompted the Electric Power Research Institute (EPRI), the Nuclear Energy Institute (NEI), and the NRC to take steps to reduce the impact of the closure on affected nuclear power plants.

EPRI's response included the development of process improvements aimed at reducing the generated volumes of Class B and C waste; revisiting issues surrounding storage of low-level waste at plant sites to assure safe, viable long-term storage; and reexamining the regulatory framework for LLW disposal classification criteria to promote more cost-effective and risk-informed waste disposal options.

The NRC's response included a strategic assessment[1] of the LLW regulatory program. In this assessment, the NRC identified seven high priority improvement activities that they intended to undertake. Two tasks in the list of seven addressed the need to update the Branch Technical Position (BTP) on Concentration Averaging and Encapsulation and develop a Guidance Document on Alternate Waste Classification (10 CFR Part 61.58). The NRC, NEI, and EPRI have all recognized the need to address some of the issues surrounding the classification of LLW to provide for the continued availability of disposal capacity for the nuclear power industry.

The EPRI LLW Disposal Classification initiative was started in parallel with the NRC's strategic assessment with the identification of similar issues. The EPRI initiative began with the simple observation that the regulatory criteria provided in the 10 CFR Part 61 had been developed almost 30 years ago as a generic licensing basis for regional disposal facilities. The NRC was directed under the LLWPA to develop these criteria and based them on knowledge, technology, and practices in use at the time. Since then, no new facilities have evolved from this act, and current disposal practices utilized at the current operating sites provide greater intruder protection barriers than originally envisioned in the Environmental Impact Statement (EIS) for 10 CFR Part 61[2]. EPRI, working with the Nuclear Energy Institute (NEI), determined that a thorough review of the bases for 10 CFR Part 61 and other guidance governing LLW classification and disposal was warranted.

[1] SECY-07-180, U.S. Nuclear Regulatory Commission, October 17, 2007.

[2] The Draft Environmental Impact Statement (NUREG-0782), DEIS, contained supporting analyses which were incorporated by reference into the Final Environmental Impact Statement (NUREG-0945), FEIS. The two documents, together, form the overall Environmental Impact Statement for 10 CFR Part 61.

Two of the major initiatives in EPRI's current research plan follow directly from the NRC's strategic assessment: first, provide input and supporting analysis to support the NRC review of the Branch Technical Position on Concentration Averaging, and second, provide input and supporting analysis to the NRC for the development of a guide for implementing a 10 CFR Part 61.58 request for developing alternative site-specific disposal classification and characterization bases.

In the recently completed EPRI Report 1016120, "An Evaluation of Alternative Classification Methods for Routine Low-Level Waste from the Nuclear Power Industry", in which the fundamental bases for the classification of LLRW were re-evaluated, three conclusions were reached. The first is that the concentration values in Tables 1 and 2 of 10 CFR Part 61.55 are based on a disposal facility with a two meter cover (i.e., minimum protection depth for Class A waste). This means that all LLRW is being classified based on this level of protection and does not account for disposal facilities providing additional protection such as more comprehensive stability requirements and greater cover depth (e.g. Clive, Utah). Higher concentration limits (a factor of 10) should apply because of the greater protection afforded by these practices. The second conclusion is that the broad range of radionuclide concentrations in waste and the potential for "hot" spots were considered and accounted for in the original dose impact assessments performed in the EIS for 10 CFR 61. This means that the restrictions on radionuclide averaging for classification purposes as contained in the NRC's BTP on Averaging and Encapsulation are not supported and, it can be argued, not justified. The third conclusion is that classification on the basis of a waste volume larger than a single container (i.e., multi-container) should be allowed if the resulting radionuclide concentrations meet the performance objectives of 10 CFR Part 61 (i.e. less than 25 mrem/yr to the general public and less than 500 mrem/yr to the inadvertent intruder). Furthermore, there is no explicit volume basis for classification stated in the regulations or in the Branch Technical Position that would limit the volume used for classification to that corresponding to a single package.

These conclusions suggest three areas which could provide substantial relief to the nuclear industry without compromising the safe disposal of LLW. The first is a revision to the NRC's BTP on Concentration Averaging and Encapsulation to address issues with the BTP that have been identified in the EPRI study cited above. The BTP includes constraints on the mixing of different waste types for the purposes of classification and on the mass and/or volumes of waste that may be included in the averaging calculation. In the EPRI study cited above it was determined that, except for discrete solid materials such as sealed sources or pieces of activated metal, the constraints are not supported by the intruder modeling included in original EIS.

The second area is an initiative proposed by EPRI in 2008 to allow the classification of LLW on a volume basis corresponding to volume assumed to be accessed by the intruder that is used to determine limiting short term exposures. This volume would correspond to a number of packages of varying concentration. Within this scenario, the average concentration in the disposal trench is maintained below the allowable classification limits even though some packages may have higher concentrations. This would allow higher activity waste to be classified for disposal at an appropriate facility. This action could be accommodated by a change in the regulations, as an alternative classification approach under 10 CFR 61.58, or as a revision to the BTP on Averaging and Encapsulation or the issuance by the NRC of a new BTP allowing this classification basis.

The third area, which will be further explored in 2009 and 2010, would be to vary the classification concentration limits for Class A waste in Tables 1 and 2 by factors that reflect the reality that current disposal practices or features at existing facilities provide greater levels of protection for Class A waste. A second set of concentration limits was evaluated and analyzed in the original EIS in support of the rule but were never implemented in this context.

This report will evaluate the radiological consequences of the proposed actions. The overall nuclear power industry waste generation was used as the primary basis for estimating the impacts of various disposal scenarios discussed in this report. However, utility waste makes less than half of the total waste disposed a commercial facilities. As a supplement to this analysis, data was gathered from the DOE maintained Manifest Information Management System (MIMS) to determine the effect of non-utility generated wastes (excluding DOE wastes disposed in commercial facilities) on the overall disposal environment. Effectively, the non-utility generated wastes are comparable in volume to the utility generated wastes but lower in activity. When the utility and non-utility wastes are combined in the disposal site, the performance assessment calculation results in estimated dose rates 43% lower than when utility wastes are evaluated by themselves. The generation and impacts of the non-utility wastes is discussed in Chapter 7 .

Discussion is added to the report in Chapter 8 to address the stakeholder issues with the classification for disposal. Some small impacts could be envisioned to Federal Government and State agencies in the context of having to revisit published rules and positions which could entail some significant analytical effort. Such impacts are very small in contrast to the loss of a disposal venue for certain institutional wastes as well as the need for storage of the bulk of the activity in LLRW at plant sites.

2
10 CFR PART 61 BACKGROUND

Published in 1983, 10 CFR Part 61[3] outlines regulatory requirements for low level radioactive waste disposal facilities. The underlying disposal concept for the regulations is near surface disposal in shallow trenches. The envisioned disposal sites would be set below grade with inherent separation from the water table to provide protection to the general public. Intruder protection is provided for by waste segregation and barriers. The intruder barriers are provided by stabilization of wastes through solidified waste forms or high integrity containers or by increased cover requirements. Wastes are selected for segregation or stabilization based on a system of classification that separates lower activity wastes from higher activity wastes. Wastes at the lowest classification, Class A, are assumed to be placed in a segregated trench with two meters of cover and do not require stabilization. Class A wastes cannot be mixed with higher class wastes unless they are stabilized and packaged in a manner equivalent to the higher class wastes. Class B wastes must be stabilized but still only require 2 meters of cover. The highest classification wastes, Class C, must meet all of the requirements of Class B wastes but also require 5 meters of non-radioactive cover material.

The classification system is based on concentration limits for long-lived radionuclides determined to be prominent in the waste streams. These were identified in a comprehensive source term assessment completed for the EIS. The concentration limits, in turn are based on limiting radiation exposures to unsuspecting intruders in the disposal site at varying times after closure of the disposal site when institutional control is no longer maintained. Figure 2-1 highlights the protection time frames provided by the intruder barriers. The initial barrier applicable to all wastes is institutional control which is assumed to be maintained for 100 years. Waste stabilization, by solidification or high integrity containers, extends the time to 300 years. This is based on the assumption that the waste will remain intact and the intruder will discover that it is not just soil. Deeper disposal depth extends the time frame to 500 years. At this point there is minimal concern with Table 2 isotopes since all have decayed to insignificant levels. The remaining Table 1 isotopes are limited to concentrations that assume eventual loss of protection.

[3] Title 10 U.S. Code of Federal Regulations, Part 61 Licensing requirements for Land disposal of Radioactive Waste.

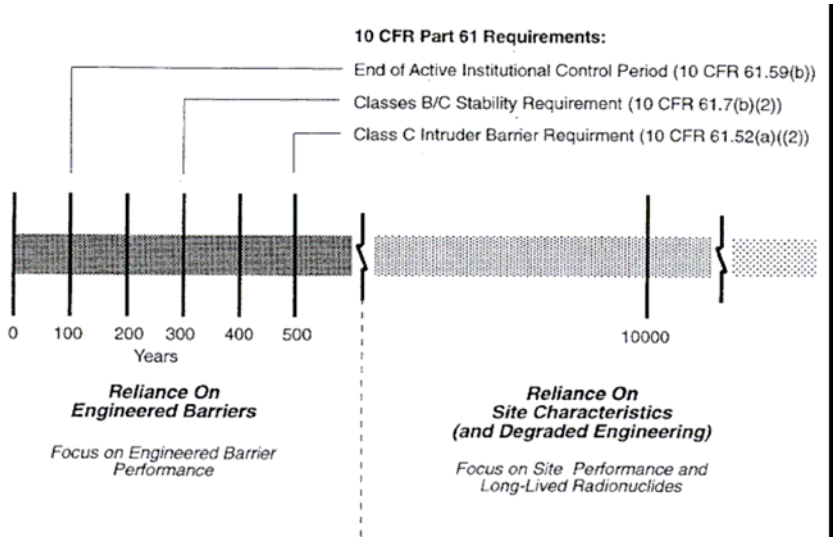

Figure 2-1
Time frames to be considered in an LLW performance assessment (taken from NUREG-1573)

The basic intruder scenarios considered in the EIS were those associated with a person or persons homesteading directly on top of the disposal site. The intruder is assumed to excavate into the waste layer for the purpose of constructing a residence (construction scenario). The excavated waste, mixed with soil, is spread in a confined area surrounding the residence. The intruder then lives in the house and maintains a garden in the contaminated soil (agriculture scenario) from which the intruder both consumes food from the garden and uses it for animal feed.

The earliest intrusion corresponds to the assumed duration of institutional controls which was conservatively set at 100 years. This intrusion is limited to the unstabilized and segregated Class A material. Since the stabilized material is assumed to be still intact, the intruder would recognize it from soil and stop excavation.

The classification system is fundamental to the intruder protection model developed in the DEIS. The system sets the scope and the time frame under which various wastes are accessed by the intruder. It is also very specific to the disposal model developed in the DEIS and upon which 10 CFR Part 61 is written.

Present day practice of LLW disposal tends to be much more conservative than that envisioned in the DEIS and the regulation. This is manifested in the use of concrete liners and covers on the segregated Class A wastes, generally deeper soil covers, placement of higher activity materials in layers underneath lower activity materials, and extensive use of reinforced concrete vaults and structures in the disposal site that protect the waste containers and provide additional assurance of site stability. In addition, current commercial disposal sites require the stabilization of Class A wastes above a certain threshold of long-lived gamma activity but well below the Class A limits for the same isotopes. Figure 2-2 shows a high integrity container being placed in a concrete vault at the Barnwell site. Once the vault is filled a concrete cap will cover the top. The effect of these practices is to reduce the importance of the classification system of 10 CFR Part 61. Since Class A wastes are stabilized and disposed in the same manner as Class B and C waste, the relevance of the intruder scenarios is reduced.

Figure 2-2
Barnwell disposal vaults (EnergySolutions/Chem-Nuclear Systems, Inc)

In the development of the source term for the DEIS, operational wastes from nuclear power plants were separated into two groups; dry active wastes (DAW) and liquid processing wastes (process wastes). For the purpose of their evaluations, it was assumed that all of the DAW was disposed as segregated Class A waste at average concentrations. The process wastes were assumed to be stabilized and placed separately as primarily Class B wastes. Individual radionuclide concentrations were determined on the basis of geometric means of data collected in constructing the source term for the DEIS. The actual ranges of data observed were not presented in the DEIS, use of geometric means, however, implies that the ranges of activities used to determine the average concentrations were much more than a factor of 10 on either side of the average. (The geometric mean is an estimate of the median value which tends to diminish the impact of extreme values that could strongly affect the arithmetic average.)

The EIS was supplemented with an exhaustive examination of the various streams, volumes and activities of low level waste from all sources including industrial, medical, reprocessing, as well as the commercial nuclear power industry. While a broad range of calculations were performed to examine potential exposure pathways from a waste facility, the ultimate concentration limits specified in 10 CFR Part 61 were derived from exposures that might be received by a future intruder unaware of prior uses of the site and unable to distinguish material in the site from ordinary soil. It was assumed in the studies that an institutional control period of 100 years would follow the site closure. The intrusion is assumed to occur just following the end of the institutional control period. It was noted that the intruder scenarios are dependent almost exclusively on the concentrations of the radionuclides available for uptake and as such intruder exposures were not particularly site specific. The EIS set 500 mrem/yr as a maximum allowable exposure for the inadvertent intruder.

EIS Intruder Scenarios[4]

Two general concentration-limited inadvertent intrusion scenarios were considered in the EIS:

1. Excavation into disposed waste or construction of a house or building at the disposal-facility (Intruder-Construction); and
2. Living on and consuming food grown at the disposal facility (Intruder-Agriculture).

Within each scenario a number of exposure pathways were considered including:

- Inhalation of contaminated dust from construction activities
- Inhalation of contaminated dust by someone living on the disposal facility
- Consumption of contaminated water from an onsite well
- Consumption of food grown on contaminated soil
- Direct gamma irradiation to construction worker
- Ground water transport of radionuclides to a river
- Sheet erosion of waste to river

Direct gamma radiation dominated the intruder exposure in both scenarios. The inhalation of contaminated dust and direct gamma radiation provided a secondary exposure in the construction scenario. In the agriculture scenario, the secondary contributions came from consumption of food grown in contaminated soil.

The intruder-construction scenario involves the assumed construction of a house directly into the disposed waste. During construction activities, some of the waste is assumed to be contacted by the workmen (this could happen, for example, through construction of a basement). During construction, some of the waste is assumed to be dispersed into the air and onto the immediate area around the-house.

The second scenario involves a potential situation in which an individual or individuals live in the house thus constructed. In addition to the exposure pathways for the construction case, the potential intruder could be exposed through consumption of food grown in the contaminated soil. The length of time that the individuals would spend in the contaminated area would be greater for this scenario than for the intruder-construction scenario. This scenario is referred to as the intruder-agriculture scenario.

A subset of the intruder construction scenario discussed in the EIS, is the intruder discovery scenario with reduced relative impacts. For the above two scenarios to be in any way plausible, it is necessary to assume that the waste is indistinguishable from dirt. In the discovery scenario it is assumed that the waste is stabilized into a form that would be recognizable for 300 years. The intruder would be deterred by the discovery of the identifiable waste forms and would suspend excavation to investigate the origin of the material.

[4] DEIS, Volume 2, Section 4.2.2.

Branch Technical Position

The Branch Technical Position on Concentration Averaging and Encapsulation (BTP) reinforces the classification system developed in the 10 CFR Part 61 without acknowledging current disposal practices. It starts from a premise that the EIS did not adequately account for the variability in the activity concentrations in various waste streams in its intruder assessments. To address the issues arising from this premise, the BTP places conditions on how averaging is conducted within containers for the purpose of determining classification. The methodology of the BTP is described by the authors as a "*subset*" of acceptable practices and that other methods may be considered acceptable if they can be demonstrated to meet the performance objectives of 10 CFR Part 61. However, the BTP methods have become the *de facto* methodology since obtaining approval for alternatives via the 10 CFR Part 61.58 process is labor intensive and not well defined.

The principal impact of the BTP has increased the complexity of waste classification analysis. However, it is not clear if the BTP has resulted in restricted classification at the upper end such as to increase the incidence of GTCC liners. There has also been little concern with the impact of concentration averaging at the low end since there has been a disposal venue for Class B and C wastes and it has made little or no practical difference if the waste is Class A or B, there has been little concern with the impact of averaging at the low end. With the closure of the Barnwell disposal site, there is an imperative to look at the impact of the averaging constraints at the low end of the classification scheme.

3
BTP ISSUES

Purpose of the Branch Technical Position

The "Branch Technical Position on Concentration Averaging and Encapsulation" was published as a revision in part to the original position[5] on waste classification. The BTP, as revised, defines a subset of concentration averaging and encapsulation practices that the NRC staff would find acceptable in determining the average concentrations of the tabulated radionuclides in 10 CFR Part 61.55 in low-level waste. The revisions to the BTP were primarily driven by concerns within the NRC and disposal site regulators relating to the adequate disposal of discrete items such as radioactive sealed sources (mainly gamma sources) and activated hardware that are potentially susceptible to not only intrusion events, but also to what was termed a "handling" event. The concept of discrete items with high concentration radioactivity is central to the concerns addressed by the BTP. In the "handling" scenario it is hypothesized that an individual could, at some point in the future (after the lifting of all institutional controls[6]), retrieve a sealed source or a small portion of an activated metal component and display or maintain it in a location where he would be exposed to it for a relatively long time (2360 hours/yr). This potential exists because of the durability of the metals used for sealed sources and reactor components (e.g., stainless steel, high nickel alloys) which could exceed several hundred years.

The BTP:

- Defines "acceptable practices" for determining concentrations of 10 CFR Part 61.55 nuclides in waste packages
- Addresses concern over the control of discrete items (i.e. sources)
- Assures "compliance" with 10 CFR Part 61 disposal concentration limits by extending applicability to other (non-discrete) waste types
- Provides for additional intruder protection that was not specifically addressed in EIS (introduces an Intruder "handling" scenario)

[5] The original position was included in the 1983 "Branch Technical Position on Classification" which was published concurrently with 10 CFR Part 61.

[6] Institutional controls generally refer to the maintenance of supervision of the site after closure. This could include periodic security monitoring and maintenance of fences and signage.

Some well publicized incidents[7] in the late 1980s underscored the need for rules governing the disposition of sealed sources. These events notably related to the loss of control of sealed sources such that they ended up in the hands of persons unaware of the danger from the sources. The problems stemmed from the abandonment of equipment containing the sources or loss of records on stored sources. The events highlighted the importance of source recordkeeping and provisions for the disposition of the sources when they are no longer needed. It was important that sources be properly classified for disposal to provide adequate encapsulation that was resistant to human intrusion and scavenging. The general concern was that the source could be disposed with a larger volume of low activity waste at a lower classification. The radiation from the source would be shielded by the larger volume and it could be disposed with the segregated, unstable waste where it would potentially be retrievable by a scavenger in the disposal site.

The principle contribution of the BTP update is to introduce the handling scenario as a regulatory basis for the disposal of radioactive waste. There was no comparable scenario defined in the DEIS or the FEIS for 10 CFR Part 61. The handling scenario as it is defined in the BTP pertains specifically to items of high specific activity that are small enough to be easily handled by an individual. Larger items, contaminated items, ion exchange resins, filter media – basically everything else falls under the scope of the intruder-agriculture and intruder-construction scenarios which were considered and evaluated in the EIS studies.

Identification of BTP Issues

Beyond the discrete item scenarios, there was no need for the additional restrictions imposed by the BTP on homogeneous waste since the risk evaluations always refer back to the original intruder scenarios. Instead, the issues addressed in the BTP could have been represented more directly. A specific set of disposal restrictions on sealed sources could have been specified (as was done at Barnwell) up to excluding them entirely from near surface disposal (as done at Clive). All other material would be acceptable for near surface disposal without regard to adjacent material providing that the disposal site concentration limits were maintained. Averaging would be based on the contents of the package without applying arcane formulas that have no connection with protection provisions of 10 CFR Part 61.

Some basic inconsistencies between the BTP and 10 CFR Part 61 are:

- The BTP only refers to an averaging volume based on individual package whereas the EIS for 10 CFR Part 61 evaluated the volume for concentration averaging as that potentially excavated by an intruder which could be equivalent to up to 232 m^3 which could be represented by a collection of packages.
- The BTP limits averaging to a factor of 10. 10 CFR Part 61 places no similar constraints. By placing an upper bound on the concentration allowed for averaging, the BTP condition acts to exclude a small volume of material for which there is no defined disposal venue.

[7] http://en.wikipedia.org/wiki/Goi%C3%A2nia_accident, Goiâna Accident, Wikipedia, The Free Encyclopedia.

- The BTP segregates particular waste types for averaging. In the EIS for 10 CFR Part 61, only DAW was segregated from other streams and only segregated on the basis of stability.
- The BTP attempts to further the definition of “greater-than-Class-C” which was not identified or defined in the context of these same sets of waste streams in 10 CFR Part 61.

The effect of these inconsistencies is to arbitrarily increase restrictions on disposal of some wastes beyond the requirements and limitations already evaluated in the EIS.

Identification of BTP Clarifications

In order to resolve the inconsistencies identified above and to bring the generally accepted practices for waste classification more in line with the original intent of the regulation, several areas of the BTP should be evaluated and clarified. Areas of the BTP which require clarification include;

- The volume basis for classification and the basis for the prohibition on mixing for classification purposes
- Averaging restrictions as applied to homogeneous waste types
- Cartridge filters as discrete items
- Reference volume for averaging activated metal components
- Applicability if the Handling Scenario to waste type othe than sealed sources
- Factor of 1.5 applied to concentration averaging for Nb-94

These are addressed further in the following Section.

4
ADDRESSING THE BTP ISSUES

Increased Averaging Volume (Multi-Container Classification)

Averaging for classification according to the BTP is limited to material contained within the boundaries of a container. It is proposed to broaden the basis for averaging to a volume consistent with the EIS intruder scenarios (232 m^3)[8].

The BTP does not address nor restrict averaging wastes between generators. Given that the BTP only deals with averaging inside of an individual container and affects classification at that level it generally precludes broader averaging except in cases where the waste is comingled by a third party processor. Conceivably, if a collection of packages meet the disposal site limits, the contents of the packages without consideration of container boundaries would meet the disposal site limits and would not result in increased risk beyond what was considered in the design of the disposal site. Therefore, classification could be assigned to all of the packages on the basis of the entire collection.

The issue of multi-container classification was the focus of EPRI Report 1016120[9], published in 2007. A comprehensive survey of waste generation from nuclear power plants currently operating was performed to obtain a current and realistic representation of waste volumes and activities by major stream. Building on the premise that intruder risk is determined on the basis of the average concentrations in the disposal site, the report demonstrated that if averaging were performed over the volume of material encountered by the intruder during construction and agricultural activities the classification would extend to the equivalent of 50 120 ft^3 liners. These would be concurrently classified without taking exception to the factor of 10 constraint of the BTP. Effectively, rather than restricting classification to 1 package, 50 packages would be simultaneously classified and transferred as a block to the disposal site. By keeping the packages together, the potential for locally exceeding disposal limits would be avoided. This practice would enable an increased volume of material to be classified as Class A and substantially reduce the amount of waste that would have to be stored following Barnwell closure. All packages in the block of packages would be tagged as Class A at the generator site. Additional processing and blending would not be required. The evaluation performed in EPRI Report 1016120 looked at varying cases of material combinations including separate cases involving resins, filters, and DAW. Figure 4-1 shows the impact of multi-container characterization for ion exchange resins. In this case the amount of waste that would have to be stored at plant sites would be reduced by almost two-thirds.

[8] DEIS, Volume 4, p.G-58.

[9] *An Evaluation of Alternative Classification Methods for Routine Low-Level Waste from the Nuclear Power Industry.* EPRI, Palo Alto, CA: November 2007. Final Report 1016120.

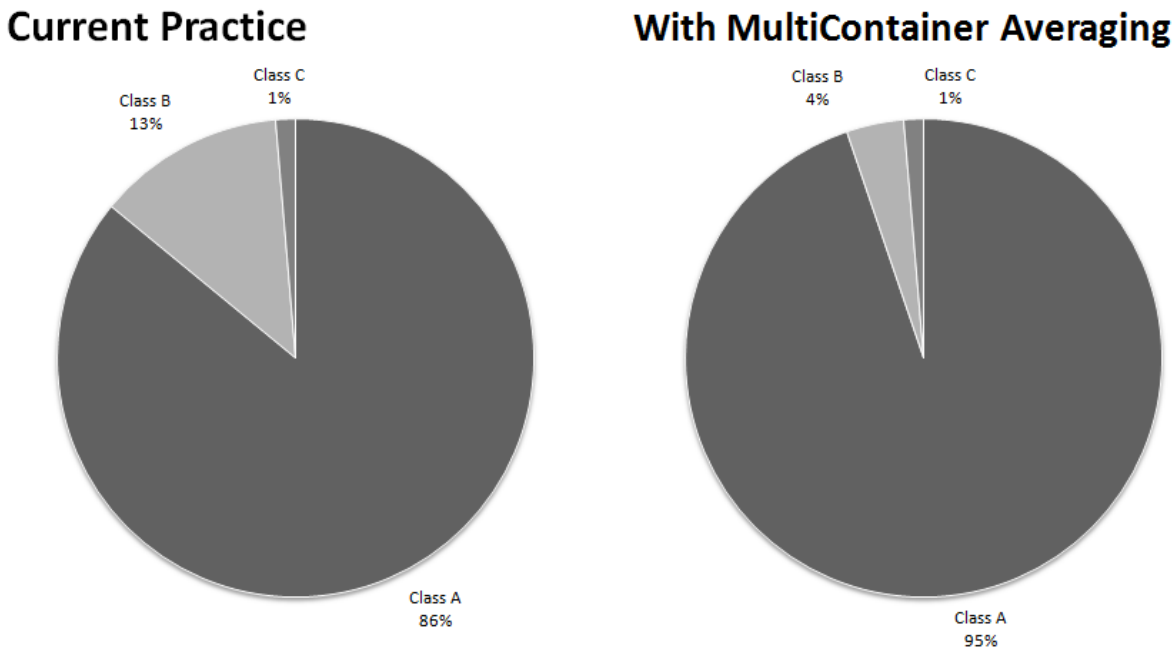

Figure 4-1
Impact of multi-container averaging (resin-only case)

In the EIS, particular waste streams were evaluated with the basic intention of determining their acceptability for near surface burial. Waste streams associated with power production were assigned to particular conditions of disposal on a blanket basis. DAW was evaluated on the basis that the waste would be unstabilized and segregated from stabilized waste at disposal with the least amount of cover material. Resin and filter waste was evaluated on the basis that the waste would be stabilized. The activity content and distribution in these wastes, on average, did not mandate deeper disposal to achieve the required performance. The concern behind the establishment of Class A waste was to ensure the physical stability of the disposal cell for the higher activity waste. Once stability is achieved, then segregation of waste becomes irrelevant since the average concentration of the mixture will meet the performance objective.

During the 1980s, the disposal site regulators effectively established another waste class by imposing stability requirements on Class A waste where the activity concentration approaches the limit. (Stable Class A was recognized in the EIS as Class A waste that need not be segregated from the Class B or Class C wastes.) What the Stable Class A classification does is blur the dividing line between Class A and Class B. The NRC, in its desire to generalize the BTP, pushed averaging ranges that may be justifiable in relation to Part 61 Table 1 limits (i.e. factor of 10) for Class C wastes to apply to averaging of Part 61 Table 2 limits for Class A wastes. Since any Class A wastes approaching the Table 2 limits would be required to be stabilized, the upper bound for averaging should be the Class C disposal limits. In all cases, the Class A wastes would be disposed as stabilized which would provide sufficiently long intruder protection to eliminate Cs-137 as limiting factor. The logical conclusion is that once stability is achieved, averaging among the waste classes should be allowed since all waste will be in the form necessary to meet the performance objectives. Therefore restrictions to prohibit averaging to reduce waste classification become unnecessary. Table 4-1 lists stabilization criteria for commercial disposal sites.

Table 4-1
Disposal site class A stabilization criteria

Disposal Site	Criteria
Barnwell	> 1 μCi/cc of Gamma emitting activity exceeding 5 years
Richland	> 1 μCi/cc of Gamma emitting activity exceeding 5 years excluding Co-60 +Co-60 Activity/50
Clive	>500 mR/hr contact on the surface of a package must be containerized (Clive does not take performance credit for stabilization) Dose rate limit corresponds to a limit of 0.027 μCi/cc for Co-60 in a 55 gallon drum)

The EPRI generation survey showed that for resin and filter wastes, Class C wastes represented only about 2% of the total volume of these wastes with most of these only marginally exceeding the Class B limits. The entire stream, including all resins and all filters from all power plants, could be advanced as the averaging volume for classification determination. Stream average concentrations could be used to determine the Part 61 Classification and corresponding minimum protection requirements (which are already provided by current disposal practice). Effectively, the entire stream is determined to be suitable for near surface disposal. Average concentrations in the disposal trench could be shown to meet corresponding disposal concentration limits without further consideration of classification and without applying a particular volume constraint.

Eliminate Averaging Constraints on Homogeneous Materials

A homogeneous waste type as defined in the BTP is one that was “likely to approach uniformity in the context of the intruder scenarios used to define the values included in Tables 1 and 2 of 10 CFR part 61.55” (Ref. BTP) Homogeneous wastes include spent ion-exchange resins, filter media, solidified liquid evaporator concentrates, or contaminated soil. The BTP notes that contaminated trash waste may also be considered homogeneous for classification *when placed in containers*. Notably, excluded from this definition are activated metals, contaminated equipment, and cartridge filters. The conditions placed on the basis for classifying homogeneous wastes are unnecessary since the variability associated with these waste streams has already been accounted for in the 10 CFR § 61.55 Table 1 and Table 2 values. Furthermore the driving force behind the BTP was concern related to the disposal of discrete items which are antithetical to homogeneous waste types.

The BTP also stipulates that a collection of homogeneous waste types from within a facility may also be treated as homogeneous if such a collection is created for operational efficiency or occupational dose reduction. The blending, in this case, is not considered mixing. Effectively the resulting stream is viewed as a homogeneous type.

The NRC stated in the BTP that they were concerned that a potential intruder might interact with waste that was not homogeneous in its activity concentrations and hence the need for the guidance in the BTP on averaging for classification. The BTP acknowledged that the 10 CFR Part 61 rule itself as well as the 1983 BTP on Classification allow for concentration averaging over the volume (or weight) of the waste, but then stated that additional guidance was required "because of the different types and forms of low-level waste." It can be inferred from this statement that both the rule and the technical position were not correct in that they did not account for the potential of "hot" spots in the waste. While this may be true for discrete items, which were not specifically addressed in the DEIS and FEIS in a "handling" scenario, the impacts of other non-discrete waste types were accounted for in the original studies. The following excerpt from FEIS[10] explicitly addresses this point.

"Finally, there is the potential for localized areas of higher activity ("hot spots") within waste containers. However, this would tend to be mitigated through averaging areas of higher concentration over areas of lower concentration. When concentration limits are calculated using the waste classification methodology, what is really being established is the average concentration across the volume of waste contacted. This could be several hundred cubic meters of soil and waste material." Volume 2 p. 5-33.

As noted above, the authors did address the potential for "hot" spots, and came to the realization that by virtue of the execution of the scenario that it is adequately represented by the average concentrations in the waste. It is clear in the EIS that the authors were aware of the variability and accounted for it in the concentration limits as well as the protection requirements. A similar situation also applies to the intruder-agriculture scenario where it is assumed that the excavated waste and soil mixture is spread around the house (which tends to homogenize the concentrations) and the resident is exposed to this material while living in the house and moving around on the property.

The basic premise of the BTP is that additional protection is required in the disposal of the various LLRW streams to preclude an inadvertent intruder from encountering wastes that would lead to exposures exceeding the intruder performance objective of 500 mrem/year. Assuming that the waste placed in the disposal site, on average, complies with the 10 CFR Part 61.55 concentration limits, the assumption of the BTP must be that the intruder would have to spend more time in the vicinity of the higher activity material. This assumption is inconsistent with the intruder scenarios examined in the DEIS. In the DEIS scenarios, it is envisioned that the intruder, while in the process of excavation, would be actively working in all areas of the excavation and would not be concentrating effort in any particular area or zone of the excavation. Furthermore waste exhumed from the disposal site would be mixed with cover soil and redistributed which would further reduce variations in the concentration. If a dwelling was created in the excavation, persons living in the dwelling would be shielded by the concrete in the foundation slab as well as by the distance to the ground level of the house. This would reduce the importance of variations in the radionuclide concentrations. This would also be true where waste is distributed with soil around the dwelling for gardening purposes. The process associated with distributing material for a garden would further reduce variations in concentration. Homogenous material by nature or by

[10] NUREG-0945, Volume 2. P. 5-33.

process does not give rise to discrete items which would be subject to particular handling scenarios as in the case of a radioactive source or piece of activated metal. This leaves us again with the intruder construction and agriculture scenarios as the principle bases for the waste classification methodology. Therefore, there is no purpose in placing additional constraints on averaging of homogeneous waste since the original evaluation accounted for the consequences of 'hot spots'.

Treat Dewatered Cartridge Filters as Equivalent to DAW

The BTP equates cartridge filters with activated metal components by constraining averaging of primary gamma emitting radionuclides by a factor of 1.5 and by limiting the basis volume to the envelope volume of the filter thus treating filters more like discreet objects. It was envisioned in the BTP that if an individual filter exceeded the factor of 1.5 for Cs-137 or factor of 10 for other radionuclides it could be encapsulated and averaging would then be allowed over the waste and encapsulant. This option allows for averaging over the encapsulated volume up 200 liters (nominally equivalent to the volume of a 55 gallon drum) for an individual filter without specifying the size of the filter. Encapsulation of multiple filters in larger volumes would require acceptance under the alternative provisions of the BTP.

Adding the constraint on averaging the primary gamma emitting nuclides makes little sense for cartridge filters since the identified primary gamma radionuclides have little bearing on the classification of this waste. Of the primary gamma radionuclides, Nb-94 is not even required to be included in the classification determination. Cs-137, owing to its solubility is never a factor in filter classification and is not reliably measured. Filters constitute only about ¼ the activity of resins in the overall disposal source term. Since filters are depleted in Cs-137 in contrast to resins, they represent only about 3% of the intruder risk (at 100 years). Co-60 is only required to be considered for classification of Class A wastes. The maximum Co-60 concentration in cartridge filters observed in the package survey (EPRI Report 1016120) was 438 Ci/m^3 well below that necessary to dictate classification. In fact, the activity content of cartridge filters is not comparable to that of activated metals. A comparison of the top 20 concentrations of Co-60 in activated metals compared with that in cartridge filters show activated metal Co-60 concentrations running up to 1000 times higher. Radionuclides which typically effect classification in cartridge filters are more likely to be transuranics and C-14 which are never a factor in the classification of activated metals.

Materials used in cartridge filters are more similar to DAW. Filters are typically composed of thin metal or plastic frames with a corrugated or wound paper or synthetic filter media. Occasionally they may have a thin metal screen. DAW consists of thin metal, paper, plastic, cloth and other debris. Averaging of DAW is allowed over the package volume. The application of the additional constraint on filters implies that there is some discrete aspect to filters. Filters neither meet the size criteria for discrete items (filters are generally on the order of 0.25 to 1 ft^3) nor do they conform to the activity levels required.

The separate treatment of cartridge filters in the BTP over-states the importance of filters in the overall risk equation. There is no similarity in waste form or activity content between activated metal and cartridge filters and therefore no comparison in response to the disposal environment. Filters are physically, chemically and radiologically more like DAW and can be treated in a manner equivalent to DAW or as part of the overall DAW stream.

Revisit Averaging Constraints Applied to Activated Metals

The BTP provides guidance on acceptable classification practices for activated metals. In the context of reactor operational waste, activated metals include control rod blades, BWR fuel channels, instrument assemblies, expendable in-core hardware. PWR activated metal volumes are confined mainly to in-core instruments and are much smaller in volume in contrast to those from BWRs. Overall, activated metal activities account for more than 85% of the activity in LLRW. The averaging constraints for activated metals described in the BTP are based on issues and concerns associated with sealed sources and exposures from scenarios involving handling of high activity discreet items. In comparison with sealed sources, activated metal components are generally much larger and are not amenable to the handling scenario even after processing to fit into disposal containers. Furthermore, activated metals do not meet the concentration levels typical of sealed sources. Therefore classification of activated metals using restrictions developed for sealed sources does not make sense.

With respect to the primary gamma-emitting radionuclides in activated metals, Co-60 is the most dominant and is the most constraining. Co-60 is not limited in Class B, C wastes because of its' short half life. Cs-137 is not a factor in activated metals (only in sealed sources) since there is no significant production mechanism. Nb-94 is a trace contaminant in most metals, is usually not well known, and may be inadvertently overlooked if not listed in a material test report. Furthermore, Nb-94 concentration limits in 10 CFR Part 61 are already defined by a chronic exposure scenario. Nb-94 is the only primary gamma in activated metal that can interact with classification, however, it rarely exceeds 1 mCi (activity above which piecemeal consideration is required) in discrete size pieces of activated metal components. (It is possible to exceed 1 mCi in some types of Inconel used in fuel assembly hardware).

Limiting the volume for averaging to the displaced volume of the metal component is not necessary to ensure the disposal site performance objectives are met. Activated metal packages rarely exceed 20% fill[11] based on the displaced volume of the metal components. There is substantial empty volume in activated metal packages that would contribute to local dilution in the disposal site. The waste as buried will occupy the volume of the package whether or not a grout or filler is added to the package. This actually limits the potential for acute exposure. The waste form is initially rigid and the high activity content constrains the type and level of processing that can be performed. Cask limits constrain the amount of activity that can be safely transported therefore limiting the activity in any single package. If the waste is accessed within 300 years it will be identified and treated in a discovery scenario. If the waste has degraded to a point where it is not identifiable then it could be assumed that the waste would be mixed with soil and sediment leaving the final concentration comparable to what it would be if it was originally averaged over the volume of the package.

For large components, which are integrally disposed, the same arguments for averaging can be applied. Once the component has reached a state of degradation that allows for inadvertent intrusion, the activity would be thoroughly blended with soil, grout, or sediment as available

[11] An exception to the required 85% fill requirements of the disposal sites is made in the case of activated metal packages, since higher fills are not generally possible and activated metal is considered an inherently stable waste form.

up to the enveloping volume of the component (package). Since only Nb-94 would significantly contribute to exposure at that point, only a relatively small dilution is required to achieve safe levels (current Class A concentration). This is because:

- the difference between the Class A and Class C concentration limits is only a factor of 10,
- a minimum factor of 5 dilution credit can be attributed to the low packaging efficiency,
- Nb-94 is only a factor in activated metals which constitute a small fraction of the overall waste volume.

Eliminating the factor of 1.5 for averaging primary gammas is appropriate for this waste stream since the limit is meaningless in the context of activated metals. For Class B or Class C components, only Nb-94 is typically relevant to classification since Co-60 is applicable only to differentiate from Class A and Cs-137 is not typically present in sufficient quantity to affect classification. Nb-94 is not typically directly detected in activated components. Its presence is inferred from activation analysis of the base metals. Niobium is a trace element in some stainless steels and its presence is frequently not reported in metallurgical profiles of the component. When it is reported, the quantity of Niobium can vary by more than a factor of 1.5 from one batch of the same type of steel to another. Therefore, the error margin in reporting the concentration of Nb-94 can exceed the factor of 1.5 for classification making the use of this isotope for control highly questionable.

In the BTP justification for applying the factor of 1.5 to activated metal, it was proposed that somehow all of the higher activity pieces from a container would be exhumed from the disposal site and placed on the ground surface. This assumption is antithetical to all other assumptions in the EIS where it is assumed that waste is randomly distributed. As discussed above, sufficient consideration was given to 'hot spots' in the waste so as to make this assumption unlikely and unreasonably restrictive. Even the factor of 10 for averaging as it is applied to activated metals has dubious value considering the limited risks associated with the actual distribution of radionuclides, disposal waste forms and the significant differences from sealed sources.

Summary of Changes

- Eliminate Single Container Restrictions on Averaging Volume
  - Establish a volume over which averaging can be performed that is consistent with the exposure scenarios in the EIS. Allow classification to be made on the basis of multiple packages up to the established volume.
  - Averaging for classification according to the BTP is limited to material contained within the boundaries of a container. It is proposed to broaden the basis for averaging to a volume consistent with the EIS intruder scenarios. The BTP does not address nor restrict averaging wastes between generators. Given that the BTP only deals with averaging inside of an individual container and effects classification at that level it generally precludes such averaging except in cases where the waste is comingled by a third party processor. Conceivably, if a collection of packages meet the disposal site limits, the contents of the packages without consideration of container boundaries would meet the disposal site limits and would not result in increased risk beyond what was considered in the design of the disposal site. Our evaluation has shown that based on the current understanding of the LLW source term, the combined streams would meet

class A disposal limits. There is no need for multiple classifications of non-discrete LLW. This finding obviates the need to prohibit mixing of waste streams to reduce the overall activity concentration in any particular package.

- Eliminate Averaging Constraints on Homogeneous Materials
  - A homogeneous waste type, as defined in the BTP and as stated here previously, is one that was likely to approach uniformity in the context of the intruder scenarios used to define the values included in Tables 1 and 2 of 10 CFR part 61.55. Homogeneous wastes include spent ion-exchange resins, filter media, solidified liquids, evaporator bottom concentrates, or contaminated soil.
  - The BTP notes that contaminated trash waste may also be considered homogeneous for classification *when placed in containers*. Notably, excluded from this definition are activated metals, contaminated equipment, and cartridge filters. The conditions placed on the basis for classifying homogeneous wastes are unnecessary since the variability associated with these waste streams has already been accounted for in the 10 CFR Part 61 Table 1 and Table 2 values. Furthermore the driving force behind the BTP was concern related to the disposal of discrete items which are antithetical to homogeneous waste types.
  - Eliminate Specific Averaging Constraints Applied to Activated Metals Eliminate the factor of 1.5 for averaging primary gammas since the limit is meaningless in the context of activated metals. Revisit the factor of 10 averaging as it is applied to activated metals taking into consideration the real risks associated with the actual distribution of radionuclides, disposal waste forms, and differences from sealed sources.
- *Add Recognition for Differences Between Activated Metals and Sealed Sources*
  - In the BTP on averaging, the NRC provided guidance on acceptable classification practices for activated metals. In the context of reactor operational waste, activated metals include control rod blades, BWR fuel channels, instrument assemblies, expendable in-core hardware. The BTP equates issues with sealed sources as applicable to activated metals despite significant differences in both form and activity that would tend to eliminate the concerns as related to activated metals.
- *Treat Dewatered Cartridge Filters as Equivalent to DAW*
  - Allow averaging over the volume of the final waste package and mixing credit with other homogeneous waste forms. Eliminate considerations relating to a factor of 1.5.
  - The BTP equates cartridge filters with activated metal components by applying the factor of 1.5 limits on averaging of primary gamma radionuclides and restrictions on the volume for averaging. The primary gamma radionuclides identified in the BTP have little bearing on the classification of cartridge filters. Nb-94 is not required to be considered and Cs-137, owing to its solubility is never a factor in filter classification and is rarely measured. Co-60 is only applicable to Class A classification. The maximum Co-60 concentration in cartridge filters observed in the package survey was 438 Ci/m^3, well below that necessary to dictate classification. A comparison of the top 20 concentrations of Co-60 in activated metals compared with that in cartridge filters show activated metal concentrations 1000 times higher. Filters are physically and chemically more similar to DAW than activated metal and can assumed to react more like DAW in the disposal environment. There is no similarity between filters and activated metals and therefore no basis for applying the same type of restrictions.

5
ESTIMATING RISK-BASED INTRUDER EXPOSURES WITH UNCONSTRAINED AVERAGING

Base Cases of the EIS

The BTP set out to provide additional guidance surrounding the implementation of 10 CFR Part 61 due to perceptions of oversights in the formulation of the regulation. In developing the DEIS for 10 CFR Part 61, twenty-five disposal scenarios were formulated. Two base cases were included in the analysis. The first base case included no restrictions on radionuclide concentrations, minimum processing, no layering and random placement of containers with excavated dirt used for fill. The second base case which is more representative of later disposal practices, excluded wastes with TRU concentrations exceeding 10 nCi/gm and provided solidification to those wastes with gamma emitting nuclides with greater than 5 year half life exceeding 1μCi/cc. The source term used for the scenarios was based on early commercial operating experience that included a very important learning curve in the design of fuel. During the 1970s fuel designs evolved rapidly to correct issues with high leakage and premature failures. In order to put the current source term in perspective with the EIS we reverted back to the base case. That is, following the disposal practice in 1980, what is the impact to the inadvertent intruder with the current source term? Looking somewhat beyond this, if the EIS analysis performed in 1980 were repeated with today's source term would a multi-tiered classification system be necessary? Given the results of this analysis, the next question is if the added restrictions imposed by the BTP on normal waste disposal are justified? If the results show that the performance objective is met without regard to waste classification and related implementation requirements, the discussion should focus on practical considerations of implementation.

Updated Modeling

This analysis was performed using the RESRAD computer program. The RESRAD program was selected because it is in current use and it reflects the most recent dose conversion factors. It appropriately weights organ doses in accordance with ICRP. While comparison calculations were performed using the methodology of the updated IMPACTS (as described in NUREG/CR-4370), the RESRAD calculations were considered to be more consistent with current performance assessment methods. Details of the RESRAD calculations are provided in Appendix C.

As discussed in Appendix C, intruder risks at 100 years are primarily related to the concentration of Cs-137. The nuclear power industry generates about 1750 Ci/year of Cs-137 in operational wastes. This represents an average concentration of Cs-137 in NPP wastes of 0.062 Ci/m^3 which is well below the Class A limit. When contrasted to the exposure scenario provided in the BTP[12], the resulting exposure would be 500 mrem/yr after about 2700 hrs assuming unshielded exposure at 1 meter.

It is expected that the concentrations of waste encountered by the intruder will be representative of the average of the mixture of materials. Since the assumed excavation volume is much larger than the volumes of individual packages, the material encountered by the intruder would be a representative sampling of the material in the disposal site.

Table 5-1 lists Cs-137 concentrations for different stream groupings. The first case shown for DAW only approximately corresponds to the EIS case where the unstable DAW streams were assumed to be segregated from wastes requiring stabilization. In the EIS it was noted that the actual average Cs-137 concentration in the segregated waste section of the disposal site would be a factor of 20 below the Class A limit. From the data collected in the EPRI survey, this factor is closer to a factor of 200. Assuming that Class A process waste is added to the DAW, there is a 10% addition in volume while the activity increases by a factor of 16 to 209 curies. The probability, that this higher activity waste would be encountered by an intruder during excavation can be calculated by dividing the volume of the higher activity waste by the total volume of waste and is 0.088 (where 1 represents the case that the event will absolutely occur and smaller numbers represent smaller and smaller chances of occurrence).

The next step is to add all of the process waste that could be admitted within a factor of 10 averaging. A Cs-137 concentration of 10 Ci/m^3 was used as an upper bound. The inclusion of this waste added 6593 ft^3 to the previous total and increased the total activity by another factor of four to 844 Ci/yr. The probability of the intruder encountering process waste in the excavation shows little change (from 0.088 to 0.094). The probability of encountering waste exceeding the class limit would be approximately 6.5E-3 or a factor 15 lower than encountering process waste in general. The addition of the remaining process waste has little additional impact on probabilities (the probability of encountering waste exceeding 1 Ci/m^3 increases to 7.5E-3 and the probability of encountering process waste increases to 0.095). The effect of dilution on the probability of an inadvertent intruder coming in contact with the higher activity waste is essentially the same as for deeper disposal (i.e. factor of 10).

[12] Assumes 100 years delay to access the material and no credit for deeper disposal. Excavated waste is spread into an infinite slab source 35 cm thick. Source soil dilution factor is 0.25, decay factor for 100 years is 0.1. Emplacement efficiency taken as 0.75. Result calculated with Microshield™. In the BTP case waste was assumed initially at the Class C limit and was decayed to 500 years. This was possible by assuming 5 meters of cover which provided an additional factor 10 dilution which was not included in our analysis.

Table 5-1
Cs-137 comparisons

Case	Ci	Total Volume (ft^3)	Average Concentration (Ci/m^3)	Incremental Volume (ft^3)	Probability of Encounter with Higher Activity Waste
DAW Only	12	921465	4.6E-04	921465	Not Applicable
DAW + Process Waste (Cs-137 concentration < 1 Ci/m^3)	209	1010740	7.3E-03	89275	0.088
DAW + Process Waste (Cs-137 concentration < 10 Ci/m^3)	844	1017333	2.9E-02	6593	0.094
DAW + All Process Waste	1750	1018459	6.1E-02	1126	0.095

Table 5-2 shows the various cases of process waste as incremental additions to DAW beginning with no process waste and progressing to all process wastes. The base case of DAW only results in an annual exposure of less than 2 mrem. Each successive addition includes the dose rate from the higher activity volume plus the dose rate from the preceding case. The dose rates are calculated using Microshield™ assuming an infinite slab source at the incremental concentration adjusted by the mixing factor. Following the model of the EIS dose rate adjustment factors are taken at 0.74 for time spent outside and 0.24 for time spent inside. Times are 1800 hours and 4380 hours respectively. Exposure distance is taken as 1 meter following the EIS model. Dose Rates are calculated at 100 years. All cases are evaluated on the basis of Class A segregated disposal as outlined in the DEIS.

Table 5-2
Cs-137 intruder-agriculture dose rates – alternative disposal scenarios

Case	Annual Volume (m^3)	Activity of Increment (Ci)	Concentration of Increment (Ci/m^3)	Probability of Encountering Last Increment	Performance (mrem/yr)[a, b]
DAW Only	26103.8	12	4.58E-04	1	2
DAW + Process Waste (Cs-137 concentration < 1 Ci/m3)	2529.0	197	7.77E-02	0.088327	34
DAW + Process Waste (Cs-137 concentration < 10 Ci/m3)	186.8	535	3.47E+00	0.006481	138
DAW + All Process Waste	31.9	926	3.46E+01	0.001105	316

a Probability of unearthing last material increment: based on waste as-packaged.

b Annual intruder exposure (Intruder-Agriculture, dose rates estimated cumulatively each successive addition includes the dose rate estimate of the previous case, considers Cs-137 contribution only).

Results

The above analysis examines the impact of increasing the activity content up to and including all process wastes within a single disposal cell. The impact of each successive addition is adjusted by its probability of encounter within the disposal site to determine its dose risk in the context of the entire facility. The dose rate corresponding to each succeeding increment in activity is added to the sum of the previous additions to assess the overall risk. The results show that on the basis of the current industry source term, all of the wastes generated by nuclear power plants could be disposed without aggressive stabilization or isolation while maintaining dose within the performance objectives of 10 CFR Part 61. These results are further reinforced by the RESRAD calculations in Appendix C. Assuming that intruder protection is the objective and that 500 mrem/year is the performance objective, there would be no need for the restrictions imposed by the BTP except in the context of a handling scenario for discreet items. There is no discrete item scenario associated with the waste included in this analysis.

Effectively, dilution of the higher activity waste provides a protection equivalent to deeper disposal. This isn't too surprising since the benefit associated with deeper disposal is determined on the basis of the dilution achieved from the deeper cover. The net effect of combining all of the waste is comparable to disposing of all of the waste in a Class C facility.

6
IMPLEMENTATION ISSUES

Defining LLW

The proposals discussed in Sections 4 and 5 basically remove averaging restrictions from all operational wastes generated by commercial nuclear power plants except for sealed sources. The restrictions in the BTP were developed with input and consent of the disposal sites who were concerned with the disposal of waste with "Greater Than Class C" (GTCC) concentrations in the disposal sites. In the EIS, the only wastes excluded from near surface disposal were streams high in transuranic (TRU) concentrations – wastes which would fall into the TRU waste category. Overall, the TRU concentrations in nuclear power plant process wastes remain on average well below the class A limits (The 10 CFR Part 61 limit for TRU in Class C wastes is 100 nCi/gm)and the average concentration in the disposal site would be less than the ICRP recommended basis for isolation for TRU containing wastes. This supports our observation that TRU in LLRW has only a small effect on the overall classification calculation. Therefore there is little reason to exclude any of this waste. In the context of PWR resins, the highest observed concentration of Cs-137, a key nuclide for scaling TRU, was 88 Ci/m3 – more than a factor 50 below the class C limit. Cartridge filters have a much greater likelihood of exceeding the class limits for TRU. This is consistent with the nature of the filtering process; however the overall addition of filters to activity totals is relatively small. While monitoring of TRU content at the plant level is a condition of operation, averaging of TRU is already accounted for in the performance assessment.

We believe that the studies performed for the EIS demonstrated the feasibility of near surface disposal for all of the waste streams under specific conditions. In the context of the EIS, it was envisioned that wastes traditionally disposed as LLRW in near surface facilities would continue to be disposed in near surface facilities. The concentration values tabulated in the regulations were derived as averages within the disposal trench.

Development and Use of Waste Profiles

The general process for managing disposal as advocated in this report can be outlined as follows:

- Develop waste stream profiles on industry wide basis.
- Develop profiles of physical characteristics (e.g. chemical composition, response in disposal environment) and radionuclide distributions including average activities and activity ranges. Consolidate streams on the basis of this activity distribution. Using the results of these evaluations specify minimum disposal requirements based on the stream wide average concentrations. Consolidate streams and data to obtain the widest possible assignment to the lowest classification.

- Negotiate packaging requirements with the disposal site – it is assumed that all waste is stabilized at some level either through waste form, packaging or other structural intruder barriers including deeper disposal.
- Monitor individual plants for compliance with the profiles – While the profile would be established based on a composite stream, disposal penalties could be assessed on plants operating at the upper extreme of the profile. This would provide some incentive to make process corrections to reduce the differences.
- Compare individual plant data against the profiles. Identify plants that are outside of the profiles. (Develop corrective actions to restore compliance with the profiles.)

Using the profiles

- Plants operating outside of the profile range limits can make corrective actions to bring operations back within the range
- Plant performs waste characterization
- Plant notifies disposal site of a transfer of waste
- Disposal site determines placement of the waste based on the reported activity content
- Disposal site authorizes shipment and provides receipt data

The process is generally represented by Figure 6-1.

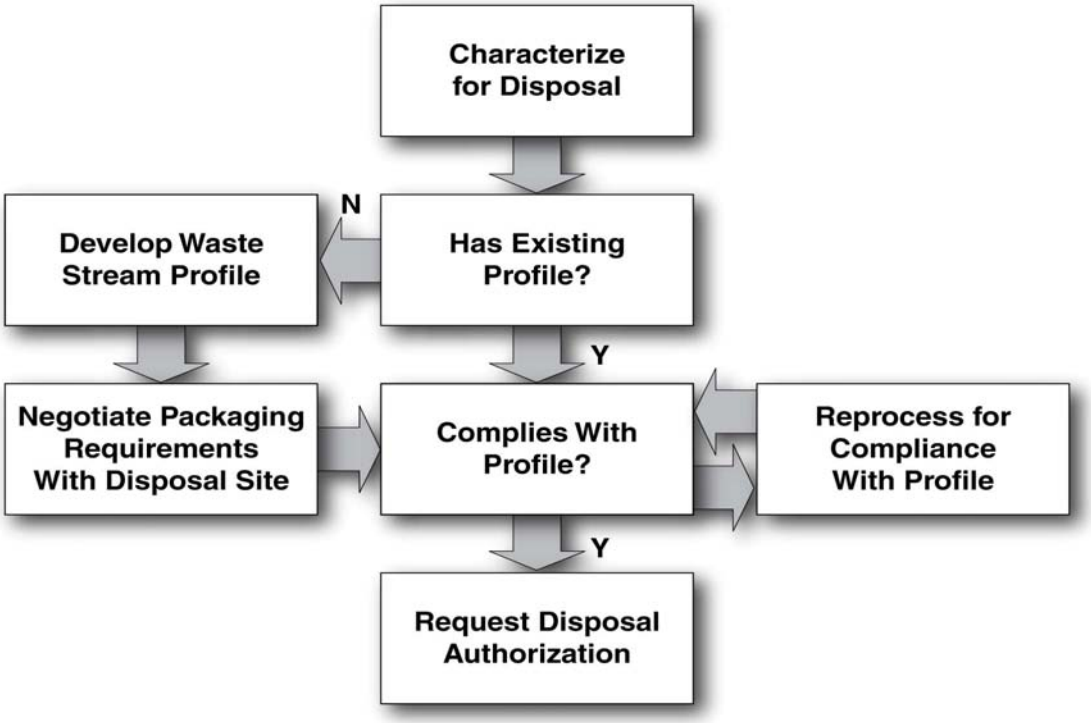

Figure 6-1
Disposal flow chart

Cost Considerations

If a program is implemented as described above it is not anticipated that significant new costs would be incurred at the plant level. Most of the activities listed are already implemented. Disposal at the EnergySolutions site at Clive, Utah requires the development of waste stream profiles and prior reporting to the disposal site. In this case, the profile would be broader, individual plants would not have to bear the entire burden of it development would may provide an overall savings.

7
NON-UTILITY LOW LEVEL WASTE

Non-Utility Waste Data

Much of the discussion related to changes in the BTP as well as broadening the base for averaging for classification, have centered on waste streams proceeding from nuclear power plants. It is recognized that any changes that would precipitate from these discussions would also affect non-utility generators. This section will focus on gaining a better understanding of the quantities and activities of non-utility generated waste. Information used in this section is largely drawn from the Manifest Information Management System (MIMS).

The Manifest Information Management System is a database used to monitor the management of commercial low-level radioactive waste (LLW) in the U.S. MIMS was developed in 1986 by the U.S. Department of Energy (DOE) in response to provisions in 42 U.S.C. 2021g(a). The Department of Energy Office of Environmental Management maintains and operates MIMS for the low-level radioactive waste community and the public.

The LLW information in MIMS is derived from manifests for waste shipments to one closed (U.S. Ecology [Beatty, Nevada]) and three operating commercial LLW disposal facilities (U.S. Ecology [Richland, Washington], EnergySolutions/Chem Nuclear [Barnwell, South Carolina] and Energy Solutions [Clive, Utah]). Reports in MIMS contain information on LLW volume, radioactivity, and number of shipments. Based on agreement reached with the disposal site operators during initial development of MIMS, waste generators are not specifically identified, but instead are given a unique code indicating the state of origin. Some shipments include waste from multiple states and or waste generators which are delivered via brokers or waste processors.

The MIMS tracks waste in five categories. These are Academic, Government, Medical, Industry, and Utility. The Utility wastes are primarily constituted of wastes from nuclear power plants which are discussed in previous sections of this report. Streams from other generator types are described in NUREG/CR-6147 which includes qualitative descriptions of the content of these wastes.

Academic

Academic institutions include universities, colleges and other specialized teaching facilities using radioactive materials. Low-level radioactive wastes produced by academic institutions are associated with such activities as medical training and research, health care administration, industrial and materials testing, and basic and applied research in various technical and scientific fields, a number of universities operate test reactors, as well as source facilities, and large hospitals.

- Dry Solids
- Compacted and non-compacted dry active waste
- Animal carcasses and other forms of biological wastes
- Aqueous wastes in vials and sorbents
- Solidified and absorbed aqueous liquids

Government

Government institutions [excluding the Department of Energy] include research and testing laboratories, environmental laboratories, medical facilities, military installations, and other types of facilities, such as warehouses, research stations, airports, and shipping ports. Low-level radioactive waste produced by government institutions is generally associated with industrial research, materials testing, organic and inorganic chemistry, geological and mineral exploration, and basic and applied research in various scientific and technical fields.

- Dry Solids
- Solidified Oils
- Compacted and non-compacted trash
- Absorbed and stabilized liquids
- Aqueous liquids in vials and sorbents
- Non-cartridge filter media
- Animal carcasses
- Solidified chelates
- Sealed sources
- Activated and contaminated hardware and concrete

Medical

Low level radioactive waste produced by medical facilities is associated with the use of radioactive materials in the practice of nuclear medicine, radiation therapy, medical research, and clinical tests.

Table 7-1
Typical radionuclides used in clinical nuclear medicine[13]

Nuclide	Half-Life	Usage
Mo-99,Tc-99m	67 hrs,6 hrs	Thyroid, brain, bone, kidney, gastro-intestinal, liver, heart imaging
I-123	13 hrs	Thyroid, brain imaging
In-11	67 hrs	Infection, spinal fluid, radio-labeled antibody imaging
Tl-120	73 hrs	Heart, parathyroid imaging
Ga-67	78 hrs	Tumor, infection imaging
I-131	8 days	Kidney, thyroid, radio-labeled antibody imaging
Cr-51	28 days	Blood volume and red cell
Yb-159	32 days	Spinal Fluid imaging
I-125	60 days	Blood volume
Co-57	270 days	Vit. B-12 Absorption

Typical isotopes included in radiation therapy include Y-90, P-32, Co-60, I-125, Cs-137, and Ir-192. In research activities these include C-14, P-32, S-35, and I-125.

Typical medical wastes are made up of:

- Compacted Trash
- Laboratory
  - Spent Generators
  - Unused radiopharmaceuticals
  - Syringes
  - Glassware
  - Gloves
- Biological
- Animal carcasses
- Absorbed liquids
- Use and spent radioactive sources

[13] Low Level Radioactive Waste Regulation, Science, politics, and Fear, Michael E. Burns Ed., Lewis Publishers, 1988.

Industry

Industrial facilities include all other commercial waste generators not falling in the institutional or utility category. Industrial facilities are involved in diverse types of activities such as research, materials testing, chemical production, mineral exploration and processing, and basic and applied research in various scientific disciplines (e.g. physics, chemistry, and biology). Some facilities manufacture consumer products, level and density gauges, and instrumentation. Industrial facilities also produce radioactive materials that are used as feed stock by other industrial facilities in making various products, e.g., Am-241 for smoke detectors and depleted uranium for military munitions. In addition, the industrial category includes fuel fabrication facilities.

- Dry Solids
- Solidified Liquids
- Absorbed aqueous liquids
- Compacted Dry active waste
- Aqueous liquids in vials and sorbents
- Cartridge filter media
- Animal carcasses in lime and sorbents
- Non-compacted dry active waste
- Solidified chelating agents
- Solidified Resins
- Other types of biological wastes
- Solidified oils
- Non-absorbed aqueous liquids
- Non-aqueous liquids in vials and sorbents
- Dewatered resins
- Activated and contaminated hardware and concrete

There is significant overlap in the non-utility categories in that academic institutions and the government can operate hospitals. In addition, many (perhaps most) institutional waste generators (hospitals, universities, companies engaged in research) employ brokers to handle their LLRW. In the MIMS database Brokers are treated as industrial generators.

Utility

Utility waste represented in MIMs may include data from other sources that are not represented in the EPRI database used previously in this report[14]. The data presented here is used for comparison with the other MIMs categories only.

Relative Generation (Generation by Year)

A report published by the NRC in 1994 (NUREG/CR-6147), provided a comprehensive review of Class A waste generation. The review crossed industry boundaries and included all of the major generator groups defined in the MIMS system. Included in Volume 1 of the report was a tabulation by years 1986 through 1990 of the total activities and volumes generated by generator type. This tabulation included classes A, B, and C wastes. The tabulations are charted on a log scale in Figure 7-1 and Figure 7-2. Notable with the comparisons is that "Industrial" and utility wastes are comparable in magnitude.

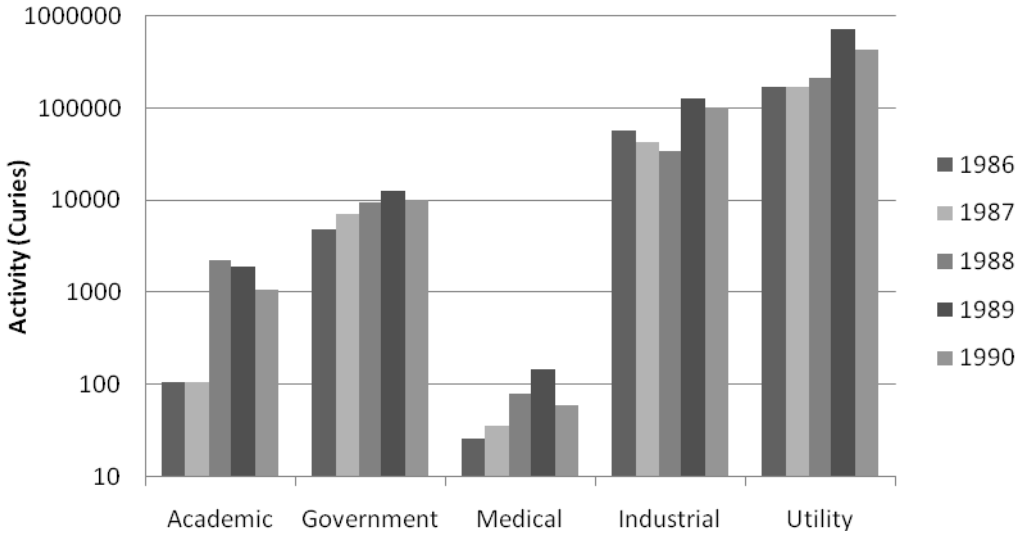

Figure 7-1
Relative volume generation by generator type, 1986-1990 (NUREG/CR-6147)

[14] The EPRI survey collected data only from operating nuclear power plants. Excluded were plants in decommissioning as well as sources collected from other types of power plants.

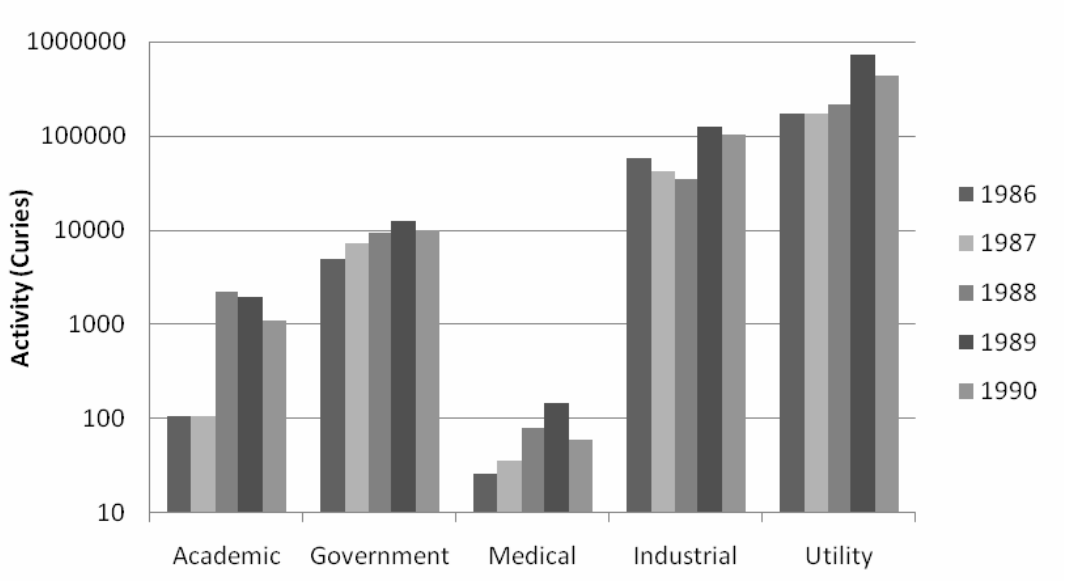

Figure 7-2
Relative activity generation by generator type, 1986-1990 (NUREG/CR-6147)

The comparison made with the 2002-2006 data shows the non-utility wastes exceeding the utility waste significantly. The industrial sector wastes by themselves are almost the same on average and along the government waste exceed the utility waste by 30%. Overall the volumes are up in magnitude from the 1986-1990 period. Medical wastes and academic wastes are lower possibly reflecting an increasing reliance on brokers to repackage and dispose of their LLRW.

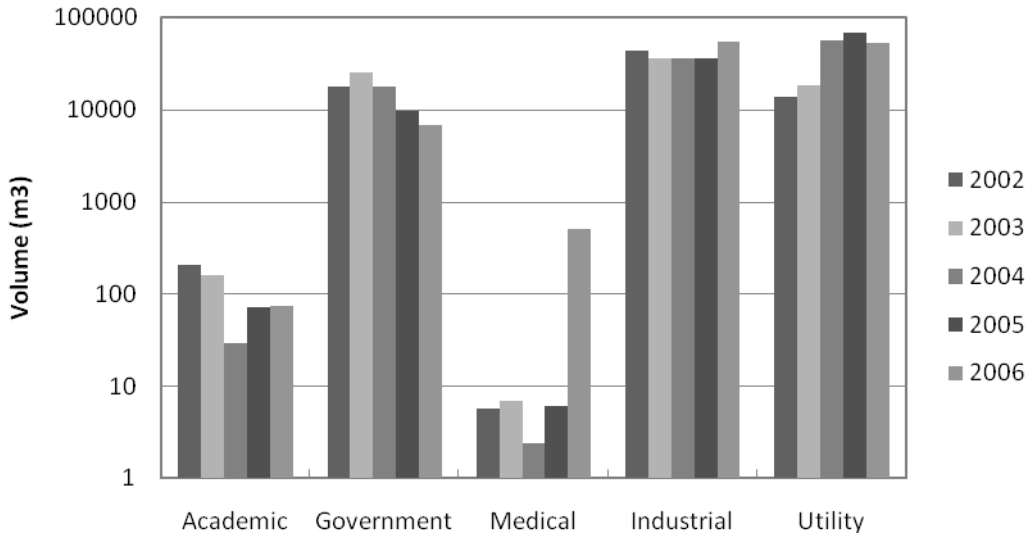

Figure 7-3
Relative volume generation by generator type, 2002-2006 (recent MIMS)

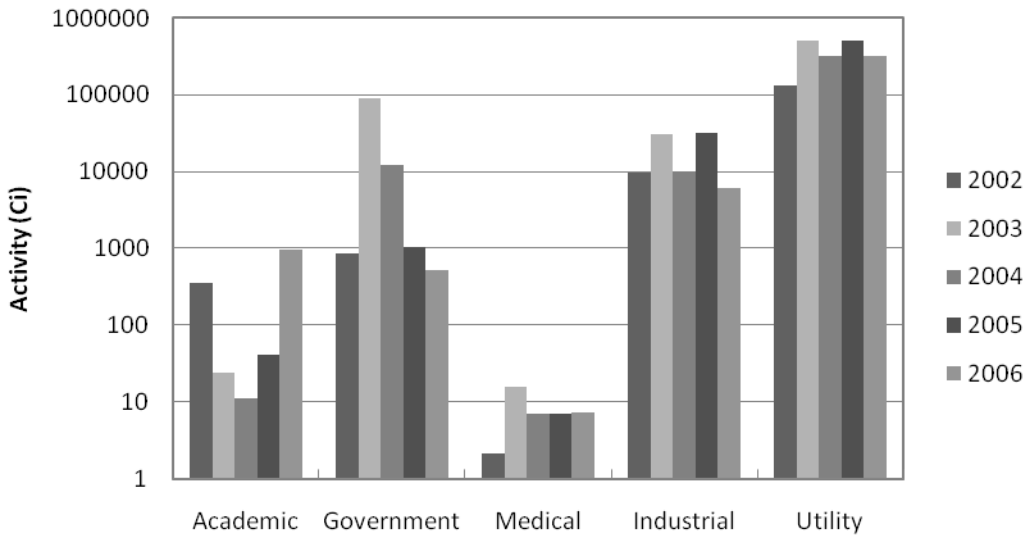

Figure 7-4
Relative activity generation by generator type, 2002-2006 (recent MIMS)

Quantities of Class B and Class C Wastes

Figure 7-5 shows another comparison of the average annual generation volume between utilities and other non-utility generators. The chart includes a volume breakdown by 10 CFR part 61 disposal Class for the different generators. The columns corresponding to activity reflect the total activities of A, B and C wastes.

While the log scale allows visualization of the lower contributions of the academic and medical generators, it doesn't convey as well the overall differences. Notably utility and industry generation are relatively comparable in both overall volume and Class A volume, the utility waste includes about 10 times the total activity and more than 10 times the volumes of Class B and Class C wastes. Also, from this tabulation for MIMs data it is observed that there is some Class B and Class C waste generation from all of the 5 generator categories. The data used to generate the bar chart is reproduced in Table 7-2.

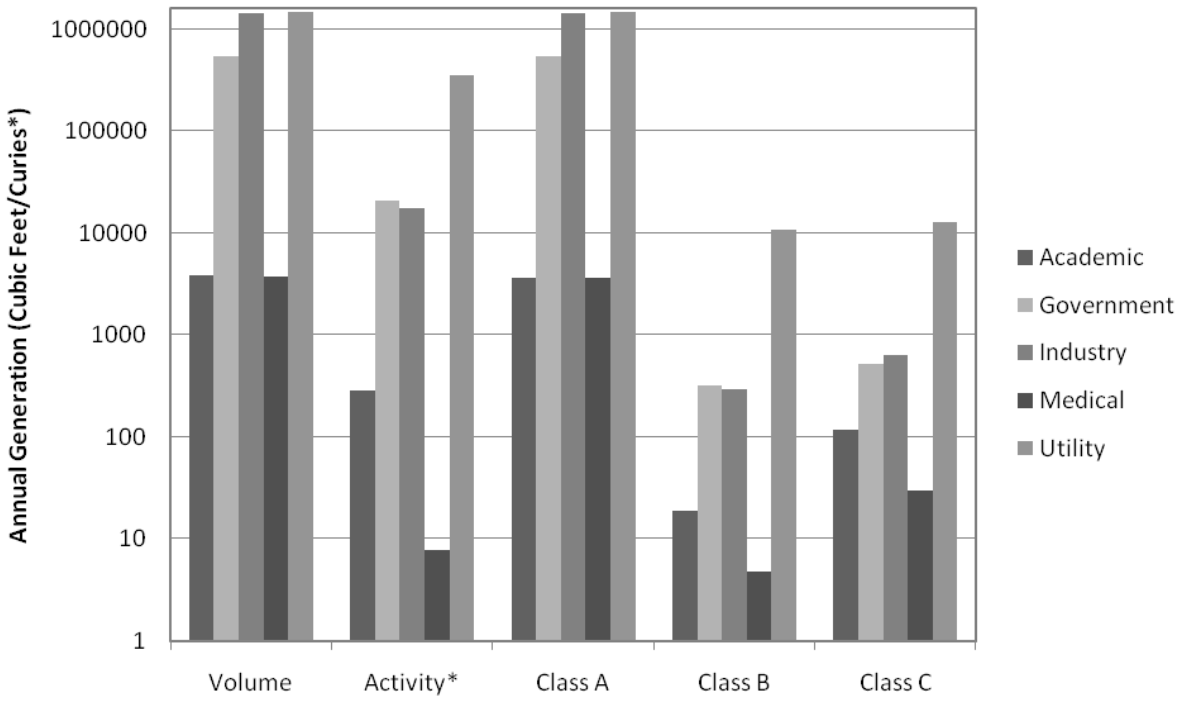

Figure 7-5
Annual generation-comparison by generator type and waste class (MIMS)

Table 7-2
Annual generation-tabulation by generator type and waste class (MIMS)

Generator Type	Volume (ft^3)	Activity* (Ci)	Class A (ft^3)	Class B (ft^3)	Class C (ft^3)
Academic	3.8E+03	2.8E+02	3.7E+03	1.9E+01	1.2E+02
Government	5.5E+05	2.1E+04	5.5E+05	3.2E+02	5.2E+02
Industry	1.4E+06	1.8E+04	1.4E+06	2.9E+02	6.5E+02
Medical	3.7E+03	7.9E+00	3.7E+03	4.9E+00	3.0E+01
Utility	1.5E+06	3.5E+05	1.5E+06	1.1E+04	1.3E+04

Figure 7-6 consolidates the non-utility waste and provides a percentage comparison with the utility wastes. The non-utility wastes comprise about 5% of the Class B waste and about 8% of the Class C wastes. While they are small relative to the overall utility quantities they remain significant in context of the overall disposal issue.

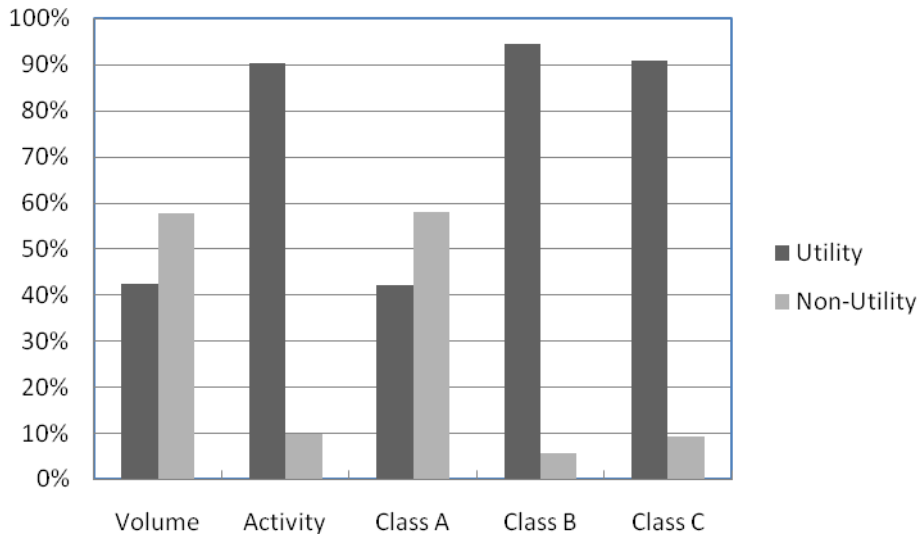

Figure 7-6
Relative generation-percent comparison utility and non-utility (MIMS)

Not too surprisingly utility wastes account for 90% of the total activity and approximately the same percentage of Class C wastes. As noted earlier for utility wastes activated metals contribute about 85 percent of the total activity and a comparable fraction of the Class C wastes. Volumes of activated metals are negligible in contrast to DAW and other operational wastes. Without including activated metals, utility and non utility wastes are very comparable in overall activity.

Radionuclide Distributions as Reported in MIMS

Table 7-3 lists generator type prominent (representing the largest fractions of the total) radionuclides recorded in MIMs. The values in the table were obtained by downloading the individual isotope reports from MIMs for the years of 2002 through 2007. Each report corresponded to a particular radionuclide corresponding to a package or shipment for disposal. The data set included almost 86,000 individual records. To construct Table 7-3, a query was run on the data table which drew out the distinct radionuclides and summed each by generator type and assembled the results in a new table. This table was then transferred to a spreadsheet where each generator type was separately sorted by activity.

Table 7-3
Prominent radionuclides reported in MIMS (by type averaged over 5 years)

Isotope	Academic	Government	Industry	Medical	Utilities
Co-60	38.59%	86.02%	5.93%	28.67%	40.42%
Cs-137	1.87%	0.29%	1.69%	61.28%	0.50%
H-3	14.04%	8.91%	73.74%	2.45%	–
Ni-63	6.08%	0.80%	2.83%	–	4.65%
Fe-55	32.50%	1.11%	7.27%	–	34.17%
Sr-90	–	–	–	1.58%	–
Nb-95	–	–	–	–	6.23%
Zr-95	–	–	–	–	5.45%
Sum	93.08%	97.13%	91.47%	93.97%	91.41%

The MIMs database records activity concentrations for over 338 radionuclides. Information included in MIMs is recorded directly from the waste descriptions provided with the disposal shipment manifests. There is no particular over-sight of this process either as the shipping papers are assembled or as they are accumulated in the database. The listings in Table 7-3 account for more than 90% of the activity in each case. Some notable observations with the data are:

- Co-60 is overall the most generally prominent.
- H-3 shows up as ¾ of all of the activity in the industry waste streams. (More than half of the ~100,000 Ci of H-3 record for the Industry group come in two entries from one generator.) Overall "industry" accounts for about 85% of all H-3.[15]
- For the utility waste streams Nb-95 and Z-95 show up prominently in the top listed isotopes. Both have short half-lives and would result from activation of Zircaloy. Closer inspection of the data base show that almost 90% of the seven year activity total of these isotopes, which are paired as parent, secular daughter, were reported in a single shipment in 2007. Based on activation of Zircaloy 4, Nb-95 activity would about 2 Ci/kg after 1 year of decay. For the shipment in question, it would have to be on the order of 80,000 kg, or well beyond any conceivable payload for activated metals.
- While medical category indicates a high proportion of Cs-137, it should be noted that this is the smallest stream for total activity and volume. The reported Cs-137 likely originates in sealed sources.

[15] Tritium is used in the manufacture of illuminated highway signs. These can account for a significant disposal source of tritium both in radioactive and commercial non-radioactive landfills.

MIMS Data Issues

There are some shortcomings related to the MIMS database as reported in GAO report, GAO-04-604. This report noted that MIMS does not perform "systematic quality checks on the data, such as reasonableness checks, cross tabulations, or exceptions reports". Errors as simple as missing a correct sign on an exponent can destroy any utility of the information if used without discretion. That being said, MIMS is the only source for this type of information across industries. We believe it is reasonably correct for comparing the waste volume between generator types and the overall gross activity amounts reported.

Additional Disposal Volumes

The scope of the data in MIMS is limited to LLW from utilities, industries including waste brokers/processors, academic/research institutions, medical facilities, and government (State and Federal government activities outside of DOE). In addition, MIMS has historically provided information on disposal of naturally-occurring radioactive material (NORM) at the U.S. Ecology site, although NORM is outside the scope of this application. Waste disposed in commercial facilities by the Department of Energy is not tracked in MIMS. Other wastes not tracked in MIMS include mixed low-level radwaste, 11e.(2) wastes, and NORM wastes. A reproduction of the report summarizing additional waste volumes disposed at the EnergySolutions Clive Disposal Site is provided in Figure 7-7.

At the EnergySolutions disposal facility at Clive, Utah, between 1992 and 2007, DOE LLRW accounted for slightly over 64 million cubic feet (1.8E6 m^3) or 4 million cubic feet per year. The other waste types in the mixed wastes, 11e.(2) and NORM accounted for an additional 4 million ft^3/yr. This was all disposed as Class A waste. The DOE LLRW historically has accounted for substantially more waste volume disposed in commercial sites than that disposed from commercial sources. The tabulation provided by EnergySolutions only accounts for wastes disposed as Class A wastes at Clive, Utah. Overall, it would seem that this waste generation is transitory and not central to revisiting long term disposal policy.

Waste Disposed at Energy Solutions Clive Utah Facility
Not in MIMS Data Base Scope (Cubic Feet) *

	LLW	MLLW	11e.(2)	NORM	Total DOE waste
DOE Waste Disposed:					
1992	0	0	0	0	0
1993	279	0		10,441	10,720
1994	85,563	27,338	135,039	100	248,040
1995	437,880	143,116	776,005		1,357,001
1996	1,000,019	242,397	1,490,572		2,732,988
1997	1,839,324	73,760	1,389,610		3,302,694
1998	884,239	113,596	648		998,482
1999	3,120,336	281,977			3,402,313
2000	3,451,595	185,477			3,637,072
2001	4,961,709	128,919			5,090,627
2002	5,636,890	186,330			5,823,220
2003	9,596,749	517,359		315	10,114,423
2004	9,098,551	315,111			9,413,662
2005	11,531,101	108,591	82,944		11,722,636
2006	10,050,207	316,239	179,801		10,546,247
2007	2,471,383	130,945	0	0	2,602,328
Total	***64,165,824***	***2,771,153***	***4,054,619***	***10,856***	***71,002,453***

	MLLW	11e.(2)	NORM	Total Non-DOE waste
Non-DOE waste** disposed:				
1992	72,862		609,534	682,396
1993	6,118		884,108	890,226
1994	43,167	1,418,373	210,580	1,672,119
1995	101,615	2,172,551	1,358,506	3,632,672
1996	115,654	1,298,294	1,816,590	3,230,538
1997	20,419	2,361,936	2,554,154	4,936,508
1998	7,616	5,722,232	1,259,939	6,989,787
1999	9,423	6,961,615	874,820	7,845,858
2000	32,630	6,390,241	818,358	7,241,230
2001	17,110	4,134,411	537,172	4,688,693
2002	32,614	2,665,161	453,526	3,151,301
2003	20,628	1,823,456	921,742	2,765,826
2004	9,649	2,253,197	764,162	3,027,008
2005	15,937	880,951	228,675	1,125,563
2006	83,388	1,305,956	393,613	1,782,957
2007	16,597	1,121,519	300,157	1,438,273
Total	***605,426***	***40,509,893***	***13,985,636***	***55,100,955***

*Waste volumes as received for disposal. Does not include waste volumes received for processing other than disposal.
**Non-DOE waste includes waste from Formerly Utilized Sites Remedial Action Program

Figure 7-7
LLRW disposed at clive, utah, not included in MIMS[16]

[16] Provided by Energy Solutions to MIMs website.

Overall Impact of Non-Utility Waste

Overall the waste volumes attributed to non-utility generators exceed those attributed to utilities. Utilities still contribute about 90% of the total disposal activity, but the bulk of that activity is in activated metal wastes. If activated metals are taken out of the mix, volumes and activities between generator sectors becomes more balanced. The relative volumes of Class C wastes are changed very little despite removing a significant fraction from the utility contribution. This is because the industry activity is so dominated by tritium which is unlimited in Class B and C wastes. However, because of the high proportion of activity attributable to H-3 and its short half-life (12.3 years), it is expected that this non-utility wastes would contribute to a significant reduction in overall disposal cell activity concentrations and contribute to further isolation of higher activity material.

The impact on radiation exposure to the inadvertent intruder as a result of including the non-utility waste with the nuclear power plant waste is significant. As noted previously, the isotope with the greatest impact on radiation exposure for this scenario is Cs-137. Non-utility waste contains a relatively small amount of Cs-137 compared to nuclear power plant waste as shown in Table 7-4.

Table 7-4
Predominant nuclides and activity for non-utility low level waste

Nuclide	Total Activity (Ci)	Percent of total
Co60	9.67E+04	45.79%
H3	8.63E+04	40.83%
Fe55	9.74E+03	4.61%
Ni63	4.41E+03	2.09%
U-Dep	3.97E+03	1.88%
Cs137	2.38E+03	1.13%
Gd153	1.16E+03	0.55%
Co58	8.18E+02	0.39%
Zn65	8.12E+02	0.38%
C14	8.10E+02	0.38%
Mn54	5.99E+02	0.28%
Co57	3.54E+02	0.17%
Total	2.08E+05	98.48%
Volume	9992,302 ft^3	
Activities and volume are the totals for a 5-year period (2002-2006).		

When the non-utility waste is included with nuclear power plant waste in the intruder scenario developed using RESRAD, the effect is to decrease the projected exposure by almost 44%. Analysis details are provided in Appendix C.

8
COLLATERAL ISSUES

Attempts at Change

Many actions taken with the best intentions often result in unintended consequences. The Barnwell Disposal Facility was the last nationally available disposal site licensed to accept 10 CFR Part 61 Class B and Class C wastes. Currently, in the U.S. there are no new sites that can provide this service. In 1980, the United States Congress passed the Low Level Waste Policy Act wherein a framework was established for the development of regional near surface disposal facilities by compacts formed of neighboring States. This was followed in 1983 by 10 CFR Part 61 and in 1985 by the Low Level Waste Policy Amendments Act. While there have been earnest attempts to develop new disposal sites, the process has not been successful. Compacts are in disarray with unlikely groupings such as California and South Dakota or South Carolina and Connecticut and with other States acting alone. No new disposal sites have been developed through this process. EPRI and NEI are examining classification alternatives to address the absence of new facilities and address the near-term closure of Barnwell. In discussions with the NRC related to these alternatives, a question was raised on the potential for unintended consequences wherein interested parties may be adversely affected should EPRI's proposals be implemented. This section attempts to address that question.

EPRI Proposal

In EPRI report 1016120, "An Evaluation of Alternative Classification Methods for Routine Low Level Waste from the Nuclear Power Industry" it was proposed to expand the averaging volume for low-level power plant waste from a single package basis to a multiple package basis that could comprise up to the equivalent of the volume that would be excavated following the intruder construction scenario defined in NUREG-0782 "Draft Environmental Impact Statement for 10 CFR Part 61". This volume, 232 m^3, would be the equivalent of 50 disposal liners at 140 ft^3. This concept was initially presented to the NRC in October of 2007.

In its evaluation in support of this concept, EPRI collected waste disposal data from 65 operating nuclear units. This data covered a 4 year period from 2003 through 2006 and was comprised of more than 10,000 individual records. Data was segregated by stream in accordance with the stream breakdown provided on the Uniform Manifest for tracking on the manifest information management system (MIMS). Data associated with homogeneous wastes including resins and various filter media was separated and evaluated for classification. It was found that on average this material would meet the 10 CFR Part 61 Class A disposal concentration limits within random collections corresponding to the volume of material excavated in the intruder construction scenario. A concurrent review of the Draft Environmental Impact Statement for 10 CFR Part 61 (DEIS, NUREG-0782) confirmed that in the intruder construction scenario the

governing concentration is the average concentration in the disposal site. It was also noted that the disposal configuration assumed in the DEIS was a shallow trench with 2 meters of cover. Current disposal practice for Class A waste provides for deeper cover than envisioned in the DEIS intruder construction scenario and, for waste with significant gamma radiation content but well below the Class A limits, disposal commensurate with Class B and C wastes is required. Both of these practices reduce the intruder risk associated with Class A waste disposal. The EPRI proposal included regulating the flow of material to the disposal site to ensure that the activity concentrations in the disposal trench would be maintained below class limits.

Implementation of this change would require either 1) a change to the Branch Technical Position on Concentration Averaging and Encapsulation (BTP)or 2) a finding by the NRC of Alternative Classification under 10 CFR Part 61.58. This change would apply to low level radioactive waste.

Potential (Unintended) Consequences

To examine potential consequences either intended or unintended it's necessary to draw a profile of the potentially affected parties. 10 CFR Part 61 and related guidance documents apply to the disposal of low-level waste. The NRC has ceded much of its responsibility for low-level waste disposal to agreement states. The State of South Carolina regulates the operation of the Barnwell disposal site under its State issued license. The State of Utah regulates the operation of the Clive disposal site under its state issued license. The State of Washington regulates the operation of the Richland disposal site under its state issued license.

Unintended Consequences to Nuclear Regulatory Commission (NRC)

In addition to NRC's responsibility for granting Agreement State authority to provide regulatory oversight of such activities and technical guidance, NRC also retains oversight responsibility to review, provide guidance, and license certain disposal activities undertaken by the Department of Energy. While DOE is responsible for providing for the disposal of GTCC (LLW) wastes, NRC has licensing authority for these sites. NRC licensing of DOE LLW sites containing Class A, B, and C wastes is not required. For Transuranic waste (GTCC waste containing more than 100 nCi/gm TRU), licensing authority was granted by Congress to EPA by the "WIPP Land Withdrawal Act of 1992". This authority currently is only applicable to WIPP disposal site. Currently, there are no proposals by DOE relating to GTCC sites.

The primary guidance provided by the NRC relating to the classification of wastes by commercial generators includes, of course, 10 CFR Part 61, the 'original BTP' on classification, and the BTP on concentration averaging and encapsulation. Since the foundation of the proposal is suggesting changes to the BTP, actually changing of the BTP would not be an unintended consequence. Since the BTP has been incorporated by reference into a wide range of instructions, procedures, guides, justifications, NUREGs, SECY documents, etc. It would be necessary to conduct an impacts review to assure that conflicts are appropriately resolved.

Specific changes to the BTP would also have to be made available for public comments. This process inevitably brings out challenges by nuclear power opponents irrespective of the benign nature of the change. An unintended consequence might be a more restrictive classification process.

Unintended Consequences to Agreement States/Disposal Sites

Disposal of low level radioactive waste from commercial sources is managed with privately operated disposal sites operated under State issued licenses. There are currently 3 disposal sites operating in the United States that receive commercial low-level waste. These are listed in Table 8-1.

Table 8-1
U.S. low-level waste disposal sites-waste classification control and methods

Disposal Site	Barnwell	Clive	Richland
State	South Carolina	Utah	Washington
Agreement State	Yes	Yes	Yes
Operated By	Chem-Nuclear Systems (EnergySolutions, LLC)	EnergySolutions, LLC	U.S. Ecology Washington, Inc.
Regulatory Reference	SC DHEC Reg. 61-63	Utah R313-15	WAC 246-249-040
Classification	10 CFR Part 61.55(3),(4)	10 CFR Part 61.55(3),(4)	10 CFR Part 61.55(3),(4)
Averaging	10 CFR Part 61.55(8)	10 CFR Part 61.55(8)	10 CFR Part 61.55(8)
Acceptance	Class A, B, C	Class A, Only	Class A,B, C
License	SC DHEC #097	#UT 2300249	# WN-I019-2
Classification	10 CFR Part 61.55(3),(4)	UT R313-15-1008	10 CFR Part 61.55(3),(4)
Averaging	10 CFR Part 61.58 (8) plus(Note 2)	“BTP, as amended”	Original BTP, ”or successor documents”
Site Waste Acceptance Criteria	Chem-Nuclear S20-AD-010, Rev 18	EnergySolutions TSC 2.0 Rev. 5 (containerized facility)	U.S. Ecology
Classification	Per License	Per License	References 10 CFR Part 61 and WAC 246-249
Averaging	BTP by Reference Irradiated Components Barnwell Rule of 10	BTP	Averaging per Original BTP on Radioactive Waste Classification

Note 2. Supplemental Averaging Restrictions in Barnwell License.

> "The concentration of a radionuclide or radionuclide mixture may be averaged over the volume of the waste and, if used, the solidification agent or matrix if the waste form is a homogeneous mixture. The concentration of radionuclides in filters/sealed source encapsulated in with a solidification agent or matrix shall be averaged over the volume of the filter/sealed source not the solidification agent. The volume of packaging, containers, liners, or over-packs shall not be included in this calculation, nor shall the volume of the waste mixture be artificially increased with the addition of non-dispersible solids or objects even if considered waste.
>
> If expressed in units of nanocuries per gram, concentration may be averaged over the weight of the waste and, if used, the solidification agent if homogeneous mixture except in the case of filters which shall be over the weight of the filter. The weight of packaging, containers, liners, or over-packs shall not be included in this calculation, nor shall the weight of the waste mixture be artificially increased by the addition of heavy non-dispersible solids or objects even if considered as waste."

The State regulatory activities are restrained by "issues of compatibility". These are defined in: C*ompatibility Categories and Health and Safety Identification for NRC Regulations and Other Program Elements*-SA-200. Although the NRC does not retain exclusive authority on all 10 CFR Part 61 issues, States are required to comply with the classification defined in 10 CFR Part 61.55. SA-200 requires the State rules to be essentially identical to those given in Tables 1 and 2 of 61.55. Effectively, by making the classification system an "issue of compatibility" NRC precludes the States regulating disposal sites from employing alternative classification evaluations. The NRC has not developed a comparable level of control for using NRC guidance documents, including BTPs.

Potential Consequences

- Modification to Tables 1 and 2 of 61.55
  Assuming that the original basis for 10 CFR Part 61 is not violated, that is under comparable or appropriate intruder scenarios, the comparable performance is achieved, this should have little impact on operating sites. Assuming that the allowed activity levels are increased for certain long-lived radionuclides, a commensurate increase in short lived gamma emitting radionuclides that would contribute to worker exposures during emplacement of the packages. Disposal sites already are required to manage wastes containing up to 700 Ci/m^3 of Co-60. Special provisions are in place if the activity concentration of short lived gammas exceeds 1 $\mu Ci/cm^3$ or less (in the case of Clive). Some additional site-specific evaluations may be necessary to demonstrate compliance with the performance objectives.
- Invoking Alternative Classification Provision
  Any changes proceed from alternative classification evaluations, even if accepted by the NRC could not be implemented at the State Level, without modifying the Guidance in SA-200 to allow substitution of the Table 1 and Table 2 concentration limits. Assuming that the state wished to take advantage of the alternative classification evaluation, it would be then necessary to change the regulation as well as the site radioactive material License.
- Changes to Averaging Criterion
  Changes to the BTP would not have a direct impact on the state regulations or the disposal site radioactive material permit. In none of the three cases, do the regulations incorporate details of the BTP. The South Carolina license for Barnwell includes some specific restrictions on averaging and does not reference the BTP directly. The Barnwell operating procedure, however, includes a reference to the BTP. Both Washington and Utah reference the BTP but do not incorporate specific conditions of the BTP. If a new version of the BTP is issued, the State programs could follow it. Alternatively, if it was desired to apply other criteria, it would be necessary to modify the reference to the BTP.

Relief on the BTP could result in an increase in the average concentration of waste that would be brought into the Clive, Utah disposal site. While remaining within the limits for Class A waste and within the parameters of the site EIS, there could be a perception of manipulating waste classification to divert to Utah B and C waste previously sent to Barnwell.

Unintended Consequences to Department of Energy (DOE)

DOE is responsible for the cleanup and removal of radioactive waste from sites used in the production of weapons material as well as miscellaneous waste collected at the DOE sponsored national laboratories. The principal guidance for DOE sponsored waste management activity is provided in DOE Order 435.1. High level waste is defined by the nuclear waste policy act as spent nuclear fuel. Other important types of waste in DOE purview include transuranic wastes, greater than Class C wastes, and low level wastes. DOE is responsible for providing for the disposal of commercially generated greater-than Class C wastes. Currently no facility is available to accept this waste. A GTCC facility would have to be licensed by the NRC. Transuranic waste is defined as waste exceeding the 100 nCi/gm limit for transuranics. Waste below this level could be evaluated as low-level waste. Much of the waste generated through DOE activities is transuranic. DOE rules prohibit dilution of this material to meet LLW classification limits. If the waste is processed for stability or other technical purpose resulting in concentration levels below 100 nCi/gm, the classification can be reduced. The classification limit on transuranic is the only fixed limit on DOE waste types. It is the same as the 10 CFR Part 61 Class C limit for NRC regulated LLW. LLW waste disposal at DOE operated facilities is not regulated by the NRC. DOE sets concentrations limits based on site specific intruder analysis and specific stream waste characteristics.

While DOE has authority to set its own criteria, it was directed in the “Ronald W. Reagan National Defense Authorization Act of 2005” for non high-level wastes incidental to fuel reprocessing activities to determine, “in consultation with the Nuclear Regulatory Commission” appropriate disposition for the material. This has led to additional collaboration between DOE and NRC with respect to waste classification approaches and new considerations with respect to appropriate averaging criteria. The NRC responded in 2005 with draft interim concentration averaging guidance for waste determinations. This document outlined various averaging scenarios for treating thin layers of contamination and tank heels as commonly encountered at various DOE facilities. The methodology advanced a risk-informed approach where site specific conditions, disposal depth, activity distributions, and accessibility to the contamination were accounted for. This guidance was published in 2006 as Draft Interim Guidance in NUREG-1854, “Standard Review Plan for Activities Related to U.S. Department of Energy Waste Determinations”. Also include in NUREG-1854, were a set of benchmark formulas to correlate site specific intruder doses with 10 CFR Part 61 classification analyses or other performance assessment benchmarks. Effectively, the concentration averaging guidance provide to DOE was more liberal than offered by BTP since it allowed for site specific parameters and performance assessment in the consideration of intruder risks. Furthermore, it opened the prospect of near surface disposal of some waste which would otherwise exceed the 10 CFR Part 61 Class C limits. The NRC maintained in the guidance given to DOE that the basic applicability of the BTP remained in force. Any evaluations resulting in a reduced classification would require NRC review and concurrence.

Potential Consequences

None of the changes proposed in the EPRI research would significantly impact operating agreements and guidance provided between NRC and DOE. The classification guidance given to DOE by NRC is in line with the relaxations sought by EPRI and NEI on behalf of the commercial nuclear power industry.

- Modification of Tables 1 and 2 of §61.55
  There would be no consequences of this change. DOE determines disposal site concentration limits base on site specific performance assessment following the alternative classification provisions of §61.58.
- Invoking Alternative Classification Provision of §61.58
  As noted above DOE already employs a process parallel to §61.58.
- Changes to Averaging Criterion
  DOE has negotiated averaging criteria with NRC for specific applications. In the process of doing this NRC maintained that the BTP principles remained in force. It is unlikely that the changes proposed by EPRI/NEI would affect the specific agreements between NRC and DOE. Broader changes proposed may be moot in context of the DOE process for developing disposal criteria.

Unintended Consequences to Environmental Protection Agency (EPA)

Principal responsibilities of the EPA are for the management of low activity wastes, mixed wastes, waste containing naturally occurring radioactive materials (NORM), and technologically enhanced naturally occurring radioactive materials (TENORM), and accelerator produced wastes.

The Resource Conservation and Recovery Act —commonly referred to as RCRA— is our nation's primary law governing the disposal of solid and hazardous waste. Congress passed RCRA on October 21, 1976 to address the increasing problems the nation faced from our growing volume of municipal and industrial waste. RCRA, which amended the Solid Waste Disposal Act of 1965, set national goals for:

- Protecting human health and the environment from the potential hazards of waste disposal.
- Conserving energy and natural resources.
- Reducing the amount of waste generated.
- Ensuring that wastes are managed in an environmentally-sound manner.

To achieve these goals, RCRA established three distinct, yet interrelated, programs:

- The solid waste program, under RCRA Subtitle D, encourages states to develop comprehensive plans to manage nonhazardous industrial solid waste and municipal solid waste, sets criteria for municipal solid waste landfills and other solid waste disposal facilities, and prohibits the open dumping of solid waste.

- The hazardous waste program, under RCRA Subtitle C, establishes a system for controlling hazardous waste from the time it is generated until its ultimate disposal – in effect, from "cradle to grave".
- The underground storage tank (UST) program, under RCRA Subtitle I, regulates underground tanks containing hazardous substances and petroleum products.

In 2003, EPA published an advance notice of proposed rulemaking (ANPR) in which it was proposed an "integrated framework for the management and disposal of low activity radioactive wastes". Under the plan RCRA Subtitle C facilities could accept certain low activity waste and low activity mixed wastes. In the APNR, the EPA indicated that based on specific risk assessments, the RCRA-C facilities may be able to accept wastes up to the Class A limits on some radionuclides. The site specific assessments could result in some individual radionuclide limits exceeding the 10 CFR Part 61 Class A limits. Issues related to blending or volume averaging of wastes was introduced as an unresolved issue. It is not clear that this concept has been advanced beyond the ANPR.

A related issue general to EPA regulatory activity is the "dilution prohibition" expressed in 40 CFR 403.6. Effectively, it is unacceptable to use dilution to meet applicable pretreatment standards or requirements. The foundation of this requirement is to limit the overall discharge by controlling concentration to conform to mass release objectives. This idea is conceptually carried over into the radioactive arena.

Potential Consequences

- **Modification of Tables 1 and 2 of §61.55**
  There would be no consequences of this change. EPA is not tied to these limits since its criterion calls for a site specific assessment.
- **Invoking Alternative Classification Provision**
  Disposal concentration limits at RCRA-C disposal facilities will and should require determination of site specific concentration limits. It is not clear that §61.55 concentration limits would have any significance in this venue.
- **Changes to Averaging Criterion**
  The proposed changes could be perceived in conflict with the EPA dilution prohibition. While EPA does not have direct authority over the disposal of LLRW in disposal sites licensed under AEA authority, this remains a sensitive issue. In the context of the EPRI/NEI proposal, it is not at all clear that the restrictions on mixing to control classification fit the underlying premise of the dilution prohibition. For the most part it involves mixing of materials that are destined for disposal in a licensed low-level waste disposal facility. The material has already been collected and will not be directly released to the environment through open pathways.

Unintended Consequences to the United States Congress

The U.S. congress is invested in this process through the Low-Level Waste policy Act (LLPWA) and Low Level Waste Policy Amendments Act (LLPWAA). The Low Level Waste Policy Act authorized the NRC to establish licensing requirements for regional disposal facilities. The NRC constructed 10 CFR Part 61 on the basis of a generic performance assessment for a shallow land facility following current examples of facility design and operation. This regulation set concentration limits for near surface burial of low level waste with the minimum requirements based on unstable segregated waste (Class A) under two meters of cover. The regulation defined additional requirements for stabilization and intruder protection for wastes with activity concentrations above the minimum cases. The LLPWAA embraced the classification requirements of 10CFR§61.55.

> **"Each State shall be responsible for providing, either by itself or in cooperation with other states, for the disposal of Low-level radioactive waste generated within the state (other than by the Federal Government) that consists of or contains class A, B, or C radioactive waste as defined by section §61.55 of title 10 of the code of Federal Regulations, as in effect on January 26, 1983."**

Effectively this provision ties the classification directly to the Table 1 and Table 2 Concentration limits provided in 10CFR§61.55. As noted above, this is also considered by the NRC Office of State Programs to be an "issue of compatibility".

Potential Consequences

- Modification of Tables 1 and 2 of §61.55
  There would be no consequences of this change. LLWPAA does not address this level of Detail.
- Invoking Alternative Classification Provision
  This would require legal acknowledgement of the option to conduct an independent performance assessment following 1-0CFR§61.58 in lieu of classifying in accordance with §61.55.
- Changes to Averaging Criterion
  There would be no consequences of this change. LLWPAA does not address this level of Detail.

Unintended Consequences to the LLRW Generators

Generators of LLRW are, in almost all cases, radioactive materials licensees subject to the regulations of the NRC or Agreement State. As such they are required to follow the applicable rules and regulations in accordance with the guidance documents provided by the regulator or, where such latitude is allowed, be able to demonstrate their practices are compliant with the objective of the regulation.

Potential Consequences

- Modification of Tables 1 and 2 of §61.55
  Generators may need to change procedures or programs used to perform the analysis for waste classification. This may involve changes to the way waste is sampled or analyzed to provide the appropriate level of confidence that the waste is properly characterized.
- Invoking Alternative Classification Provision
  There would be no additional consequence to this action. The condition currently exists and can be invoked or ignored by the generator as desired. Generators wishing to take advantage of any alternative classification provisions would have to demonstrate compliance with the provision.
- Changes to Averaging Criterion
  In addition to the potential consequences noted for changes to Tables 1 & 2, changes to averaging criterion may require the generator to implement changes to storage and shipping practices which may include temporary storage of some LLRW until the ‘averaging criteria’ are met for a batch or at the disposal site.

9
RESULTS AND CONCLUSIONS

The Low Level Radioactive Waste (LLRW) Policy Act in 1980 mandated the development of new regional low level radioactive waste disposal sites. These would replace existing disposal sites and were expected to be in service by 1986. In support of this act, the NRC published regulations in 1983 defining conditions and criteria for the development of these regional sites. The criteria were conceived as generic and incorporated the limiting conditions associated with each of the four regional geologies and climates. Since the publication of the regulations, no new regional disposal sites have been developed. A single new site has evolved outside of the compacting process but is restricted to receive only Class A wastes. The recent closure of the Barnwell, SC site to out of compact generators has initiated a situation where most operating plants are denied a disposal venue for Class B and Class C wastes. The current system of classification including rules controlling the averaging of activity are aimed toward maximizing the higher classifications through restrictions on what can be averaged as well as pressures to reduce the volumes of wastes disposed. This report examines the NRC's Branch Technical Position (BTP) on Concentration Averaging and determines whether it achieves the additional protection that it purports to provide.

Taking into account a current representation of the nuclear power industry LLRW source term and current disposal practices it is observed that there are orders of magnitude of margin built into the process that effectively obviate the need for the restrictions the BTP places on averaging. This assessment identifies four significant areas for change in the BTP.

All four areas relate to clarification of the overall averaging basis for disposal. Disposal concentration limits in 10CFR61 are based on a volume corresponding to 232 m^3 (intruder volume) being excavated by an intruder. Intruder exposures are based on the average concentrations in the excavated materials and not the volume of an individual package as implied by the BTP. Changes specific to provisions of current BTP call for unrestricted averaging of homogeneous waste, classifying cartridge filters in a manner similar to DAW, and modify the treatment of activated metals as non-discrete to eliminate the factor of 1.5 restriction on Nb-94 and allow averaging over the volume of the disposal package.

The analysis presented in this report shows that if the industry waste stream is treated as a single stream without consideration of activity variations, it would meet the Class A concentration limits of 10 CFR Part 61.55. Furthermore, the existing concentration limits were based on the environmental and hydro-geological conditions of the most restrictive reference site evaluated during the development of the regulation. Given more favorable conditions, as exist in some current sites, the performance objectives of 10CFR61 can be met with minimum disposal technology and without additional regard to material classification. The addition of non-utility wastes to the mix further strengthens this argument. When disposal technology and operating practices are added, protection factors far exceeding the original 10 CFR Part 61 intruder protection objectives can be realized.

In addition, consideration was given to potential impacts to other entities by making changes to the existing regulatory interpretations. For the most part changes to BTP's are entirely within the domain of the NRC, other effected parties have the option of subscribing to the BTP or defining and implementing their own interpretations. For the most part a change to the BTP would not have significant impact on existing regulations or criteria. It could result in some change in operating practices at power plants but such changes would be optional.

Based on our analysis, wide spread implementation of less restrictive and more risk informed averaging criteria would reduce the amount of waste that would have to be maintained and stored at the 65 nuclear power plant sites effected by the Barnwell closure. This would reduce operating costs at the sites as well enhance operational performance.

10
REFERENCES

1. Title 10 U.S. Code of Federal Regulations, Part 61 Licensing requirements for Land disposal of Radioactive Waste.
2. ACNW&M, "History and Framework of Commercial Low-Level Radioactive Waste Management in the U.S.," NUREG-1853, January 2007.
3. Improved Guidance, Oversight, and Planning Are Needed To Better Identify Cost-Saving Alternatives for Managing Low-Level Radioactive Waste, U.S. Government Accountability Office, Washington, DC, GAO-06- 94, October 2005.
4. Strategic Assessment of Low-Level Radioactive Waste Regulatory Program, SECY-07-180, U.S. Nuclear Regulatory Commission, October 17, 2007.
5. Branch Technical position on Classification, U.S. Nuclear Regulatory Commission, May 1983.
6. Low-Level Waste Licensing Branch Technical Position on Radioactive Waste Classification, USNRC May 1983.
7. Branch Technical Position on Concentration Averaging and Encapsulation, U.S. Nuclear Regulatory Commission, January 17, 1995.
8. Low-Level Radioactive Waste Policy Act of 1980, Title 42, §2021b.
9. Low-Level Radioactive Waste Policy Amendments Act of 1985 (Title I), (P.L. 99-240).
10. http://en.wikipedia.org/wiki/Goi%C3%A2nia_accident, Goiâna Accident, Wikipedia, The Free Encyclopedia.
11. *An Evaluation of Alternative Classification Methods for Routine Low-Level Waste from the Nuclear Power Industry.* Final Report, Electric Power Research Institute, Palo Alto, CA: November 2007. EPRI Report 1016120.
12. Branch Technical Position on a Performance Assessment Methodology for Low-Level Waste Disposal Facilities, NUREG-1573.
13. HTTP://www.energysolutions.com.
14. "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes, U.S. Nuclear Regulatory Commission," Washington, D.C., Office of Nuclear Material Safety and Safeguards, NUREG-0782, September 1981.
15. Final Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes, U.S. Nuclear Regulatory Commission, Washington, D.C., Office of Nuclear Material Safety and Safeguards, NUREG-0945, November 1982.
16. Standard Review Plan for Activities Related to U.S. Department of Energy Waste Determinations, NUREG-1854, U.S. Nuclear Regulatory Commission, May 2005.

17. NUREG/CR-6142, Vol.1, Characterization of Class A Low-Level Radioactive Waste, 1986-1990, S. Cohen and Associates for USNRC, January 1994.
18. Manifest Information Management System, http://mims.apps.em.doe.gov, Managed by Department of Energy.
19. WIPP Land Withdrawal Act of 1992, Public Law 102-579.
20. State of South Carolina, DHEC, Regulation 61-63.
21. State of Utah, Regulation R313-5.
22. State of Washington, Regulation Was246-249-040.
23. SA-200, Compatibility Categories and Health and Safety Identification for NRC Regulations and Other Program Elements, U.S. Nuclear Regulatory Commission, Office of State Programs.
24. Order 435-1, Radioactive Waste Management, U.S. Department of Energy, Office of Environmental Management, July 9, 1999.
25. Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Public Law 108-375.
26. Resource Conservation and Recovery Act, 42 U.S.C. §§6901-6992k, October 1986.
27. Advance Notice of Proposed Rulemaking, Approaches to an Integrated Framework for Management and Disposal of Low-Activity Radioactive Waste, Federal Register Volume 65, No. 222, U.S. Environmental Protection Agency, ANPR, November 18, 2003.
28. Title 40 U.S. Code of Federal Regulations, § 403.6, National Pretreatment Standards, Categorical Standards, (Dilution Prohibition).
29. Policy and Guidance Directive PG-8-08, Scenarios for Assessing Potential Doses Associated with Residual Radioactivity, USNRC May 1994.
30. User's Manual for RESRAD Version 6. Argonne National Laboratory, July, 2001.
31. LLRW Disposal Database, EPRI, 2002-2006.
32. Ledoux, M.R., Cade, M.S., "Licensing and Operations of the Clive, Utah Low-Level Containerized Radioactive Waste Disposal Facility – A Continuation of Excellence", Waste Management Symposium, WN'02, February 24-28-2002, Tucson AZ.

A
GLOSSARY

ACNW	Advisory Committee on Nuclear Waste
ACRS	Advisory Committee on Reactor Safety
AEA	Atomic Energy Act of 1954
AEC	Atomic Energy Commission
AGV	above-ground vault
AIF	assured isolation facility
ALARA	as low as reasonably achievable
ANPR	advance notice of proposed rulemaking
BEIR	biological effects of ionizing radiation
BLM	Bureau of Land Management
BRC	below regulatory concern
BTP	branch technical position (as used here refers specifically to the Branch Technical Position on Classification as amended by the 1995 guidance on concentration averaging and encapsulation)
BWR	boiling-water reactor
CAA	Clean Air Act of 1977, as amended
CDPHE	Colorado Department of Public Health and Environment
CEQ	Council on Environmental Quality
CFR	*Code of Federal Regulations*
Ci	curie

CORAR	Council on Radionuclides and Radiopharmaceuticals
CRCPD	Conference of Radiation Control Program Directors
D	day
DCG	disposal concentration guide
DEIS	draft environmental impact statement
DHEC	department of health and environmental control (South Carolina)
DNFSB	Defense Nuclear Facilities Safety Board
DOI	U.S. Department of Interior
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DSI	direction-setting issue
EMCB	earth-mounded concrete bunker
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
FEIS	final environmental impact statement
FFCA	Federal Facility Compliance Act of 1992
FR	*Federal Register*
FRC	Federal Radiation Council
ft3	cubic feet
GAO	U.S. General Accounting Office (before July 2004); U.S. Government Accountability Office (after July 2004)
GEIS	generic environmental impact statement

GTCC	greater-than-Class C (radioactive waste)
HIC	high-integrity container
HLW	high-level radioactive waste
HDPE	high-density polyethylene
hr	Hour
ICRP	International Commission on Radiation Protection
ISFSI	independent spent fuel storage installation
LAW	low-activity radioactive waste
LFRG	LLW Disposal Facility Federal Review Group (of DOE)
LLW	low-level radioactive waste
LLW	Forum Low-Level Radioactive Waste Forum
LLWPA	Low-Level Waste Policy Act of 1980
LLWPAA	Low-Level Waste Policy Amendments Act of 1985
LSV	liquid scintillation vial
LWR	light-water reactor
$\mu Ci/cm^3$	microcurie per cubic centimeter
$\mu g/L$	microgram per liter
m^3	cubic meter
MAC	maximum average concentration
MCL	maximum concentration limit
MIMS	Manifest Information Management System (of DOE)
MLLW	mixed low-level radioactive waste
MOU	memorandum of understanding

MOX	mixed-oxide (fuel)
mR/hr	millirem per hour
mrem/yr	millirem per year
MRS	monitored retrievable storage
nCi/g	nanocurie per gram
NACOA	National Advisory Committee on Oceans and the Atmosphere
NARM	naturally occurring or accelerator-produced radioactive material
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act of 1970
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NFS	Nuclear Fuel Services, Inc.
NMSS	Office of Nuclear Materials Safety and Safeguards
NOI	notice of inquiry
NORM	naturally occurring radioactive material
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OTA	Office of Technology Assessment
pCi/g	picocurie per gram
pCi/L	picocurie per liter

PAM	performance assessment methodology (for LLW)
PCB	polychlorinated biphenyl
PNL	Pacific Northwest Laboratory
PRA	probabilistic risk assessment
PRESTO	Protection of Radiation Effects from Shallow Trench Operations (EPA computer code)
psi	pounds per square inch
PWR	pressurized-water reactor
QA	quality assurance
R&D	research and development
RCRA	Resource Conservation and Recovery Act of 1976
RES	Office of Nuclear Regulatory Research
s	Second
SA	specific activity
SLB	shallow land burial
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
SRM	staff requirements memorandum
SS	source and special nuclear material
TCEQ	Texas Commission on Environmental Quality
TEDE	total effective dose equivalent
TENR	technologically enhanced natural radiation
TENORM	technologically-enhanced naturally occurring radioactive materials
TRU	transuranic (radioactive waste)

USGS	U.S. Geological Survey
WCS	Waste Control Specialists, LLC (of Texas)
WIPP	Waste Isolation Pilot Plant
yr	Year

B
INDUSTRY WASTE GENERATION PROFILE

In 2007, EPRI conducted a survey of its member plants on the generation of low level radioactive waste. The survey response covered four years of operation. The data was gathered from plant shipping records. Responses to the survey covered 65 of 101 operating unit including 41 PWRs and 24 BWRs. More than 10,000 records were collected covering the period from January 2003 through February 2007. Using this data, a scenario was constructed wherein all of the waste was averaged together as a single stream. For evaluation purposes the sub-streams identified in the study were consolidated into 4 groups including wastes from water treatment (comprised of resins, charcoal, and other filter media), Mechanical Filters, Dry Active Waste (DAW), and Activated metals. Activated metals, which accounted for approximately 85 % of the total activity of wastes, are addressed separately from the other streams. A breakdown of the volumes of the remaining wastes is shown in Figure B-1. Overall, the industry generates about 1 million cubic feet of these types of wastes per year, with the volume evenly split between the two dominant plant types. BWRs on average generate about 50% more volume per unit. DAW constitutes about 90% of the volume, resins about 9%.

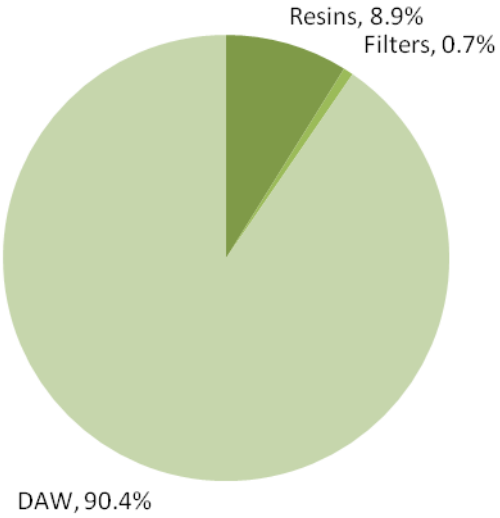

Figure B-1
Process waste distribution by volume

The corresponding distribution by activity is shown in Figure B-2. While resins and filters constitute only about 10 percent of the volume they account for more the 99% of the activity. Again, excluding activated metals, the industry generates about 28,000 curies per year with BWRs contributing about 18,000 curies and PWRs the remaining 10,000 curies. BWRs per unit generate about four times as much activity.

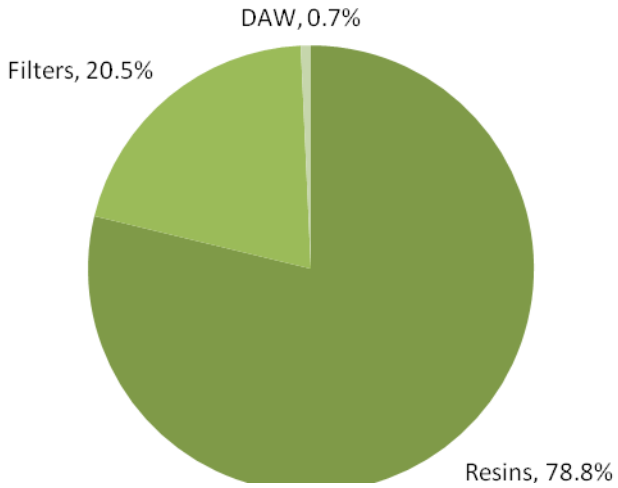

Figure B-2
Process waste distribution by activity

Based on the survey performed, Class A wastes account for almost 99% of the total volume of wastes. This leaves a total volume of class B and C waste of approximately 15,000 cubic feet per year or, roughly, the equivalent of one large liner per plant unit. A chart showing the volume distribution by unit is shown in Figure B-3.

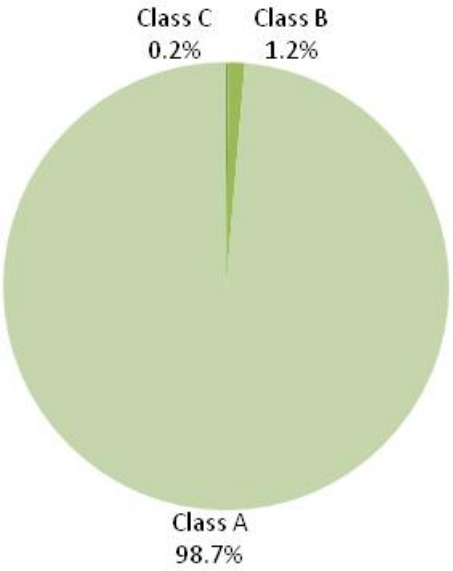

Figure B-3
Volume distribution by classification

Figure B-4 focuses again on classification. This time we are looking at the activity distribution by classification. Class A wastes account for about 35% of the total activity. Class B wastes account for more than half. Surprisingly, the total reported activity in Class C wastes is less than that of the Class A wastes. In the case of the Class B wastes, classification is driven by the short lived radionuclides in particular Cs-137 and Ni-63.

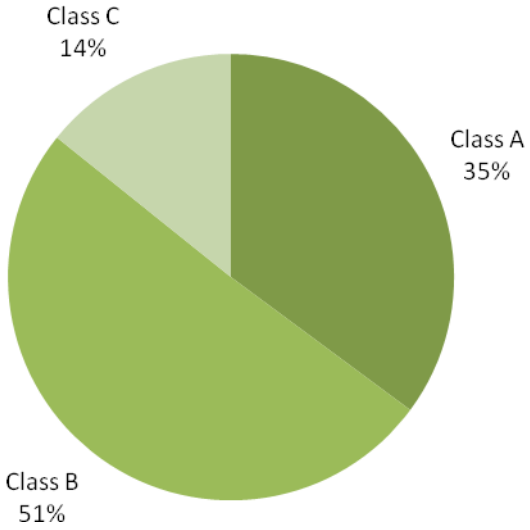

Figure B-4
Activity distribution by classification

Following current practice, waste classification is performed at the package level at individual plants. If we look at the overall classification of the waste tabulated in the EPRI survey, the weighted average classification basis is about 10% of the Class A limit for Part 61 Table 2 and only about 1.4% of the Class A limit for Part 61 Table 1. Assuming that a representative collection of this material is placed in the disposal site all of the parameters would be met to provide for the public protection sought through such disposal. This scenario assumes averaging overall of the wastes without consideration of stream or who would generate it. Since this waste, in bulk meets Class A limits, and would be eligible for Class A disposal as defined in 10 CFR Part 61, the streams themselves could be treated as Class A by definition.

Based on previous work where the activity distributions were examined in detail, the dominant classification controlling radionuclide is Cs-137. Cs-137 is also found to be the dominant source of radioactivity exposure to the 100 year intruder. Exposure from other radionuclides contributing to classification including Ni-63 and Sr-90 were found to be negligible. The average Cs-137 concentration found in the data collected was 0.061 Ci/m^3. This corresponds relatively closely to the original EIS assumption that the average Cs-137 concentration would be diluted by a factor of 20 below the Class A limit within a Class A facility. However, since in this scenario we are including all wastes including those exceeding the Cs-137 Class A limit of 1 Ci/m^3, the actual dilution, if we didn't add these wastes, is closer to like a factor of 135. The distribution of Cs-137, based on an annualized waste volume is shown in Figure B-5. For process wastes (excluding DAW) the overall average Cs-137 concentration in the EPRI database was 0.63 Ci/m^3

averaged over 2,750 m^3 per year (~96,000 ft^3). This contrasts with the generation rates estimated for the EIS where the overall average was 0.53 Ci/m^3 of Cs-137 averaged over an annual generation rate of ~38,000 m^3. While the current average concentration is about 20% higher, the overall Cs-137 generation estimated in the EIS is more than 10 times higher than recent experience.

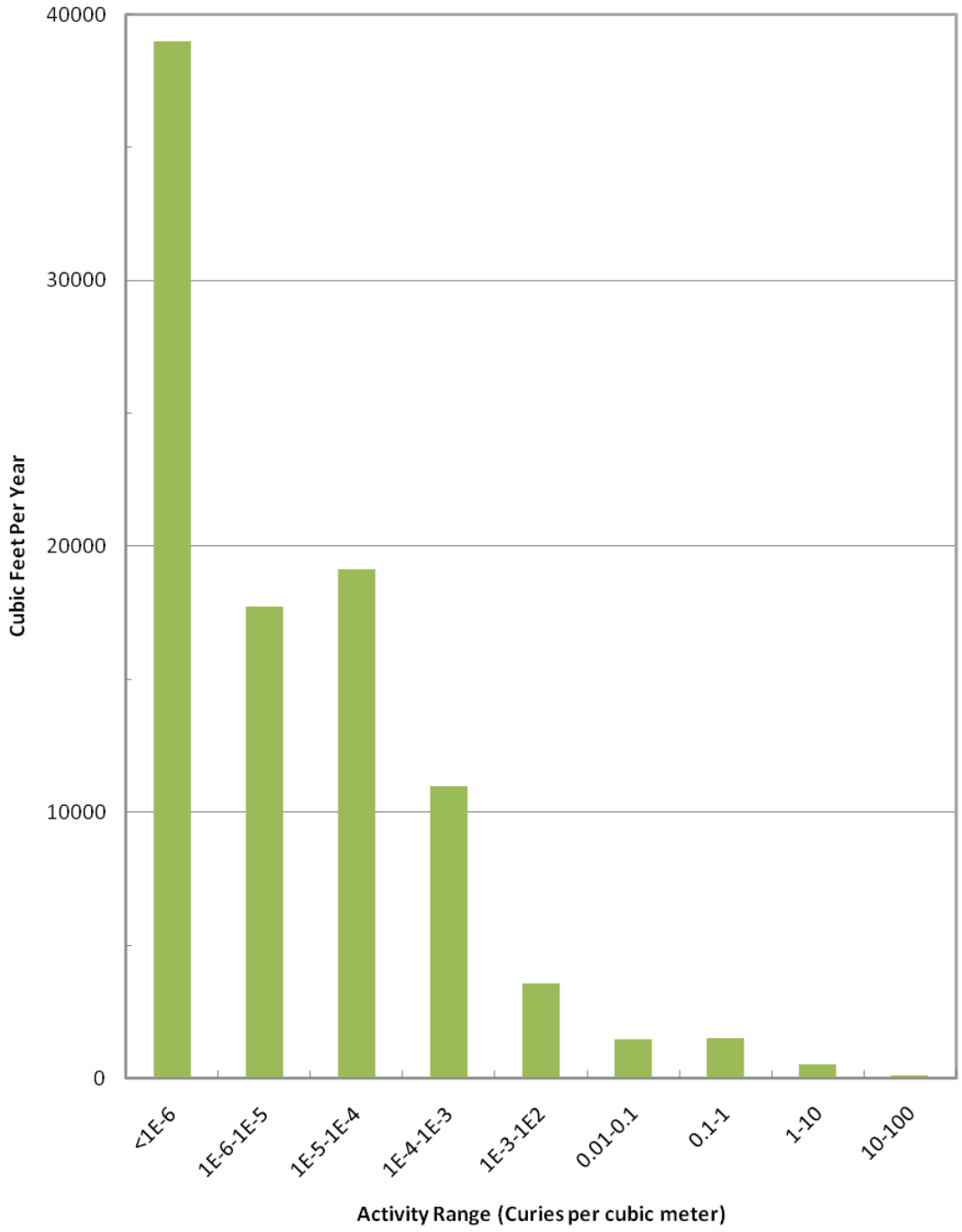

Figure B-5
Volume distribution of Cs-137 in NPP operational wastes

All of the wastes, included in the discussion above were originally viewed in the EIS as suitable for near surface disposal. Since no exemption level has been adopted, all waste within the streams identified in the EIS, whatever the level of contamination, are all subject to the same disposal venue. Basically if the wastes are not TRU wastes there is no other disposal venue suggested, planned or foreseen for these wastes. GTCC references a non entity. The wastes are either TRU or LLW. LLW is suitable for near-surface disposal.

Cartridge Filters – Activity Considerations

The activity distribution in cartridge filters is dominated by short half-lived activated corrosion products. Iron 55 on average constitutes nearly half to the total activity. This, followed by Co-58, Co-60 and Ni-63 constitute almost 90 percent of the total activity. Ni-63 is the only one of the major radionuclides that contributes significantly to classification. Where filters are observed to exceed Class A limits, Ni-63 is the most likely nuclide to effect the classification. However, Ni-63 concentrations rarely exceed Class B limits. Only 4 out of 399 entries in the data base comprising 0.16% of the volume reported Ni-63 exceeding the Class B limits. Where filters are observed at or above Class C limits the leading contributor is alpha emitting transuranics followed with much lower frequency by C-14. Together these account for about 44% of the class C filter wastes. The remaining Class C wastes can be accounted for by Ni-63 in combination with Sr-90. In our data base, some filter waste was reported with sufficiently high concentrations of Cs-137 and Tc-99 to effect classification. On closer inspection, it is likely that the concentrations were determined from detection limits since almost the total of these nuclides in filters were concentrated in less than 10 entries in the database. Effectively, 80% of Class B and C filter waste is based on the concentrations of the shorter half-lived Table 2 radionuclides. There are no primary gamma nuclides contributing significantly to classification. Overall filters follow generally the same activity distribution. Overall contributions of the long-lived Table 1 radionuclide account for a very small activity contribution to the overall stream.

In the case of the Part 61 Table 1 nuclides, the difference between Class A and Class C limits is only a factor of 10. For the Part 61 Table 2 radionuclides the jump to the class C limit can be factor of 200 to more than1000 or there is no class C limits at all. Since Ni-63 is present in class proportion to Co-60 (0.1-0.5), for a filter to exceed the Class C based on Part 61 Table 2 limits the Co-60 activity would be prohibitively high to allow any kind of handling of the filter. It is not expected nor observed that a significant volume of filters would exceed Class B limits on Table 2 concentrations. It is expected and observed that filters will exceed Class C limits based on Table 1 radionuclides. However, by and large, the industry has been successful and passing the higher activity through the current averaging process. Whether or not averaging is achieved, however, it needs also to be pointed out that this part of the overall filter stream only constitutes 20% of the greater than class A filters and about 2.7% of the overall filter stream. If we assume that the GTCC filters would account for half of activity of filters grouped as Part 61 Class C, the total curie contribution to overall disposal would be only about 140 curies. The relative activity contributions to TRU and C-14 would be negligible in the context of an entire disposal venue. Furthermore, it needs to be kept in mind that none of the other wastes that have been profiled here contribute significantly to TRU or C-14.

Activated Metals – Activity Considerations

The data collected from power plant shipping records included over the four year period a total of 6,450 ft^3 of activated metals or about 1,600 ft^3 per year. It is recognized that this estimate may be small since shipping documentation for activated metal shipments is often prepared by outside contractors. Specific shipment records are not always included in the plant shipping computer program database. It will be conservatively assumed, for the sake of argument, that the data included records of only half of the shipments.

Activity distributions in activated metals are strongly represented by short half-life isotopes. Dominant isotopes in stainless steel include Fe-55, Co-58, and Co-60. Distributions vary based on the constituents of the original metals. Zirconium alloys are high in Zr-95 and Zr-97, along with Nb-95. Inconel alloys, since they are nickel based, are strongly dominated by Ni-9 and Ni-63. Both cobalt and niobium are trace contaminates in the original metals. While often not well known, they are considered to be present in all of the various types of metals to greater or lesser extents. The presence of cobalt is typically readily observable by the strength of its emissions.

From the sampling in our database, the average concentration of Co-60 is 1,428 Ci/m^3 which is only about 1/5 of the Class A limit. Given the high Class A limit for Co-60 it would be expected that ALARA compliant handling of activity quantities associated with activated components would be well within the capability of disposal sites. Figure B-6 shows the decay profile of activated components as represented in our database. Short lived activity which dominates activity totals, as expected, effectively no longer represents an exposure hazard after 100 years. Cs-137 and Sr-90 which are of low importance in activated metals persist for about 300 years. Beyond this point, Ni-63 dominates activity totals for another 700 years. However, none of the remaining radionuclides figure prominently in the short term intruder scenarios. Rather, the concern is based on long term transport considerations and controlling general population doses. The concerns then focus on the total inventories of C-14, Ni-59, and Nb-94. Within our database, concentrations of these isotopes in activated metals (without accounting for any dilution) are observed to be low percentages of the Class A limits when considered in the context of the entire stream. The volume tabulated in the database was disposal volume. Under current requirements for disposal of activated metals, this would correspond to the displaced volume within a package of the metal itself. It does not include the package volume which would more effectively represent the displaced volume in the disposal site. While Ni-59 and Nb-94 are not specifically tracked in other waste streams, their contributions to activity totals are inconsequential in contrast to the quantities in activated metals. Local concentrations of these radionuclides would be well below levels of concern. Facility wide concentrations would be inconsequential.

While a large component such as reactor vessel with internals inside would represent a very substantial disposal activity, the long term risk, after a suitable period of isolation, would not be prohibitive. An example would be the disposal of a reactor pressure vessel with the internals in place. The internals would contain about 99% of the activation activity. The vessel itself would contain little activity and generally be approachable. The vessel would serve both as 300 to 500 year containment and shielding for the internals. While we believe it could be safely buried in a near surface facility without additional preparation, the logistics of transport and handling would demand detailed planning and an informed decision by the disposal site operator. Due to their inherent stability and dominantly short-lived activity, specific Part 61 classification of activated metal packages and components has little relevance.

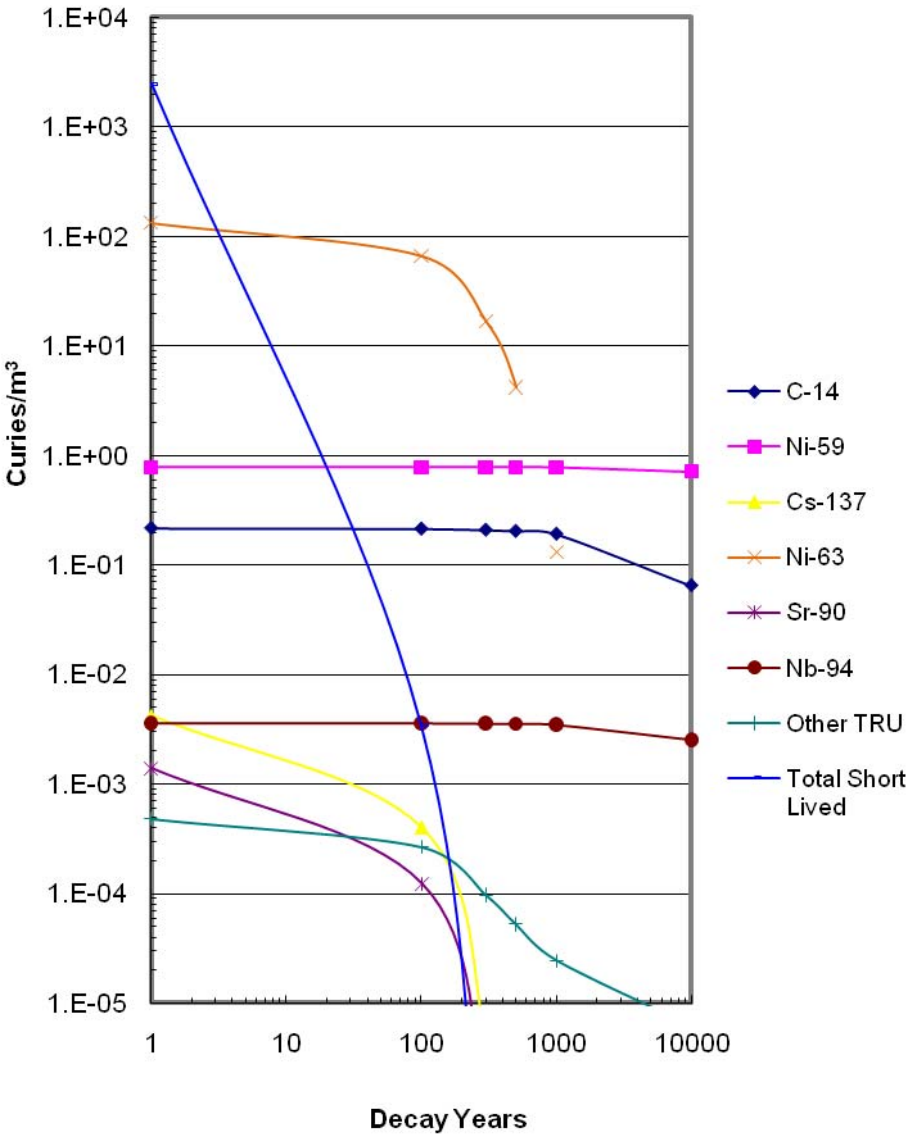

Figure B-6
Decay of activated metals (database spectrum)

C
ANALYSIS OF NUREG 0782 WESTERN LLW DISPOSAL SITE WITH UPDATED SOURCE TERM USING RESRAD

Purpose

The purpose of the this analysis is to estimate radiation exposures from the disposal of Low Level Radioactive Waste (LLRW) at a hypothetical western United States disposal site based on current generation data using modern analysis tools and compare them to the performance objectives of Title 10, Code of Federal Regulations, Part 61.

Summary

The disposal of LLRW in the United States is controlled by the regulations promulgated in Title 10, Code of Federal Regulations, Part 61, 'Licensing Requirements for Land Disposal of Radioactive Waste' (10 CFR Part 61). These regulations are based on the estimates and analyses published in NUREG-0782, 'Draft Environmental Impact Statement on 10 CFR Part61…' and NUREG-0945, 'Final Environmental Impact Statement on 10 CFR Part 61…'. These last described the performance objectives that a shallow-land LLRW disposal facility had to meet. The performance objective is based on a goal of maintaining radiation exposure to a member of the public less than 25 millirem/year from the disposal site and its long-term environmental impacts and less than 500 millirem/year to an inadvertent intruder.

NUREG-0782 evaluated a range of scenarios and conditions thought to be representative of waste generation and processing techniques used at the time. It was theorized that waste disposal would occur in geographical regions relatively close to the point of generation. Therefore, several theoretical regional sites were developed and analyzed corresponding to the three LLRW disposal sites in existence at the time and the expected needs of LLW generators.

The evaluations revealed that both short-term and long-term radiation exposures are significantly affected by both environmental factors and the stability of the waste in the disposal site. For this reason, the activity concentrations developed for waste classification were based on the most restrictive (from an environmental perspective) disposal site. In addition, three sub-classes of LLRW were identified by activity concentration and requirements for physical stability. Class A waste having the lowest activity concentrations would have the least or no physical stability requirements. Class B and Class C waste have higher activity concentrations and require processing or packaging to achieve physical stability if the waste is not inherently stable in and of itself. Recognition was given to the wide range of radiation exposure possible given the

varying conditions of the disposal site and the forms that waste could be processed into. Therefore, the regulations incorporated alternative classification provisions whereby other methods, not specifically addressed in the regulations, could be evaluated as compliant with the performance objectives.

In this analysis, radiation dose calculations were performed using RESRAD version 6.3. The site parameters for the Western site as per NUREG-0782 were used. Dose was calculated for the long-term exposure scenario to 1000 years post-closure and for the Intruder Agriculture Scenario at 100 years post-closure as specified in NUREG-0782. The source term was developed from the EPRI database of LLW disposal from U.S. nuclear utilities. Waste volumes and activities were extrapolated for a 20-year disposal site operating life. All waste, including those evaluated as Class A, Class B and Class C waste, including non-fuel bearing activated metal components (ACM) were mixed and evaluated together. The activity concentration of the resulting mixture was well within the limits of Class A waste using the values for non-activated metal per 10 CFR Part 61.55. Exposure to the Maximum Exposed Individual for the long-term scenario was 8.92E-06 mrem/year. The exposure to the Maximum Exposed Individual for the Intruder Agriculture Scenario (the most limiting of the NUREG-0782 scenarios) was 388.45 mRem/year.

The evaluation shows that all waste currently generated by nuclear power plants, with the exception of sealed sources and discreet objects as described in the Final Branch Technical Position on Concentration Averaging and Encapsulation, may be mixed and averaged to meet the classification specifications of Class A waste and meet the performance objectives of 10 CFR Part 61 for shallow land disposal.

Analysis

Radiation exposures were calculated using RESRAD version 6.3. The RESRAD code was developed by Argonne National Laboratory for the U.S. Department of Energy (DOE) to implement residual radioactive material guidelines. RESRAD has been widely used by the DOE, the U.S. Nuclear Regulatory Commission (NRC), the U.S. Environmental Protection Agency (EPA) and many other organizations to determine dose from radioactive material in soil. The code includes inhalation and ingestion dose conversion factors from EPA's Federal Guidance Report No. 11 (FGR-11), direct external exposure dose conversion factors from FGR-12, risk slope factors primarily from the latest health effects and summary tables, radionuclide half-lives from International Commission on Radiological Protection Publication 38 and risk coefficients from FGR-13.

Source Term

The source term for this analysis was developed from the EPRI LLW database. This database contains all LLRW disposal information from 65 of the 100 operating nuclear power plants for 4 years (2002-2006). While not all inclusive, the database is comprehensive and representative of the waste generation types, activities and volumes that can be expected from a nuclear power plant during an operational life time with the exception of decommissioning waste.

To develop the source term for this analysis the activity and volume was averaged for the 4 years reported and corrected for the total number of nuclear plants in operation to determine an annual waste generation for the fleet. This annual waste generation used to develop a 20-year source term for the disposal facility.

The nuclides selected represented the most significant radionuclides by hazard as evaluated in NUREG-0872 and include most of the radionuclides from Table 1 and Table 2 of 10 CFR Part 61.55. I-129, Tc-99 and H-3 are not included because their activities are not well known, to the extent that they are known, they don't contribute significantly to long-term risks and they do not contribute to short-term risk. They are therefore unlikely to be actually present in the waste in significant quantities. Fe-55 which accounts for a little over 47% of the total activity contributes little to radiation exposure and is also excluded. The remaining nuclides are excluded due to relatively insignificant activity, short half-life or insignificant dose consequence. The evaluation was performed on waste that did not include activated metals to avoid biasing the distribution toward that waste stream.

Table C-1
LLRW waste volume, weight and activity from EPRI database (excluding ACM)

Totals for 4 Years Generation	Data for 65 Units	Extrapolation for 100 Units		
Nuclide	**mCi**	**mCi**	**Percent of Total Activity**	**Inclusion (Yes/No)**
H-3	3.08E+05	4.55E+05	0.39%	No
C-14	2.38E+05	3.53E+05	0.30%	Yes
Cr-51	4.60E+05	6.81E+05	0.58%	No
Mn-54	4.38E+06	6.48E+06	5.48%	No
Fe-55	3.78E+07	5.60E+07	47.40%	No
Fe-59	9.41E+04	1.39E+05	0.12%	No
Co-57	6.55E+04	9.69E+04	0.08%	No
Co-58	3.94E+06	5.82E+06	4.93%	No
Co-60	1.52E+07	2.24E+07	19.01%	Yes
Ni-59	2.61E+05	3.86E+05	0.33%	No
Ni-63	8.18E+06	1.21E+07	10.25%	Yes
Zn-65	1.59E+06	2.36E+06	2.00%	No
Sr-90	3.42E+04	5.07E+04	0.04%	Yes
Zr-95	2.98E+04	4.41E+04	0.04%	No
Zr-97	3.23E+00	4.78E+00	0.00%	No
Nb-94	4.82E+01	7.13E+01	0.00%	Yes

Table C-1
LLRW waste volume, weight and activity from EPRI database (excluding ACM) (continued)

Totals for 4 Years Generation	Data for 65 Units	Extrapolation for 100 Units		
Nuclide	**mCi**	**mCi**	**Percent of Total Activity**	**Inclusion (Yes/No)**
Tc-99	1.58E+05	2.34E+05	0.20%	No
Ag-110m	4.38E+04	6.48E+04	0.05%	No
Sb-125	1.84E+05	2.72E+05	0.23%	No
Cs-134	2.18E+06	3.22E+06	2.73%	No
Cs-137	4.51E+06	6.68E+06	5.65%	Yes
Ce-144	1.46E+05	2.16E+05	0.18%	No
Pu-238	3.64E+02	5.38E+02	0.00%	Yes
Pu-239	4.17E+02	6.17E+02	0.00%	Yes
Pu-241	1.53E+04	2.27E+04	0.02%	Yes
Am-241	4.51E+02	6.67E+02	0.00%	Yes
Cm-242	2.39E+02	3.54E+02	0.00%	Yes
Cm-243	2.46E+02	3.63E+02	0.00%	Yes
Cm-244	1.32E+02	1.96E+02	0.00%	No
Total Activity	7.98E+07	1.18E+08		
Volume (ft^3)	2.69E+06	3.98E+06		
Weight (lbs)	4.59E+07	6.80E+07		

The activity was further broken down by 10 CFR Part 61.55 waste class and if the waste was ACM or not as shown in Table C-2.

Table C-2
EPRI database activity by waste class and ACM activity

	Excludes ACM			ACM Only		
Waste Class	**A**	**B**	**C**	**A**	**B**	**C**
Volume (ft^3)	2.65E+06	3.14E+04	4.83E+03	6.13E+03	4.09E+01	2.78E+02
Weight (lbs)	4.42E+07	1.50E+06	1.89E+05	2.39E+05	1.03E+04	9.70E+04
Activity in Millicuries						
Ni63	4.00E+05	5.58E+06	2.20E+06	1.18E+04	5.02E+04	2.43E+07
Cs137	3.93E+05	2.22E+06	1.90E+06	2.33E+02	1.38E+02	3.96E+02
Co60	6.37E+06	7.68E+06	1.12E+06	2.07E+05	3.46E+05	2.60E+08
Sr90	4.96E+03	2.03E+04	8.95E+03	2.42E+01	5.23E+00	2.25E+02
C14	6.47E+04	4.88E+04	1.25E+05	1.57E+02	6.53E+01	3.95E+04
Pu238	1.04E+02	1.17E+02	1.42E+02	2.66E-01	4.72E-01	7.40E+01
Pu239	2.79E+02	5.49E+01	8.27E+01	7.79E-01	1.73E-01	5.42E-01
Pu241	4.51E+03	5.97E+03	4.87E+03	1.61E+02	9.60E+00	1.21E+02
Am241	1.09E+02	1.23E+02	2.18E+02	8.10E-01	1.44E+00	2.60E+00
Cm242	9.46E+01	5.67E+01	8.80E+01	5.25E+00	3.02E-01	1.23E+00
Cm243	1.33E+02	1.21E+02	1.25E+02	1.68E+00	8.48E-01	3.58E+00
Nb94	1.64E+01	2.62E+01	5.68E+00	1.76E+00	4.12E+00	6.50E+02

To accomplish the objective of this analysis, a comparative study must be performed to show the effect of averaging over the existing waste classes. The source terms for the comparative studies was based on the above data. ACM represents a significant difference in activity concentration and total activity compared to more homogeneous wastes and so it was necessary to develop the source term with and without the contribution for ACM. The data shows that 99.78% of the activity is contained in Class C ACM and that Class C ACM represents 98.15% of the activity in all Class C waste. Class A and Class B ACM represent only 2.94% and 2.48% of the total activity of all Class A and Class B wastes respectively and may therefore be included in the Class A and Class B waste activity. The annual waste generation for the analysis is shown in Table C-3.

Table C-3
Annual waste generation

Waste Class	A	B	C (no ACM)	C (ACM)	Total
Volume (cm^3)	2.89E+10	3.43E+08	5.26E+07	3.03E+06	2.93E+10
Weight (g)	7.77E+09	2.64E+08	3.30E+07	1.69E+07	8.08E+09
Nuclide	**Activity in mCi**				**Total**
C14	2.49E+04	1.88E+04	4.80E+04	1.52E+04	1.07E+05
Co60	2.53E+06	3.09E+06	4.31E+05	1.00E+08	1.06E+08
Ni63	1.59E+05	2.17E+06	8.45E+05	9.34E+06	1.25E+07
Sr90	1.92E+03	7.82E+03	3.44E+03	8.66E+01	1.33E+04
Cs137	1.51E+05	8.52E+05	7.32E+05	1.52E+02	1.74E+06
Nb94	6.97E+00	1.16E+01	2.19E+00	2.50E+02	2.71E+02
Pu238	4.03E+01	4.53E+01	5.45E+01	2.85E+01	1.69E+02
Pu239	1.08E+02	2.12E+01	3.18E+01	2.09E-01	1.61E+02
Pu241	1.80E+03	2.30E+03	1.87E+03	4.66E+01	6.01E+03
Am241	4.24E+01	4.80E+01	8.38E+01	1.00E+00	1.75E+02
Cm242	3.84E+01	2.19E+01	3.39E+01	4.71E-01	9.47E+01
Cm243	5.17E+01	4.68E+01	4.79E+01	1.38E+00	1.48E+02
Total	**2.87E+06**	**6.14E+06**	**2.06E+06**	**1.10E+08**	**1.21E+08**

A 20-year site inventory was developed for the long-term exposure scenario. The inventory is based on the annual waste generation. The volumes and activities are assumed to be constant during the life of the disposal facility. Each year's waste is decayed to the closure date of the theoretical disposal site. The total inventory of radioisotopes is therefore decay corrected over the period of generation and exposures are calculated based on the resulting mixture. The decay-corrected site inventory representing 20 years of waste generation is shown in Table C-4.

Table C-4
20-year disposal site inventory

Nuclide	A	B	C (no ACM)	C (ACM)
C14	4.98E+05	3.75E+05	9.59E+05	3.04E+05
Co60	1.70E+07	2.07E+07	2.89E+06	6.72E+08
Ni63	2.93E+06	4.01E+07	1.56E+07	1.73E+08
Sr90	2.98E+04	1.22E+05	5.36E+04	1.35E+03
Cs137	2.40E+06	1.35E+07	1.16E+07	2.42E+03
Nb94	1.39E+02	2.33E+02	4.37E+01	5.00E+03
Pu238	7.42E+02	8.34E+02	1.00E+03	5.24E+02
Pu239	2.16E+03	4.24E+02	6.36E+02	4.17E+00
Pu241	2.17E+04	2.79E+04	2.27E+04	5.64E+02
Am241	8.35E+02	9.45E+02	1.65E+03	1.97E+01
Cm242	4.05E+01	2.31E+01	3.58E+01	4.98E-01
Cm243	8.31E+02	7.52E+02	7.70E+02	2.22E+01
Total	2.28E+07	7.48E+07	3.12E+07	8.45E+08
Percent of Total Activity	2.35%	7.69%	3.20%	86.77%
Volume (cm^3)	5.79E+11	6.85E+09	1.05E+09	6.06E+07
Weight (g)	1.55E+11	5.28E+09	6.59E+08	3.39E+08

Site Parameters

The disposal site for this analysis was modeled using RESRAD version 6.3. The disposal site design, geographical, geological and hydro-geological characteristics were taken from NUREG-0782 for the Western Site. Where data was not available in NUREG-0782 to specific RESRAD input criteria, those data were derived from other sources. A summary of the RESRAD input and data sources is shown in Table C-5.

Table C-5
NUREG-0782 western site RESRAD input specifications

Parameter	RESRAD Input Value	Unit	Value from
1. Contaminated Zone			
a. Area	Variable	meters^2	NUREG 0782 App G Figure G.6 modified to predicted waste volume for each grouping Class A,B,C with ACM=1.17E+06 m^2. Class A, B, C=1.17E+06 m^2. Class A,B=1.17E+06 m^2. Class A=1.16E+06 m^2.
b. Thickness	8	meters	NUREG 0782 App E
c. Length parallel to aquifer flow	450	meters	NUREG 0782 Appendix J. Site orientation is N/S. Groundwater gradient is generally W/E. Therefore contaminated area length parallel to aquifer is equal to the width of the disposal area = 450m
2. Cover & Hydrological data			
a. Cover depth	2	meters	NUREG 0782 Appendix J.
b. Density of cover material	1.5	g/cm^3	RESRAD default
c. Cover erosion rate	0.001	meters/ year	RESRAD default
d. Density of contaminated zone	1.5	g/cm^3	NUREG 0782 Appendix J.
e. Contaminated zone erosion rate	0.001	meters/ year	RESRAD default
f. Contaminated zone total porosity	0.42		From RESRAD Table E.8 for Clay. NUREG 0782 Appendix J Section 1.4.1 states the upper 15m of the formation is a caliche (sandy clay that acts as a hardpan) under-laid by 15m of dense brown clay.
g. Contaminated zone field capacity	0.2		RESRAD default
h. Contaminated zone hydraulic conductivity.	4.05E+01	meters/ year	From RESRAD Table E.2 for Clay
i. Contaminated zone *b* parameter	11.4		From RESRAD Table E.2 for Clay
j. Humidity in air	4.7	g/m^3	From RESRAD figure L.1

Table C-5
NUREG-0782 western site RESRAD input specifications (continued)

Parameter	RESRAD Input Value	Unit	Value from
k. Evapotranspiration coefficient	0.999		Calculated value using RESRAD Formula E.4 solving for C_e using the infiltration rate (percolation rate) of 1mm/year from NUREG 0782 Section 1.4.3
l. Wind speed	6.4	meters/ s	NUREG 0782 Appendix J Section 1.4.5
m. Precipitation	0.485	meters/ year	NUREG 0782 Appendix J Section 1.4.5
n. Irrigation	1	meters/ year	RESRAD value for arid regions
o. Irrigation mode (overhead or ditch)	overhead		RESRAD default
p. Runoff coefficient.	0.2		NUREG 0782 Appendix J Section 1.4 description of site topography & soil.
q. Watershed area for nearby stream or pond	See 'Source Term' Y88-AB88	$meters^2$	RESRAD minimum value equivalent to area of contaminated zone. There is no nearby stream or pond with continuous water identified in NUREG 0782 Appendix J Section 1.4.4
r. Accuracy for water/soil computations.	0.001		RESRAD default
3. Saturated zone hydrologic data			
a. Density of saturated zone	1.5	g/cm^3	RESRAD default and typical of medium sand as identified in NUREG 0782 Appendix J Figure J.7
b. Saturated zone total porosity	0.4		RESRAD default and typical of medium sand as identified in NUREG 0782 Appendix J Figure J.7
c. Saturated zone effective porosity	0.32		From RESRAD Table E.8 for medium sand as identified in NUREG 0782 Appendix J Figure J.7
d. Saturated zone field capacity	0.2		RESRAD default
e. Saturated zone hydraulic conductivity	2.97E+03	meters/ year	NUREG 0782 Appendix J Section 1.4.3
f. Saturated zone hydraulic gradient	0.02		RESRAD default
g. Saturated zone *b* parameter	4.05		From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix J Figure j.7
h. Water table drop rate	0.001	meters/ year	RESRAD default

Table C-5
NUREG-0782 western site RESRAD input specifications (continued)

Parameter	RESRAD Input Value	Unit	Value from
i. Well pump intake depth (below water table)	10	meters	RESRAD default
j. Model for water transport parameters (Non dispersion/mass balance)	Non dispersion		RESRAD default
k. Well pumping rate.	250	meters/ year	RESRAD default
4. Uncontaminated Unsaturated zone parameters			
Zone 1			
a. Thickness	20	meters	NUREG 0782 Appendix J Section 1.4.3. Sum of caliche and clay layers minus waste depth.
b. Density	1.2	g/cm^3	Average density of Clay soils.
c. Total porosity	0.42		From RESRAD Table E.8 for Clay as identified in NUREG 0782 Appendix J Figure J.7
d. Effective porosity	0.06		From RESRAD Table E.8 for Clay as identified in NUREG 0782 Appendix J Figure J.7
e. Field capacity	0.2		RESRAD default
f. Hydraulic conductivity	4.05E+01	meters/ year	From RESRAD Table E.2 for Clay as identified in NUREG 0782 Appendix J Figure J.7
g. b parameter	11.4		From RESRAD Table E.2 for Clay as identified in NUREG 0782 Appendix J Figure J.7
Zone 2			
a. Thickness	56	meters	NUREG 0782 Appendix J Section 1.4.3. Distance to water table is 84m from surface-disposal trench depth of 8m-Zone 1
b. Density	1.5	g/cm^3	RESRAD default and typical of medium sand as identified in NUREG 0782 Appendix J Figure J.7
c. Total porosity	0.43		From RESRAD Table E.8 for fine sand as identified in NUREG 0782 Appendix J Figure J.7 (Medium sand with fines)
d. Effective porosity	0.33		From RESRAD Table E.8 for fine sand as identified in NUREG 0782 Appendix J Figure J.7 (Medium sand with fines)
e. Field capacity	0.2		RESRAD default

Table C-5
NUREG-0782 western site RESRAD input specifications (continued)

Parameter	RESRAD Input Value	Unit	Value from
f. Hydraulic conductivity	5.55E+03	meters/ year	From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix J Figure J.7
g. b parameter	4.05		From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix J Figure J.7
5. Carbon 14			
C-14 evasion flux rate from soil	3.80E-07	sec-1	From RESRAD Appendix L Table L.2 for clay soils as identified in NUREG 0782 Appendix J Figure J.7

The Intruder Agriculture scenario from NUREG-0782 required certain changes to the RESRAD site model to properly evaluate the exposure. The changes are shown in Table C-6. All other site parameters remain the same.

Table C-6
NUREG-0782 western site RESRAD input specifications for intruder agriculture (differences only)

Parameter	RESRAD Input Value	Unit	Value from
1. Contaminated Zone			
a. Area	2000	$meters^2$	NUREG 0782 Appendix G Intruder Construction/Agriculture
b. Thickness	0.456	meters	NUREG 0782 Appendix G Intruder Construction/Agriculture
c. Length parallel to aquifer flow	450	meters	NUREG 0782 Appendix J. Site orientation is N/S. Groundwater gradient is generally W/E. Therefore contaminated area length parallel to aquifer is equal to the width of the disposal cell = 450m
2. Cover & Hydrological data			
a. Cover depth	0	meters	NUREG 0782 Appendix G Intruder Construction/Agriculture
d. Density of contaminated zone	1.5	g/cm^3	NUREG 0782 Appendix G Intruder Construction/Agriculture.

The RESRAD site model did not feature any design or engineered barriers in the disposal facility that may affect movement of radioisotopes in the environment. The LLRW is assumed to be placed in the disposal cell and have the same characteristics as the surrounding soil. This is consistent with the description of waste modeling in NUREG-0782.

Long-Term Exposure Scenario

The purpose of the long-term exposure scenario is to evaluate the radiation exposures from the site during the hazardous life of the waste. The scenario is intended to measure exposure assuming the site remains intact. Long-lived nuclides are expected to dominate exposures through food and water ingestion pathways. Therefore, the model must account for groundwater movement and drinking-water consumption.

The RESRAD Resident-Farmer scenario is an acceptably close approximation to the NUREG-0782 evaluations. RESRAD performs all of the ingestion and direct-exposure analyses identified in the original Environmental Impact Statement (EIS). The RESRAD parameters for the long-term exposure scenario are shown in Table C-7.

Table C-7
Long-term exposure scenario parameters

Exposure Parameters	Value	Unit	Value from
Exposure duration	30	years	RESRAD default value
Inhalation rate	8,400	m^3/yr	RESRAD default value for Scenario
Mass loading for inhalation	0.0001	g/m^3	RESRAD default value
Fraction of time indoors	0.5		RESRAD default value for Scenario
Fraction of time outdoors	0.25		RESRAD default value for Scenario
Indoor dust filtration factor	0.4		RESRAD default value
External gamma shielding factor	0.7		RESRAD default value
Contaminated fractions of food	**Value**	**Unit**	**Value from**
Plant food	0.5		RESRAD default value for Scenario
Milk	1		RESRAD default value for Scenario
Meat	1		RESRAD default value for Scenario
Aquatic food	0.5		RESRAD default value for Scenario
Soil ingestion	36.5	g/yr	RESRAD default value
Drinking water intake	510	L/yr	RESRAD default value for Scenario
Analysis Duration	1000	yrs	PG-8-08 Scenarios for Assessing Potential Doses Associated with Residual Radioactivity, May 1994
Scenario Pathways	**Analyzed**		
External gamma Exposure	Yes		
Inhalation of dust	Yes		
Radon Inhalation	Yes		
Ingestion of plant foods	Yes		
Ingestion of meat	Yes		
Ingestion of milk	Yes		
Ingestion of fish	Yes		
Ingestion of soil	Yes		
Ingestion of water	Yes		

The activity concentrations in soil for the source term were developed from the activities in EPRI Report 1016120, "An Evaluation of Alternative Classification Methods for Routine Low-Level Waste from the Nuclear Power Industry". Activities are decay corrected over the life of the disposal facility which is assumed in NUREG-0782 to be 20-years. ACM activities are also adjusted by a factor of 0.1 to account for accessibility. No other correction factors are taken for waste form or site design. Activity was averaged over the entire volume of the waste/soil mixture.

RESRAD input for activity concentrations in soil require activity per unit mass and are entered as pCi/g. According to NUREG-0782, the mixture of waste and soil in the disposal cell is 50% by volume. This accounts for filling of void spaces in and around containers. The activity concentration is therefore the activity of the waste disposed divided by the volume of the waste as shipped for disposal plus the volume of the soil mixed with the waste. The volumetric concentration is then divided by the density of the mixture which is specified in NUREG-0785 as 1.5 g/cm^3. The input activity concentrations are shown in Table C-8.

Table C-8
Activity concentrations for long-term exposure evaluation

Nuclide	mCi	pCi	pCi/cm^3	Concentration @ 1.5g/cc pCi/g
20-Year waste volume/decayed activity A, B, C including ACM				
C14	1.86E+06	1.86E+15	1.59E+03	1.06E+03
Co60	1.08E+08	1.08E+17	9.18E+04	6.12E+04
Ni63	7.60E+07	7.60E+16	6.47E+04	4.31E+04
Sr90	2.05E+05	2.05E+14	1.75E+02	1.17E+02
Cs137	2.75E+07	2.75E+16	2.34E+04	1.56E+04
Nb94	9.16E+02	9.16E+11	7.80E-01	5.20E-01
Pu238	2.63E+03	2.63E+12	2.24E+00	1.49E+00
Pu239	3.22E+03	3.22E+12	2.74E+00	1.83E+00
Pu241	7.23E+04	7.23E+13	6.16E+01	4.11E+01
Am241	3.43E+03	3.43E+12	2.92E+00	1.95E+00
Cm242	9.95E+01	9.95E+10	8.48E-02	5.65E-02
Cm243	2.35E+03	2.35E+12	2.01E+00	1.34E+00
Waste/Soil Volume	1.17E+12	cm^3		
20-Year Waste Volume/decayed activity A, B, C no ACM				
C14	1.83E+06	1.83E+15	1.56E+03	1.04E+03
Co60	4.05E+07	4.05E+16	3.45E+04	2.30E+04

Table C-8
Activity concentrations for long-term exposure evaluation (continued)

Nuclide	mCi	pCi	pCi/cm^3	Concentration @ 1.5g/cc pCi/g
Ni63	5.87E+07	5.87E+16	5.00E+04	3.33E+04
Sr90	2.05E+05	2.05E+14	1.75E+02	1.17E+02
Cs137	2.75E+07	2.75E+16	2.34E+04	1.56E+04
Nb94	4.16E+02	4.16E+11	3.54E-01	2.36E-01
Pu238	2.58E+03	2.58E+12	2.20E+00	1.47E+00
Pu239	3.21E+03	3.21E+12	2.74E+00	1.83E+00
Pu241	7.23E+04	7.23E+13	6.16E+01	4.11E+01
Am241	3.43E+03	3.43E+12	2.92E+00	1.95E+00
Cm242	9.94E+01	9.94E+10	8.47E-02	5.65E-02
Cm243	2.35E+03	2.35E+12	2.00E+00	1.34E+00
Waste/Soil Volume	1.17E+12	cm^3		
20-Year Waste Volume/decayed activity A, B Waste				
C14	8.73E+05	8.73E+14	7.45E+02	4.97E+02
Co60	3.77E+07	3.77E+16	3.21E+04	2.14E+04
Ni63	4.30E+07	4.30E+16	3.67E+04	2.45E+04
Sr90	1.52E+05	1.52E+14	1.29E+02	8.63E+01
Cs137	1.59E+07	1.59E+16	1.36E+04	9.05E+03
Nb94	3.72E+02	3.72E+11	3.18E-01	2.12E-01
Pu238	1.58E+03	1.58E+12	1.34E+00	8.97E-01
Pu239	2.58E+03	2.58E+12	2.20E+00	1.47E+00
Pu241	4.96E+04	4.96E+13	4.23E+01	2.82E+01
Am241	1.78E+03	1.78E+12	1.52E+00	1.01E+00
Cm242	6.37E+01	6.37E+10	5.44E-02	3.62E-02
Cm243	1.58E+03	1.58E+12	1.35E+00	9.01E-01
Waste/Soil Volume	1.17E+12	cm3		
20-Year Waste Volume/decayed activity A Waste				
C14	4.98E+05	4.98E+14	4.30E+02	2.87E+02
Co60	1.70E+07	1.70E+16	1.46E+04	9.76E+03

Table C-8
Activity concentrations for long-term exposure evaluation (continued)

Nuclide	mCi	pCi	pCi/cm^3	Concentration @ 1.5g/cc pCi/g
Ni63	2.93E+06	2.93E+15	2.53E+03	1.69E+03
Sr90	2.98E+04	2.98E+13	2.58E+01	1.72E+01
Cs137	2.40E+06	2.40E+15	2.07E+03	1.38E+03
Nb94	1.39E+02	1.39E+11	1.20E-01	8.02E-02
Pu238	7.42E+02	7.42E+11	6.41E-01	4.27E-01
Pu239	2.16E+03	2.16E+12	1.86E+00	1.24E+00
Pu241	2.17E+04	2.17E+13	1.88E+01	1.25E+01
Am241	8.35E+02	8.35E+11	7.21E-01	4.81E-01
Cm242	4.05E+01	4.05E+10	3.50E-02	2.33E-02
Cm243	8.31E+02	8.31E+11	7.17E-01	4.78E-01
Waste/Soil Volume	1.16E+12	cm3		

Radiation exposure cases were calculated for each grouping of waste at 0, 1, 5, 10, 30, 100, 300, 500 and 1,000 years after closure. In all cases, the maximum radiation exposure occurs during the first year post-closure (t=max) and well below the 25 millirem/year performance objective. There is no significant exposure throughout the evaluation period.

Table C-9
Radiation exposures over time (mrem/yr)

Time (Years):	0 (t=max)	1	5	10	30	100	300	500	1000
A,B,C w/ACM	3.57E-05	3.17E-05	1.96E-05	1.08E-05	9.90E-07	5.34E-09	1.06E-09	2.76E-09	1.74E-06
A,B,C w/o ACM	1.34E-05	1.19E-05	7.38E-06	4.06E-06	3.78E-07	5.19E-09	9.56E-10	1.33E-09	7.89E-07
A,B	1.25E-05	1.11E-05	6.86E-06	3.77E-06	3.48E-07	3.04E-09	5.83E-10	1.15E-09	7.09E-07
A	5.69E-06	5.05E-06	3.13E-06	1.72E-06	1.57E-07	4.89E-10	1.07E-10	4.16E-10	2.68E-07

The exposure at t=max is dominated by Co-60 through the direct exposure pathway in all cases. C0-60 accounts for more than 99% of the dose at this time. Cs-137 contributes less than 0.09% of the dose. The contribution from the other nuclides is negligible at this time.

Table C-10
Percent contribution to dose by isotope at t=max exposure

Nuclide	A,B, C w/ACM	A, B, C w/o ACM	A,B	A
C14	0.00%	0.00%	0.00%	0.00%
Co60	99.97%	99.91%	99.94%	99.98%
Ni63	0.00%	0.00%	0.00%	0.00%
Sr90	0.00%	0.00%	0.00%	0.00%
Cs137	0.03%	0.09%	0.06%	0.02%
Nb94	0.00%	0.00%	0.00%	0.00%
Pu238	0.00%	0.00%	0.00%	0.00%
Pu239	0.00%	0.00%	0.00%	0.00%
Pu241	0.00%	0.00%	0.00%	0.00%
Am241	0.00%	0.00%	0.00%	0.00%
Cm242	0.00%	0.00%	0.00%	0.00%
Cm243	0.00%	0.00%	0.00%	0.00%
Total	100.00%	100.00%	100.00%	100.00%

As Co-60 decays, it becomes less predominant and eventually does not contribute to total dose. At t=300 years, dose is dominated by Nb-94 with a small contribution by Pu-238. At t=500 years, the relative contributions have reversed and Pu-238 is dominant. By t=1,000 years, Pu-238 contributes 100% of the dose.

Table C-11
Percent contribution to dose by isotope at 300, 500 and 1,000 years

	300 Years				500 Years				1000 Years			
Nuclide	**A,B, C w/o ACM**	**A, B, C w/o ACM**	**A,B**	**A**	**A,B, C w/AC M**	**A, B, C w/o ACM**	**A,B**	**A**	**A,B, C w/A CM**	**A, B, C w/o ACM**	**A,B**	**A**
C14	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Co60	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ni63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Sr90	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cs137	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Nb94	82%	91%	86%	72%	5%	11%	7%	3%	0%	0%	0%	0%
Pu238	18%	9%	14%	28%	95%	89%	93%	97%	100 %	100 %	100 %	100 %
Pu239	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Pu241	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Am241	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cm242	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cm243	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %

Throughout the analysis period, the direct exposure pathway is responsible for all dose. There is negligible migration of radioisotopes through the groundwater or uptake by plants or animals. Radiation exposure details are shown in Table C-12, Table C-13, Table C-14 and Table C-15.

Table C-12
Radiation exposures for A, B, C waste with ACM at Max Exposure (t=0 years)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	7.64E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	7.69E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-243	1.12E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Co-60	3.57E-05	1.00E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs-137	1.24E-08	3.00E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nb-94	3.93E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	6.29E-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-239	6.75E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-241	1.20E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr-90	6.42E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.57E-05	1.00E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.641E-23	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.688E-29	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.115E-18	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.566E-05	1.00E+00

Table C-12
Radiation exposures for A, B, C waste with ACM at Max Exposure (t=0 years) (continued)

Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.237E-08	3.00E-04
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.926E-12	0.0
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.285E-25	0.0
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.748E-22	0.0
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.195E-23	0.0
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.415E-16	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.57E-05	1.00E+00

Table C-13
Radiation exposures for A, B, C waste without ACM at Max Exposure (t=0 years)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	7.64E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	7.69E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-243	1.12E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Co-60	1.34E-05	9.99E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs-137	1.24E-08	9.00E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nb-94	1.78E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table C-13
Radiation exposures for A, B, C waste without ACM at Max Exposure (t=0 years) (continued)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	6.20E-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-239	6.75E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-241	1.20E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr-90	6.42E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.34E-05	1.00E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.64E-23	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.69E-29	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.12E-18	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.34E-05	9.99E-01
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.24E-08	9.00E-04
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.78E-12	0.0
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.20E-25	0.0
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.75E-22	0.0
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.20E-23	0.0
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.42E-16	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.34E-05	1.00E+00

Table C-14
Radiation exposures for A, B waste at Max Exposure (t=0 years)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	3.96E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	4.93E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-243	7.49E-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Co-60	1.25E-05	9.99E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs-137	7.18E-09	6.00E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nb-94	1.60E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	3.78E-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-239	5.42E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-241	8.20E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr-90	4.73E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.248E-05	1.000E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.96E-23	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.93E-29	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.49E-19	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.25E-05	9.99E-01

Table C-14
Radiation exposures for A, B waste at Max Exposure (t=0 years) (continued)

Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.18E-09	6.00E-04
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.60E-12	0.0
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.78E-25	0.0
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.42E-22	0.0
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.20E-24	0.0
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.732E-16	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.248E-05	1.000E+00

Table C-15
Radiation exposures for A waste at Max Exposure (t=0 years)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	1.89E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	3.17E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-243	3.98E-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Co-60	5.69E-06	1.00E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs-137	1.09E-09	2.00E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nb-94	6.06E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table C-15
Radiation exposures for A waste at Max Exposure (t=0 years) (continued)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	1.80E-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-239	4.57E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-241	3.63E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr-90	9.43E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	5.69E-06	1.00E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.89E-23	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.17E-29	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.98E-19	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.69E-06	1.00E+00
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.09E-09	2.00E-04
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.06E-13	0.0
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.80E-25	0.0
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.57E-22	0.0
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.63E-24	0.0
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.43E-17	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.69E-06	1.00E+00

Intruder Agriculture Scenario

An intruder agriculture case was developed using RESRAD version 6.3 to test the NUREG-0782 Western site with the EPRI database waste activities. The RESRAD parameters were based on the NUREG-0782 Intruder Agriculture Scenario. In this case, an intruder enters the site at approximately 100 years after closure. Administrative controls are assumed to have failed and the intruder does not know about the LLRW disposal site. The intruder constructs a house and begins to live and farm the area. During construction, the intruder does not encounter any waste that is distinguishable from the surrounding soil. The intruder excavates approximately 232 m^3 of waste while digging the foundation for the house. Approximately 680 m^3 of cover material is also excavated, mixed with the waste and used for back fill around the house and spread over approximately 2,000 m^2 of the surrounding land. The site parameters for RESRAD for this evaluation are shown in Table C-5 and Table C-6. Scenario parameters are shown in Table C-16.

Table C-16
Intruder agriculture scenario parameters

Exposure Parameters	Value	Unit	Value from
Exposure duration	30	years	RESRAD default value
Inhalation rate	8,400	m^3/yr	RESRAD default value
Mass loading for inhalation	0.0001	g/m^3	RESRAD default value
Fraction of time indoors	0.500		NUREG 0782 value of 4380 hrs indoors
Fraction of time outdoors	0.205		NUREG 0782 value of 1800 hrs outdoors
Indoor dust filtration factor	0.400		RESRAD default value
External gamma shielding factor	0.030		NUREG 0782 Appendix G
Contaminated fractions of food	**Value**	**Unit**	**Value from**
Plant food	0.5		RESRAD default value for Resident Farmer Scenario
Milk	1		RESRAD default value for Resident Farmer Scenario
Meat	1		RESRAD default value for Resident Farmer Scenario
Aquatic food	0.5		RESRAD default value for Resident Farmer Scenario
Soil ingestion	36.5	g/yr	RESRAD default value
Drinking water intake	510	L/yr	RESRAD default value for Resident Farmer Scenario
Analysis Duration	1000	yrs	PG-8-08 Scenarios for Assessing Potential Doses Associated with Residual Radioactivity, May 1994

Table C-16
Intruder agriculture scenario parameters (continued)

Scenario Pathways	Analyzed
External gamma Exposure	Yes
Inhalation of dust	Yes
Radon Inhalation	Yes
Ingestion of plant foods	Yes
Ingestion of meat	Yes
Ingestion of milk	Yes
Ingestion of fish	Yes
Ingestion of soil	Yes
Ingestion of water	Yes

The source term is based on the EPRI database waste activities. As in NUREG-0782, the intruder is assumed to enter a cell containing waste from the last year's operations and is therefore not decayed over the life of the disposal facility.

RESRAD input for activity concentrations in soil require activity per unit mass and are entered as pCi/g. According to NUREG-0782, the mixture of waste and soil in the disposal cell is 50% by volume. This accounts for filling of void spaces in and around containers. The activity is also diluted with some of the cover material as described above. These result in a total correction factor of 0.125 applied to the waste activity concentration to account for dilution with soil. The activity concentration is therefore the activity of the waste disposed divided by the volume of the waste as shipped for disposal multiplied by the mixing correction factor. The volumetric concentration is then divided by the density of the mixture which is specified in NUREG-0785 as 1.5 g/cm^3. ACM activities are also adjusted by a factor of 0.1 to account for accessibility. No other correction factors are taken for waste form or site design. Activity was averaged over the entire volume of the waste/soil mixture.

The input activity concentrations are shown in Table C-17.

Table C-17
Activity concentrations for intruder agriculture scenario

Nuclide	mCi	pCi	pCi/cm^3	Concentration w/0.125 Mixing Correction Factor pCi/cm^3	Concentration @ 1.5g/cc pCi/g
1-Year waste volume/un-decayed activity A, B, C including ACM					
C14	9.33E+04	9.33E+13	3.18E+03	3.97E+02	2.65E+02
Co60	1.61E+07	1.61E+16	5.47E+05	6.84E+04	4.56E+04
Ni63	4.10E+06	4.10E+15	1.40E+05	1.75E+04	1.17E+04
Sr90	1.32E+04	1.32E+13	4.49E+02	5.62E+01	3.75E+01
Cs137	1.74E+06	1.74E+15	5.91E+04	7.39E+03	4.93E+03
Nb94	4.58E+01	4.58E+10	1.56E+00	1.95E-01	1.30E-01
Pu238	1.43E+02	1.43E+11	4.87E+00	6.09E-01	4.06E-01
Pu239	1.61E+02	1.61E+11	5.48E+00	6.85E-01	4.57E-01
Pu241	5.97E+03	5.97E+12	2.04E+02	2.54E+01	1.70E+01
Am241	1.74E+02	1.74E+11	5.94E+00	7.42E-01	4.95E-01
Cm242	9.42E+01	9.42E+10	3.21E+00	4.01E-01	2.68E-01
Cm243	1.47E+02	1.47E+11	4.99E+00	6.24E-01	4.16E-01
1-Year Waste Volume/un-decayed activity A, B, C no ACM					
C14	9.17E+04	9.17E+13	3.13E+03	3.91E+02	2.61E+02
Co60	6.05E+06	6.05E+15	2.06E+05	2.58E+04	1.72E+04
Ni63	3.17E+06	3.17E+15	1.08E+05	1.35E+04	9.01E+03
Sr90	1.32E+04	1.32E+13	4.49E+02	5.62E+01	3.74E+01
Cs137	1.74E+06	1.74E+15	5.91E+04	7.39E+03	4.93E+03
Nb94	2.08E+01	2.08E+10	7.09E-01	8.86E-02	5.91E-02
Pu238	1.40E+02	1.40E+11	4.77E+00	5.97E-01	3.98E-01
Pu239	1.61E+02	1.61E+11	5.48E+00	6.85E-01	4.57E-01
Pu241	5.97E+03	5.97E+12	2.03E+02	2.54E+01	1.69E+01
Am241	1.74E+02	1.74E+11	5.94E+00	7.42E-01	4.95E-01
Cm242	9.42E+01	9.42E+10	3.21E+00	4.01E-01	2.67E-01
Cm243	1.46E+02	1.46E+11	4.99E+00	6.24E-01	4.16E-01

Table C-17
Activity concentrations for intruder agriculture scenario (continued)

Nuclide	mCi	pCi	pCi/cm^3	Concentration w/0.125 Mixing Correction Factor pCi/cm^3	Concentration @ 1.5g/cc pCi/g
1-Year Waste Volume/un-decayed activity A, B Waste					
C14	4.37E+04	4.37E+13	1.49E+03	1.87E+02	1.24E+02
Co60	5.62E+06	5.62E+15	1.92E+05	2.40E+04	1.60E+04
Ni63	2.33E+06	2.33E+15	7.94E+04	9.93E+03	6.62E+03
Sr90	9.74E+03	9.74E+12	3.33E+02	4.16E+01	2.77E+01
Cs137	1.00E+06	1.00E+15	3.43E+04	4.28E+03	2.86E+03
Nb94	1.86E+01	1.86E+10	6.35E-01	7.94E-02	5.30E-02
Pu238	8.56E+01	8.56E+10	2.92E+00	3.65E-01	2.43E-01
Pu239	1.29E+02	1.29E+11	4.40E+00	5.50E-01	3.67E-01
Pu241	4.10E+03	4.10E+12	1.40E+02	1.75E+01	1.17E+01
Am241	9.04E+01	9.04E+10	3.09E+00	3.86E-01	2.57E-01
Cm242	6.03E+01	6.03E+10	2.06E+00	2.57E-01	1.72E-01
Cm243	9.85E+01	9.85E+10	3.36E+00	4.20E-01	2.80E-01
1-Year Waste Volume/un-decayed activity A Waste					
C14	2.49E+04	2.49E+13	8.61E+02	1.08E+02	7.18E+01
Co60	2.53E+06	2.53E+15	8.74E+04	1.09E+04	7.28E+03
Ni63	1.59E+05	1.59E+14	5.48E+03	6.85E+02	4.56E+02
Sr90	1.92E+03	1.92E+12	6.62E+01	8.28E+00	5.52E+00
Cs137	1.51E+05	1.51E+14	5.23E+03	6.54E+02	4.36E+02
Nb94	6.97E+00	6.97E+09	2.41E-01	3.01E-02	2.01E-02
Pu238	4.03E+01	4.03E+10	1.39E+00	1.74E-01	1.16E-01
Pu239	1.08E+02	1.08E+11	3.72E+00	4.65E-01	3.10E-01
Pu241	1.80E+03	1.80E+12	6.20E+01	7.75E+00	5.17E+00
Am241	4.24E+01	4.24E+10	1.47E+00	1.83E-01	1.22E-01
Cm242	3.84E+01	3.84E+10	1.33E+00	1.66E-01	1.11E-01
Cm243	5.17E+01	5.17E+10	1.79E+00	2.23E-01	1.49E-01

Radiation exposure cases were calculated for each grouping of waste at 100 years after closure. In all cases, the maximum radiation exposure is well below the 500 millirem/year performance objective as shown in Table C-18.

Table C-18
Radiation exposures at t=100 years (mrem/year)

A, B, C w/ACM	A, B, C w/o ACM	A,B	A
389	387	226	34.5

The exposure is dominated by Cs-137 through the direct exposure pathway in all cases. Cs-137 accounts for more than 96% of the dose for all groupings. Since Cs-137 is not normally found as a significant part of ACM activity, there is very little difference in dose between the Class A, B, C cases with and without ACM. Ni-63 and Sr-90 are the next highest contributors to dose although at less than 2% of the total. The contribution from the other nuclides is negligible.

Table C-19
Percent contribution to dose by isotope at t=100 years

Nuclide	A,B, C w/ACM	A, B, C w/o ACM	A,B	A
C14	0.00%	0.00%	0.00%	0.00%
Co60	0.07%	0.03%	0.00%	0.13%
Ni63	1.76%	1.36%	1.71%	0.77%
Sr90	1.46%	1.47%	1.86%	2.43%
Cs137	96.59%	97.04%	96.32%	96.25%
Nb94	0.02%	0.01%	0.02%	0.04%
Pu238	0.01%	0.01%	0.00%	0.00%
Pu239	0.03%	0.03%	0.04%	0.20%
Pu241	0.03%	0.03%	0.04%	0.10%
Am241	0.03%	0.03%	0.02%	0.07%
Cm242	0.00%	0.00%	0.00%	0.00%
Cm243	0.00%	0.00%	0.00%	0.01%
Total	100.00%	100.00%	100.00%	100.00%

The direct exposure pathway is responsible for 85% of all dose. The plant ingestion pathway is responsible for a little over 11% of the remaining dose with the meat, milk and soil ingestion pathways accounting for the remaining 4%. There is no significant contribution to dose from any water dependent pathway including drinking water. Radiation exposure details are shown in Table C-20, Table C-21, Table C-22 and Table C-23.

Table C-20
Intruder agriculture scenario radiation exposures for A, B, C waste with ACM

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	3.74E-03	0.0	3.34E-03	0.0	0.0	0.0	5.23E-02	1.00E-04	2.52E-04	0.0	1.46E-05	0.0	3.91E-02	1.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	2.01E-08	0.0	4.38E-06	0.0	0.0	0.0	6.81E-05	0.0	6.57E-07	0.0	9.73E-09	0.0	5.09E-05	0.0
Cm-243	4.33E-03	0.0	2.04E-04	0.0	0.0	0.0	3.17E-03	0.0	6.55E-06	0.0	8.78E-07	0.0	2.37E-03	0.0
Co-60	2.70E-01	7.00E-04	3.29E-07	0.0	0.0	0.0	6.15E-03	0.0	7.46E-04	0.0	9.21E-05	0.0	5.75E-05	0.0
Cs-137	3.32E+02	8.54E-01	2.79E-04	0.0	0.0	0.0	3.32E+01	8.56E-02	7.20E+00	1.85E-02	2.44E+00	6.30E-03	6.22E-01	1.60E-03
Nb-94	8.52E-02	2.00E-04	3.27E-07	0.0	0.0	0.0	1.08E-04	0.0	4.55E-10	0.0	4.13E-09	0.0	8.04E-06	0.0
Ni-63	0.0	0.0	6.43E-04	0.0	0.0	0.0	5.61E+00	1.45E-02	1.90E-01	5.00E-04	9.54E-01	2.50E-03	8.41E-02	2.00E-04
Pu-238	5.96E-06	0.0	1.30E-03	0.0	0.0	0.0	2.02E-02	1.00E-04	1.95E-04	0.0	2.89E-06	0.0	1.51E-02	0.0
Pu-239	2.77E-05	0.0	3.53E-03	0.0	0.0	0.0	5.55E-02	1.00E-04	5.36E-04	0.0	7.74E-06	0.0	4.15E-02	1.00E-04
Pu-241	4.40E-03	0.0	3.95E-03	0.0	0.0	0.0	6.17E-02	2.00E-04	3.00E-04	0.0	1.72E-05	0.0	4.61E-02	1.00E-04
Sr-90	1.70E-02	0.0	8.05E-05	0.0	0.0	0.0	5.37E+00	1.38E-02	2.25E-01	6.00E-04	6.72E-02	2.00E-04	1.34E-02	0.0
Total	3.32E+02	8.55E-01	1.33E-02	0.0	0.0	0.0	4.44E+01	1.14E-01	7.61E+00	1.96E-02	3.46E+00	9.00E-03	8.64E-01	2.10E-03
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.87E-02	2.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.24E-04	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.01E-02	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.77E-01	7.00E-04

Table C-20
Intruder agriculture scenario radiation exposures for A, B, C waste with ACM (continued)

Water Dependent Pathways														
	Water		Fish	Radon		Plant			Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.75E+02	9.66E-01
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.53E-02	2.00E-04
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.84E+00	1.77E-02
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.68E-02	1.00E-04
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.01E-01	2.00E-04
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.17E-01	3.00E-04
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.69E+00	1.46E-02
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.88E+02	1.00E+00

Table C-21
Intruder agriculture scenario radiation exposures for A, B, C waste without ACM

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	3.74E-03	0.0	3.34E-03	0.0	0.0	0.0	5.23E-02	1.00E-04	2.52E-04	0.0	1.46E-05	0.0	3.91E-02	1.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	2.00E-08	0.0	4.36E-06	0.0	0.0	0.0	6.78E-05	0.0	6.55E-07	0.0	9.70E-09	0.0	5.07E-05	0.0
Cm-243	4.33E-03	0.0	2.04E-04	0.0	0.0	0.0	3.17E-03	0.0	6.55E-06	0.0	8.78E-07	0.0	2.37E-03	0.0
Co-60	1.02E-01	3.00E-04	1.24E-07	0.0	0.0	0.0	2.32E-03	0.0	2.82E-04	0.0	3.47E-05	0.0	2.17E-05	0.0
Cs-137	3.32E+02	8.58E-01	2.79E-04	0.0	0.0	0.0	3.32E+01	8.60E-02	7.20E+00	1.86E-02	2.44E+00	6.30E-03	6.22E-01	1.60E-03
Nb-94	3.88E-02	1.00E-04	1.49E-07	0.0	0.0	0.0	4.89E-05	0.0	2.07E-10	0.0	1.88E-09	0.0	3.66E-06	0.0

Table C-21
Intruder agriculture scenario radiation exposures for A, B, C waste without ACM (continued)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Ni-63	0.0	0.0	4.95E-04	0.0	0.0	0.0	4.32E+00	1.12E-02	1.46E-01	4.00E-04	7.35E-01	1.90E-03	6.47E-02	2.00E-04
Pu-238	5.84E-06	0.0	1.27E-03	0.0	0.0	0.0	1.98E-02	1.00E-04	1.91E-04	0.0	2.83E-06	0.0	1.48E-02	0.0
Pu-239	2.77E-05	0.0	3.53E-03	0.0	0.0	0.0	5.55E-02	1.00E-04	5.36E-04	0.0	7.74E-06	0.0	4.15E-02	1.00E-04
Pu-241	4.37E-03	0.0	3.93E-03	0.0	0.0	0.0	6.14E-02	2.00E-04	2.98E-04	0.0	1.71E-05	0.0	4.59E-02	1.00E-04
Sr-90	1.69E-02	0.0	8.03E-05	0.0	0.0	0.0	5.35E+00	1.38E-02	2.24E-01	6.00E-04	6.70E-02	2.00E-04	1.34E-02	0.0
Total	3.32E+02	8.58E-01	1.31E-02	0.0	0.0	0.0	4.31E+01	1.12E-01	7.57E+00	1.96E-02	3.24E+00	8.40E-03	8.44E-01	2.10E-03
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.87E-02	2.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.24E-04	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.01E-02	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.04E-01	3.00E-04
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.75E+02	9.70E-01
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.88E-02	1.00E-04
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.27E+00	1.37E-02
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.61E-02	1.00E-04
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.01E-01	2.00E-04
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.16E-01	3.00E-04
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.67E+00	1.46E-02
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.87E+02	1.00E+00

Table C-22
Intruder agriculture scenario radiation exposures for A, B, waste

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	1.94E-03	0.0	1.74E-03	0.0	0.0	0.0	2.71E-02	1.00E-04	1.31E-04	0.0	7.57E-06	0.0	2.03E-02	1.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	1.29E-08	0.0	2.81E-06	0.0	0.0	0.0	4.37E-05	0.0	4.22E-07	0.0	6.25E-09	0.0	3.27E-05	0.0
Cm-243	2.92E-03	0.0	1.37E-04	0.0	0.0	0.0	2.14E-03	0.0	4.41E-06	0.0	5.91E-07	0.0	1.60E-03	0.0
Co-60	9.46E-02	4.00E-04	1.15E-07	0.0	0.0	0.0	2.16E-03	0.0	2.62E-04	0.0	3.23E-05	0.0	2.02E-05	0.0
Cs-137	1.92E+02	8.51E-01	1.62E-04	0.0	0.0	0.0	1.93E+01	8.53E-02	4.18E+00	1.85E-02	1.41E+00	6.30E-03	3.61E-01	1.60E-03
Nb-94	3.48E-02	2.00E-04	1.33E-07	0.0	0.0	0.0	4.38E-05	0.0	1.85E-10	0.0	1.68E-09	0.0	3.28E-06	0.0
Ni-63	0.0	0.0	3.64E-04	0.0	0.0	0.0	3.18E+00	1.40E-02	1.07E-01	5.00E-04	5.40E-01	2.40E-03	4.76E-02	2.00E-04
Pu-238	3.57E-06	0.0	7.78E-04	0.0	0.0	0.0	1.21E-02	1.00E-04	1.17E-04	0.0	1.73E-06	0.0	9.05E-03	0.0
Pu-239	2.23E-05	0.0	2.83E-03	0.0	0.0	0.0	4.46E-02	2.00E-04	4.30E-04	0.0	6.22E-06	0.0	3.33E-02	1.00E-04
Pu-241	3.03E-03	0.0	2.72E-03	0.0	0.0	0.0	4.25E-02	2.00E-04	2.06E-04	0.0	1.18E-05	0.0	3.18E-02	1.00E-04
Sr-90	1.26E-02	1.00E-04	5.94E-05	0.0	0.0	0.0	3.96E+00	1.75E-02	1.66E-01	7.00E-04	4.97E-02	2.00E-04	9.89E-03	0.0
Total	1.93E+02	8.52E-01	8.79E-03	0.0	0.0	0.0	2.65E+01	1.17E-01	4.45E+00	1.97E-02	2.00E+00	8.90E-03	5.14E-01	2.10E-03
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.12E-02	2.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.96E-05	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.79E-03	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.71E-02	4.00E-04

Table C-22
Intruder agriculture scenario radiation exposures for A, B, waste (continued)

Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.18E+02	9.63E-01
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.48E-02	2.00E-04
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.87E+00	1.71E-02
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.20E-02	1.00E-04
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.12E-02	3.00E-04
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.02E-02	3.00E-04
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.20E+00	1.85E-02
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.26E+02	1.00E+00

Table C-23
Intruder agriculture scenario radiation exposures for A waste

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	9.22E-04	0.0	8.24E-04	0.0	0.0	0.0	1.29E-02	4.00E-04	6.22E-05	0.0	3.59E-06	0.0	9.63E-03	3.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	8.32E-09	0.0	1.81E-06	0.0	0.0	0.0	2.82E-05	0.0	2.72E-07	0.0	4.03E-09	0.0	2.11E-05	0.0
Cm-243	1.55E-03	0.0	7.29E-05	0.0	0.0	0.0	1.14E-03	0.0	2.34E-06	0.0	3.14E-07	0.0	8.50E-04	0.0
Co-60	4.30E-02	1.20E-03	5.25E-08	0.0	0.0	0.0	9.81E-04	0.0	1.19E-04	0.0	1.47E-05	0.0	9.18E-06	0.0
Cs-137	2.93E+01	8.51E-01	2.46E-05	0.0	0.0	0.0	2.94E+00	8.52E-02	6.36E-01	1.85E-02	2.16E-01	6.20E-03	5.50E-02	1.60E-03
Nb-94	1.32E-02	4.00E-04	5.06E-08	0.0	0.0	0.0	1.66E-05	0.0	7.03E-11	0.0	6.38E-10	0.0	1.24E-06	0.0

Table C-23
Intruder agriculture scenario radiation exposures for A waste (continued)

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Ni-63	0.0	0.0	2.51E-05	0.0	0.0	0.0	2.19E-01	6.30E-03	7.40E-03	2.00E-04	3.72E-02	1.10E-03	3.28E-03	1.00E-04
Pu-238	1.70E-06	0.0	3.71E-04	0.0	0.0	0.0	5.77E-03	2.00E-04	5.57E-05	0.0	8.25E-07	0.0	4.32E-03	1.00E-04
Pu-239	1.88E-05	0.0	2.39E-03	1.00E-04	0.0	0.0	3.76E-02	1.10E-03	3.63E-04	0.0	5.25E-06	0.0	2.82E-02	8.00E-04
Pu-241	1.34E-03	0.0	1.20E-03	0.0	0.0	0.0	1.88E-02	5.00E-04	9.11E-05	0.0	5.22E-06	0.0	1.40E-02	4.00E-04
Sr-90	2.50E-03	1.00E-04	1.18E-05	0.0	0.0	0.0	7.90E-01	2.29E-02	3.31E-02	1.00E-03	9.89E-03	3.00E-04	1.97E-03	1.00E-04
Total	2.94E+01	8.52E-01	4.93E-03	1.00E-04	0.0	0.0	4.02E+00	1.17E-01	6.78E-01	1.97E-02	2.63E-01	7.60E-03	1.17E-01	3.40E-03
Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.43E-02	7.00E-04
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cm-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.14E-05	0.0
Cm-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.61E-03	0.0
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.42E-02	1.20E-03
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.32E+01	9.62E-01
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.32E-02	4.00E-04
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.67E-01	7.70E-03
Pu-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.05E-02	3.00E-04
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.86E-02	2.00E-03
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.54E-02	9.00E-04
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.37E-01	2.44E-02
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.45E+01	1.00E+00

Impact of Non-Utility Waste on Intruder Agriculture Scenario

Non-utility waste overall consists of a large volume of relatively low activity waste. The isotopic distribution is also different from nuclear power plant wastes. The MIMs database was mined to develop volume and isotopic activity data that could be used in the RESRAD models for evaluation of the impact of this waste on overall exposure. The years 2002-2006 were used.

The distribution of waste volume and activity by the non-utility generator categories from the MIMs database are shown in Table C-24.

Table C-24
Distribution of non-utility waste activity and volume

Academic			Government		
Isotope	**Activiy (Ci)**	**Percent of Total**	**Isotope**	**Activiy (Ci)**	**Percent of Total**
Total	1.44E+03	98.64%	Total	1.03E+05	99.92%
Co60	5.72E+02	39.74%	Co60	8.90E+04	86.43%
Fe55	4.82E+02	33.47%	H3	9.22E+03	8.96%
H3	1.74E+02	12.05%	U-Dep	2.08E+03	2.02%
Ni63	8.95E+01	6.21%	Fe55	1.04E+03	1.01%
Zn65	4.87E+01	3.38%	Ni63	8.17E+02	0.79%
Cs137	2.44E+01	1.70%	Cs137	2.98E+02	0.29%
Eu152	6.58E+00	0.46%	Co58	1.11E+02	0.11%
C14	5.49E+00	0.38%	Pm147	7.35E+01	0.07%
Mn54	4.10E+00	0.28%	Cr51	6.52E+01	0.06%
Ir192	2.48E+00	0.17%	Zn65	3.70E+01	0.04%
Sr90	2.04E+00	0.14%	Mn54	3.11E+01	0.03%
Cr51	1.87E+00	0.13%	Pu239	1.95E+01	0.02%
S35	1.71E+00	0.12%	U238	1.89E+01	0.02%
Fe59	1.27E+00	0.09%	Sb125	1.76E+01	0.02%
I125	1.21E+00	0.08%	Sr90	1.70E+01	0.02%
Ra226	1.20E+00	0.08%	Pu241	1.66E+01	0.02%
U238	1.18E+00	0.08%	Kr85	1.56E+01	0.02%
Co57	1.13E+00	0.08%	C14	1.46E+01	0.01%
Volume	5.42E+08	cm^3	Volume	7.75E+10	cm^3

Table C-24
Distribution of non-utility waste activity and volume (continued)

Industry			Medical		
Isotope	**Activiy (Ci)**	**Percent of Total**	**Isotope**	**Activiy (Ci)**	**Percent of Total**
Total	1.07E+05	98.63%	Total	4.23E+01	98.84%
H3	7.69E+04	71.97%	Cs137	3.55E+01	83.94%
Fe55	8.22E+03	7.70%	H3	1.80E+00	4.26%
Co60	7.16E+03	6.71%	Gd153	1.15E+00	2.72%
Ni63	3.50E+03	3.28%	Sr90	8.00E-01	1.89%
Cs137	2.03E+03	1.90%	Co57	5.70E-01	1.35%
U-Dep	1.89E+03	1.77%	C14	4.50E-01	1.06%
Gd153	1.16E+03	1.08%	Ba133	2.80E-01	0.66%
C14	7.89E+02	0.74%	Ra226	2.70E-01	0.64%
Zn65	7.27E+02	0.68%	Pd109	2.10E-01	0.50%
Co58	7.07E+02	0.66%	Co60	1.80E-01	0.43%
Mn54	5.64E+02	0.53%	I129	1.50E-01	0.35%
Co57	3.52E+02	0.33%	U238	1.00E-01	0.24%
Sr90	2.91E+02	0.27%	Ni63	8.00E-02	0.19%
U234	2.74E+02	0.26%	I125	7.00E-02	0.17%
Cd109	2.26E+02	0.21%	Eu152	5.00E-02	0.12%
Cr51	2.15E+02	0.20%	Ge68	5.00E-02	0.12%
I125	2.05E+02	0.19%	U-Nat	5.00E-02	0.12%
S35	1.66E+02	0.16%	Ca45	4.00E-02	0.09%
Volume	2.04E+11	cm^3	Volume	5.26E+08	cm^3

To develop a source term for analysis, the activities for all categories were combined. The isotopes were sorted by highest activity to identify the predominant radionuclides. The activity and volume totals were then averaged over the number of years of the data range to determine the annual activity for disposal. The results are shown in Table C-25.

Table C-25
Predominant nuclides, activity and volumes for non-utility waste

Nuclide	Total Activity (Ci)	Percent of Total	Activity (mCi)	Annual Activity (Total Activity/# Years) (mCi)
Co60	9.67E+04	45.79%	9.67E+07	1.93E+07
H3	8.63E+04	40.83%	8.63E+07	1.73E+07
Fe55	9.74E+03	4.61%	9.74E+06	1.95E+06
Ni63	4.41E+03	2.09%	4.41E+06	8.82E+05
U-Dep	3.97E+03	1.88%	3.97E+06	7.94E+05
Cs137	2.38E+03	1.13%	2.38E+06	4.77E+05
Gd153	1.16E+03	0.55%	1.16E+06	2.32E+05
Co58	8.18E+02	0.39%	8.18E+05	1.64E+05
Zn65	8.12E+02	0.38%	8.12E+05	1.62E+05
C14	8.10E+02	0.38%	8.10E+05	1.62E+05
Mn54	5.99E+02	0.28%	5.99E+05	1.20E+05
Co57	3.54E+02	0.17%	3.54E+05	7.09E+04
Total	2.08E+05	98.48%	2.08E+08	4.16E+07
Volume (cm3)	2.83E+11			5.66E+10

This source term and volume was combined with the utility source term and volume for Class A, B and C Waste including activated metals shown in Table C-17 with the following result.

Table C-26
1-year waste volume/un-decayes activity A, B, C utility waste including ACM and non-utility waste

Waste Volume	8.59E+10	cm3		Concentration w/0.125 Mixing Factor	Concentration @ 1.5g/cc
Nuclide	**mCi**	**pCi**	**pCi/cm3**	**pCi/cm3**	**pCi/g**
H3	1.73E+07	1.73E+16	2.01E+05	2.51E+04	1.67E+04
C14	2.55E+05	2.55E+14	2.97E+03	3.71E+02	2.47E+02
Mn54	1.20E+05	1.20E+14	1.39E+03	1.74E+02	1.16E+02
Fe55	1.95E+06	1.95E+15	2.27E+04	2.83E+03	1.89E+03
Co57	7.09E+04	7.09E+13	8.25E+02	1.03E+02	6.87E+01
Co58	1.64E+05	1.64E+14	1.90E+03	2.38E+02	1.59E+02
Co60	3.54E+07	3.54E+16	4.12E+05	5.15E+04	3.43E+04
Ni63	4.99E+06	4.99E+15	5.80E+04	7.25E+03	4.84E+03
Zn65	1.62E+05	1.62E+14	1.89E+03	2.36E+02	1.57E+02
Sr90	1.32E+04	1.32E+13	1.53E+02	1.92E+01	1.28E+01
Nb94	4.58E+01	4.58E+10	5.33E-01	6.66E-02	4.44E-02
Cs137	2.21E+06	2.21E+15	2.57E+04	3.22E+03	2.15E+03
Gd153	2.32E+05	2.32E+14	2.70E+03	3.37E+02	2.25E+02
U238	7.94E+05	7.94E+14	9.23E+03	1.15E+03	7.70E+02
Pu238	1.43E+02	1.43E+11	1.66E+00	2.08E-01	1.39E-01
Pu239	1.61E+02	1.61E+11	1.87E+00	2.34E-01	1.56E-01
Pu241	5.97E+03	5.97E+12	6.95E+01	8.69E+00	5.79E+00
Am241	1.74E+02	1.74E+11	2.03E+00	2.53E-01	1.69E-01
Cm242	9.42E+01	9.42E+10	1.10E+00	1.37E-01	9.14E-02
Cm243	1.47E+02	1.47E+11	1.70E+00	2.13E-01	1.42E-01

Radiation exposure for the scenario for this waste group was 218 millirem/year at t=100 years. Radiation exposure continues to be dominated by Cs-137.

Table C-27
Percent contribution to dose by isotope at t=100 years

Nuclide	Percent Contribution to Dose	Nuclide	Percent Contribution to Dose
Am-241	0.02%	H-3	0.00%
C-14	0.00%	Mn-54	0.00%
Cm-242	0.00%	Nb-94	0.01%
Cm-243	0.00%	Ni-63	1.30%
Co-57	0.00%	Pu-238	0.01%
Co-58	0.00%	Pu-239	0.02%
Co-60	0.10%	Pu-241	0.02%
Cs-137	75.12%	Sr-90	0.89%
Fe-55	0.00%	U-238	22.52%
Gd-153	0.00%	Zn-65	0.00%

The direct exposure pathway is responsible for 77% of all dose. The plant ingestion pathway is responsible for a little over 16% of the dose with the meat, milk and soil ingestion pathways accounting for the remaining 7%. There is no significant contribution to dose from any water dependent pathway including drinking water. Radiation exposure details are shown in Table C-28.

Table C-28
Intruder agriculture scenario radiation exposures for A, B, C utility waste with ACM and non-utility waste

Water Independent Pathways														
	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	1.28E-03	0	1.14E-03	0	0	0	1.79E-02	1.00E-04	8.62E-05	0	4.98E-06	0	1.33E-02	1.00E-04
C-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cm-242	6.85E-09	0	1.49E-06	0	0	0	2.32E-05	0	2.24E-07	0	3.32E-09	0	1.74E-05	0
Cm-243	1.48E-03	0	6.95E-05	0	0	0	1.08E-03	0	2.23E-06	0	3.00E-07	0	8.10E-04	0
Co-57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co-58	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co-60	2.03E-01	9.00E-04	2.47E-07	0	0	0	4.62E-03	0	5.61E-04	0	6.93E-05	0	4.33E-05	0
Cs-137	1.45E+02	6.64E-01	1.22E-04	0	0	0	1.45E+01	6.65E-02	3.14E+00	1.44E-02	1.06E+00	4.90E-03	2.71E-01	1.20E-03
Fe-55	0	0	5.74E-16	0	0	0	2.47E-13	0	4.76E-13	0	1.03E-14	0	1.85E-13	0
Gd-153	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mn-54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nb-94	2.91E-02	1.00E-04	1.12E-07	0	0	0	3.67E-05	0	1.55E-10	0	1.41E-09	0	2.75E-06	0
Ni-63	0	0	2.66E-04	0	0	0	2.32E+00	1.07E-02	7.85E-02	4.00E-04	3.95E-01	1.80E-03	3.48E-02	2.00E-04
Pu-238	2.04E-06	0	4.45E-04	0	0	0	6.92E-03	0	6.68E-05	0	9.89E-07	0	5.17E-03	0
Pu-239	9.46E-06	0	1.21E-03	0	0	0	1.89E-02	1.00E-04	1.83E-04	0	2.64E-06	0	1.42E-02	1.00E-04
Pu-241	1.50E-03	0	1.35E-03	0	0	0	2.10E-02	1.00E-04	1.02E-04	0	5.85E-06	0	1.57E-02	1.00E-04
Sr-90	5.80E-03	0	2.75E-05	0	0	0	1.83E+00	8.40E-03	7.67E-02	4.00E-04	2.29E-02	1.00E-04	4.57E-03	0
U-238	2.35E+01	1.08E-01	1.64E+00	7.50E-03	0	0	1.77E+01	8.13E-02	2.51E-01	1.10E-03	6.31E-01	2.90E-03	5.30E+00	2.43E-02
Zn-65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.68E+02	7.73E-01	1.64E+00	7.50E-03	0	0	3.64E+01	1.67E-01	3.54E+00	1.63E-02	2.11E+00	9.70E-03	5.66E+00	2.60E-02

Table C-28
Intruder agriculture scenario radiation exposures for A, B, C utility waste with ACM and non-utility waste (continued)

Water Dependent Pathways														
	Water		Fish		Radon		Plant		Meat		Milk		All Pathways	
	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction	mrem/yr	Fraction
Am-241	0	0	0	0	0	0	0	0	0	0	0	0	3.37E-02	2.00E-04
C-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cm-242	0	0	0	0	0	0	0	0	0	0	0	0	4.23E-05	0
Cm-243	0	0	0	0	0	0	0	0	0	0	0	0	3.44E-03	0
Co-57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co-58	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co-60	0	0	0	0	0	0	0	0	0	0	0	0	2.08E-01	9.00E-04
Cs-137	0	0	0	0	0	0	0	0	0	0	0	0	1.64E+02	7.51E-01
Fe-55	0	0	0	0	0	0	0	0	0	0	0	0	9.19E-13	0
Gd-153	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mn-54	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nb-94	0	0	0	0	0	0	0	0	0	0	0	0	2.91E-02	1.00E-04
Ni-63	0	0	0	0	0	0	0	0	0	0	0	0	2.83E+00	1.31E-02
Pu-238	0	0	0	0	0	0	0	0	0	0	0	0	1.26E-02	0
Pu-239	0	0	0	0	0	0	0	0	0	0	0	0	3.45E-02	2.00E-04
Pu-241	0	0	0	0	0	0	0	0	0	0	0	0	3.97E-02	2.00E-04
Sr-90	0	0	0	0	0	0	0	0	0	0	0	0	1.94E+00	8.90E-03
U-238	0	0	0	0	0	0	0	0	0	0	0	0	4.91E+01	2.25E-01
Zn-65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	2.18E+02	1.00E+00

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