OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

CALCULATION COVER SHEET

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Performance Assessment of Disposal of Selected U. S. Department of Energy Spent Fuel in High Integrity Cans

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1. PURPOSE

The purpose of this calculation is to determine the effects on long-term dose from disposing of selected U. S. Department of Energy (DOE) spent nuclear fuel (DSNF) in high integrity cans (HICs). The Civilian Radioactive Waste Management System Management and Operating contractor (CRWMS M&O) prepared the calculation as part of Performance Assessment (PA) activities for the DOE Yucca Mountain Project. DSNF encompasses approximately 2,500 MTHM (metric tons heavy metal) consisting of over 200 fuel types that have been categorized into 11 groups, referred to as Groups 1 to 11, to facilitate their performance assessment (DOE 1999a, Sec. 5). DSNF and high level waste (HLW) have been allocated 7,000 MTHM or 10% of the 70,000 MTHM of nuclear waste scheduled for disposal at Yucca Mountain (DOE 1999a, Sec. 8.1). Of the 7,000 MTHM, 2,333 will be DSNF, or 93% of all 2,500 MTHM of DSNF, and 4,667 MTHM equivalent will be HLW (DOE 1999a, Sec. 8.1). The DOE spent fuels selected for HIC disposal are those that are poorly characterized, fragmented, or damaged, and the HIC concept is intended to provide additional protection by delaying the radionuclide release to ensure that environmental and/or regulatory standards are met.

The Quality Assurance (QA) program applies to the development of this calculation. The activity was evaluated in accordance with QAP-2-0, Rev. 5, ICN 1, *Conduct of Activities* (CRWMS M&O 1999). The QAP-2-0 activity evaluation determined that the preparation and review of this document is subject to the *Quality Assurance Requirements and Description*, DOE/RW-0333P, Rev. 10, (QARD) (DOE 2000) requirements. In accordance with AP-3.12Q, Rev. 0, ICN 3, *Calculations*, and AP-2.13Q, Rev. 0, ICN 4, *Technical Product Development Planning*, a Technical Work Plan (CRWMS M&O 2000a) was developed, issued, and used in the preparation of this document and the activity described in this report was evaluated in accordance with AP-2.21Q, Rev. 0, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities*.

2. METHOD

The calculations presented in this document were performed using the Yucca Mountain Project total system performance assessment (TSPA) model developed for the Site Recommendation (SR) (CRWMS M&O 2000b). The TSPA-SR model is simulated with GoldSim software (GoldSim V. 6.04.007, 10344-6.04.007-00). GoldSim is an update to the baseline software RIP (RIP V. 5.19.01, CSCI: 30055) (Golder Associates 1998). The TSPA-SR model was developed to conduct performance-assessment calculations within a probabilistic framework combining the most likely ranges of behavior for the various component models, processes, and corresponding parameters. Results from the TSPA-SR nominal case contain the following data for radionuclides released from waste packages placed in the potential Yucca Mountain repository: (1) probability distributions for peak dose due to the released radionuclides, and (2) the time histories of the total dose, due to all released radionuclides and to the individual radionuclides, to potential receptors located 20 km downgradient from the potential Yucca Mountain repository (64 FR 46976, alternative location three). The results of the HIC calculations were compared to the TSPA-SR nominal case (DTN: MO0009MWDNM601.018).

All related process models are directly implemented in the TSPA-SR model as described in the *Total System Performance Assessment (TSPA) Model for Site Recommendation* (CRWMS M&O 2000b). The TSPA-SR model integrates sub-system models using a Monte Carlo, simulation-based methodology to create multiple random combinations of the uncertain variables, and computes the probable performance of the entire waste-disposal system in terms of dose to potential receptors. For the HIC calculations, the results were simulated using the median value of the distribution of values for each stochastic model parameter.

The calculations presented in this report were obtained by placing the HIC radionuclide inventory in a simulated HIC and using the TSPA-SR model to calculate the resulting dose to potential receptors as a time history (deterministic) calculation. Median-value simulations were performed for the HIC calculations instead of probabilistic simulations because the TSPA-SR model could not be implemented in probabilistic mode with the additional corrosion barrier provided by the HIC. The following cases were considered for this calculation:

- The HIC-designated radionuclide inventory placed in HICs constructed of Alloy 22 and loaded in stainless-steel DSNF canisters in configurations of:
  - 1 HIC per DSNF canister;
  - 3 HICs per DSNF canister;
  - 5 HICs per DSNF canister;
  - 7 HICs per DSNF canister;
- The "no-HIC" case, or the case where HIC-designated radionuclide inventory is placed in HICs constructed of stainless steel and loaded in stainless-steel DSNF canisters in a 1-HIC-per-DSNF-canister configuration (i.e. the release of the waste experienced no delay due to Alloy 22 construction); and
- The HIC-designated radionuclide inventory placed in HICs constructed of stainless steel and loaded in 18-inch, Alloy 22 DSNF canisters in a 1-HIC-per-DSNF-canister configuration.

The input data for these calculations consist of material properties and a combined radionuclide inventory for HIC-designated DSNF from Groups 2 through 11 (DOE 1999a, attached electronic files 11RW_2Input699B.xls and HIC_499WC.xls). The methods used to control the electronic management of data as required by AP-SV.1Q, Rev. 0, ICN 2, *Control of the Electronic Management of Information*, were as specified in the Technical Work Plan (CRWMS M&O 2000a).

3. ASSUMPTIONS

This section identifies assumptions that are essential for this calculation. The discussion of each assumption includes four elements: (1) a statement of the assumption; (2) the rationale for the assumption; (3) a statement on the need for further confirmation, if any, of the assumption (i.e.

the "to be verified" (TBV) status); and (4) a statement where the assumption is used in the calculation.

3.1 MODEL SOFTWARE

Assumption: The nominal-case configuration for the TSPA-SR model was assumed for the calculations presented in Section 6 below, including all assumptions incorporated into the nominal case (CRWMS M&O 2000b, Section 5). The nominal-case TSPA-SR model was developed to calculate dose to receptors at 20 km from the repository.
Rationale: This assumption is consistent with DOE guidance included in the Technical Work Plan *Technical Work Plan For: Department of Energy Spent Nuclear Fuel Work Packages* (CRWMS M&O 2000a) and in the calculations associated with *Total System Performance Assessment (TSPA) Model for Site Recommendation* (CRWMS M&O 2000b).
Confirmation Status: The TSPA-SR model is in review and is being approved under AP-3.10Q, Rev. 2, ICN 3, *Analyses and Models*.
Use within the Calculation: The TSPA-SR model, simulated using GoldSim software, was used to develop the results presented in Sections 6.1 and 6.2.

3.2 RADIONUCLIDE INVENTORY

Assumption: The radionuclide inventories for the HIC materials assumed in the calculations presented in Section 6 for Groups 2 through 11 DSNF were provided by the DOE (1999a, attached electronic file HIC_499WC.xls).
Rationale: This assumption is consistent with the calculations associated with previous analyses of DSNF as presented in *Performance Assessment Sensitivity Analyses of Selected U.S. Department of Energy Spent Fuel* (CRWMS M&O 2000c).
Confirmation Status: The DOE is currently qualifying this information as design input under the QARD (DOE 2000, Section 3.0), but until the qualification is complete, the HIC radionuclide inventory is considered to be unqualified. No further confirmation of the radionuclide inventories in the referenced documents is required.
Use within the Calculation: The radionuclide-inventory information, summarized in tables in Section 5, was input into the TSPA-SR model used to perform the simulations used to develop the results presented in Sections 6.1 and 6.2.

3.3 HIC LENGTH

Assumption: The HICs analyzed for the calculations presented in Section 6 were assumed to be ten-feet long (Section 5.1) and are loaded into the DSNF 18-inch canister in four separate configurations consisting of one, three, five, and seven HICs per DSNF canister (Section 5.3.2).
Rationale: The TSPA-SR model requires all package to have a uniform size for a given type of waste. The 10-ft length is a nominal size within the range of all expected HICs. This assumption results in fewer individual HICs per co-disposal waste package and a more rapid failure rate of HICs with a consequent greater release of radionuclides than would be expected from the HIC inventory.

Confirmation Status: This greater release of radionuclides is conservative because it causes a greater dose rate to potential receptors. Because of this conservatism, this assumption does not require verification.
Use within the Calculation: The HIC length was input into the TSPA-SR model used to perform the simulations used to develop the results presented in Sections 6.1 and 6.2.

3.4 SURFACE AREA OF HICS

Assumption: For the calculations leading to the results presented in Section 6 for multiple HICs per canister, the HICs are assumed to be replaced by a single HIC that has a surface area equivalent to that for the sum of all the HICs placed in an individual DSNF canister for a particular HIC-loading configuration.
Rationale: The TSPA-SR model can only make calculations for one HIC. This surface-area assumption is similar to Assumption 3.3 and yields a greater release of radionuclides than would be expected from the failed HIC canister.
Confirmation Status: This greater release of radionuclides is conservative because it causes a greater dose rate to potential receptors. Because of this conservatism, this assumption does not require verification.
Use within the Calculation: The HIC surface area for each simulation scenario was input into the TSPA-SR model used to perform the simulations used to develop the results presented in Sections 6.1 and 6.2.

3.5 STAINLESS STEEL DEGRADATION

Assumption: Similar to the TSPA-SR, the HIC calculations presented in Section 6 assume no credit, vis-à-vis delay in radionuclide release, for the 18-inch-diamater stainless-steel DSNF canister. Rather, the 18-inch-diamater stainless steel DSNF canister is assumed to fail at the same time that the waste package fails.
Rationale: Steel corrosion is much faster than that of Alloy 22. Therefore, not assuming credit for steel corrosion provides a conservative rationale for dose calculations.
Confirmation Status: This assumption yields a more rapid release of radionuclides from the waste package than would be expected, and is, therefore, conservative. Because of this conservatism, this assumption does not require verification.
Use within the Calculation: The HIC surface area for each simulation scenario was input into the TSPA-SR model used to perform the simulations used to develop the results presented in Sections 6.1 and 6.2.

3.6 PER-HIC INVENTORY AND DISSOLUTION MODEL

Assumption: The calculations leading to the results presented in Section 6 assumed an average radionuclide inventory (Section 5.3.2) for the DSNF fuel groups placed in the individual HICs. Also, because of the composition and condition of the HIC material, the uranium-metal dissolution rate is assumed for the dissolution of the DSNF scheduled for HIC disposal (Section 5.3.5). The average radionuclide inventory was obtained by dividing the total curies of the HIC inventory by the total number of HICs.
Rationale: This assumption is conservative because using the total number of curies represents the same inventory as if the HIC material was modeled according to the amount of material in

the separate DSNF groups. Further, the uranium-metal dissolution rate is greater than that of the dissolution rates for materials in other fuel groups (CRWMS M&O 2000c, Figure 6-15).

Confirmation Status: Because of the conservatism provided by these assumptions, this assumption does not require verification.

Use within the Calculation: The HIC average inventory and uranium-metal dissolution rate used for each simulation scenario was input into the TSPA-SR model used to perform the simulations used to develop the results presented in Sections 6.1 and 6.2.

4. USE OF COMPUTER SOFTWARE AND MODEL

The calculations in this document were performed using the unqualified TSPA-SR model (CRWMS M&O 2000b) with qualified GoldSim software (Golder Associates 2000) that was developed by Golder Associates as an update to the performance-assessment software RIP (Golder Associates 1998). GoldSim is a Windows-based software that is computationally similar to RIP as used for TSPA calculations for the Viability Assessment (DOE 1998). GoldSim is designed so that median-value and probabilistic simulations can be conducted and represented graphically. GoldSim fulfills the specific functional requirements for the TSPA-SR.

Per AP-SI.1Q, Rev. 2, ICN 4, ECN 1, *Software Management*, a Software Activity Number (LV-2000-147) and Software Tracking Number (STN: 10344-6.04.007-00) was obtained for GoldSim from Configuration Management (CM), and the software was installed under CM supervision. The GoldSim software is considered appropriate for this application. The HIC calculations using the TSPA-SR model were performed at Duke Engineering and Services, 9111 Research Boulevard, Austin, Texas. The simulations were conducted on a Dell Workstation 400 with a Pentium II Processor, and on a Dell PowerEdge Workstation 2200 with Dual Pentium Processors. The hardware was operated under Windows NT 4.0 Operating System, Workstation and Server, Service Pack 4.

5. CALCULATION

5.1 BACKGROUND

The DOE spent-fuel inventory has, since it was first incorporated into TSPA analyses, been represented as a surrogate spent fuel (CRWMS M&O 1998, Section A-1.2). Representation of DSNF as a surrogate spent fuel was necessary because of the number of groups of DSNF with different material properties (see Section 5.3.1, below). Reducing the number of groups by combining the inventories of like fuel materials reduces the complexity of the model configuration thus reducing the running time of the TSPA model, thereby making the analyses tractable. A surrogate spent fuel was also used in later analyses using the TSPA model that was developed for the Viability Assessment (VA) (CRWMS M&O 2000c, Section 6.3.2). In a similar manner, the HIC inventory used in the calculations presented in Section 6 is a subset of the complete DSNF inventory and represents a combined inventory for all DSNF material scheduled for HIC disposal.

A HIC is a special-purpose container being designed and evaluated for the disposal of certain material in the DSNF inventory (DOE 1999b). The spent fuel designated for HIC disposal will be fuel that can not be disposed in a standard waste package because the material has lost its integrity. The material will be some combination of fuel sections used for laboratory analysis, powdered fuel, damaged or broken parts of fuel, severely degraded fuel, and small lots of fuel used for experiments in research facilities in the United States and around the world. The HIC is needed to allow containment of this poorly categorized, fragmented, or damaged spent fuel in order to meet environmental and/or regulatory requirements.

Because the spent fuel designated for HIC disposal will include fuels with substantial inventories of radionuclides, the HIC will be manufactured from material designed to provide a barrier that delays release of these materials until well after waste-package failure. The design of the HIC will allow the fuel in the HIC to be isolated from other waste in the waste package so as to prevent any unintended synergistic reactions or criticality. The HIC design also provides a pressure seal to prevent any outward leakage of particulates, gaseous fission products, and radiolytic and galvanically produced hydrogen and water vapor that could be possibly contaminated with fission products.

The HIC will be capable of being manufactured with different lengths depending on the quantity of fuel and whether or not chemically compatible fuels from different fuel categories are combined for disposal. Figure 5-1 shows a diagrammatic representation of the HIC concept where HICs are disposed in the co-disposal package with HLW. Theoretically, the HIC-containing DSNF canisters could contain up to seven HICs. However, preliminary analysis of potential criticality indicates that the DSNF canisters would contain only one HIC. The remainder of the seven positions in the 18-inch DSNF stainless-steel canister (Figure 5-1) will be either left empty or will contain benign material (material that does not contain radionuclides or that would not affect dissolution). Although a HIC may be designed to be of any length, this calculation of HIC disposal considered a standard-length (10-foot long) HIC. In practice, the waste destined for HIC disposal may be either combined, placed in standard-length HICs with spacers to separate waste materials, or placed in shorter HICs that would be stacked in the HIC position in the 18-inch DSNF stainless-steel canister.

5.2 TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL

The calculations presented in Section 6 for the analysis of the performance of the HICs were performed using the TSPA-SR model configuration which utilizes GoldSim software (Golder Associates 2000). The methodology for mathematical and numerical modeling of each process and component in the TSPA-SR model (CRWMS M&O 2000b), including their uncertainties, and the approach for combining the submodels into a comprehensive model applicable to the potential Yucca Mountain repository are described in the TSPA-SR report (CRWMS M&O 2000d, Section 2.2). This report also contains a description of TSPA-SR model architecture and the GoldSim software configuration used to conduct the simulations associated with the TSPA-SR.

5.3 SOURCE TERM

The source term for the calculation of the dose associated with disposal of selected DSNF in the HIC includes the waste forms that are contained in the disposal package. The information provided to the TSPA-SR model for the HIC simulations includes the types of waste, the radionuclide inventory, the packaging, the physical properties, and the dissolution models of the waste forms.

5.3.1 Waste Forms

Table 5-1 shows the DSNF groups used in the analyses in this calculation along with a typical fuel matrix and the amount of fuel in each group. The amount of fuel and the radionuclide inventory used in the HIC analyses is modified in that it represents approximately 93% (see Section 1) of the HIC-designated material in each fuel group containing HIC material. The spent fuel for disposal in the HIC is from Groups 2, 4, 5, 8, 9, 10, and 11 (DOE 1999a, Table 8-2). Because of the diverse nature of the fuel groups, the spent fuel disposed in the HIC is assumed to be represented by uranium-metal spent fuel (Assumption 3.6). The fuel canister containing the HICs is disposed in a co-disposal package (Figure 5-1) with five canisters of HLW. Thus, for the calculation of dose attributed to the HICs, only one waste form is considered, uranium-metal spent fuel.

5.3.2 Radionuclide Inventories

The radionuclide inventory of waste scheduled for HIC disposal, as shown on Table 5-2, includes spent fuel from DSNF Groups 2, 4, 5, 8, 9, 10, and 11 (DOE 1999a, attached electronic file HIC_499WC.xls). Because of the distribution of the radionuclides among the seven waste groups of DSNF and the fact that simulations for each individual group would have too few waste packages to provide a representative simulation, the waste inventory was distributed among all the HICs according to the following system. Ninety-three per cent (93%) of the total curies of each of the 24 radionuclides used in the simulation for the seven groups with HIC material (DOE 1999a, attached electronic file HIC_499WC.xls) was converted to grams of material as required for input into the TSPA-SR model. The amount of material in grams was then divided by the total number of HICs (Table 5-3) to provide the grams of each radionuclide of interest for the one-HIC-per-canister case. Table 5-2 shows the radionuclide inventory tabulated in curies and grams and the specific-activity values (See Attachment III) used in the conversion from curies to grams. The four separate HIC cases considered in the calculations in this document are 1, 3, 5, and 7 HICs per 18-in DSNF stainless-steel canister with one DSNF canister per co-disposal waste package. The radionuclide inventory per HIC in the 3-, 5-, and 7-HIC cases is the radionuclide inventory shown in Table 5-2 multiplied by the number of HICs per canister to obtain the per-package inventories for each particular case.

5.3.3 Waste Packaging

The number of co-disposal waste packages calculated for the cases described in Section 2 was modified from the full waste inventory of 178 HICs (DOE 1999a, Table 9-2). The full inventory of 178 HICs was divided by 1, 3, 5, and 7 HICs per canister and that result was multiplied by 93% to arrive at the number of waste packages for the modified inventory (Attachment II, Table II-2). Table II-2 shows that the DSNF HIC-designated waste in Groups 2, 4, 5, 8, 9, 10, and 11 will be disposed of in 166 co-disposal waste packages at a loading of one-HIC per canister per waste package. Table II-2 also shows that there are 56 waste packages for the 3-HIC case, 34 waste packages for the 5-HIC case, and 25 waste packages for the 7-HIC case. The number of HICs in each of the seven spent-fuel groups is shown in Table 5-3 for the 1-HIC case. The

DSNF canister containing the HICs is disposed in a co-disposal package (Figure 5-1) with five canisters of HLW.

5.3.4 Waste Form Physical Properties

The physical properties of the uranium-metal spent fuel (DOE 1999a, attached electronic file 11RW_2Input699B.xls) are shown in Table 5-4. These properties are used in conjunction with the dissolution model presented below.

5.3.5 Waste Form Dissolution Model

The dissolution model for uranium-metal spent fuel is used for the analysis of the degradation of the DSNF placed in HICs. The uranium-metal-dissolution rate equation contained in the TSPA-SR model is based on the recommendation in *DSNF and Other Waste Form Degradation Abstraction* (CRWMS M&O 2000e, Section 7.2.1). The HIC analysis used the recommended conservative degradation-model rate of the DOE uranium-metal spent fuel (CRWMS M&O 2000e, Section 7.2.1, Eq. 5):

$$k = 1.75 \text{ x } 10^6 \, (\rho_{matrix}/\rho_{U\text{-}metal}) \text{mg/m}^2\text{-d} \qquad \text{(Eq. 5-1)}$$

where

ρ_{matrix} = density of the spent-fuel matrix
$\rho_{U\text{-}metal}$ = density of the uranium metal

This value of the degradation rate is 10 times the best estimate for the matrix-dissolution rate of N-Reactor fuel (Group 7) (CRWMS M&O 2000e, Section 7.2.1, Eq.6). The matrix specific surface area is the area estimated for N-Reactor fuel (7.0 x 10^{-5} m^2/g) (DOE 1999a, attached file 11RW_2Input699B.xls).

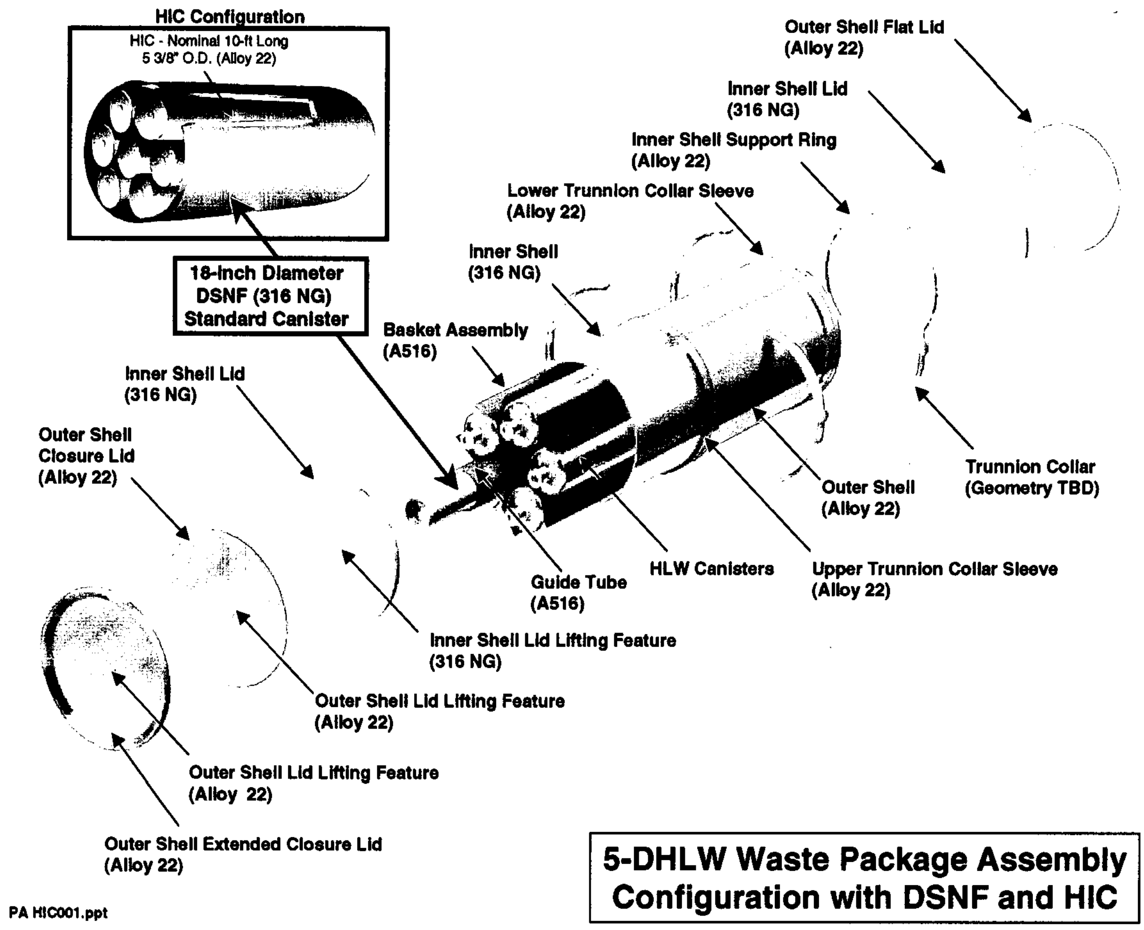

Figure 5-1. Schematic Illustration of the High-Integrity-Can Disposal Concept

Table 5-1. Spent Fuel Type and Typical Fuels in Each Spent Fuel Group

Group	Fuel Matrix	Typical Fuel in Group	Modified Fuel Amount (MTHM)
1	Classified	Naval	65
2	Plutonium/Uranium alloy	Enrico Fermi Reactor (Fermi) core 1 & 2	8.50
3	Plutonium/Uranium carbide	Fast Flux Test Facility (FFTF) Test Fuel Assembly	0.10
4	Plutonium/Uranium oxide and Plutonium oxide	Fast Flux Test Facility (FFTF) Driver Fuel Assembly	11.59
5	Thorium/Uranium carbide	Ft. St. Vrain	24.52
6	Thorium/Uranium oxide	Shippingport Light Water Breeder Reactor	46.98
7	Uranium metal	N Reactor	1,984.81
8	Uranium oxide	Three Mile Island core debris	166.22
9	Aluminum based fuel	Foreign Research Reactor pin cluster	19.54
10	Unknown	Miscellaneous	4.24
11	Uranium-Zirconium hydride	Research Training Isotope General Atomic (TRIGA)	1.51
TOTAL			**2,333.00**

(DOE 1999a, Table 5-2 and attached electronic file 11RW_Input399A.xls)

Table 5-2. Radionuclide Inventory for the High Integrity Can

Isotope	Total Radionuclide Inventory (Ci)[a]	93% Total Radionuclide Inventory (Ci)	Radionuclide Specific Activity (Ci/g)[b]	Total Grams[c]	Radionuclide Inventory for One HIC per Waste Package (g/waste package)[d]
^{227}Ac	2.4456E-02	2.2744E-02	7.2433E+01	3.1400E-04	1.8916E-06
^{241}Am	4.8330E+03	4.4947E+03	3.4386E+00	1.3071E+03	7.8743E+00
^{243}Am	1.4790E+01	1.3754E+01	1.9990E-01	6.8807E+01	4.1450E-01
^{14}C	1.1096E+01	1.0320E+01	4.4627E+00	2.3124E+00	1.3930E-02
^{137}Cs	7.1816E+05	6.6789E+05	8.6121E+01	7.7553E+03	4.6719E+01
^{129}I	4.0325E-01	3.7502E-01	1.7345E-04	2.1621E+03	1.3025E+01
^{237}Np	2.5031E+00	2.3279E+00	7.0586E-04	3.2979E+03	1.9867E+01
^{231}Pa	4.5171E-02	4.2009E-02	4.7249E-02	8.8909E-01	5.3560E-03
^{210}Pb	3.1303E-06	2.9112E-06	7.6447E+01	3.8081E-08	2.2940E-10
^{238}Pu	6.3058E+03	5.8644E+03	1.7144E+01	3.4207E+02	2.0607E+00
^{239}Pu	1.3527E+03	1.2580E+03	6.2128E-02	2.0248E+04	1.2198E+02
^{240}Pu	9.8367E+02	9.1481E+02	2.2739E-01	4.0231E+03	2.4236E+01
^{242}Pu	1.0958E+00	1.0191E+00	3.9344E-03	2.5901E+02	1.5603E+00
^{226}Ra	8.5197E-06	7.9233E-06	9.9004E-01	8.0030E-06	4.8211E-08
^{228}Ra	3.0448E-04	2.8317E-04	2.7260E+02	1.0388E-06	6.2576E-09
^{90}Sr	6.5327E+05	6.0754E+05	1.3650E+02	4.4508E+03	2.6812E+01
^{99}Tc	1.8371E+02	1.7085E+02	1.6977E-02	1.0063E+04	6.0623E+01
^{229}Th	1.2426E-03	1.1557E-03	2.1415E-01	5.3964E-03	3.2509E-05
^{230}Th	2.2074E-03	2.0529E-03	2.0644E-02	9.9446E-02	5.9907E-04
^{232}Th	2.3182E-04	2.1559E-04	1.1022E-07	1.9560E+03	1.1783E+01
^{232}U	1.3383E-01	1.2446E-01	2.2365E+01	5.5652E-03	1.7682E-01
^{233}U	3.0461E-01	2.8329E-01	9.6513E-03	2.9353E+01	3.3525E-05
^{234}U	4.2636E+01	3.9651E+01	6.2445E-03	6.3498E+03	3.8252E+01
^{235}U	1.2639E+00	1.1755E+00	2.1639E-06	5.4321E+05	3.2723E+03
^{236}U	4.1997E+00	3.9057E+00	6.4772E-05	6.0300E+04	363.2522991
^{238}U	3.4521E-01	3.2104E-01	3.3666E-07	9.5361E+05	5744.66662

NOTE: [a] Value is Total Curies (DOE 1999a, attached electronic file HIC_499WC.xls).
[b] Values calculated in Attachment III.
[c] Value is 93%Total Curies divided by Specific Activity.
[d] Value is Total Grams divided by 166 HICs.

Table 5-3. Number of High Integrity Cans in Each Group of Spent Fuel for the Modified Amount (2,333 MTHM) of Spent Fuel

Spent Fuel Group	Number of HICs per Group @ 1 HIC per Waste Package
1	N/A
2	15
3	0
4	49
5	1
6	0
7	0
8	66
9	23
10	5
11	7
Total	166

(See Attachment II, Table II-1)

Table 5-4. Waste Form Physical Properties

Waste Form	Matrix Surface Area (m^2/g)	Free Radionuclide Inventory (fraction)	Fuel Area (m^2/pkg)	Fuel Volume (m^3/pkg)
Uranium metal spent fuel	7.0E-05	0.001	1.2E+03	1.0E+00

(DOE 1999a, attached electronic file 11RW_2Input699B.xls)

6. RESULTS

The TSPA-SR model simulations used to calculate the performance of the HICs estimate the total radiological dose and dose per radionuclide to maximally exposed individuals at 20 km downgradient from the potential Yucca Mountain repository location for the 1, 3, 5, and 7 HIC-per-waste-package cases, the "no-HIC" case, and the case of a high-integrity DSNF canister used to dispose of HIC-designated waste. The total dose was calculated for the time from repository closure to 1,000,000 years after repository closure. The results represent calculations based on the TSPA-SR nominal case modified to apply to waste disposed of in HICs. The output files for these calculations are included in DTN: MO0009MWDHIG03.010.

The TSPA-SR model, utilizing GoldSim, calculates the radionuclide release and radiological dose due to all nuclides released from the repository from failed waste packages containing only HIC-designated DSNF. The TSPA-SR model calculates the median-value of the output.

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6.1 WASTE-PACKAGE FAILURE CURVES

The failure of the waste packages containing HICs and the failure of the HICs was simulated using the waste-package degradation sub-model of the TSPA-SR model. Sequentially, the model was able to first simulate failure of the outer layers of the waste package. These failure results were put back into the model and the model was rerun to simulate the failure of the HIC. Only after HIC failure can transport of the released HIC inventory be modeled. Figure 6-1 shows the failure curves for the cases described in Section 2. Figure 6-1 shows that the first failure is for the 1-HIC case and that the last configuration to fail is the Alloy 22 18-inch diameter DSNF canister. The range in first failure times is from approximately 40,000 years for the 1-HIC case to approximately 60,000 years for the Alloy 22 DSNF canister. As expected, the failure curve for the no-HIC case is identical to the TSPA-SR nominal case.

6.2 SIMULATIONS

The TSPA-SR model was used to calculate the dose-to-receptor effect of the use of the HIC to dispose of certain portions of the DSNF inventory. The inventory used for the simulations is presented in Section 5.3. Waste-form dissolution was modeled with the metallic waste-form dissolution model described in Section 5.3. The simulations included waste-package configurations for cases representing 1, 3, 5, and 7 10-foot long HICs contained in a DSNF 18-inch diameter stainless-steel canister. These cases were simulated for HICs constructed of Alloy 22. The simulations were run for one million years to allow the time of peak dose to be evaluated.

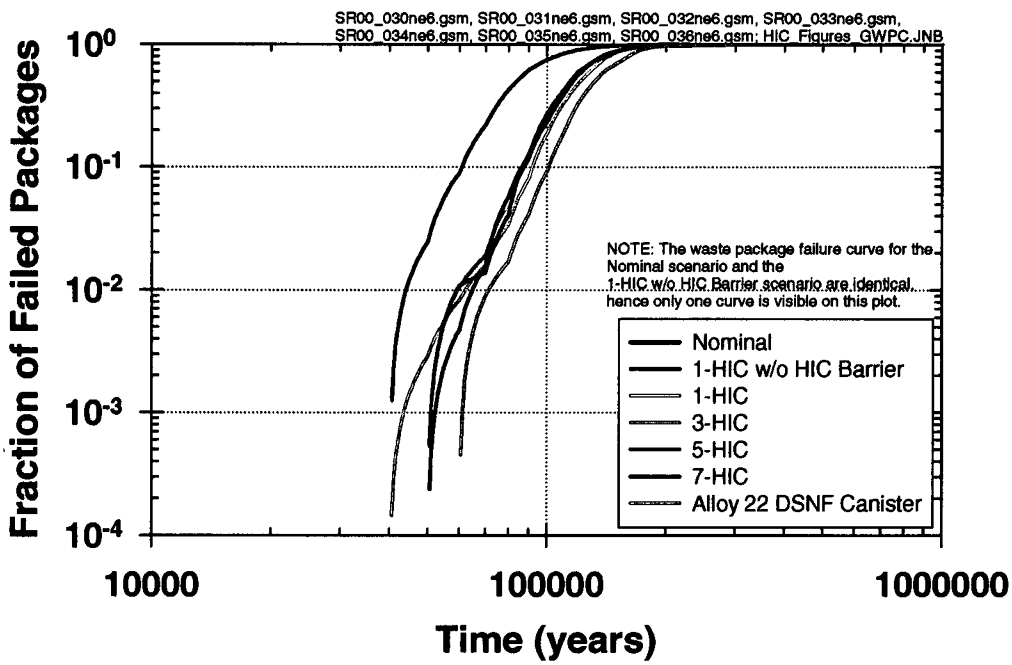
Figure 6-2 shows the 1-HIC case, median-value dose rates at 20 km from the repository for selected radionuclides analyzed with the TSPA-SR model, including ^{229}Th and ^{226}Ra that are part of the groundwater protection evaluation. The figure shows the results for HICs constructed of Alloy 22. The peak dose occurs from 150,000 to 200,000 years after repository closure. The very early, post-10,000-year total dose is controlled by ^{99}Tc and ^{129}I. The radionuclides ^{234}U and ^{239}Pu control the total dose from about 80,000 to 160,000 years after closure, and the total dose from 200,000 to 1,000,000 years is mostly the sum of ^{230}Th, ^{226}Ra, and ^{237}NP.

Figure 6-3 shows the median-value total dose for the various HIC cases. The figure shows that in general, as the number of HICs per package increases, the beginning of the total dose curve is delayed in time. However, the 5-HIC and 7-HIC cases are very similar because there is a similar number of waste packages for these two cases.

Two additional cases were considered in the analysis of the performance of the HIC. One case considered disposal of the HIC inventory in the 1-HIC configuration using a HIC made of stainless steel contained in a DSNF 18-inch diameter canister constructed of Alloy 22 with the same 3/8-inch wall thickness as that of a standard stainless-steel DSNF canister (CRWMS M&O 2000f, Section 4.1.3, Table 4). Another case considered the disposal of the HIC inventory in stainless steel HICs contained in a stainless-steel 18-inch DSNF canister, also called the no-HIC case. Figure 6-4 shows a comparison of the total dose from all Alloy-22 HIC cases compared to the case for the Alloy 22 18-inch DSNF canister. The difference in delay of the start of the total-dose curve is due to the thicker 3/8-inch wall for the DSNF canister (CRWMS M&O 2000f, Section 4.1.3, Table 4). The HIC has a 1/4-inch wall thickness (DOE 1999c). The results indicate that using an 18-inch Alloy 22 DSNF canister with a one-HIC per waste package delays the total-dose curve about 10,000 years. Otherwise, the general character of the Alloy 22 18-inch canister curve resembles the Alloy 22 HIC cases. The variation in the shapes of the total-dose curves is because of the stochastic nature of the GoldSim software.

Figure 6-5 shows the median-value total dose for the various HIC cases including the "no-HIC" case and the case with the Alloy 22 DSNF canister. The figure also shows the median-value total dose calculated for the TSPA-SR nominal-case configuration that includes 70,000 MTHM of commercial spent fuel, DOE spent fuel and HLW. The figure shows that the median-value peak dose for the HIC inventory is approximately three orders of magnitude less than the median-value TSPS-SR total dose. The curves show that the median-value total dose for the TSPA-SR nominal case and 1-HIC case are somewhat closer in magnitude during the first 100,000 years and more widely separated at times greater than 400,000 years after closure.

For the no-HIC case, the entire HIC inventory is configured as one HIC per waste package (1-HIC without HIC barrier), but without the use of a high integrity can or an 18-inch DSNF canister constructed of high-integrity materials. With only a steel DSNF canister and steel cans for the HIC inventory, the canister and cans essentially fail as soon as the waste package is breached and the HIC inventory is added directly to the radionuclides released from other waste forms in the standard waste packages. Figure 6-5 shows that the start of the total dose for the no-HIC case is before the HIC cases but after the TAPA-SR nominal case. The delay in the start of the no-HIC case as compared to the TSPA-SR nominal case occurs because the no-HIC case has fewer packages than the nominal case, which in the TSPA-SR model, causes the first package failure to occur later in time.



DTN: MO0009MWDNM601.018 (Nominal Case Data)

Figure 6-1. Failure Curves for the Different HIC Cases and the Alloy 22 DSNF Canister

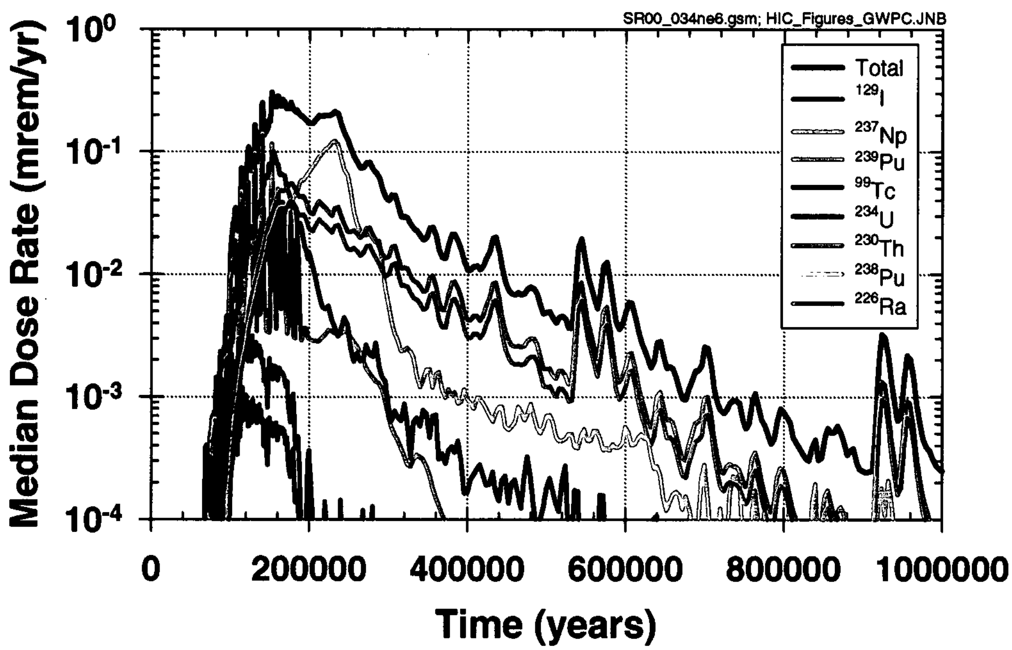


Figure 6-2. Total and Radionuclide Dose for the Median-Value Case of 1-HIC per Waste Package

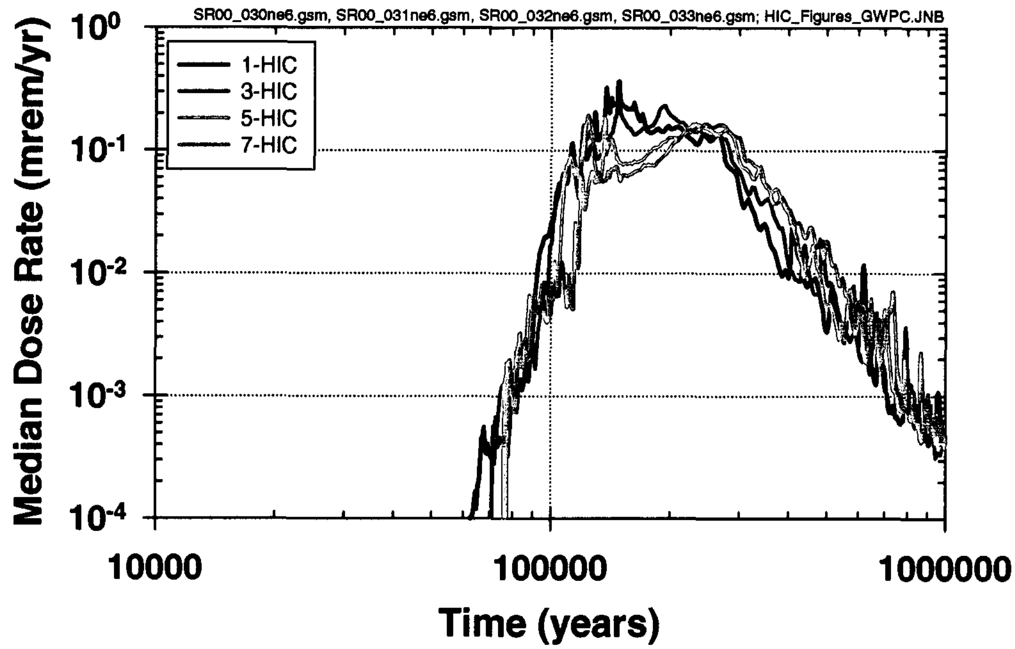


Figure 6-3. Total Dose for the Median-Value Cases of 1, 3, 5, and 7-HICs per Waste Package

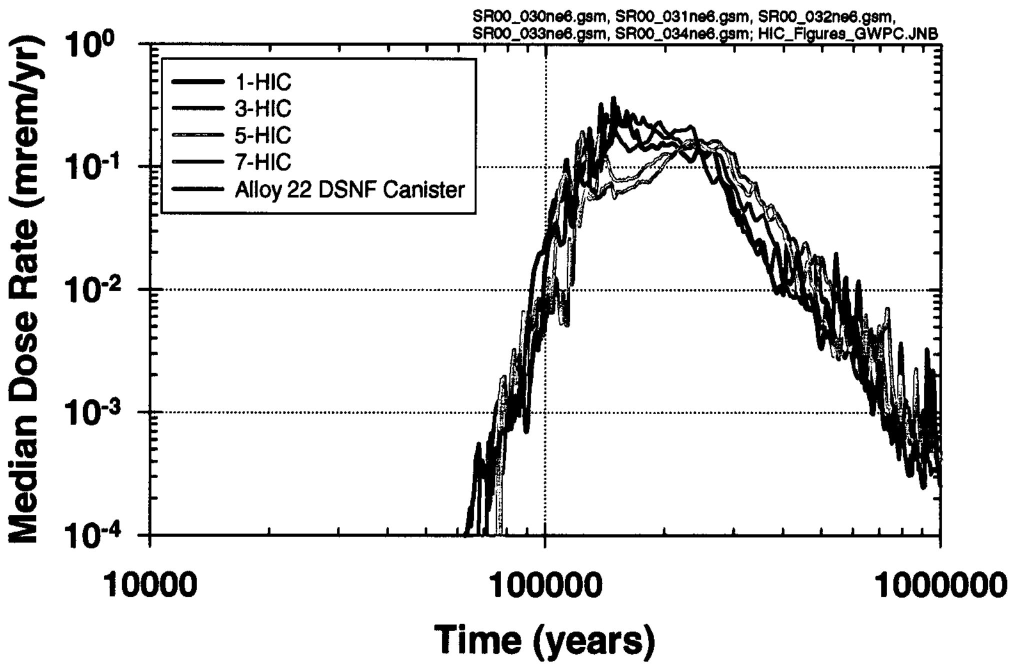
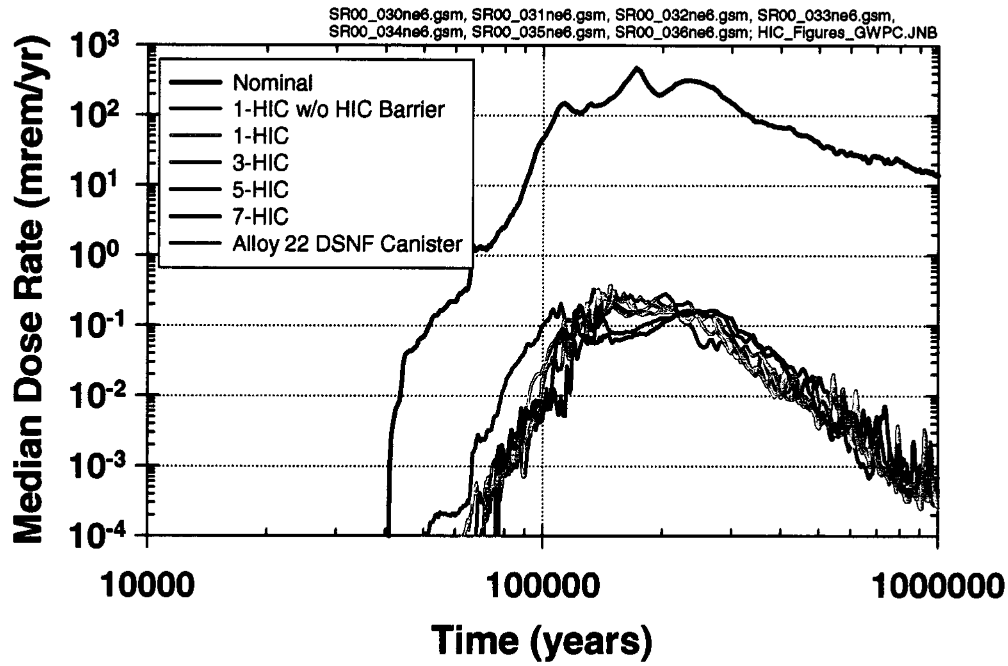


Figure 6-4. Total Dose for the Median-Value Cases of 1, 3, 5, and 7-HICs per Waste Package and the Alloy 22 DSNF Canister



DTN: MO0009MWDNM601.018 (Nominal Case Data)

Figure 6-5. Total Dose for the Median-Value TSPA-SR Nominal Case, the Median-Value Cases of 1, 3, 5, and 7-HICs per Waste Package, one HIC per Waste Package without a HIC Barrier Case, and the Alloy 22 DSNF Canister Case

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7.3 SOURCE DATA, LISTED BY DATA-TRACKING NUMBER

7.3.1 Input Data

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Supporting DTNs for MO0009MWDNM601.018.

GS000308315121.003
MO0001SPASUP03.001
MO0002SPADVE03.001
MO0002SPALOO46.010
MO0002SPASDC00.002
MO0003SPACLD07.042
MO0003SPAHLO12.004
MO0003SPAION02.003
MO0003SPASGU01.003
MO0004SPACLD07.043
MO0004SPADEC00.002
MO0004SPAFRE00.003
SN0002T0571599.002
SN0003T0503100.001
SN0006T0502900.002
SN9908T0872799.004
SN9910T0581699.002
SN9912T0511599.002
SN9912T0512299.002
SN9912T0810599.007
SNT05070198001.001

7.3.2 Output Data

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7.4 SOFTWARE

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8. ATTACHMENTS

ATTACHMENT I

ACRONYMS AND ABBREVIATIONS

ACRONYMS AND ABBREVIATIONS

CM	Configuration Management
CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
DSNF	DOE Spent Nuclear Fuel
Fermi	Enrico Fermi Reactor
FFTF	Fast Flux Test Facility
HIC(s)	High Integrity Can(s)
HLW	High-Level Waste
MTHM	Metric Tons Heavy Metal
M&O	Management and Operating Contractor
OCRWM	Office of Civilian Radioactive Waste Management
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description
RIP	Repository Integration Program
SR	Site Recommendation
TRIGA	Training Research Reactor General Atomic
TSPA	Total System Performance Assessment
VA	Viability Assessment
WAPDEG	Waste Package Degradation "model"

ATTACHMENT II

WASTE-PACKAGES FOR ANALYSIS CASES

Table II-1. Number of HICs for Each DSNF Fuel Group for the Full DSNF Inventory and 93% of that Inventory (One-HIC-per-Canister Case)

Group	Total Number of HICs[a]	93 % of HICs
2	16	15
3	0	0
4	53	49
5	1	1
6	0	0
7	0	0
8	71	66
9	25	23
10	5	5
11	7	7
Total	**178**	**166**

[a](DOE 1999a, Table 9-2)

Table II-2. Number of Waste Package for Each Simulation Case for the Full DSNF Inventory and 93% of that Inventory

	HICs/Case	Calculated Number of Waste Packages	Rounded-up Number of Waste Packages	93% of Total Waste Packages	Rounded-up Number of Waste Packages
1-HIC Case	178/1=	178	178	165.5	166
3-HIC Case	178/3=	59.33	60	55.8	56
5-HIC Case	178/5=	35.60	36	33.48	34
7-HIC Case	178/7=	25.43	26	24.18	25

ATTACHMENT III

SPECIFIC ACTIVITIES FOR RADIONUCLIDES

Table III-1. Specific Activity Values Used to Estimate the Radionuclide Inventory in Grams for the Model Simulations

Nuclide	Molecular Weight (g)[a]	Half life (yr)[a]	Decay Rate (1/yr)[b]	Specific Activity (Ci/g)[c]
^{227}Ac	227	21.773	3.1835E-02	7.24E+01
^{241}Am	241	432	1.6045E-03	3.44E+00
^{243}Am	243	7.37E+03	9.4050E-05	2.00E-01
^{14}C	14	5715	1.2097E-04	4.47E+00
^{137}Cs	137	3.03E+01*	2.2846E-02	8.61E+01
^{129}I	129	1.60E+07	4.3322E-08	1.73E-04
^{237}Np	237	2.14E+06	3.2390E-07	7.06E-04
^{231}Pa	231	3.28E+04	2.1133E-05	4.72E-02
^{210}Pb	210	22.3	3.1083E-02	7.64E+01
^{238}Pu	238	87.74	7.9000E-03	1.71E+01
^{239}Pu	239	2.41E+04	2.8749E-05	6.21E-02
^{240}Pu	240	6.56E+03	1.0566E-04	2.27E-01
^{242}Pu	242	3.76E+05	1.8435E-06	3.93E-03
^{226}Ra	226	1600	4.3322E-04	9.90E-01
^{228}Ra	228	5.76	1.2034E-01	2.73E+02
^{90}Sr	90	2.91E+01*	2.3819E-02	1.37E+02
^{99}Tc	99	2.13E+05	3.2542E-06	1.70E-02
^{229}Th	229	7.30E+03	9.4952E-05	2.14E-01
^{230}Th	230	7.54E+04	9.1929E-06	2.06E-02
^{232}Th	232	1.40E+10	4.9511E-11	1.10E-07
^{232}U	232	6.89E+01*	1.0060E-02	2.24E+01
^{233}U	233	1.59E+05	4.3539E-06	9.65E-03
^{234}U	234	2.45E+05	2.8292E-06	6.24E-03
^{235}U	235	7.04E+08	9.8458E-10	2.16E-06
^{236}U	236	2.34E+07	2.9596E-08	6.48E-05
^{238}U	238	4.47E+09	1.5514E-10	3.37E-07

[a] (Lide 1991, pp. 11-28 to 11-132, except * from DOE 1987, Table 1B.1)
[b] Decay Rate = ln(0.5)/-half life(yr)
[c] Specific Activity = -358000/(((ln(0.5)/Decay Rate))*Molecular Weight)