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1. Purpose

The objective of this analysis is to characterize a codisposal canister containing MIT or ORR fuel in the Five-Pack defense high level waste (DHLW) waste package (WP) to demonstrate concept viability related to use in the Mined Geologic Disposal System (MGDS) environment for the postclosure time frame. The purpose of this analysis is to investigate the disposal criticality and shielding issues for the DHLW WP and establish DHLW WP and codisposal canister compatibility with the MGDS, and to provide criticality and shielding evaluations for the preliminary DHLW WP design.

2. Quality Assurance

The Quality Assurance (QA) program applies to this analysis. The work reported in this document is part of the preliminary Waste Package (WP) design analysis that will eventually support the License Application Design phase. This activity, when appropriately confirmed, can impact the proper functioning of the MGDS waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (pp. 4, 15, Ref. 5.1). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 *Classification of Permanent Items* evaluation. The Waste Package Development Department responsible manager has evaluated this activity in accordance with QAP-2-0, *Conduct of Activities*. The DOE Spent Fuel Characterization (Ref. 5.3) activity evaluation has determined that work associated with the aluminum-based DOE Spent Fuel task is subject to *Quality Assurance Requirements and Description* (QARD; Ref 5.2) requirements. As specified in NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analyses, and Technical Documents*, this activity is subject to QA controls.

Design inputs which are identified in this document are for the preliminary stage of the WP design process; all of these design inputs will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. Consequently, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

3. Method

The solution method is to use the Monte Carlo N-Particle Version 4A computer code (MCNP4A; CSCI: 30006 V4A) to calculate k-effective for criticality safety evaluations and to also to use MCNP4A to calculate neutron and gamma fluxes on the WP surface for dose rate evaluations. The SAS2H sequence of the SCALE 4.3 code package (CSCI: 30011 V4.3) is used to develop source terms for shielding (and thermal) evaluations. All calculations are performed with initial fresh fuel enrichment values; i.e., there is no credit for fuel burnup. (Assumption 4.3.1)

4. Design Inputs

All design parameters and assumptions which are identified in this document are for the preliminary stage of the WP design process and are considered unqualified; all of these design parameters and assumptions will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and therefore is not required to be procedurally controlled as TBV. In addition, the inputs associated with this analysis are not required to be procedurally controlled as TBV. However, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

4.1 Design Parameters

Criticality evaluations of both Massachusetts Institute of Technology (MIT) Spent Nuclear Fuel (SNF) and Oak Ridge Research (ORR) SNF are performed to evaluate a range of fresh fuel enrichments from 93.5 weight percent to 20 weight percent. These enrichments are representative of the various enrichments which may be found in Al-based DOE-owned SNF as identified by Savannah River Site (SRS) (Ref. 5.4).

4.1.1 Massachusetts Institute of Technology (MIT) SNF

The details of the MIT fuel assembly were obtained from the MIT fuel Appendix A data and the MIT plate/assembly drawings (R3F-3-2, R3F-1-4) provided by SRS (Ref. 5.4)(TBV). The MIT fuel assembly is constructed from a collection of 15 flat plates tilted at a sixty degree angle so that the resulting assembly has a parallelogram cross-section instead of the more common square or hexagon shape. The MIT fuel length values used in these analyses are shorter than the original as-built length of the MIT assembly because the top and bottom ends of the assembly, which do not contain uranium materials, have been removed by cutting. The fuel plates consist of an aluminum cladding over an aluminum/uranium alloy. The maximum fuel mass for the MIT assembly are 514.25 grams of U-235 with an enrichment of 93.5 weight percent and one weight percent of U-234 (assumption 4.3.2). The amount of aluminum present in the U-Al_x alloy is 30.5 weight percent. The uranium/aluminum alloy has a significant void volume if distributed over the maximum dimensions, and thus can become waterlogged with a resultant increase in reactivity.

The conservative values on which burnup is based were taken from the MIT fuel Appendix A data provided by SRS (Ref. 5.4). The maximum exposure for the MIT fuel is rounded up to 8100 MWD/MTU. The time in reactor (including down time) is rounded down to 2500 days and the power level is 9.68 MW/MTU.

Fuel Plates

The flat plates are 2.552 (+0.000, -0.002) inches wide, and 23 inches long. All 15 plates are the same and have a finned cladding surface with a thickness of 0.080 ±0.003 inches and a fin height of 0.010 ± 0.002 inches. The fuel alloy is 0.030 +0.0, -0.002 inches thick, 2.177 +0.000, -0.1875 inches wide, and 22.375 ±0.375 inches long.

Fuel Element

The aluminum outer shroud which encloses the 15 fuel plates on 4 sides is a 2.405 inch outside dimension rhomboid with two 0.044 inch thick walls parallel with the fuel plates and two 0.188 inch thick comb plates into which the fuel plates fit. The length (after cutting) is 23.368 inches. The fuel plates are evenly spaced within this rhomboid and angled 60 degrees off the comb plate. Drawing R3F-1-4 (Ref. 5.4)) shows a fuel plate center-to-center spacing of 0.158 inches, which is the spacing of the notches on the comb plates.

4.1.2 Oak Ridge Research (ORR) SNF

Details of the construction of the ORR fuel element are contained in drawings M-11495-OR-001 ("19 Plate Fuel Element Assy & Finish Machining", Ref. 5.4)(TBV), M-11495-OR-003 ("Misc. Details for ORR Fuel Element", Ref. 5.4)(TBV), and M-11495-OR-004 ("Fuel Plate Details", Ref. 5.4)(TBV). The element is constructed from 19 curved fuel plates which are held within a square aluminum box by two opposing aluminum comb plates. The ORR fuel length values used in these analyses are shorter than the original as-built length of the ORR assembly because the top and bottom ends of the assembly, which do not contain uranium materials, have been removed by cutting. The ORR fuel Appendix A (Ref. 8.3) contains the material information. The fuel plates consist of an aluminum cladding over an U-Si-Al fuel material. The maximum fuel mass for the ORR assembly is 347 grams of U-235 with an enrichment of 20.56 weight percent. The uranium present in the U-Si-Al alloy is 77.5 weight percent. There are 2 atoms of Si per 3 atoms of U, and Al fills out the bulk of the fuel material.

Fuel Plates (Ref. 5.4)

The curved plates are 2.770 minimum (2.775 maximum) inches wide with a 5.5 inch inner radius of curvature. Seventeen of the plates are inner plates, with a thickness of 0.0494 to 0.0510 inches total with a 0.0105 inch minimum aluminum cladding on both sides of a 0.020 inch nominal fuel foil, which is assumed to have a tolerance of 0.005 inches since this is the default for the drawing. Two of the plates are outer plates, with a thickness of 0.063 to 0.066 inches, with a 0.018 inch minimum cladding on both sides of a 0.020 inch nominal fuel foil. The inner and outer fuel plates are manufactured as flat laminated sheets with a minimum width of 2.7925 inches (2.7955 maximum) that are formed to the 5.5 inch radius of curvature. The fuel foil is not as wide as the aluminum cladding, and an aluminum strip is used to close each side of the finished fuel plate. For the inner fuel plates, the width of the fuel foil allows a 0.126 to 0.200 inch inset from the edge of the plate on both sides. The overall length of the inner fuel plate is 24.620 to 24.630 inches and the fuel foil is centered within the plate longitudinally, with an inset at each end of 0.318 to 0.775 inches. For the outer fuel plates, the width of the fuel foil allows a 0.126 to 0.198 inch inset from the edge of the plate on both sides. The overall length of the outer fuel plate is 27.120 to 27.130 inches and the fuel foil is centered within the plate longitudinally, with an inset at each end of 1.574 to 2.011 inches. The top and bottom ends of the inner and outer fuel foils are chamfered, but this trimming of the fuel alloy will be neglected. The plates are fixed relative to each other by comb plates along two sides and by a comb strap across the top and bottom. Note that the upper and lower ends of each fuel plate (for a short length) are rolled slightly - this feature is neglected in the MCNP geometry model since the spacing of the plates is unaffected.

Fuel Element (Ref. 5.4)

The aluminum comb plates enclose the 19 fuel plates on 2 sides fixing the fuel plates and creating an approximately 3.25 inch by 3.00 inch outside dimension rectangle, with a nominal length (after cutting) of 27 1/8 inches. The fuel plates are centered within this box, and form a square fuel/water region with a 3.169 inch reference dimension (the longitudinal comb plate width). Drawing M-11495-OR-003 ("Misc. Details for ORR Fuel Element") shows a fuel plate edge-to-edge spacing of 0.166 inches, which is the spacing of the notches on the comb plates.

4.1.3 HLW Glass Pour Canisters

The Savannah River glass pour canister is a cylindrical stainless steel 304 can with a 609 mm outer diameter, a 9.525 mm wall thickness (Ref. 5.11, p. 3.3-4)(TBV), and a nominal length of 3 m. The canister inside volume is 0.736 m^3 and the glass weight is 1682 kg (Ref. 5.11, p. 3.3-6). HLW glass (Ref. 5.11, p. 3.3-1) is poured into the canisters until 85% of the volume is filled. The nominal dimensions of the pour canister are used for these analyses. Glass neutron, gamma, and heat sources are provided in Reference 5.23 and are given in Tables 7.4-1 and 7.4-2. Savanah River HLW glass number densities were obtained from Reference 5.20, Attachment II.

4.1.4 Codisposal Canister

The preliminary design (TBV) for the codisposal canister is a stainless steel 316L, right circular cylinder which contains a 316L basket. DOE-owned SNF is to be loaded into the basket. An initial conceptual design for the MIT SNF is described in Section 7.2.3 and for the ORR SNF, in Section 7.2.4. The initial dimensions for the codisposal canister are a 422 mm outer diameter and a 6.35 mm wall thickness. The length of the canister is defined for this analysis as the length of four stacked fuel assemblies plus tolerances plus between-layer (axial) separator plate thicknesses as required. The codisposal canister contains 16 MIT or 10 ORR DOE-SNF fuel basket locations in four layers. Stainless steel/boron alloy (described in Section 7.2.5) is used to separate each layer from the adjacent layer within the canister.

The design of the DOE-SNF canisters is modifed in this analysis in order to meet criticality requirements as discussed in Section 7.3 and in a companion structural (Ref. 5.27) analyses to meet structural requirements. The structural analysis indicated that 15 mm thick XM-19 is required for the DOE-SNF canister. The evaluation of the final design resulting from the preliminary criticality and structural analyses is presented in Section 7.4. A companion thermal analysis (Ref. 5.26) was also performed but required no additional changes to the design.

The composition of Type XM-19 stainless steel (Ref. 5.5) is shown in Table 4.1.4-1.

Table 4.1.4-1 Type XM-19 Stainless Steel Composition

Element	Composition, Weight Percent
Carbon	0.06 Max
Manganese	4.00-6.00
Phosphorus	0.040 Max
Sulfur	0.030 Max
Silicon	0.75 Max
Chromium	20.50-23.50
Nickel	11.50-13.50
Molybdenum	1.50-3.00
Nitrogen	0.20-0.40
Copper	0.0

4.1.5 DHLW Five-Pack Waste Package

The DHLW Five-Pack waste package (TBV) consists of a double-walled waste package which can accept five canisters in a pentagonal array. The central region of the pentagonal array is an empty space, which can accept the codisposal canister. Dimensions for the DHLW Five-Pack waste package are provided by the sketches included in Attachment I. The materials of construction selected for the DHLW WP are: corrosion allowance barrier - ASTM A 516 Gr 55, corrosion resistant barrier - ASTM B 443 ("Alloy 625") (Ref 5.24). The densities and isotopic contents of the materials of construction for the waste package are given in reference 5.22. Reference 5.22 does not contain a definition of the alloy 625 which is used for the inner barrier of the waste package, so the Alloy 825 definition is used instead since no discernible neutronic effect will result from this substitution.

4.2 Criteria

The *Engineered Barrier Design Requirements Document* (EBDRD; Ref. 5.9) contains several criteria which relate to criticality control or WP shielding. The "TBD" (to be determined) items identified in these criteria will not be carried to the conclusions of this analysis based on the rationale that the conclusions are for preliminary design, and will not be used as input in design documents supporting construction, fabrication, or procurement. A review of the EBDRD identified the following relevant requirements:

4.2.1 Criticality Control

The EBDRD requirements 3.2.2.6 and 3.7.1.3.A both indicate that a WP criticality shall not be possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. These requirements also indicate that the design must provide for criticality safety under normal and accident conditions, and, that the calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a five percent margin after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation. The latter requirement contains a "TBD" at the end.

Controlled Design Assumptions document (CDA) assumption EBDRD 3.7.1.3.A (Ref. 5.10, p. 4-32) clarifies that the above requirement is applicable to only the preclosure phase of the MGDS, in accordance with the current DOE position on postclosure criticality. This assumption also indicates that for postclosure, the probability and consequences of a criticality provide reasonable assurance that the performance objective of 10CFR60.112 is met. While the Nuclear Regulatory Commission (NRC) has not yet endorsed any specific change for postclosure, they have indicated that they agree that one is necessary.

[EBDRD 3.7.1.3.A]

Finally, EBDRD 3.3.1.G indicates that "The Engineered Barrier Segment design shall meet all relevant requirements imposed by 10CFR60." The NRC has recently revised several parts of 10CFR60 which relate to the identification and analysis of design basis events (Ref. 5.16) including the criticality control requirement, which was moved to 60.131(h). These changes are not reflected in the current versions of the EBDRD or the CDA. The change to the criticality requirement simply replaces the phrase "criticality safety under normal and accident conditions" with "criticality safety assuming design basis events."

This analysis contributes to satisfying the above requirements for preclosure by demonstrating that the intact codisposal canisters for MIT and ORR fuel will remain subcritical, given a five percent administrative margin (Ref. 5.16) and allowing for bias and uncertainty in the method of calculation, during the WP flooding event defined in the WP Design Basis Events analysis (Ref. 5.17). The misload events discussed in that analysis are not applicable in this case, as the codisposal canisters are specifically designed for the unique physical forms of the MIT and ORR fuel, and do not take credit for burnup. This analysis provides information which will be used in probabilistic analyses of postclosure criticality as part of Total System Performance Assessment (TSPA)-Viability Assessment (VA) to demonstrate compliance with the performance objective of §60.112 (or, as appropriate, other applicable performance objectives in effect or proposed by the NRC at the time the TSPA-VA analysis is performed).

4.2.2 Shielding

EBDRD requirement 3.2.4.5 indicates that allocation of shielding requirements to the WP, if any, is TBD. The CDA has clarified this TBD in Key Assumption 031, by indicating that the WP shielding criteria should be as follows:

A. WP containment barriers will provide sufficient shielding for protection of WP materials from radiation enhanced corrosion,

B. Individual WPs will not provide any additional shielding for personnel protection, and,

C. Additional shielding for personnel protection will be provided on the subsurface transporter and in surface and subsurface facilities.

[EBDRD requirement 3.2.4.5]

Furthermore, EBDRD requirements 3.7.1.A, 3.7.1.B, and 3.7.1.2.G indicate that the design of the WP should be such that the nuclear properties of the contained waste not compromise the function of the WP, and that the design of the WP consider radiolysis effects.

This analysis contributes to satisfying the above criteria by demonstrating that the dose rate at the surface of the WP will not result in significant corrosion enhancement of the outer barrier due to radiolysis.

[EBDRD 3.7.1.A, 3.7.1.B, and 3.7.1.2.G]

4.3 Assumptions

4.3.1 It is assumed that all fuel is fresh and unburned for criticality analyses; i.e., there is no credit for burnup. The fresh fuel isotopic concentrations are used for all calculations. This assumption is used in Sections 3 and 4.1 and throughout Sections 7.2 and 7.3. The basis for this assumption is that it is conservative, because fresh fuel is more neutronically reactive than spent fuel.

4.3.2 It is assumed that the MIT fuel contains one weight percent U-234. The basis for this assumption is comparison to published information on other research reactor fuel of similar enrichment (Ref. 5.21). This assumption is used in Section 4.1.1.

4.3.3 It is assumed that the codisposal canister contains 16 MIT or 10 ORR DOE-SNF assemblies per layer (4 layers total). MIT assemblies are representative of the many types of DOE-SNF which will be disposed of in codisposal waste packages since the enrichment and reactivity of these assemblies is larger than other fuel types. This assumption is used throughout Section 4.1 and throughout Section 7. The basis for this assumption is engineering judgement on the number of assemblies which will fit in the central space of the 5-pack DHLW WP with allowance for conceptual structural supports.

4.3.4 The waste package is assumed to be fully flooded with water for criticality calculations. The basis for this assumption is that it is conservative and is developed as a scenario in previous probabilistic analyses (Ref. 5.30). This assumption is used throughout Sections 7.2, 7.3 and 7.4.

4.3.5 The waste package is assumed to be filled with air for shielding calculations. .The basis for this assumption is that the use of air or helium has no effect upon the calculated dose rate results due to the very low density of gases. This assumption is used throughout Section 7.6.

4.3.6 It is assumed that credit can be taken for only 75% of the B-10 in any boron neutron absorber. The basis for this assumption is that the NRC typically allows credit for only 75% of the boron, unless content and uniform coverage can be verified by measurement. This assumption is used throughout Section 7.

4.3.7 The Savannah River pour canister is assumed to be representative for HLW canisters. Reference 5.11 specifies the geometry and materials of construction. Reference 5.23 provides the shielding source term. The basis for this assumption is that the specified reference is the best information available concerning the pour canister design. This assumption is used throughout Section 7.

4.3.8 The emplacement time for MIT and ORR SNF is assumed to be based upon emplacement after a five year cool time has elapsed. The basis for this assumption is that five years is the minimum time for waste acceptance per 10CFR961 Appendix E. This assumption is used in Section 7.5.

4.3.9 CDA assumptions Key 031 and EBDRD 3.7.1.3.A have been used to replace TBVs in requirements applicable to this document. These assumptions are used in Section 4.2. The bases for these assumptions are given in the CDA (Ref. 5.10).

4.4 Codes and Standards

Not Applicable. Neutronic design of the waste package is not controlled by codes and standards.

5. References

5.1 *Yucca Mountain Site Characterization Project Q-List*, YMP/90-55Q, REV 4, Yucca Mountain Site Characterization Project.

5.2 *Quality Assurance Requirements and Description*, DOE/RW-0333P REV 7, U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM).

5.3 *QAP-2-0 Activity Evaluations*, ID No. WP-30 Perform Criticality, Thermal, Structural, and Shielding Analyses as Required for DOE Spent Fuel Characterization, Dated 8/3/97, CRWMS M&O.

5.4 *Data Package from Savannah River Criticality Analysis of MIT and ORR SNF*, (includes WSRC-TR-95-0302 Appendix A data sheets 59 and 217 for MIT and ORR fuel, as well as drawings R3F-3-2, R3F-1-4, M-11495-OR-001, 003, and 004), Records Batch # MOY-970605-02.

5.5 Standard Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels, ASTM A240/A240M REV91A, American Society for Testing and Materials, Philadelphia, PA.

5.6 *Standard Review Plan for Spent Fuel Dry Storage Facilities*, NUREG-1567, U.S. Nuclear Regulatory Commision, October 1996.

5.7 MCNP-A General Monte Carlo N-Particle Transport Code, Version 4A, LA-12625-M, Los Alamos National Laboratory, November 1993.

5.8 ANSI/ANS-6.1.1-1977, "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors", American Nuclear Society, LaGrange Park, Illinois (1977).

5.9 *Engineered Barrier Design Requirements Document*, YMP/CM-0024, REV 0, ICN 1, Yucca Mountain Site Characterization Project.

5.10 *Controlled Design Assumptions Document*, Document Identifier (DI) Number: B00000000-01717-4600-00032 REV 04, ICN 01, Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O).

5.11 *Characteristics of Potential Repository Wastes*, DOE/RW-0184-R1; Volume 1, U.S. DOE OCRWM.

5.12 *Software Qualification Report for MCNP4A*, CSCI: 30006 V4A, DI Number: 30006-2003 REV 02, CRWMS M&O.

5.13 *Software Qualification Report for The SCALE Modular Code System Version 4.3*, CSCI: 30011 V4.3, DI Number: 30011-2002 REV 01, CRWMS M&O.

5.14 *BW-2901Transportation Package*, USNRC Certificate of Compliance 71-9251.

5.15 *American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors*, ANSI/ANS-6.1.1-1977, American Nuclear Society, LaGrange Park, IL, 1977.

5.16 *10CFR Part 60; Disposal of High-Level Radioactive Wastes in Geologic repositories; Design Basis Events; Final Rule,* U.S. Nuclear Regulatory Commission, Federal Register, volume 61, Number 234, pp. 64257-64270, December 4, 1996.

5.17 *Waste Package Design Basis Events*, DI Number: BBA000000-01717-0200-00037 REV 00, CRWMS M&O.

5.18 *Electronic Attachments for: BBA000000-01717-0200-00052 REV00, Criticality Safety & Shielding Evaluations of the Codisposal Canister in the 5 Pack DHLW Waste Package*, Colorado BackupTape, RPC Batch Number MOY-970613-11, CRWMS M&O.

5.19 Ma, Benjamin M., *Nuclear Reactor Materials & Applications*, Van Nostrand Reinhold Company Inc., 1983.

5.20 *DHLW Glass Waste Package Criticality Analysis*, DI Number: BBAC00000-01717-0200-00001 REV 00, CRWMS M&O.

5.21 *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03/I, Volume II.b, Nuclear Energy Agency, Organization for Economic Co-operation and Development, November 4, 1996 update.

5.22 *Material Compositions and Number Densities For Neutronics Calculations*, DI Number: BBA000000-01717-0200-00002 REV 00, CRWMS M&O.

5.23 *DHLW Canister Source Terms for Waste Package Design*, DI Number: BBA000000-01717-0200-00025 REV 00, CRWMS M&O.

5.24 *Waste Package Materials Selection Analysis*, DI Number: BBA000000-01717-0200-00020 REV 00, CRWMS M&O.

5.25 *Mined Geologic Disposal System Advanced Conceptual Design Report*, DI Number:

B00000000-01717-5705-00027 REV 00, CRWMS M&O.

5.26 *Thermal Evaluation of the Codisposal Canister in the 5-Pack DHLW Waste Package*, DI Number: BBAA00000-01717-0200-00021 REV 01, CRWMS M&O.

5.27 *Structural Evaluation of the MIT SNF Codisposal Canister*, DI Number: BBA000000-01717-0200-00051 REV 00, CRWMS M&O.

5.28 Weiss, N. L., ed., *SME Mineral Processing Handbook*, Volume I, Society of Mining Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, 1985.

5.29 *Summary of Information Exchange*, Interoffice Communication From Peter Gottlieb to File, LV.WP.PG.08/97-172, CRWMS M&O.

5.30 *Second Waste Package Probabilistic Criticality Analysis: Generation and Evaluation of Internal Criticality Configurations*, DI Number: BBA000000-01717-0200-00005 REV 00, CRWMS M&O.

5.31 *Electronic Attachments for: BBA000000-01717-0200-00052 REV01, Criticality Safety & Shielding Evaluations of the Codisposal Canister in the 5 Pack DHLW Waste Package*, Colorado BackupTape, RPC Batch Number MOY-970815-20, CRWMS M&O.

6. Use of Computer Software

The calculation of nuclear reactivity of fresh fuel configurations was performed with the MCNP4A computer code, CSCI: 30006 V4A. MCNP4A calculates k-effective for a variety of geometric configurations with neutron cross sections for elements and isotopes described in the Evaluated Nuclear Data File version B-V (ENDF-B/V). MCNP4A is appropriate for the fuel geometries and materials required for these analyses. The calculations using the MCNP4A software were executed on a Hewlett-Packard 9000 Series 735 workstation. The software qualification of the MCNP4A software, including problems related to calculation of k-effective for fissile systems, is summarized in the Software Qualification Report for the Monte Carlo N-Particle code (Ref. 5.12). The MCNP4A evaluations performed for this design are fully within the range of the validation for the MCNP4A software used. Access to and use of the MCNP4A software for this analysis was granted by Software Configuration Management and performed in accordance with the QAP-SI series procedures. Inputs and outputs for the MCNP4A software are included as attachments (see Table 9-2) as described in the following design analysis.

The calculation of the neutron, gamma, and thermal sources in spent MIT fuel was performed with the SAS2H code sequence, which is a part of the SCALE 4.3 code system, CSCI: 30011 V4.3. SAS2H is designed for spent fuel depletion calculations to determine spent fuel isotopic content (including radioisotopes which produce alpha particles), decay heat rates, and radiation source terms. Thus, SAS2H is appropriate for the generation of thermal and radiation sources for the calculations of this analysis. The calculations using the SAS2H software were executed on a Hewlett-Packard 9000 Series 735 workstation. The software qualification of the SAS2H software, including benchmark problems related to generation of isotope contents, is summarized in the Software Qualification Report for the SCALE Modular Code system (Ref. 5.13). The SAS2H evaluations performed for this design are fully within the range of the validation for the SAS2H software used. | The associated 238GROUPNDF5 cross section library was used for these calculations. Access to and use of the SAS2H software for this analysis was granted by Software Configuration Management and performed in accordance with the QAP-SI series procedures. Inputs and outputs for the SAS2H software are included as attachments (see Table 9-2) as described in the following design analysis.

The data interpolation for MIT SNF heat load and computation of number densities of intact and degraded states were performed with Microsoft Excel Version 5.0. Microsoft Excel 5.0 was executed on an IBM PC compatible personal computer. Microsoft Excel Version 5.0 was used simply to provide data manipulation for the analyses and is considered Computational Support Software. These files located in the attached tape, and are indicated in Table 9-2 with an "xls" extension.

7. Design Analysis

7.1 Background

As part of an engineered barrier system for the containment of radionuclides, the DHLW WP k-effective must not exceed 0.95 during the pre-closure phase. Further, potential degradation of the aluminum clad, U-Al metal (or U-Si-Al) fuel plates must not cause the reactivity of the fuel to exceed 0.95 while it is contained within the codisposal canister. Degradation of the fuel will not occur while the WP is intact due to the inert helium fill gas; however, oxidation of the aluminum cladding and fuel alloy would occur at a much faster rate than degradation of the codisposal basket if the WP were breached. The codisposal baskets for MIT fuel and ORR are both evaluated in the intact configuration. In addition, enough degraded fuel cases are run to determine the amount and distribution of borated stainless steel required to be placed into the intact configuration to prevent criticality within the DOE-SNF codisposal canister.

The MIT and ORR fuel would be expected to degrade through oxidation within a few hundred years of breach of the DOE-SNF canister. Uranium and aluminum oxides in water have been observed to form hydrates with a gel-like appearance and an effective solid density of as low as 10% (Ref 5.28). Both floculent and gel-like forms of aluminum have been observed in association with test coupons at SRS (Ref. 5.29). The rate of formation of these hydrated oxides has not been quantified and is not well understood. Because of this limitation, the Al-based fuel forms will conservatively be assumed to degrade to a mix of hydrated Al and U oxides in water within the limits of the available volume as a bounding condition. Development of detailed degradation scenarios is beyond the scope of Phase I of this work, but consideration of degraded fuel forms is necessary to evaluate the DOE-SNF canister. The hydrated oxides and water mix is approximated by homogenizing the Al-based fuel and water into the basket cell resulting in a solids density of down to 35% in this analysis.

The scenarios analyzed included:

> Intact - Conceptual designs of baskets suitable for transport/storage (any transport design can be stored)/disposal. The intent was not to design a transport basket per se but rather to design a basket which would be representative of the types of transport basket which might be developed for DOE-SNF. A fully flooded condition is analyzed for both MIT and ORR fuel in their respective baskets within the waste package.
>
> Degraded within codisposal canister - potential progressive degradation of fuel with all the degradation products remaining within the codisposal canister bounds. Optimum moderation was evaluated by varying the water content of the fuel alloy and surrounding moderator volume.
>
> The progressive degradation of the fuel was evaluated in stages as follows:

1. Homogenize fuel plates and inter-plate moderator volume
2. Homogenize entire assembly (fuel plates plus structural combs plus water)
3. Disperse homogenized material throughout basket free space

7.2 Criticality Models

Material number densities for the constituents of the MCNP4A models are provided for intact MIT SNF in Attachment II, for intact ORR SNF in Attachment III, and for other materials in Reference 5.22. The number densities for the various degraded MIT and ORR canister geometries are provided in the MITNUM.XLS (Attachement IV) and ORRNUM3.XLS (Attachment V) spreadsheets, respectively. The geometries of the MCNP4A models are described below. The MCNP4A models utilized the "worst case" dimensions from the range of values for each fuel assembly dimension. The procedure is to maximize the fuel volume and moderator volume by applying the minimum thicknesses of the aluminum cladding components and the maximum width and length extents of the fuel plates.

An allowance for calculational bias and experimental uncertainties in benchmark calculations must be made per the requirements listed in Section 4.2. Forty-seven benchmark calculations representative for MIT and ORR research reactor fuel were run based on reviewed experiments and MCNP models (Ref. 5.21). The sum of bias and uncertainty is less than 0.02 in k_{eff} for all cases. The cases run are shown below in Tables 7.2-1 and 7.2-2 with the benchmark identification number, their results and attachment number. Complete descriptions are provided in reference 5.21. The SPERT-D experiments reported in Table 7.2-1 utilize a Materials Test Reactor (MTR) type Al-based fuel element with 22 plates/element and a uranium U-235 enrichment of 93.17 wt% and have an experimental (measurement) uncertainty of less than ±0.004 in k_{eff}. The remaining experiments reported in Table 7.2-2 are based on a cross-shaped fuel rod composed of a coagulated mixture of UO_2 enriched to 80-90 wt% in U-235 and Cu powder and have an experimental (measurement) uncertainty of less than ±0.006 in k_{eff} for all cases.

Table 7.2-1. Calculational Results for Critical Experiments Using the SPERT-D Fuel in Water - HUE-MET-THERM-006 (Ref. 5.21)

Case Name	Description	$k_{eff} \pm 2\sigma$
SPERT1	4 X 3.77 lattice, 4.63 kg U-235, 0.0" spacing	0.9968 ±0.0037
SPERT2	4 X 3.16 lattice, 3.87 kg U-235, 0.25" spacing	0.9990 ±0.0035
SPERT3	4 X 3.09 lattice, 3.79 kg U-235, 0.50" spacing	1.0059 ±0.0021
SPERT4	Circular, 3.48 kg U-235, 0.50" spacing	0.9983 ±0.0037
SPERT5	4 X 3.16 lattice, 3.87 kg U-235, 0.75" spacing	1.0050 ±0.0038
SPERT6	4 X 3.70 lattice, 4.54 kg U-235, 1.00" spacing	1.0006 ±0.0033
SPERT7	5 X 4.03 lattice, 6.16 kg U-235, 1.25" spacing	1.0002 ±0.0035
SPERT8	6 X 5.34 lattice, 9.82 kg U-235, 1.50" spacing	0.9965 ±0.0032
SPERT9	7 X 6.68 lattice, 14.33 kg U-235, 1.60" spacing	0.9982 ±0.0030
SPERT10	4 X 3.2 X 3 lattice, 11.78 kg U-235, 0.0" spacing	1.0093 ±0.0037
SPERT11	3 X 3.36 X 3 lattice, 9.28 kg U-235, 0.50" spacing	1.0079 ±0.0038
SPERT12	4 X 4 X 3 lattice, 14.71 kg U-235, 1.25" spacing	1.0070 ±0.0036
SPERT13	slab 16 X 2.32, 11.37 kg U-235, 0.0" spacing	1.0293 ±0.0035
SPERT14	slab 16 X 3, 14.71 kg U-235, 0.50"/2.19" spacing	1.0017 ±0.0033
SPERT15	slab 16 X 4, 19.62 kg U-235, 0.50"/2.56" spacing	0.9938 ±0.0020
SPERT16	2 slabs 16 X 2, 19.62 kg U-235, 0.50"/0.50"/6.37" spacing	1.0058 ±0.0033
SPERT17	slab 4 X 5.04 w/ Cd, 6.19 kg U-235, 0.0"/0.75" spacing	1.0064 ±0.0040
SPERT18	slab 4 X 7.04 w/ Cd, 8.64 kg U-235, 0.0"/0.75" spacing	1.0016 ±0.0044

Case Name	Description	$k_{eff} \pm 2\sigma$
SPERT19	U Nitrate (3.99 g U-235/liter) & 3 X 3.09, 2.86 kg U-235, 0.5" spacing, 0.0 g B/liter	0.9961 ±0.0028
SPERT20	U Nitrate (3.99 g U-235/liter) & 4 X 4.20, 5.15 kg U-235, 0.5" spacing, 0.389 g B/liter	0.9946 ±0.0034
SPERT21	U Nitrate (3.99 g U-235/liter) & 5 X 4.41, 6.76 kg U-235, 0.5" spacing, 0.579 g B/liter	0.9978 ±0.0039
SPERT22	U Nitrate (3.99 g U-235/liter) & 6 X 4.96, 8.90 kg U-235, 0.5" spacing, 0.773 g B/liter	1.0023 ±0.0035
SPERT23	U Nitrate (3.99 g U-235/liter) & 6 X 5.55, 10.15 kg U-235, 0.5" spacing, 0.871 g B/liter	1.0079 ±0.0023

Table 7.2-2. Calculational Results for the Critical Experiments Using Cross-shaped Fuel Rods Composed of UO_2 Enriched to 80-90% in U-235 and Cu Powder - Kurchatov Institute (Ref. 5.21)

Case Name	Description	$k_{eff} \pm 2\sigma$
	HEU-COMP-THERM-003 2-Zone Critical Arrays with $U(80\%)O_2$+Cu Fuel and Lightwater Moderator	
HCT3-1	Center Zone: 12.2 mm Pitch, 19 Rods Outer Zone: 6.1 mm Pitch, 1390 Rods	0.9949 ±0.0029
HCT3-2	Center Zone: 12.2 mm Pitch, 61 Rods Outer Zone: 6.1 mm Pitch, 1182 Rods	0.9953 ±0.0031
HCT3-3	Center Zone: 12.2 mm Pitch, 121 Rods Outer Zone: 6.1 mm Pitch, 897 Rods	0.9944 ±0.0029
HCT3-4	Center Zone: 12.2 mm Pitch, 199 Rods Outer Zone: 6.1 mm Pitch, 577 Rods	1.0001 ±0.0028
HCT3-5	Center Zone: 12.2 mm Pitch, 271 Rods Outer Zone: 6.1 mm Pitch, 325 Rods	1.0012 ±0.0029
HCT3-6	Center Zone: 6.1 mm Pitch, 1099 Rods Outer Zone: 12.2 mm Pitch, 167 Rods	1.0096 ±0.0030

Case Name	Description	$k_{eff} \pm 2\sigma$
HCT3-7	Center Zone: 6.1 mm Pitch, 793 Rods Outer Zone: 12.2 mm Pitch, 250 Rods	1.0121 ±0.0030
HCT3-8	Center Zone: 6.1 mm Pitch, 757 Rods Outer Zone: 12.2 mm Pitch, 249 Rods	1.0114 ±0.0029
HCT3-9	Center Zone: 6.1 mm Pitch, 445 Rods Outer Zone: 12.2 mm Pitch, 319 Rods	1.0101 ±0.0030
HCT3-10	Center Zone: 6.1 mm Pitch, 217 Rods Outer Zone: 12.2 mm Pitch, 372 Rods	1.0120 ±0.0029
HCT3-11	Center Zone: 6.1 mm Pitch, 85 Rods Outer Zone: 12.2 mm Pitch, 415 Rods	1.0113 ±0.0030
HCT3-12	Center Zone: 18.3 mm Pitch, 121 Rods Outer Zone: 6.1 mm Pitch, 985 Rods	0.9896 ±0.0028
HCT3-13	Center Zone: 18.3 mm Pitch, 301 Rods Outer Zone: 6.1 mm Pitch, 426 Rods	0.9963 ±0.0026
HCT3-14	Center Zone: 6.1 mm Pitch, 763 Rods Outer Zone: 18.3 mm Pitch, 186 Rods	1.0074 ±0.0030
HCT3-15	Center Zone: 6.1 mm Pitch, 337 Rods Outer Zone: 18.3 mm Pitch, 325 Rods	1.0036 ±0.0026
	HEU-COMP-THERM-004 Water Moderator Hexagonally Pitched (5.3 mm) Lattices of U(90%)O_2+Cu Fuel With Gd or Sm Rods	
HCT4-1	106 Gd Rods on 27.54 mm Pitch, 2760 Fuel Rods	0.9891 ±0.0024
HCT4-2	55 Gd Rods on 36.72 mm Pitch, 2520 Fuel Rods	0.9902 ±0.0023
HCT4-3	121 Sm Rods on 27.54 mm Pitch, 3198 Fuel Rods	0.9889 ±0.0024
HCT4-4	58 Gd Rods on 36.72 mm Pitch, 2727 Fuel Rods	0.9928 ±0.0024

Case Name	Description	$k_{eff} \pm 2\sigma$
	HEU-COMP-THERM-006 Water Moderator Hexagonally Pitched Lattices of U(80%)O_2+Cu Fuel	
HCT6-T1	1819 Fuel Rods on a 5.6 mm Pitch	0.9893 ±0.0027
HCT6-T2	457 Fuel Rods on a 10.0 mm Pitch	1.0084 ±0.0026
HCT6-T3	554 Fuel Rods on a 21.13 mm Pitch	0.9987 ±0.0021
	HEU-COMP-THERM-008 Water Moderator Hexagonally Pitched(5.3 mm) Double Lattices of U(80%)O_2+Cu Fuel and Boron Carbide Rods	
HCT8-1	217 B_4C Rods (1.0 gm B/rod) on 21.2 mm Pitch, 3460 Fuel Rods	0.9892 ±0.0025
HCT8-2	169 B_4C Rods (3.5 gm B/rod) on 26.5 mm Pitch, 4130 Fuel Rods	0.9888 ±0.0023

7.2.1 MIT Fuel Geometry

Explicit geometric models of the MIT fuel assembly were constructed. The fuel alloy and aluminum cladding were modeled as separate layers in close contact. The actual design spacing of the fuel plates within the assembly was used. The assemblies are shortened by removing the end fittings, and the resulting shorter length was modeled to permit the fuel zones to minimize their separation in the axial direction to maximize k-effective. A picture of the resulting MCNP4A model is shown below in Figure 7.2.1-1.

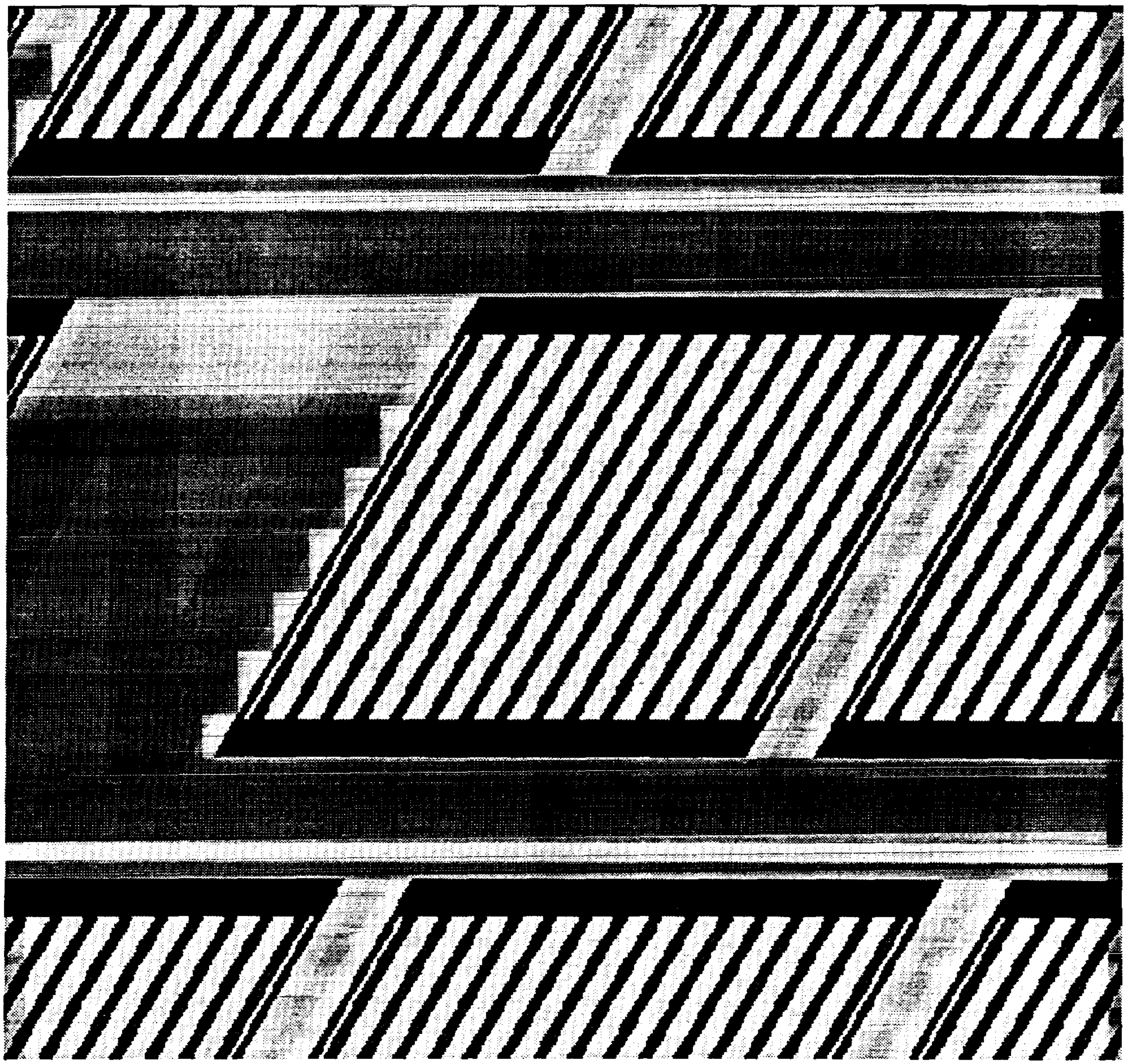


Figure 7.2.1-1. MIT Fuel Assemblies in Codisposal Basket

7.2.2 ORR Fuel Element Geometry

The individual curved plates of the ORR fuel assembly were individually modeled, including the slightly different fuel alloy U-235 content of the plates at either end of the curved plate array. The aluminum cladding and the fuel alloy were individually as separate layers in close contact. The aluminum side plates of the fuel assembly were also modeled explicitly. A picture of the resulting MCNP4A geometry is show below in Figure 7.2.2-1.

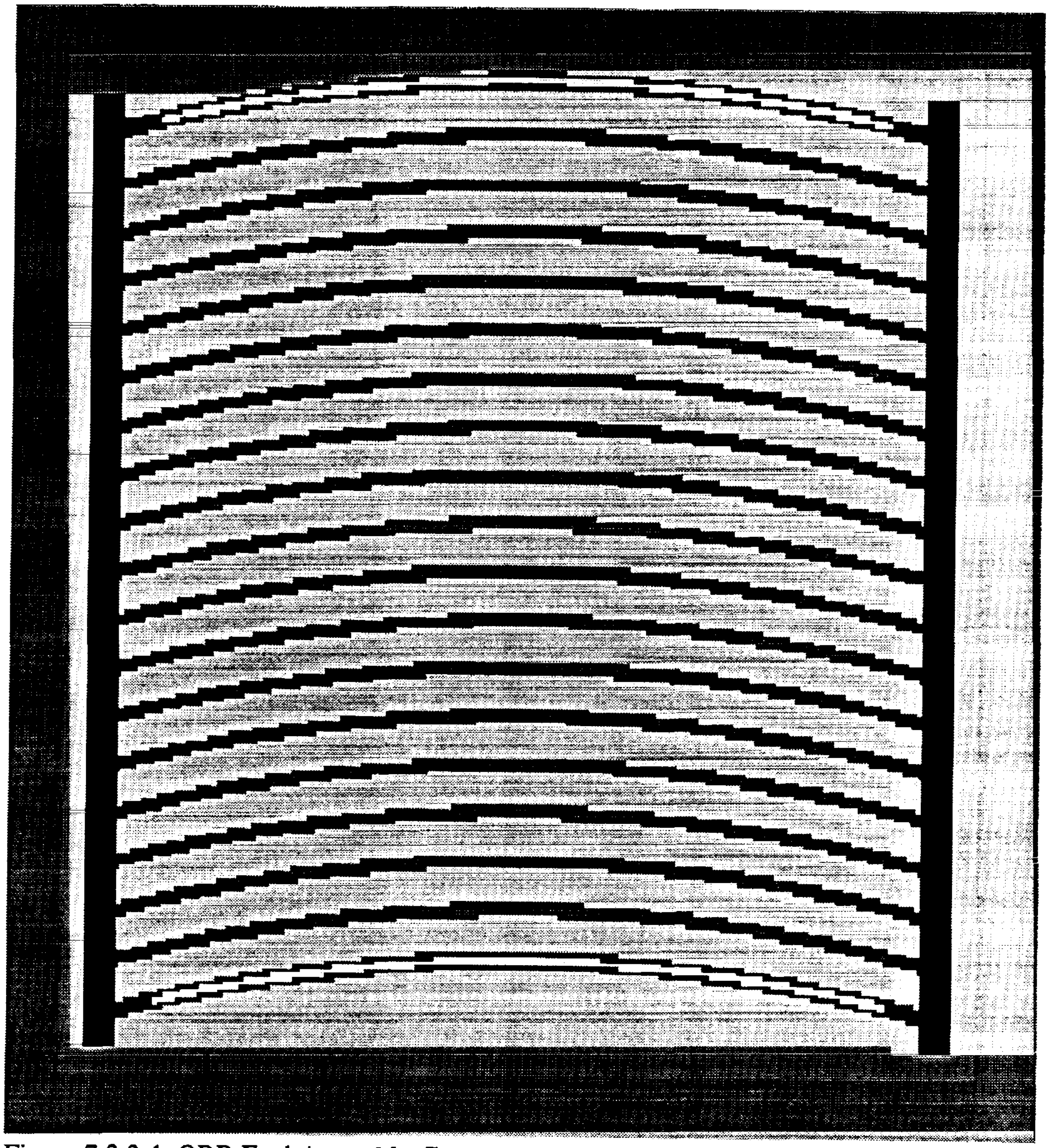


Figure 7.2.2-1. ORR Fuel Assembly Geometry

7.2.3 MIT Codisposal Basket Geometry

The MIT codisposal basket is a 4 layer by 16 assembly array. Each layer of the MIT codisposal basket consists of plates formed into parallelogram shaped slots in a steel disk that provide structural support for the SNF. The round disk to which the basket plates are attached serves as a base for each layer of assemblies and as an between-layer (axial) separator between layers. The between-layer separator plates are composed of stainless steel/boron and are 10 mm thick. Slot locations within the basket can accomodate one, two, or four MIT assemblies, and adjacent assemblies can be separated by 2.13 mm thick stainless steel or stainless steel/boron in-row separator plates. Cases were run with and without boron in these plates to determine if boron is necessary. Similar plates fabricated from Boralyn® are used in the BW-2901 transport package (Ref. 5.14). Panels of stainless steel/boron 2.54 mm thick are attached to one side of each slot to provide neutron absorption between the slots (as viewed in Figure 7.2.3-1). A radial cross-sectional view of the model is shown in Figure 7.2.3-1. The rhomboidal slots provide a 1.72 mm clearance around the MIT assembly. The inner radius of the codisposal canister is 204.65 mm.

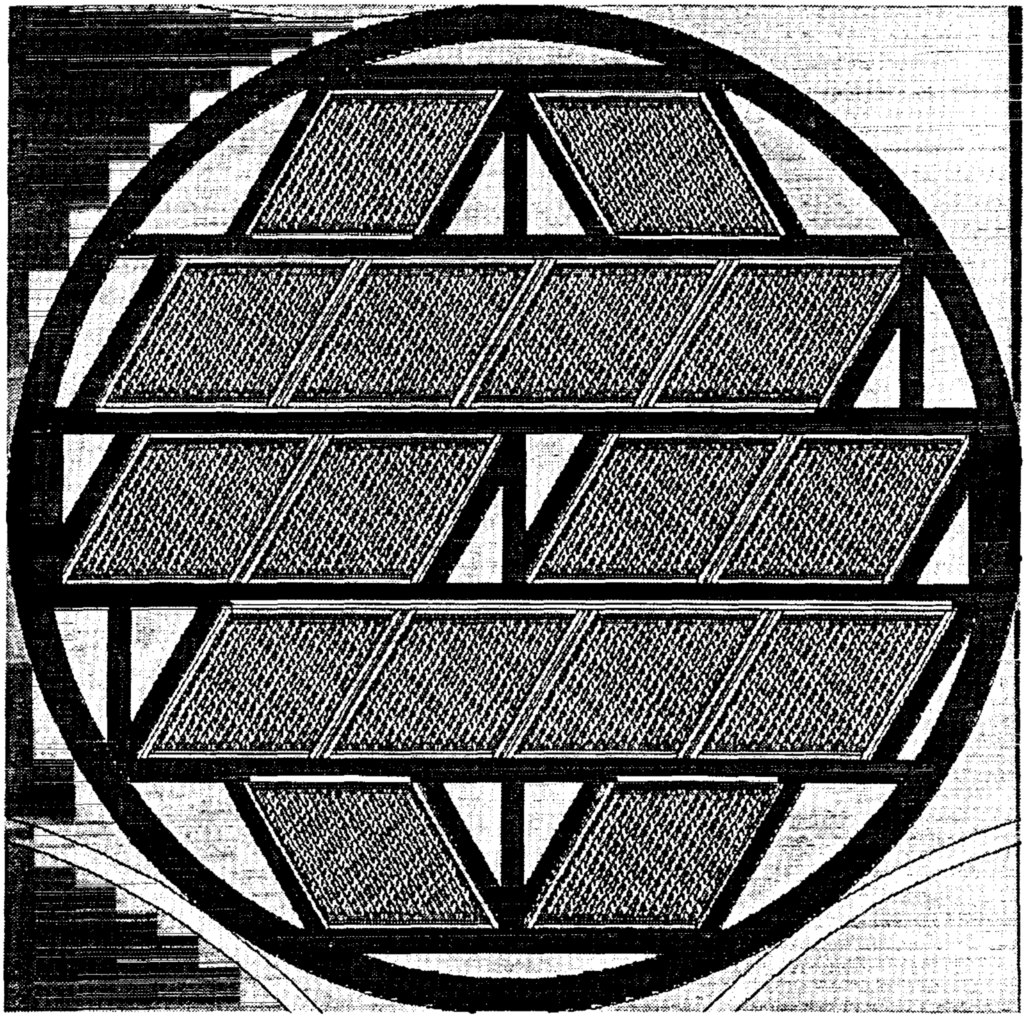


Figure 7.2.3-1 MIT SNF Codisposal Canister Conceptual Design

7.2.4 ORR Codisposal Basket Geometry

The ORR SNF canister consists of a 4 layer by 10 assembly array. On each layer, the ORR conceptual basket design consists of ten square tubes aligned so that straight structural load paths progress from one side of the basket to the other. The tubes do not contain boron neutron absorber materials due to the moderate enrichment (20 weight percent U-235 initial) of the ORR fuel assemblies. Stainless steel/boron separator plates were used to isolate axial layers of ORR assemblies, as was done in the MIT codisposal basket design. This ensures that adequate neutron absorption is provided if the fuel were to degrade while still contained in the codisposal canister. The thicknesses of the between-layer separator plates are similar to the MIT design, which is considered adequate given the relatively low reactivity of the ORR fuel basket compared to the MIT basket, even without the provision of any neutron absorber in the radial direction. A radial cross-sectional view of the ORR codisposal fuel basket is shown below in Figure 7.2.4-1. Note that the center tube of the nine-tube square is offset relative to the center of the codisposal canister by 18.0 mm. This offset results from the asymmetry of the basket. The use of asymmetric baskets is an accepted practice in the design of large storage and transport packages. A clearance of at least 2.54 mm is provided for the assembly in the basket.

7.2.5 Codisposal Basket Neutron Absorber Materials

Initially, neutron absorbers for both the MIT and ORR codisposal basket conceptual designs employed stainless steel/boron alloy SS316B2A (0.6 wt% boron), with credit taken for 100% of the boron content (Assumption 4.3.6). Current practice for commercial SNF package design is to take credit for only 75 percent of the actual minimum boron content. This practice is in accord with current NRC practice for transportation packages when 100 percent inspection of the neutron absorber panels has not been performed. The use of SS316B3A (0.87 wt% boron) stainless steel/boron alloy, which has a greater boron concentration, provides sufficient margin to accomodate the derating of boron effectiveness. The final design calculations are performed with SS316B3A with 75% of the natural B-10 loading.

7.2.6 Waste Package

A simplified model of the waste package was constructed for the initial calculations discussed in Section 7.3 with the codisposal canister centered, and five HLW canisters (stainless steel canister walls omitted) arrayed about the codisposal canister. The waste package structural wall was modeled in the radial direction as a single layer of 82.55 mm thick Alloy 825; however, the ends of the waste package were simply modelled as water reflectors since details outside the DOE-SNF canister separated by more than 150 mm of water will have very little effect on the canister reactivity. A radial cross-sectional view of the orientation of the canisters and waste package barrier for the MIT fuel is shown in Figure 7.2.6-1.

A detailed model of the waste package and canisters in which all components were included was constructed for the final calculations discussed in Section 7.4.

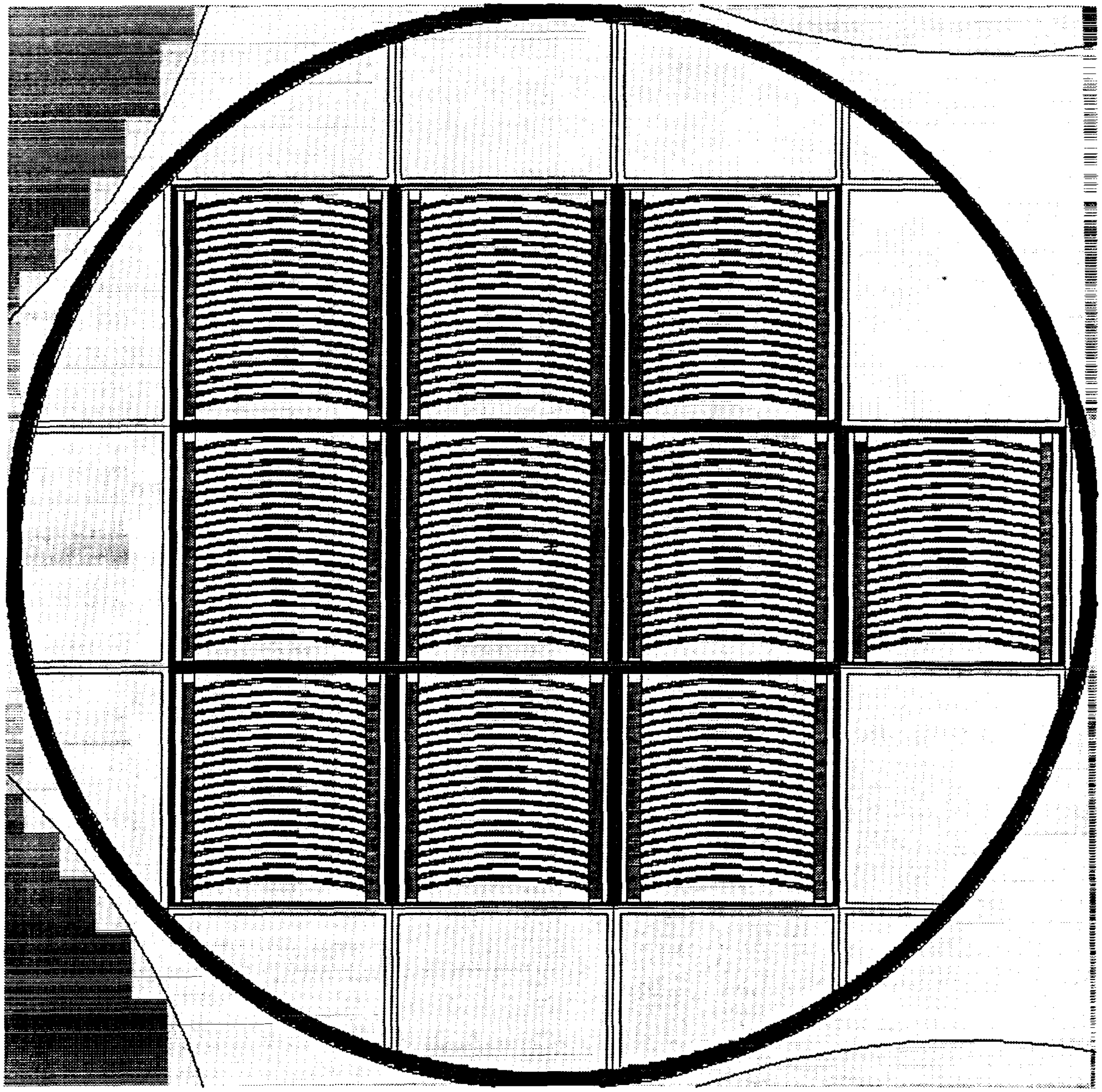


Figure 7.2.4-1. ORR SNF Codisposal Canister Conceptual Design

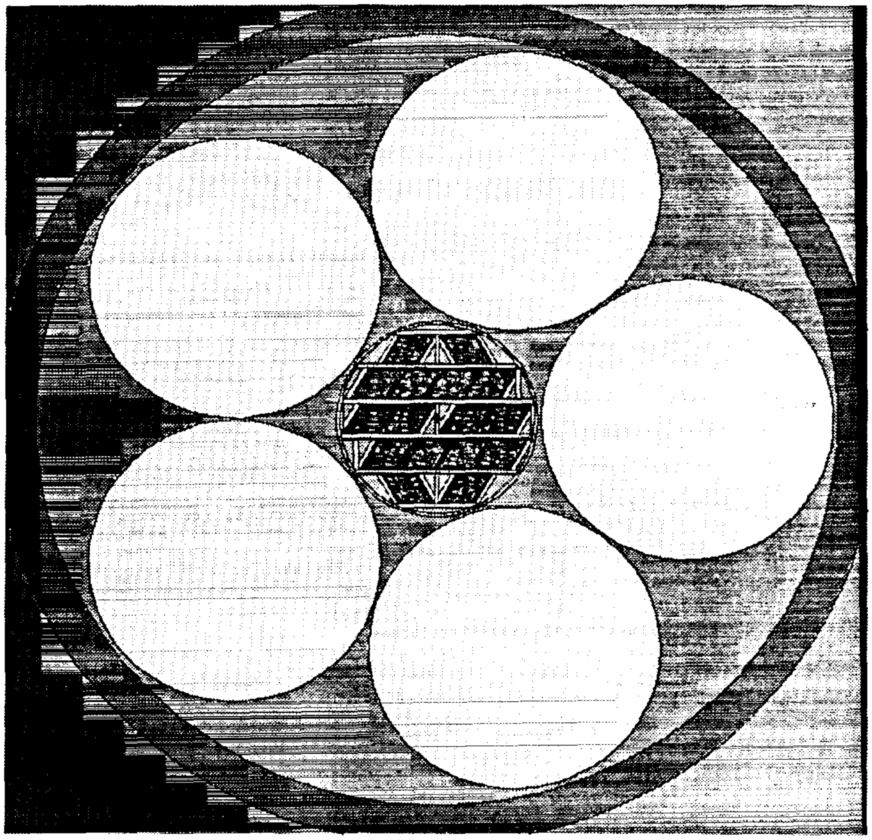


Figure 7.2.6-1 Simplified Waste Package Configuration

7.3 Initial Criticality Results

Criticality calculations based on the simplified waste package model described in Section 7.2.6 and the preliminary DOE-SNF canister designs are presented in this section. Only modifications needed to meet criticality requirements are investigated in this section. The k-effective values listed in the tables below are equal to the calculated value from MCNP4A plus two sigma plus the 0.02 bias allowance defined in Section 7.2.

7.3.1 MIT SNF Criticality

Intact

Results for the MIT fuel in the intact configuration are provided below in Table 7.3.1-1. The intact configuration was evaluated for varying amounts of water moderator by varying the density of H_2O

from zero to 100 percent (one gram per cubic centimeter density) within the fuel alloy. These calculations showed that the maximum reactivity is reached when the fuel alloy is waterlogged to the maximum extent. Note that the in-row separater plates between assemblies shown in Figure 7.2.3-1 are unborated for these cases. Stainless steel boron (SS316B2A) is used in the between-slot plates and in the between-layer (axial) separator plates.

7.3.1-1. MIT Mk2 Intact Fresh Fuel in Codisposal Canister

Case Name	Percent H2O* in Fuel Alloy	k-calculated	sigma	k-effective
MITA	0	0.81181	0.00116	0.83413
MITD	25	0.83265	0.00138	0.85541
MITC	50	0.84897	0.00147	0.87191
MITE	75	0.86581	0.00150	0.88881
MITF	95	0.87857	0.00151	0.90159
MITB	100	0.88019	0.00138	0.90295

* Percentage of a maximum of 63.53 volume percent water in fuel alloy.

Degraded-within-canister

The calculations for the degraded fuel, contained within the codisposal canister, for the various degradation stages described in Section 7.1, are summarized in Table 7.3.1-2. These calculations evaluate the reactivity of the MIT fuel as it degrades by modeling the fuel material and moderator with the codisposal basket components in succesive stages. Stainless steel boron (SS316B2A) is used in the between-slot plates and in the between-layer (axial) separator plates for all cases in Table 7.3.1-2. The first set of calculations, cases MITH through MITK1, show that the reactivity of the fuel is excessive if stainless steel alone is used to separate adjacent assemblies within a basket slot (in-row separator plates). The second set of calculations, cases MITL through MITO1, evaluate the fuel and codisposal basket with in-row separator plates fabricated from stainless steel/boron alloy SS316B2A. In all of these cases, k-effective remains below the 0.95 limit.

7.3.1-2. MIT Mk2 Degraded Fuel in Codisposal Canister

Case Name	Divider Plates Between Asbls	Degraded Fuel Geometry	k-calculated	sigma	k-effective
MITH	Stainless	Plate Array with Comb Teeth in Asbl. Envelope	0.92513	0.00170	0.94853
MITI	Stainless	Plate Array Homogenized	0.95879	0.00119	0.98117
MITJ	Stainless	Entire Assembly (including Side Plates)	0.95779	0.00133	0.98045
MITK	Stainless	Entire Cell Homogenized	0.99362	0.00128	1.01618
MITK1	Stainless	High Boron (1.6 wt%) in Between-Row and Between-Layer Separater Plates	0.95003	0.00153	0.97309
MITL	SS316B2A	Plate Array with Comb Teeth in Asbl. Envelope	0.85351	0.00158	0.87667
MITM	SS316B2A	Plate Array Homogenized	0.88749	0.00130	0.91009
MITN	SS316B2A	Entire Assembly (including Side Plates)	0.88015	0.00154	0.90323
MITO	SS316B2A	Entire Cell Homogenized	0.91901	0.00149	0.94199
MITO1	SS316B2A	Fuel Smeared into Basket Open Locations	0.79308	0.00149	0.81606

7.3.2 ORR SNF Criticality

Intact

The criticality calculations in Table 7.3.2-1 below show that the ORR fuel remains subcritical regardless of the water content within the fuel alloy due to the moderate 20 percent initial enrichment. This is in spite of the lack of boron neutron absorber material within the basket structure in the radial direction. Between-layer axial separator plates of stainless steel/boron were provided similar to those developed for the MIT codisposal basket.

7.3.2-1. ORR Intact Fresh Fuel in Codisposal Canister

Case Name	Percent H2O* in Fuel Alloy	k-calculated	sigma	k-effective
ORR10E	0	0.84474	0.00147	0.86768
ORR10G	25	0.85567	0.00150	0.87867
ORR10H	50	0.85998	0.00154	0.88306
ORR10I	75	0.87018	0.00158	0.89334
ORR10J	95	0.87422	0.00146	0.89714
ORR10F	100	0.87446	0.00139	0.89724

* Percentage of maximum of volume percent water in fuel alloy. (40.64%)

Degraded-within-canister

The calculations for the degraded ORR fuel, contained within the codisposal canister, for the various degradation stages described in Section 7.1, are presented below in Table 7.3.2-2. These calculations evaluate the reactivity of the ORR fuel as it degrades by modeling the fuel material and moderator with the codisposal basket components in succesive stages. The first set of calculations, cases ORRHASBL and ORRHSAB1, show that the reactivity of the fuel is excessive if the four layers of assemblies contained within each basket tube are stacked directly on top of one another. The second set of calculations, cases ORR1 and ORR2, evaluate the fuel and codisposal basket with axial separator plates fabricated from stainless steel/boron alloy SS316B2A. In both of these cases, k-effective remains below the 0.95 limit. This analysis demonstrates the need for neutron-absorbing materials in the ORR fuel basket to accomodate degradation of fuel within the basket.

7.3.2-2. ORR Degraded Fuel - In CoDisposal Basket

No Axial Separater Plates		k-caculated	sigma	k-effective
ORRHASBL	Homogenized Assembly	0.92887	0.00149	0.95185
ORRHSAB1	Homogenized Water Gap	0.94404	0.00148	0.96700
Boron in Axial Separater Plates				
ORR1	Homogenized Assembly	0.86127	0.00142	0.88411
ORR2	Homogenized Water Gap	0.88901	0.00140	0.91181

7.4 Final Criticality Results

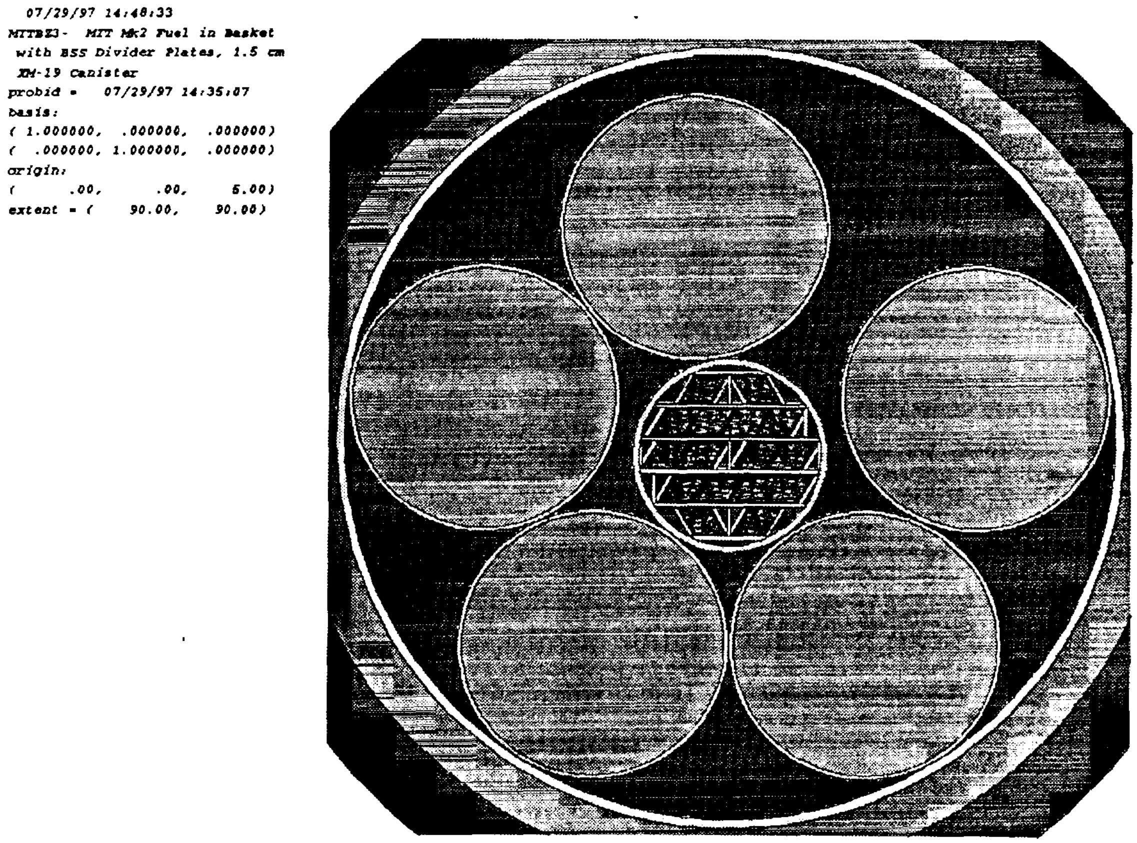
The preliminary designs indicated in Sections 7.2 and 7.3 were used in companion thermal (Ref. 5.26) and structural (Ref. 5.27) analyses. No changes to the design were required based on the thermal analysis, but the structural analysis indicated that the material and thickness of the DOE-SNF canister was required to be changed to XM-19 and 15 mm, respectively. This section is added in REV 01 of this document to include modifications to the DOE-SNF canister as required in the structural analysis (Ref. 5.27) and to include all details of the HLW canisters and waste package in the models. The effect of varying the orientation of HLW canisters with the DOE-SNF canister from the loaded configuration to the probable orientation at the time the waste package and canisters would be penetrated and filled with water is also investigated. The k-effective values listed in the tables below are equal to the calculated value from MCNP4A plus two sigma plus the 0.02 bias allowance defined in Section 7.2.

7.4.1 Final MIT SNF Canister Criticality Calculations

The simplified waste package model used in Section 7.3 was modified to include all components and dimensions for the waste package and HLW canisters (including stainless steel canister walls). In addition, the wall thickness of the the DOE-SNF canister was increased to 15 mm and the container material was changed to XM-19 as required based on the structural analysis for this canister (Ref. 5.27). The stainless steel/boron in all separator plates was changed to SS316B3A with a 75% B-10 loading. The atom densities in the fuel were also modified to correct the minor error found in the check of REV 00 as indicated in Attachment II. A radial cross-sectional view of the model for the loaded configuration is shown in Figure 7.4.1-1. The MIT configuration with 2.13 mm thick stainless steel/boron in-row separater plates and homogenized fuel cells, previously identified as most reactive in Section 7.3.1 (MITO), was rerun with this model and configuration (MITOZ1). The result is shown in Table 7.4.1, and falls below the k-effective limit of 0.95. The spacing of the canisters was modified to represent a probable configuration in the time frame that the waste packages would be penetrated and filled with water - shifted to the bottom and supported on the walls of the waste package and/or on other canisters. A radial cross-sectional view of this configuration is shown in Figure 7.4.1-2, and an axial cross-sectional view is shown in Figure 7.4.1-3. The result for this probable configuration (MITOZ3) is shown in Table 7.4.1-1. The previous cases with homogenized fuel did not extend the homogenization in the axial direction beyond the length of the fuel assembly (radial only). An additional case in which the MIT assemblies were homogenized into the entire volume of the basket cells (MITOZ3A) was run corresponding to case MITOZ3 with the result shown in Table 7.4.1-1. The result for this configuration still falls below the 0.95 limit on k-effective. The MIT canister configuration with intact waterlogged fuel (MITB) with the addition of the in-row borated separater plates between assemblies was rerun in this model (MITBZ3) with the result shown in Table 7.4.1-1. Note that the homogenization of the fuel into the cell which represents a possible degradation configuration (MOTOZ cases) is much more reactive than intact fuel.

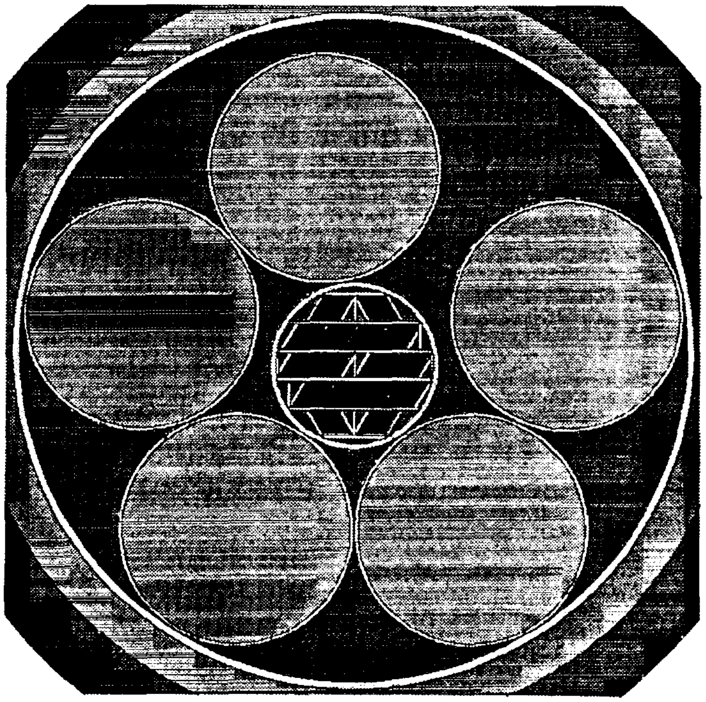
7.4.1-1. MIT Mk2 Fuel in Codisposal Canister - Final Calculations

Case Name	Divider Plates Between Asbls	Degraded Fuel Geometry	k-calculated	sigma	k-effective
MITOZ1	SS316B3A(75%)	Entire Cell Homogenized, WP Loaded Configuration	0.91123	0.00156	0.93435
MITOZ3	SS316B3A(75%)	Entire Cell Homogenized, Probable WP Degraded Configuration	0.91602	0.00148	0.93898
MITOZ3A	SS316B3A(75%)	Entire Cell Homogenized to Fill Axial Space Between Separater Plates, Probable WP Degraded Configuration	0.92635	0.00149	0.94933
MITBZ3	SS316B3A(75%)	Intact Waterlogged Fuel, Probable WP Degraded Configuration	0.81013	0.00147	0.83307



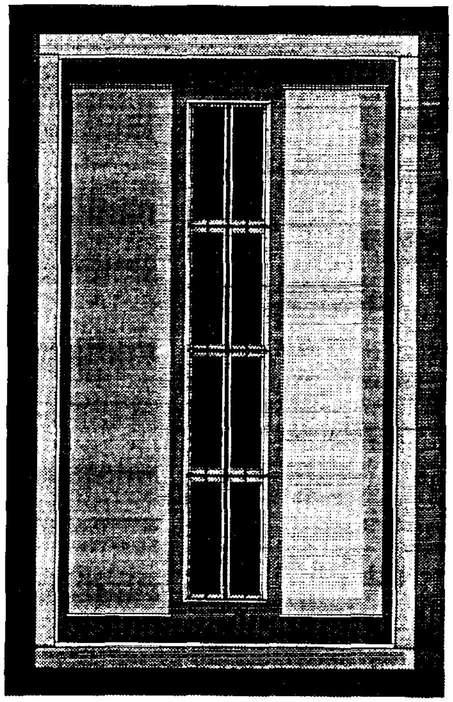
```
   07/29/97 14:48:33
MITBZ3-  MIT Mk2 Fuel in Basket
 with BSS Divider Plates, 1.5 cm
 XM-19 Canister
probid =   07/29/97 14:35:07
basis:
( 1.000000,  .000000,  .000000)
(  .000000, 1.000000,  .000000)
origin:
(       .00,       .00,     5.00)
extent = (    90.00,    90.00)
```

Figure 7.4.1-1 Radial Cross-Sectional View of the Waste Package Loaded Configuration - MIT SNF Canister



```
  07/28/97 13:07:35
HOMOGENIZED MIT CELL inc. WATER
 LAYER, SS/B Dividers, 1.5 cm
 EM-19, Detailed
probid =   07/28/97 13:07:23
basis:
( 1.000000,  .000000,  .000000)
(  .000000, 1.000000,  .000000)
origin:
(      .00,      .00,     5.00)
extent = (    90.00,    90.00)
```

Figure 7.4.1-2 Radial Cross-Sectional View of the Waste Package Probable Degraded Configuration - MIT SNF Canister



```
  07/29/97 13:13:11
HOMOGENIZED MIT CELL inc. WATER
 LAYER, SS/B Dividers, 1.5 cm
 EM-19, Detailed
probid =   07/29/97 13:07:05
basis:
( 1.000000,  .000000,  .000000)
(  .000000,  .000000, 1.000000)
origin:
(      .00,    -4.20,      .00)
extent = (   180.00,   180.00)
```

Figure 7.4.1-3 Axial Cross-Sectional View of the Waste Package Loaded Configuration - MIT SNF Canister

7.4.2 Final ORR SNF Canister Criticality Calculations

The waste package model described in the in Section 7.4.1 for the probable degraded configuration was used with the ORR SNF canister. The stainless steel/boron in the between-row separator plates was changed to SS316B3A with a 75% B-10 loading. A radial cross-sectional view of the model for the probable degraded configuration is shown in Figure 7.4.2-1 and an axial cross-sectional view is shown in Figure 7.4.2-2. The ORR SNF canister configuration with homogenized fuel cells, previously identified as most reactive in Section 7.3.2 (ORR2), was rerun with this model and configuration (ORROZ3F). The stainless steel structural members outside the basket are included in this model. The result is shown in Table 7.4.2-1, and falls below the k-effective limit of 0.95. The previous cases with homogenized fuel did not extend the homogenization in the axial direction beyond the length of the fuel assembly (radial only). An additional case in which the ORR assemblies were homogenized into the entire volume of the basket cells (ORROZ3A) was run with the result shown in Table 7.4.2-1. The result for this configuration still falls below the 0.95 limit on k-effective. The ORR SNF canister configuration with intact waterlogged fuel (ORR10F) was rerun in this new model (ORROZ3F) with the result shown in Table 7.4.2-1. Note that the homogenization of the fuel into the cell which represents a possible degradation configuration (ORROZ cases) is much more reactive than intact fuel.

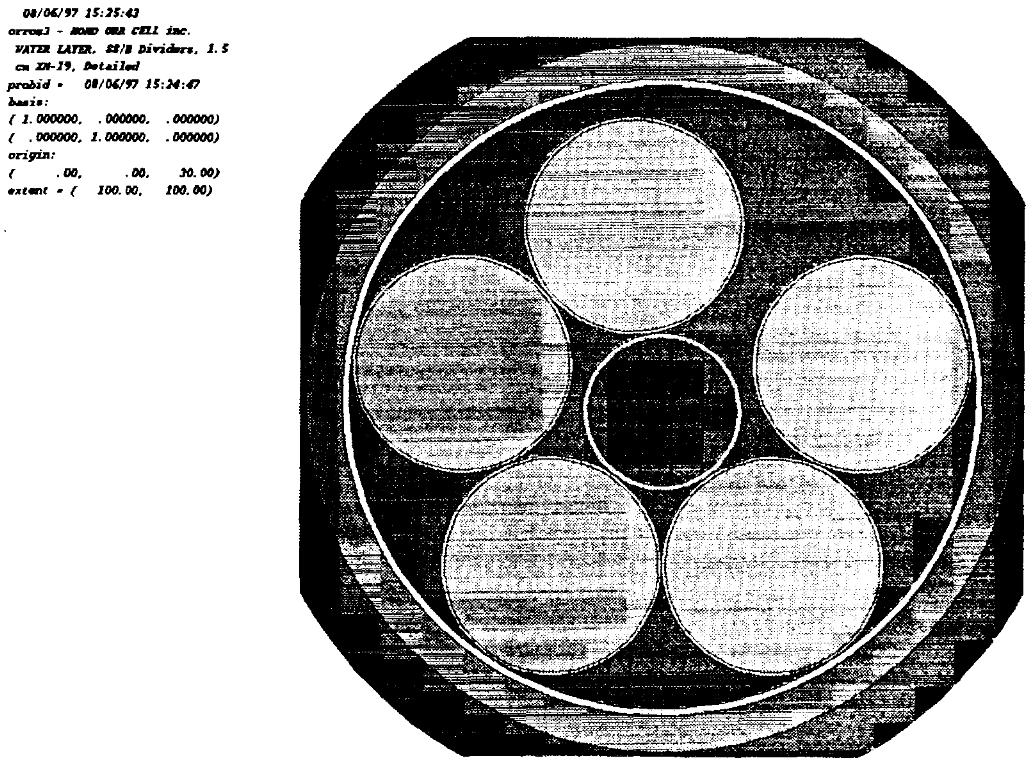


Figure 7.4.2-1 Radial Cross-Sectional View of the Waste Package Probable Degraded Configuration - ORR SNF Canister

```
  08/06/97 15:41:50
orroz3 - HOMO ORR CELL inc.
 WATER LAYER, SS/B Dividers, 1.5
 cm XH-19, Detailed
probid =   08/06/97 15:24:47
basis:
( 1.000000,  .000000,  .000000)
(  .000000,  .000000, 1.000000)
origin:
(      9.00,     -4.00,    -10.00)
extent = (   200.00,   200.00)
```

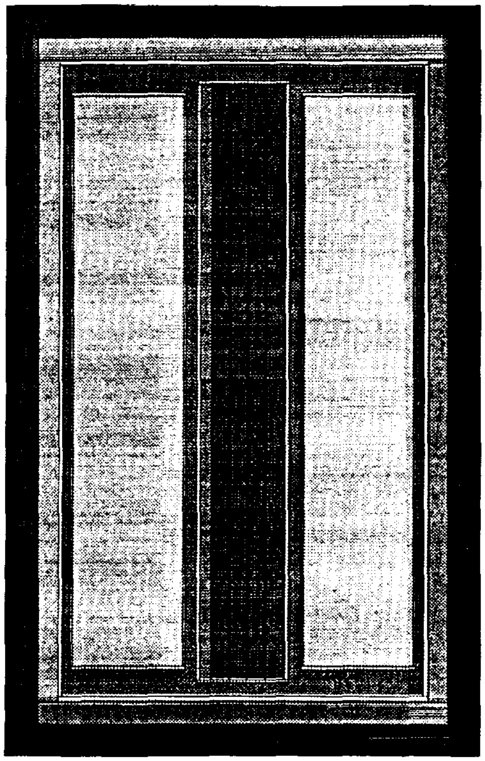


Figure 7.4.2-2 Axial Cross-Sectional View of the Waste Package Probable Degraded Configuration - ORR SNF Canister

7.4.2-1. ORR Fuel in Codisposal Canister - Final Calculations

Case Name	Between-row Separator Plates	Degraded Fuel Geometry	k-calculated	sigma	k-effective
ORROZ3F	SS316B3A(75%)	Entire Cell Homogenized, Probable WP Degraded Configuration	0.88043	0.00133	0.90309
ORROZ3A	SS316B3A(75%)	Entire Cell Homogenized to Fill Axial Space Between Separater Plates, Probable WP Degraded Configuration	0.91441	0.00136	0.93713
ORR10FZ	SS316B3A(75%)	Intact Waterlogged Fuel, Probable WP Degraded Configuration	0.86583	0.00126	0.88835

7.5 Source Terms

A model using the SAS2H Sequence of SCALE4.3 (Ref. 5.13) was developed based on the burnup and decay data provided by SRS for MIT fuel. For the SAS2H calculation the maximum exposure was rounded up to 8100 MWD/MTU and the time in reactor was rounded down to 2500 days, as indicated in Section 4.1. The power level is 9.68 MW/MTU. Pool type reactors generally operate at 2 atmospheres pressures with coolant/moderator temperatures of less than boiling. For these calculations the fuel and clad were modelled at 500 K and the coolant/moderator was modelled at 400 K. The exposure time is calculated as 8100 MWD/MTU ÷ 9.68 MW/MTU = 836.8 days. The down time is then calculated as 2500 days - 836.8 days = 1663.2 days. Actual operation would have been up and down on a day-to-day basis. For the SAS2H calculation the exposure time was divided into quarters with one-third the down time between each exposure step. This will provide a conservative estimate of the source term and decay heat. The exposure time and decay time used in each of the steps is thus 209.2 days and 554.4 days, respectively. A separate ORIGEN-S (also part of SCALE4.3) decay case was run to provide decay heat results at a variety of decay times. The gamma and neutron sources for the MIT spent fuel (MITBURN.OUTPUT) are provided in Table 7.5-1 and 7.5-2, respectively for 5 years decay after removal from the reactor. The input and summarized output are listed in Attachment VII. The sources for the glass pour canisters are provided in Tables 7.5-1 and 7.5-2 (Ref. 5.23, Attachment X and IX, respectively).

Table 7.5-1. Photon Sources for MIT Fuel and HLW Canisters

Upper Energy Boundary of Group	MIT Fuel Source (per MTU)		HLW Source (per Canister)	
MeV	photons/sec	Fraction of Source	photons/sec	Fraction of Source
5.00e-2	5.69e+14	3.45e-01	1.3215e+15	3.60e-01
1.00e-1	1.69e+14	1.03e-01	3.9581e+14	1.08e-01
2.00e-1	1.22e+14	7.39e-02	3.0959e+14	8.42e-02
3.00e-1	3.58e+13	2.17e-02	8.7394e+13	2.38e-02
4.00e-1	2.62e+13	1.58e-02	6.3931e+13	1.74e-02
6.00e-1	2.61e+13	1.58e-02	8.8265e+13	2.40e-02
8.00e-1	6.94e+14	4.20e-01	1.3478e+15	3.67e-01
1.00	4.21e+12	2.55e-03	2.1344e+13	5.81e-03
1.33	2.71e+12	1.64e-03	2.9649e+13	8.07e-03

Upper Energy Boundary of Group	MIT Fuel Source (per MTU)		HLW Source (per Canister)	
1.66	8.64e+11	5.23e-04	6.4161e+12	1.75e-03
2.00	1.49e+11	9.01e-05	5.1377e+11	1.40e-04
2.50	7.55e+11	4.57e-04	2.9370e+12	7.99e-04
3.00	4.46e+09	2.70e-06	2.0440e+10	5.56e-06
4.00	4.84e+08	2.93e-07	2.2835e+09	6.21e-07
5.00	1.69e+02	1.03e-13	5.2534e+05	1.43e-10
6.50	5.57e+01	3.37e-14	2.1058e+05	5.73e-11
8.00	8.76e+00	5.31e-15	4.1263e+04	1.12e-11
10.00	1.55e+00	9.37e-16	8.7544e+03	2.38e-12
TOTAL	1.65e+15	1.00e+00	3.6750e+15	1.00e+00

Table 7.5-2. Neutron Sources for MIT Fuel and HLW Canisters

Upper Energy Boundary of Group	MIT Fuel Source (per MTU)		HLW Source (per Canister)	
MeV	neutrons/sec	Fraction of Source	neutrons/sec	Fraction of Source
4.00e-1	1.64e+02	4.89e-03	2.087e+06	2.54e-02
9.00e-1	9.96e+02	2.91e-02	6.34e+06	7.72e-02
1.40	2.93e+03	8.56e-02	6.92e+06	8.43e-02
1.85	5.02e+03	1.47e-01	6.12e+06	7.45e-02
3.00	1.84e+04	5.39e-01	2.61e+07	3.18e-01
6.43	6.64e+03	1.94e-01	3.42e+07	4.17e-01
20.00	1.90e+01	5.55e-04	3.07e+05	3.74e-03
TOTAL	3.42e+04	1.00e+00	8.21e+07	1.00e+00

The heat load for an MIT assembly was also calculated by the SAS2H code and decayed to various times using ORIGEN-S (DECAYMIT.OUT). The heat generation per MIT assembly at various cool times is provided below, in Table 7.4-3. The cool time is time after discharge from the reactor, and the emplacement time is assumed to be based upon emplacement after a five year cool time has elapsed (Assumption 4.3.8).

Table 7.4-3. MIT SNF Heat Load per Assembly

Cool Time (yrs)	Emplacement Time (yrs)	Heat (Watts)
5	0	0.164
7	2	0.145
9	4	0.135
20	15	0.102
40	35	0.0637
60	55	0.0397
80	75	0.0250
100	95	0.0159

7.6 Shielding Analysis

7.6.1 Source Term Comparison

A comparison of the neutron and gamma sources for the MIT and HLW canisters presented in Section 7.4, indicates that the neutron source is insignificant to the total surface dose of the codisposal waste package considering that the total neutron source is at least 7 orders of magnitude lower than the photon source. The photon sources were normalized to the total in the waste package as indicated in Table 7.5-1. The MIT photon source was normalized to the mass of 64 assemblies which are present in the DOE-SNF canister; the HLW canister photon source was normalized to 5 canisters which reflects the total source in the waste package. Note that the MIT fuel source is over 2 orders of magnitude lower than that for the HLW canisters; for the energy groups above 4 MeV, the MIT fuel source is over 5 orders of magnitude lower. Given this much lower source and the fact that the DOE-SNF canister will reside in the center of the waste package with the waste package walls shielded by the bulk of the HLW canisters, the effect of the DOE-SNF canister on the total surface dose is insignificant. The overwhelming contribution to the waste package surface dose will be the HLW canisters.

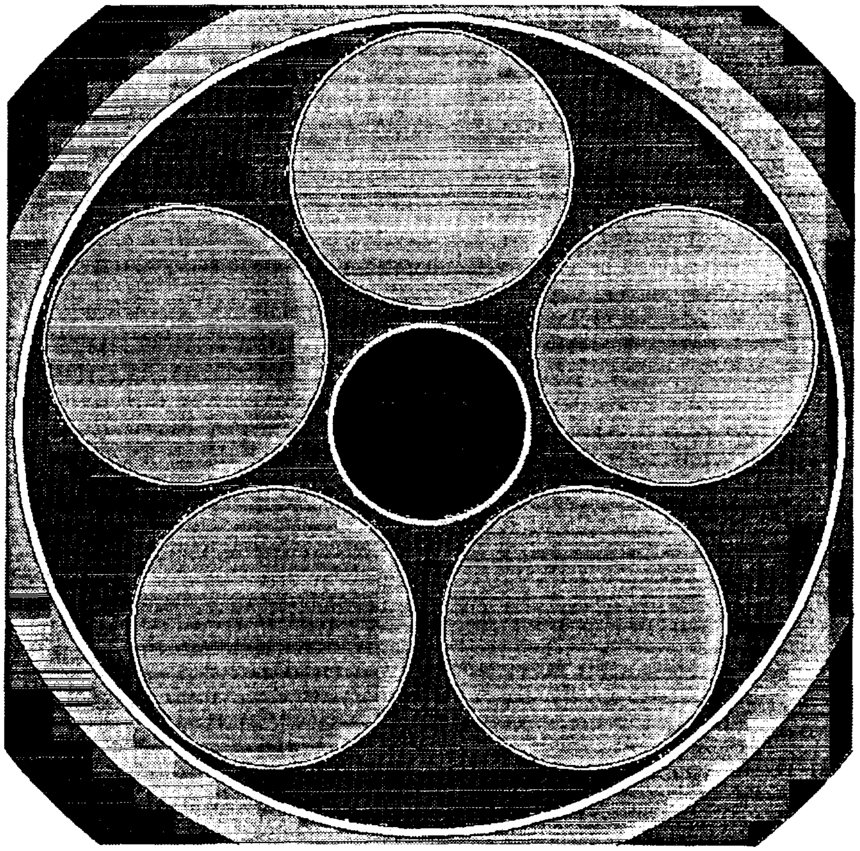
Table 7.5-1 Normalized Photon Sources for MIT Fuel and HLW Canisters

Upper Energy Boundary of Group	MIT Fuel Source	HLW Source
MeV	photons/sec/Codisposal Canister	photons/sec/WP (5 HLW Canisters)
5.00e-2	2.00e+13	6.61e+15
1.00e-1	5.97e+12	1.98e+15
2.00e-1	4.30e+12	1.55e+15
3.00e-1	1.26e+12	4.37e+14
4.00e-1	9.21e+11	3.20e+14
6.00e-1	9.18e+11	4.41e+14
8.00e-1	2.44e+13	6.74e+15
1.00	1.48e+11	1.07e+14
1.33	9.54e+10	1.48e+14
1.66	3.04e+10	3.21e+13
2.00	5.23e+09	2.57e+12

Upper Energy Boundary of Group	MIT Fuel Source	HLW Source
2.50	2.66e+10	1.47e+13
3.00	1.57e+08	1.02e+11
4.00	1.70e+07	1.14e+10
5.00	5.96e+00	2.63e+06
6.50	1.96e+00	1.05e+06
8.00	3.08e-01	2.06e+05
10.00	5.44e-02	4.38e+04
TOTAL	5.81e+13	1.84e+16

7.6.2 Shielding Model

The gamma and neutron sources were inserted into MCNP4A models which employed the geometry and isotopic material descriptions used for the criticality safety calculations for the MIT codisposal canister within a codisposal waste package in the loaded configuration. The basket and fuel assemblies were homoginized to fill the MIT SNF canister. A radial cross-sectional view of this model is shown in Figure 7.6.2-1. For the gamma dose cases only the gammas with energy of greater than 0.4 Mev were specified because lower energies will not contribute significantly to the dose rate outside the waste package (Ref. 5.6) and the remaining group contributions previously listed in Section 7.5 were renormalized. Because of the extremely low neutron source strength for the MIT SNF, no dose case is run for this source. The source for the three dose cases run, as specified in the MCNP models, are listed in Table 7.6.2-1. Tallies were set up in the model to determine the dose rates at various points including segments on the waste package outer surface for all energies. Flux-To-Dose conversion factors for gammas and neutrons are provided in the MCNP manual (Ref. 5.7, Appendix H) from ANSI/ANS-6.1.1-1977 (Ref. 5.8). These were used on the appropriate tally cards to convert the neutron and/or photon flux tallies to dose rate (rem/hr). The neutron and photon Flux-To-Dose conversion cards used in the tallies are listed in Table 7.6.2-2. The MCNP input file for the HLW gamma source case is shown in Attachment X (MITSLD1).



```
  07/30/97 08:05:32
GLASS, Homogenized MIT Cylinder,
 Shielding Model, Source in
 Glass Logs Only
probid =   07/30/97 08:05:17
basis:
( 1.000000,  .000000,  .000000)
(  .000000, 1.000000,  .000000)
origin:
(      .00,      .00,      .00)
extent = (    90.00,    90.00)
```

Figure 7.6.2-1 Radial Cross-Sectional View of the Waste Package Shielding Model

Table 7.6.2-1. MCNP Source Specifications for Shielding Cases.

HLW Gamma Source

```
SDEF  POS=D1 RAD=D2 EXT=D3  ERG=D4 AXS= 0 0 1
SI1   L  0. 55. 0.  52. 17. 0.  33. -43.5 0.    -33. -43.5 0.  -52. 17. 0.
SP1     .2 .2 .2 .2 .2
SI2     0 29.527
SI3   137.1
SI4   H  .40 .60 .80 1.00 1.33 1.66 2.00 2.50  3.00 4.00 5.00 6.50 8.00 10.00
SP4     0. 5.90E-2 9.03E-1 1.43E-2 1.98E-2 4.30E-3 3.44E-4 1.97E-3 1.37E-5
        1.53E-6 3.52E-10 1.41E-10 2.75E-11 5.85E-12
```

MIT Gamma Source

```
SDEF  POS=0 0 0 RAD=D2 EXT=D3  ERG=D4 AXS= 0 0 1
SI2     0 20.4
SI3   129.9
SI4   H  .40 .60 .80 1.00 1.33 1.66 2.00 2.50  3.00 4.00 5.00 6.50 8.00 10.00
SP4     0. 3.59E-2 9.53E-1 5.79E-3 3.72E-3 1.19E-3 2.04E-4 1.04E-3 6.13E-6
        6.65E-7 2.34E-13 7.65E-14 1.21E-14 2.13E-15
```

HLW Neutron Source

```
SDEF  POS=D1  RAD=D2 EXT=D3 ERG=D4 AXS 0 0 1
SI1   L  52.407 0. 0.  16.25 49.602 0.  -42.219 30.68 0.
         -42.219 -30.68 0.  16.2 -49.602 0.
SP1     .2 .2 .2 .2 .2
SI2     0 29.527
SI3   137.1
SI4   H  0.1 0.4 0.9 1.4 1.85 3. 6.43 20.
SP4      0. 2.54-2 7.72-2 8.43-2 7.45-2 3.18-1 4.17-1 3.74-3
```

Table 7.6.2-2. MCNP Tally Flux-To-Dose Conversion Factors for Shielding Cases.

Photon Flux-To-Dose Conversion Factors

```
DE2   .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 .7 .8
      1.0 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 5.75 6.25
      6.75 7.5 9.0 11.0 13.0 15.0
DF2   3.96-6 5.82-7 2.90-7 2.58-7 2.83-7 3.79-7 5.01-7 6.31-7 7.59-7
      8.78-7 9.85-7 1.08-6 1.17-6 1.27-6 1.36-6 1.44-6 1.52-6 1.68-6
      1.98-6 2.51-6 2.99-6 3.42-6 3.82-6 4.01-6 4.41-6 4.83-6 5.23-6
      5.60-6 5.80-6 6.01-6 6.37-6 6.74-6 7.11-6 7.66-6 8.77-6 1.03-5
      1.18-5 1.33-5
```

```
                    Neutron Flux-To-Dose Conversion Factors
DE2   .001 .01 .1 .5 1. 2.5 5.0 7. 10. 14. 20.
DF2   3.76-6 3.56-6 2.17-5 9.26-5 1.32-4 1.25-4 1.56-4 1.47-4
   1.47-4 2.08-4 2.27-4
```

7.6.3 Shielding Results

The HLW gamma dose case (MITSLD1) provides the following results where the dose is reported as a value and its relative error (1σ). The radial centerline dose rate is 9.3967 (0.0831) rem/hr based on a surface tally subdivision of the waste packages outer surface with a 100 mm tall ring about the centerline. The dose rate out the bottom of the waste package tallied over the outer barrier lid is 1.8450 (0.0854) rem/hr.

The MIT gamma dose case (MITSLD2) provides an average radial centerline dose rate of 5.4821E-3 (0.2311) rem/hr based on a surface tally subdivision of the waste packages outer surface with a 100 mm tall ring about the centerline. The peak radial centerline dose rate was calculated to be 3.6733E-2 (0.2515) rem/hr based on a surface tally subdivision of the waste packages outer surface with a 400 mm tall 100 mm wide segment about the centerline directly below the MIT SNF canister as shown in Figure 7.6.2-1. The area for this peak tally falls in a zone unshielded by the HLW canisters. The dose rate out the top of the waste package tallied over the outer barrier lid is 5.0199E-3 (0.0829) rem/hr.

The HLW neutron dose case (MITSLD3) provides a radial centerline neutron dose rate of 7.3501E-2 (0.0034) rem/hr and a gamma (N,gamma) dose rate of 1.7627E-4 (0.0133) rem/hr based on a surface tally subdivision of the waste packages outer surface with a 100 mm tall ring about the centerline. The dose rate out the bottom of the waste package tallied over the outer barrier lid is 3.5364E-2 (0.0019) rem/hr for neutrons and 7.6486E-5 (0.0083) rem/hr for gammas.

Inspection of the gamma shielding results shows that the MIT fuel in the codisposal canister contributes very little to the dose rate on the surface of the codisposal waste package. The neutron dose contribution from neutrons for either waste form is also insignificant. The dose rates on the exterior of the Codisposal waste package with the MIT codisposal canister is within acceptable limits for disposal.

With regards to addressing the shielding requirement in Section 4.2.2 on increased corrosion due to radiolysis, Reference 5.25 (Vol. III, p. 8-4) indicates that for iron based materials in an air/steam environment, a 100 R/hour dose rate results in a 5 times increase in corrosion rate at 250°C, and no increase in corrosion rate at 150°C. Since the waste package surface dose rates are less than 10 R/hr, and the thermal analysis (Ref. 5.26, p. 26) indicates that the codisposal WP peak surface temperature is only 153°C, it is concluded that there will be no increase in corrosion due to radiolysis.

8. Conclusions

8.1 MIT and ORR SNF Criticality

The criticality analyses performed for the MIT and ORR fuel show that the intact highly enriched MIT fuel can be safely disposed of within a codisposal canister in the DHLW Five-Pack waste package (both pre and postclosure) with stainless steel/boron absorber plates. Similarly, the intact moderately enriched ORR fuel is critically safe within the codisposal canister. The analyses show the need for a corrosion resistant neutron absorber material within the codisposal canister to accomodate the potential increase in reactivity which occurs as the fuel (MIT and ORR) and basket degrade, while remaining within the canister. They also indicate that further analysis of degraded canister configurations which consider the chemistry and physical configuration of the fuel and basket corrosion products will be required during Phase II. Evaluations of the neutronic behavior of the fuel materials outside the codisposal canister, both within the waste package and within the repository drifts, will be performed as part of Phase II.

8.2 MIT SNF Shielding

The source term comparison and shielding analysis performed for the MIT spent fuel and the HLW canisters show that the waste package surface dose rates would not be affected by the MIT spent fuel. The analyses show that the gamma radiation dose rate contribution from the codisposal canister fuel and the neutron radiation dose rate contributions, from both the fuel and HLW canisters, are not significant relative to the much more intense canister gamma source. The overall dose rates on the exterior of the codisposal waste package with the MIT codisposal canister is within acceptable limits for disposal and would not increase in corrosion due to radiolysis.

9. Attachments

The hardcopy attachments are listed in Table 9-1 below. Electronic attachments are provided on Colorado Trakker® tapes and are listed in Table 9-2 below for REV 00 Cases (Ref. 5.18) and in Table 9-3 for REV 01 Cases (Ref.5.31).

Table 9-1. Attachments of Supporting Documentation for Codiposal Canister / Five-Pack DHLW WP Criticality and Shielding Analyses

Attachment Number	Description	Pages
I	DHLW Five-Pack Codisposal Waste Package Drawings	3
II	MIT Data for SRS Concurrence	3
III	ORR Data for SRS Concurrence	6
IV	Printout of MITNUM.XLS - Spreadsheet for Homogenized MIT Fuel Number Densities	8
V	Printout of ORRNUM3.XLS - Spreadsheet for Homogenized ORR Fuel Number Densities	10
VI	Printout of MCNP Input File MITOZ3 - MIT Homogenized Fuel in 15 mm Thick XM-19 Canister	6
VII	Printout of MCNP Input File ORROZ3F - ORR Homogenized Fuel in 15 mm Thick XM-19 Canister	4
VIII	Printout of MITBURN.INPUTSUM - SAS2H Input for MIT SNF Burnup and Decay with Summary Output	2
IX	Printout of DECAYMIT.INPUTSUM - ORIGEN-S Input for Decay Heat for MIT SNF and Summary Output	6
X	Printout of MITSLD1 - MCNP Input File for HLW Gamma Dose Calculation	3

Table 9-2: Attachments of Computer Outputs for Codiposal Canister / Five-Pack DHLW WP

File Name	File Size (Bytes)	File Date	File Time of Day
HCT3-10O	353,000	6/4/97	11:17a
HCT3-11O	351,582	6/4/97	11:17a
HCT3-12O	353,273	6/4/97	11:17a
HCT3-13O	353,559	6/4/97	11:17a
HCT3-14O	416,988	6/4/97	11:16a
HCT3-15O	363,399	6/4/97	11:16a
HCT3-1O	352,163	6/4/97	11:17a
HCT3-2O	372,095	6/4/97	11:16a
HCT3-3O	352,427	6/4/97	11:17a
HCT3-4O	352,653	6/4/97	11:17a
HCT3-5O	351,493	6/4/97	11:17a
HCT3-6O	352,954	6/4/97	11:17a
HCT3-7O	353,044	6/4/97	11:17a
HCT3-8O	353,141	6/4/97	11:17a
HCT3-9O	353,179	6/4/97	11:17a
HCT4-1O	529,144	6/4/97	11:10a
HCT4-2O	528,573	6/4/97	11:11a
HCT4-3O	528,321	6/4/97	11:11a
HCT4-4O	528,415	6/4/97	11:11a
HCT6-T1O	530,866	6/4/97	11:10a
HCT6-T2O	435,196	6/4/97	11:11a
HCT6-T3O	437,330	6/4/97	11:11a
HCT8-1O	309,948	6/4/97	11:21a
HCT8-2O	310,514	6/4/97	11:17a
MITA	21,619	4/10/97	8:22a
MITA O	491,524	5/18/97	2:04p
MITB	21,609	4/6/97	7:15p
MITB O	448,982	4/6/97	11:39p
MITC	21,613	4/6/97	8:20p
MITC O	448,982	4/7/97	2:10a
MITD	21,614	4/6/97	8:20p
MITD O	449,293	4/7/97	5:31a
MITE	21,613	4/6/97	8:21p
MITE O	448,982	4/7/97	3:01a
MITF	21,613	4/6/97	8:22p
MITF O	449,045	4/7/97	6:16a

Table 9-2: Attachments of Computer Outputs for Codiposal Canister / Five-Pack DHLW WP (Continued)

File Name	File Size (Bytes)	File Date	File Time of Day
MITG	21,599	4/7/97	1:58p
MITG O	420,541	4/8/97	2:47p
MITH	21,841	4/17/97	11:46p
MITH O	454,378	4/18/97	5:01a
MITI	21,059	4/19/97	1:16p
MITI O	430,688	4/19/97	2:07p
MITJ	20,756	4/19/97	1:24p
MITJ O	425,515	4/19/97	3:30p
MITK	20,426	4/19/97	1:35p
MITK O	449,919	5/18/97	2:04p
MITK1	20,500	4/28/97	9:26a
MITK1 O	422,268	4/28/97	12:29p
MITL	21,863	4/20/97	12:38a
MITL O	452,838	4/20/97	4:10a
MITM	21,055	4/20/97	12:39a
MITM O	459,322	5/18/97	2:04p
MITN	20,761	4/20/97	12:39a
MITN O	425,959	4/20/97	1:04a
MITNUM XLS	56,320	4/28/97	9:55a
MITO	20,490	4/22/97	11:07a
MITO O	422,110	4/20/97	2:22a
MITO1	20,371	4/28/97	11:10a
MITO1 O	434,567	4/28/97	2:02p
MITP	20,593	4/22/97	10:20p
MITP O	421,328	4/22/97	10:52p
MITQ	20,168	4/22/97	11:43p
MITQ O	413,666	4/23/97	12:24a
MITR	11,645	4/24/97	5:56p
MITR O	304,387	5/18/97	2:04p
orr1	8217	6/8/97	1:02p
orr1O	483230	6/9/97	6:53a
orr10e	27407	6/6/97	6:00p
orr10eO	741586	6/6/97	7:38p
orr10f	27595	6/6/97	6:00p
orr10fO	746550	6/7/97	3:05a

Table 9-2: Attachments of Computer Outputs for Codiposal Canister / Five-Pack DHLW WP (Continued)

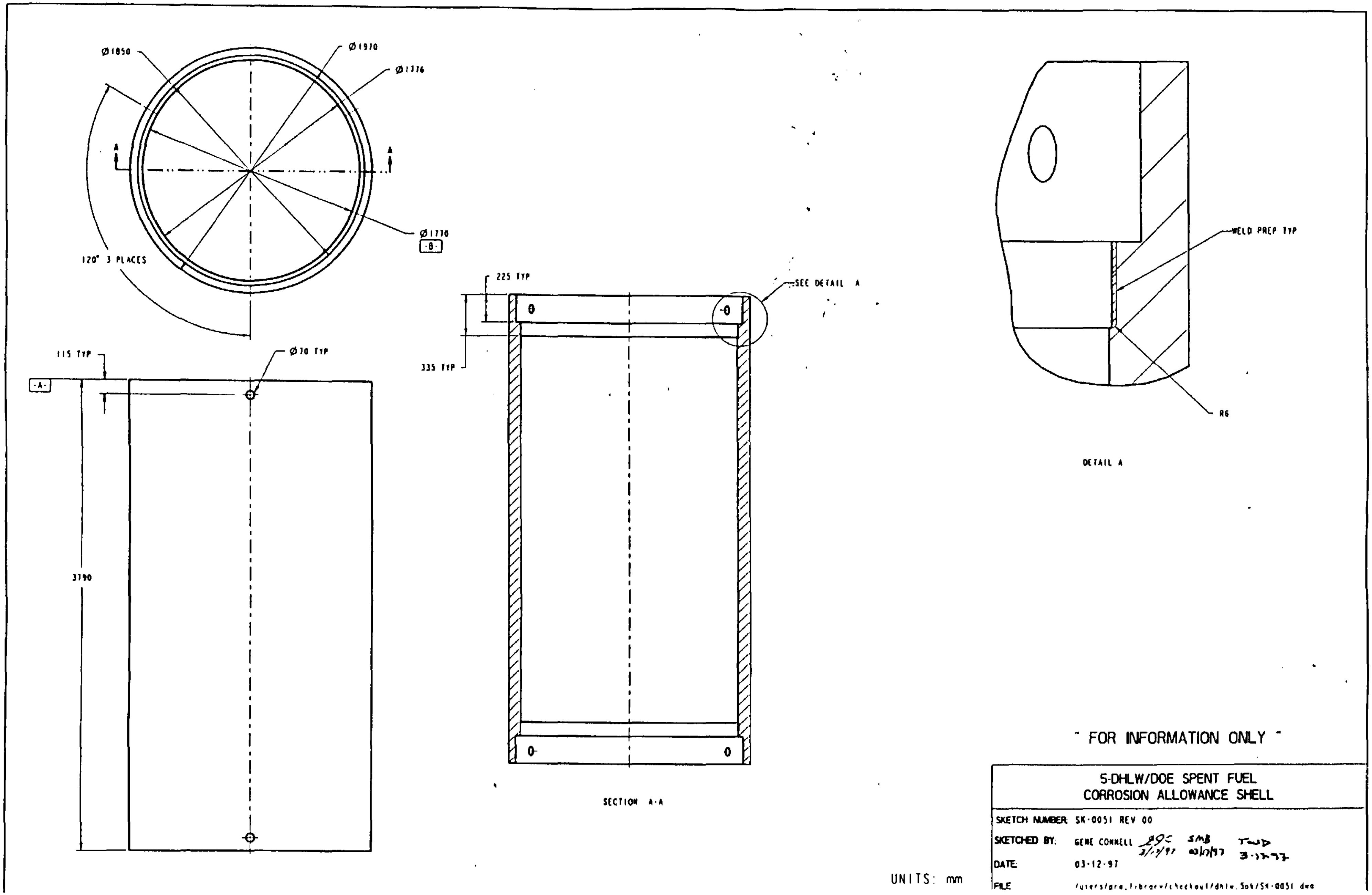
File Name	File Size (Bytes)	File Date	File Time of Day
orr10g	27587	6/6/97	5:31p
orr10gO	746449	6/6/97	9:07p
orr10h	27589	6/6/97	5:41p
orr10hO	746557	6/6/97	10:37p
orr10i	27590	6/6/97	5:52p
orr10iO	746557	6/7/97	12:07a
orr10j	27591	6/6/97	5:57p
orr10jO	746658	6/7/97	1:37a
orr2	8151	6/8/97	1:09p
orr2O	482280	6/9/97	6:53a
orr3	8491	6/8/97	1:12p
orr3O	485490	6/9/97	6:53a
orr4	8303	6/11/97	1:08p
orr4O	472265	6/11/97	2:13p
orrasblO	458995	6/9/97	6:53a
orrhasbl	6591	6/8/97	1:02p
orrhsab1	6524	6/8/97	1:09p
orrhsab2	6860	6/8/97	1:12p
orrhsab3	6348	6/11/97	1:12p
orrsab1O	458127	6/9/97	6:53a
orrsab2O	462453	6/9/97	6:53a
orrsab3P	442675	6/11/97	2:02p
orrnum3 XLS	52,224	6/11/97	1:32p
SPERT10O	279,351	6/4/97	11:15a
SPERT11O	271,935	6/4/97	11:15a
SPERT12O	264,463	6/4/97	11:15a
SPERT13O	274,967	6/4/97	11:15a
SPERT14O	266,094	6/4/97	11:15a
SPERT15O	273,925	6/4/97	11:15a
SPERT15P	273,925	6/4/97	11:15a
SPERT16O	269,835	6/4/97	11:15a
SPERT17O	280,088	6/4/97	11:15a
SPERT18O	284,325	6/4/97	11:15a
SPERT19O	285,652	6/4/97	11:15a
SPERT1O	273,839	6/4/97	11:15a

Table 9-2: Attachments of Computer Outputs for Codiposal Canister / Five-Pack DHLW WP (Continued)

File Name	File Size (Bytes)	File Date	File Time of Day
SPERT20O	289,792	6/4/97	11:15a
SPERT21O	278,727	6/4/97	11:15a
SPERT22O	289,841	6/4/97	11:15a
SPERT23O	284,129	6/4/97	11:15a
SPERT23P	284,129	6/4/97	11:15a
SPERT2O	281,752	6/4/97	11:15a
SPERT3O	281,276	6/4/97	11:15a
SPERT3P	281,276	6/4/97	11:15a
SPERT4O	313,358	6/4/97	11:15a
SPERT5O	281,768	6/4/97	11:15a
SPERT6O	281,524	6/4/97	11:15a
SPERT7O	281,098	6/4/97	11:15a
SPERT8O	281,635	6/4/97	11:15a
SPERT9O	273,257	6/4/97	11:15a
DECAYMIT OUT	620,977	6/4/97	5:10p
MITBURN OUT	22,076,827	6/4/97	5:09p

Table 9-3: Attachments of Computer Outputs for Codiposal Canister / Five-Pack DHLW WP REV 01

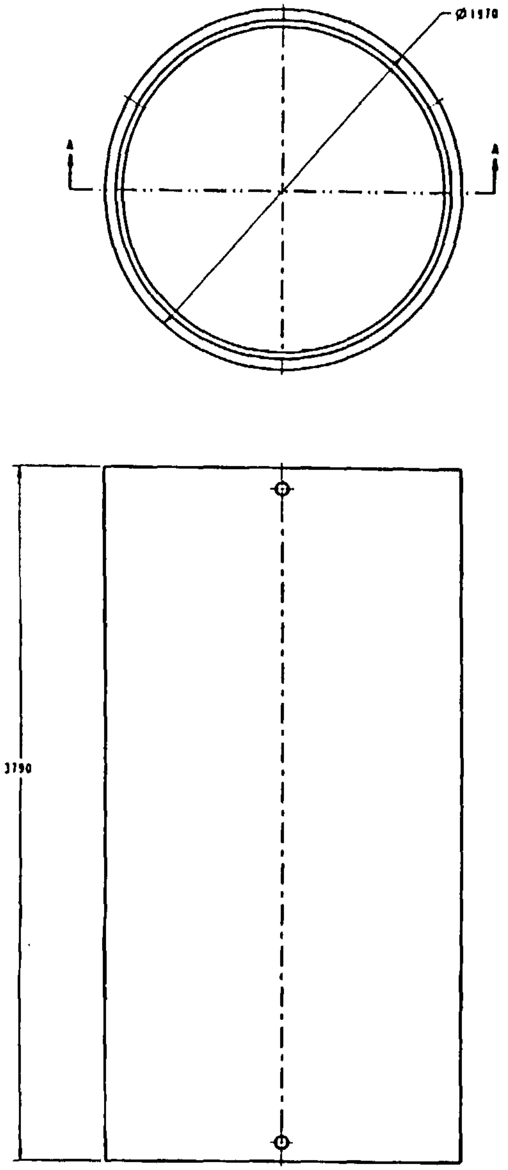
File Name	File Size (Bytes)	File Date	File Time of Day
MITO.O	419900	8/11/97	7:21p
MITOZ1O	430419	8/11/97	7:21p
MITOZ3O	435754	8/11/97	7:21p
MITOZ3AO	435666	8/11/97	7:21p
MITBZ3.O	460456	8/11/97	7:21p
ORROZ3FO	293381	8/11/97	7:21p
ORROZ3AO	293415	8/11/97	7:21p
ORR10FZO	569000	8/11/97	7:21p
MITSLD1O	2971141	8/11/97	7:17p
MITSLD2O	2146722	8/11/97	7:17p
MITSLD3O	4843971	8/11/97	7:18p

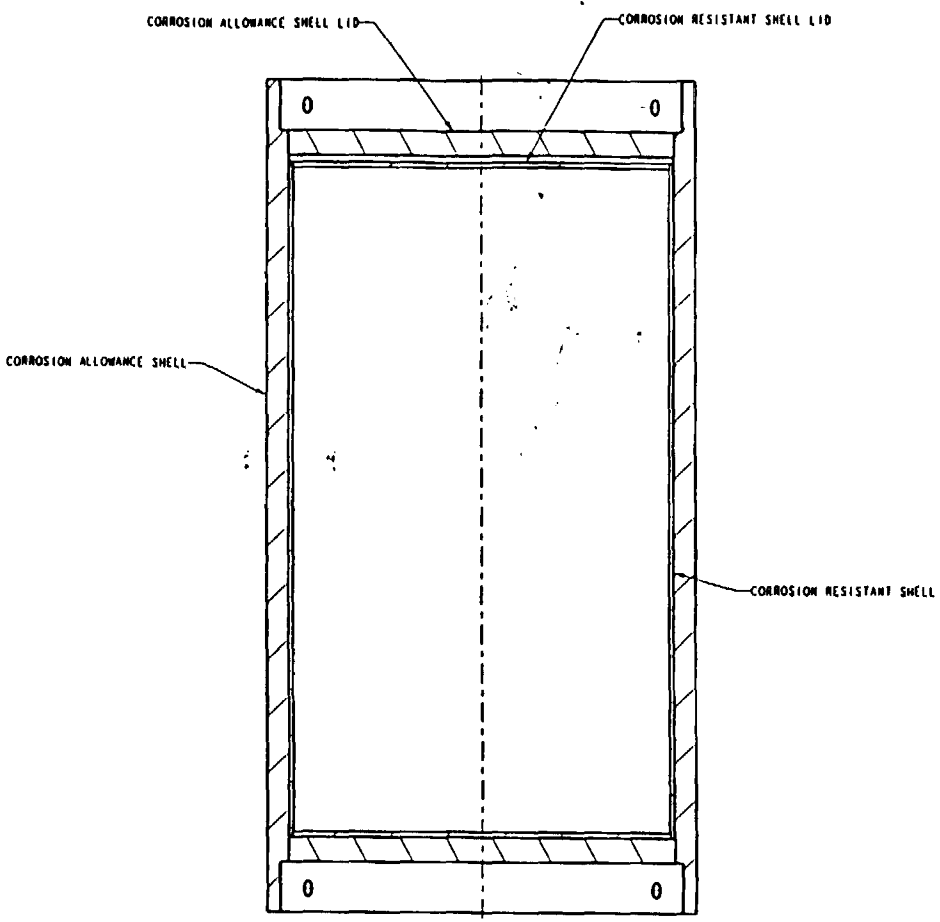


" FOR INFORMATION ONLY "

5-DHLW/DOE SPENT FUEL
CORROSION ALLOWANCE SHELL

SKETCH NUMBER: SK-0051 REV 00
SKETCHED BY: GENE CONNELL 3/17/97 SMB 03/17/97 TWD 3-17-97
DATE: 03-12-97
FILE /users/pro_library/checkout/dhlw_5sh/SK-0051.dwg





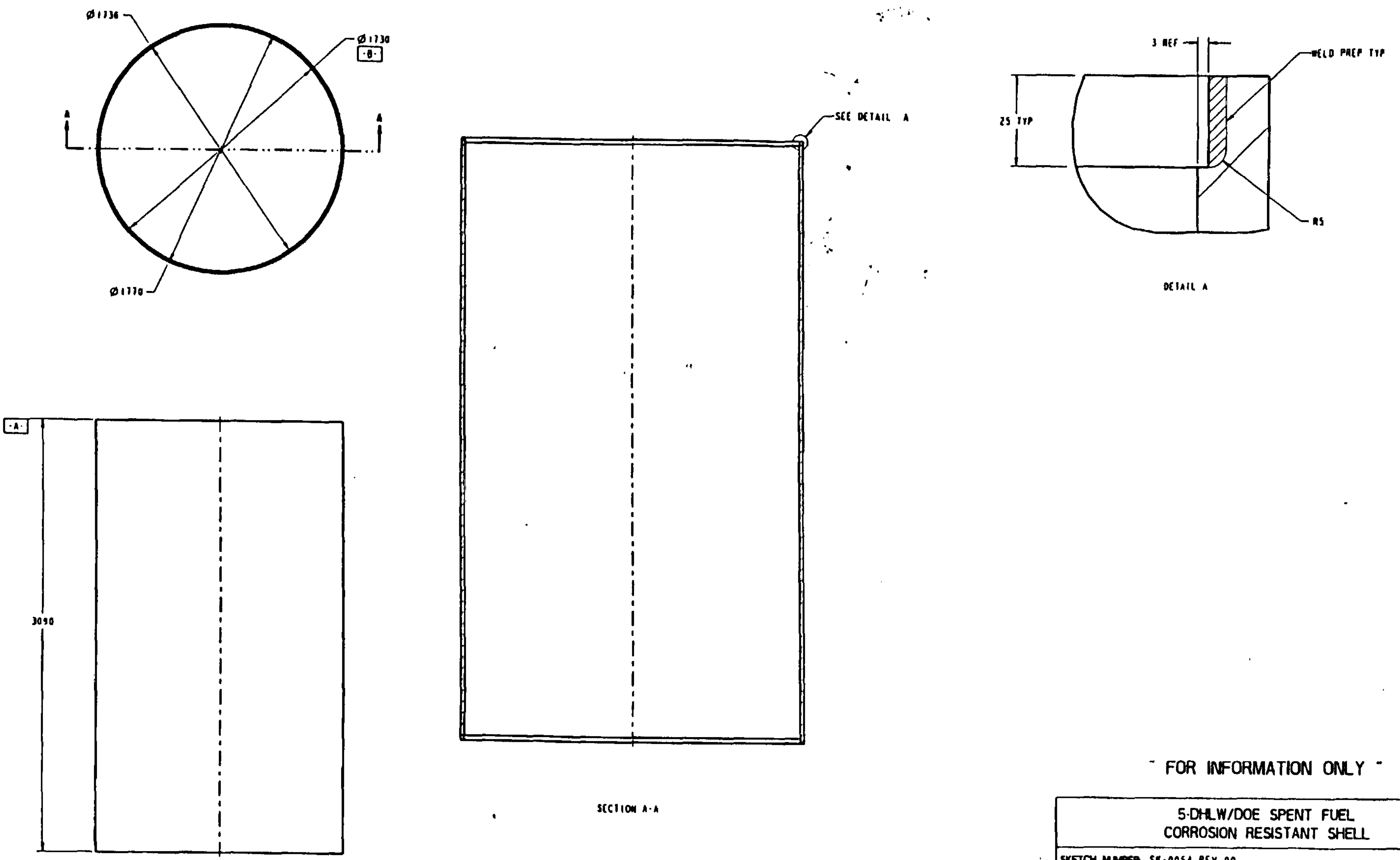
SECTION A-A

" FOR INFORMATION ONLY "

5-DHLW/DOE SPENT FUEL
BARRIERS ASSEMBLY

SKETCH NUMBER: SK-0049 REV 00
SKETCHED BY: GENE CONNELL 3-12-97 03/12/97 3-12-97
DATE: 03-12-97

UNITS: mm



" FOR INFORMATION ONLY "

5-DHLW/DOE SPENT FUEL
CORROSION RESISTANT SHELL

SKETCH NUMBER: SK-0054 REV 00
SKETCHED BY: GENE CONNELL 3/17/97 SMG 03/17/97 3-17-97
DATE: 03-12-97
FILE

UNITS: mm

Attachment II - MIT FUEL ASSEMBLY CALCULATIONS

15 Plates/Assembly

From Drawing R3F-3-2

Max length of Fuel Alloy

23" - 2 X (2/16)"= 22.75" 22.75 inches (2.54 cm/inch) = 57.785 cm

Max width of Fuel Alloy

2.552" - 2 X (3/16)" = 2.177" 2.177" (2.54 cm/inch) = 5.52958 cm

Max thickness of Fuel Alloy

0.030"

.03"(2.54 cm/inch) = 0.0762 cm

Max Fuel Alloy Volume

57.785 cm X 5.52958 cm X 0.0762 cm = 24.3479 cm^3

Max Mass U-235/Assembly = 514.25 g

93.5 wt% U-235 Assume ~ 1 wt% U-234

U-Al_x 69.5 wt% U Al wt% = 100 - 69.5 = 30.5 wt%

Mass & atom densities (in atoms/b-cm)

U-235 mass = 514.25 g

atom density = 514.25 g / (24.3479 cm^3 X 15 plates) X 0.602252/235.043915

= 3.60787E-3 atoms/b-cm

U-234 mass = 514.25 g X 0.01/0.935 = 5.50 g

atom density = 5.50 g / (24.3479 cm^3 X 15 plates) X 0.602252/234.040904

= 3.87522E-5 atoms/b-cm

U-238 mass = 514.25 g X 0.055/0.935 = 30.250 g

atom density = 30.250 g / (24.3479 cm^3 X 15 plates) X 0.602252/238.05077

= 2.09547E-4 atoms/b-cm

Al mass = 514.25 / 0.935 X 0.315/0.695 = 249.28058 g (241.36691 g)

atom density = 249.28058 g / (24.3479 cm^3 X 15 plates) X 0.602252/26.9815389

= 1.52352E-2 atoms/b-cm (1.4752E-2 atoms/b-cm)

(Note: during check of REV 00 it was discovered that the Al weight fraction was incorrectly specified as 0.315, rather than 0.305, in the above equation. If 0.305 had been used, the number densities for H and O in the fuel meat from water logging would have been 0.56% higher. Inspection of Table 7.3.1-1 reveals that an increase from 95% to 100% water in the fuel at the current volume fraction resulted only a 0.15% increase in k_{eff}. Therefore, this error will have a negligible impact on the calculated k_{eff}.) Corrected results are shown in parenthesis next to the original results.

Al atoms / U atoms = 1.52352E-2 / 3.85616E-3 = 3.9509 (3.8254)

UAl_4 density = 6.0 g/cm^3 (Ref. 5.19, p. 142)

Calculated Density = 514.25 g + 5.50 g + 30.25 g + 249.28 g / (24.3479 cm^3 X 15)

= 2.188 g/cm^3 (2.167 g/cm^3)

Void Space in Fuel Alloy = 1 - 2.188 g/cm^3 / 6.0 g/cm^3 = 0.63533 (0.6389)

Water Logging

Water Atom Densities density = 1 g/cm^3

H 6.6878E-2 atoms/b-cm

O 3.3439E-2 atoms/b-cm

Max Water Atom Density in Water Logged Fuel

H (6.6878E-2).6353 = 4.2490E-2 atoms/b-cm (4.2726E-2 atoms/b-cm)

O (3.3439E-2).6353 = 2.1245E-2 (2.1363E-2 atoms/b-cm)

H/U-235 = 4.2490E-2 / 3.60787E-3 = 11.8 (11.8)

H/U-235 within Intact Assembly

Assume all regions are approximately same height - ratios based on width

Plate Cell Width (plate center-to-center spacing) = 0.158" X 2.54 cm/in = 0.40132 cm

Effective Plate Thickness (fins+clad-tolerances) =

[(0.06"- 0.005") + (0.01"- 0.002")] X 2.54 cm/in = 1.6002E-1 cm

Fuel Thickness = 7.620E-02 cm

Water Thickness = 0.40132 - 0.16002 = 0.2413 cm

Fuel Alloy Volume Fraction = 7.62E-2 / (7.62E-2 + 2.413E-1) = 0.24

H/U-235 ratio within Assembly = 6.6878E-2 X 0.76 / (3.60787E-3 X 0.24)

= 58.7

Attachment III - ORR 20 wt% Enriched Fuel Density Calculations

Assembly Type:

MTR-type fuel with 19 plates, 17 inner and 2 outer curved plates

Initially enriched to 20.56 wt% U-235, with 77.5 wt% U in U-Al-Si alloy and a maximum weight of 347.0 grams per assembly.

Fuel plates are curved with a 5.5" inner radius of curvature. Active fuel length is 24"

Inner Fuel Plate (17 each):

Uranium alloy:

Length: derived as 24.63 in -2(.318 in)=23.994 in (60.945 cm, ½ value = 30.472 cm)

Width: derived as 2.775 in -2(.126 in)=2.523 inches (6.408 cm, ½ value = 3.204 cm)

Thickness: 0.020 inches nominal (0.051 cm), 0.025 maximum (0.064 cm)

Cladding:

Length: 24.63 in (62.56 cm, ½ value = 31.28 cm)

Width (between side plates): derived as 2.996 inches - 2(.187 inches) = 2.622 inches

(6.66 cm, ½ value = 3.330 cm)

Thickness: Two layers of 0.0105 in (0.027 cm each)

Curved on a 5.5 in (13.97 cm) inner radius

Outer Fuel Plate (2 each):

Uranium alloy:

Length: derived as 27.13 in -2(1.574 in)=23.982 in (60.914 cm, ½ value = 30.457 cm) *

Width: derived as 2.775 in -2(.126 in)=2.523 in derived (6.408 cm, ½ value = 3.204 cm)

Thickness: 0.020 in nominal (0.051 cm), 0.025 in maximum (0.064 cm)

* Essentially the same as inner plate, so inner plate values used in MCNP model.

Cladding:

Length: 27.130 inches nominal (68.910 cm, ½ value = 34.455 cm)

Width (between side plates): derived as 2.996 inches - 2(.187 inches) = 2.622 inches

(6.66 cm, ½ value = 3.330 cm)

Thickness: two layers of 0.0180 inches (0.046 cm each)

Curved on a 5.5 in (13.97 cm) inner radius

Assembly:

Inner Fuel Plate Spacing: 0.166 inches (0.422 cm)

Outer-to-Inner Plate Spacing: 0.182 inches (0.462 cm)

References for Dimensions:

Drawings M-11495-OR-001E ("19 Plate Fuel Element Assy & Finish Machining"), M-11495-OR-003E ("Misc. Details for ORR Fuel Element"), and M-11495-OR-004E ("Fuel Plate Details") (Ref. 5.4).

Uranium Densities in Fuel Alloy

Masses:

From "Nuclear Safety Data Sheet", each assembly contains a maximum of 347.0 grams of U-235. For 19 plates, this provides 18.263 g per plate, and at 20.56 wt% U-235 enrichment, the total uranium mass would be 88.829 g and the U-238 mass would be 70.566 g (neglecting U-234 and U-236). Since uranium is 77.5 percent of the total, the Al and Si contributions are 25.789 g. [The "Appendix A" data indicates that the chemical form of the fuel is U_3Si_2 with Al as a dispersing material.]

U-235: 18.263 g/plate

U-238: 70.566 g/plate

Si: 2/3(18.263g U-235/235.043915 amu + 70.566 g U-238/238.05077 amu) X 28.086 amu

= 7.005 g Si/plate

Al: 88.829 g/0.775 - 88.829 g - 7.005 g = 18.784 Al g/plate

Volumes:

Since the fuel plates are curved and the dimensions given are planar, additional information is required to calculate the volume of the fuel alloy. A graphical plot of the fuel alloy allows the included angle subtended by the fuel alloy to be measured as 26.478 degrees and the volume between the cladding layers to be calculated as follows:

Inner Plate Volume = $(26.478° / 360°) * \text{Pi} * (14.060^2 - 13.997^2) * 60.945 = 24.9589\ \text{cm}^3$

similarly,

Outer Plate Volume = $(26.478° / 360°) * \text{Pi} * (14.079^2 - 14.016^2) * 60.914 = 24.9998\ \text{cm}^3$

Densities:

Inner Plates:	Outer Plates:
ρ (U-235) = 18.263 g/24.9589 cm^3 = 0.7317 g/cm^3	ρ (U-235) = 0.7305 g/cm^3
ρ (U-238) = 70.566 g/24.9589 cm^3 = 2.8273 g/cm^3	ρ (U-238) = 2.8227 g/cm^3
ρ (Si) = 7.005 g/24.9589 cm^3 = 0.2807 g/cm^3	ρ (Si) = 0.2802 g/cm^3
ρ (Al) = 18.784 g/24.9589 cm^3 = 0.7526 g/cm^3	ρ (Al) = 0.7514 g/cm^3

Atom Densities (atoms/barn-cm)**:**

Inner Plates:	Outer Plates:
N_{25} = 0.7317 * 0.602252 / 235.043915 = 1.8749E-3	N_{25} = 1.8718E-3
N_{28} = 2.8273 * 0.602252 / 238.05077 = 7.1528E-3	N_{28} = 7.1411E-3
N_{Si} = 0.2807 * 0.602252 / 28.086 = 6.0183E-3	N_{Si} = 6.0084E-3
N_{Al} = 0.7526 * 0.602252 / 26.9815389 = 1.6799E-2	N_{Al} = 1.6771E-2

Free Volume Calculation

Given:

U-235: 18.263 g/plate

U-238: 70.566 g/plate

Si: 7.005 g/plate

Al: 18.784 g/plate

Volume = 24.9589 cm^3

Uranium:

The total U_3Si_2 = 18.263 + 70.566 + 7.005 = 95.834 g

and at a theoretical density of 12.20g/cm^3 (Ref. 5-19, p. 200), the displaced volume of the U_3Si_2 is 95.834/12.20 = 7.8552 cm^3.

Aluminum:

Aluminum at 2.699 g/cm^3 (Ref. 5.19, p. 584) and a mass of 18.784 g, has a displaced volume of 6.9596 cm^3

The total metal alloy volume is thus 7.8552 + 6.9596 = 14.8148 cm^3, or 59.36 volume percent of the fuel alloy.

If all of the remaining 40.64 volume percent is treated as if it were flooded with water at 1.00 g/cm^3, then the maximum effective density of the water spread over the fuel alloy volume is 0.4064 g/cm^3. The number densities of hydrogen and oxygen which would then exist are

N_H = (6.6878E-2)0.4064 = 2.7179E-2 atoms/barn-cm

N_O = (3.3439E-2)0.4064 = 1.3590E-2 atoms/barn-cm

H/U-235 in fuel = 2.7179E-2 / 1.8749E-3 = 14.5

Homogenized MIT Fuel Assembly

Volume Fractions				
Fuel	0.61554			
Water	0.16481			
Steel	0.21965			
	Water	SS316	Homogenized Fuel Cells	**Homogenized Cylinder**
92234.50C			4.2203E-06	**2.5977E-06**
92235.50C			3.9292E-04	**2.4186E-04**
92238.50C			2.2821E-05	**1.4047E-05**
5010.50C			1.6021E-05	**9.8618E-06**
5011.56C			6.6379E-05	**4.0859E-05**
6000.50C		1.1883E-04	3.7099E-06	**2.8384E-05**
7014.50C		3.3977E-04	1.0608E-05	**8.1159E-05**
12000.50C			1.2644E-04	**7.7832E-05**
13027.50C			1.2810E-02	**7.8851E-03**
14000.50C		1.2705E-03	1.0532E-04	**3.4389E-04**
15031.50C		6.9123E-05	2.1580E-06	**1.6511E-05**
16032.50C		4.4643E-05	1.3937E-06	**1.0664E-05**
24000.50C		1.5556E-02	5.5757E-04	**3.7600E-03**
25055.50C		1.7321E-03	5.4075E-05	**4.1374E-04**
26000.50C		5.5840E-02	1.6343E-03	**1.3271E-02**
28000.50C		9.7247E-03	3.4157E-04	**2.3463E-03**
29000.50C			1.2091E-05	**7.4422E-06**
1001.50C	6.6878E-02		4.8483E-02	**4.0865E-02**
8016.50C	3.3439E-02		2.4241E-02	**2.0433E-02**
42000.50C		1.2398E-03	3.8704E-05	**2.9614E-04**
Totals:	1.0032E-01		8.8924E-02	**9.0146E-02**

MIT Basket Volume Calculations

Codisposal Tube:								
	Radius	Area						
	20.465	1315.749						
Water-Filled Cells:								
Cell 1	Half-Moon Shape							
	Chord Length	Radial Base	Angle	Area				Fraction
	13.471	19.303	39.191	13.222				0.01005
Cell 2	Half-Moon + Triangle							
	Chord Length	Radial Base	Angle	Moon Area	Triang. Ht.	Triangle Area	Total	Fraction
	10.719	19.745	30.301	4.923	2.664	14.278	19.200	0.01459
Cell 3	Triangle							
	Base	Height	Area					Fraction
	2.985	5.108	7.624					0.00579
Cell 4	Triangle							Fraction
	Same as Cell 3							0.00579
Cell 5	Half-Moon + Triangle							Fraction
	Same as Cell 2							0.01459
Total Fractions for TOP Row				0.05082				
Cell 6	Half-Moon + Trapezoid				(Trapezoidal Area)			
	Chord Length	Radial Base	Angle	Moon Area	Ave. Base	Height		Fraction
	7.069	20.134	19.881	1.499	7.270	1.426	11.866	0.00902
					Area:	10.36702		
Cell 7	Triangle							
	Base	Height	Area					Fraction
	2.757	4.925	6.789					0.00516
Cell 8	Half-Moon + Triangle							
	Chord Length	Radial Base	Angle	Moon Area	Triang. Ht.	Triangle Area	Total	Fraction
	6.705	20.139	18.924	1.649	2.227	7.466	9.115	0.00693
Total Fractions for UPPER MIDDLE Row				0.02111				
Cell 9	Triangle							
	Base	Height	Area					Fraction
	2.826	4.879	6.894					0.00524
Cell 10	Triangle							
	Same as Cell 9							Fraction
								0.00524

MIT Basket Volume Calculations
(CONTINUED)

Cell 11	Triangle							
	Same as Cell 9							Fraction
								0.00524
Cell 12	Triangle							
	Same as Cell 9							Fraction
Total Fractions for CENTER Row				0.02096				0.00524
Total Fractions for UPPER MIDDLE Row				0.02111				
Total Fractions for BOTTOM Row				0.05082				
GRAND TOTAL FRACTION FOR ALL WATER CELLS:					0.16481			
Fuel-Filled Cells:			Fuel Area	50.15268		Divider Area	0.93134	
			Area	Fraction				
Top Row:	Two Fuel Cells, No Dividers		100.305	0.07623				
Upper-Middle	Four Cells, Three Dividers		203.405	0.15459				
Central	Four Cells, Two Dividers		202.473	0.15388				
Lower-Middle	Equal to Upper-Middle		203.405	0.15459				
Bottom	Equal to Top		100.305	0.07623				
GRAND TOTAL FRACTION FOR ALL FUEL CELLS:					0.61554			
TOTAL FRACTION FOR STEEL BASKET:					0.21965			

Homogenized MIT Fuel Assembly
Fuel Cell Plus SS316B2A Divider Plates

Homogenization of Fuel Cell (including Divider Plates) and Axial Water									
	Fuel Meat	Al / H2O	Fuel Plate	Water	Fuel&Water	SS316B2A	Total		H2O/(Al+H2O)
Length	57.785	0.635	58.42	5.58	64	1	65		0.654686073
Vol. Fraction	**0.88900**	**0.00977**		**0.08585**		**0.01538**	1.00000		
Number Densities in Homogenized Fuel including Side Plates							SS316B2A	Fuel Cell	**Axial**
	Fuel Meat	Aluminum	Water	Plate Array	Assembly	Cell	Dividers	& Dividers	**Homogenization**
92234.50C	3.8752E-05			6.3722E-06	5.8030E-06	4.9235E-06		4.7472E-06	**4.2203E-06**
92235.50C	3.6079E-03			5.9327E-04	5.4027E-04	4.5839E-04		4.4198E-04	**3.9292E-04**
92238.50C	2.0955E-04			3.4457E-05	3.1380E-05	2.6624E-05		2.5670E-05	**2.2821E-05**
5010.50C							5.1188E-04	9.1634E-06	**1.6021E-05**
5011.56C							2.1208E-03	3.7966E-05	**6.6379E-05**
6000.50C							1.1853E-04	2.1219E-06	**3.7099E-06**
7014.50C							3.3891E-04	6.0670E-06	**1.0608E-05**
12000.50C		6.7211E-04		1.2157E-04	1.7075E-04	1.4487E-04		1.3968E-04	**1.2644E-04**
13027.50C	1.5235E-02	5.9272E-02		1.3226E-02	1.7339E-02	1.4711E-02		1.4185E-02	**1.2810E-02**
14000.50C		3.4898E-04		6.3123E-05	8.8657E-05	7.5220E-05	1.2673E-03	9.5214E-05	**1.0532E-04**
15031.50C							6.8948E-05	1.2343E-06	**2.1580E-06**
16032.50C							4.4530E-05	7.9716E-07	**1.3937E-06**
24000.50C		7.8542E-05		1.4207E-05	1.9953E-05	1.6929E-05	1.7342E-02	3.2677E-04	**5.5757E-04**
25055.50C							1.7277E-03	3.0929E-05	**5.4075E-05**
26000.50C							5.2215E-02	9.3473E-04	**1.6343E-03**
28000.50C							1.0913E-02	1.9536E-04	**3.4157E-04**
29000.50C		6.4267E-05		1.1625E-05	1.6327E-05	1.3852E-05		1.3356E-05	**1.2091E-05**
1001.50C	4.2490E-02		6.6878E-02	5.0771E-02	4.6236E-02	4.9364E-02		4.7597E-02	**4.8483E-02**
8016.50C	2.1245E-02		3.3439E-02	2.5385E-02	2.3118E-02	2.4682E-02		2.3798E-02	**2.4241E-02**
42000.50C							1.2366E-03	2.2137E-05	**3.8704E-05**
Totals:	8.2826E-02	6.0436E-02	1.0032E-01	9.0227E-02	8.7566E-02	8.9499E-02	8.7905E-02	8.7868E-02	**8.8924E-02**

Homogenized MIT Fuel Assembly
Fuel Cell Plus SS316B2A Divider Plates

Homogenization of Fuel Cell and Divider Plates								
	Fuel Cell	Each Divider	Cell+Dividers					
Width	7.64989	0.14203	7.93395					
Vol. Fraction	**0.96420**	**0.01790**						
Number Densities in Homogenized Fuel including Side Plates							SS316B2A	**Fuel Cell**
	Fuel Meat	Aluminum	Water	Plate Array	Assembly	Cell	Dividers	**& Dividers**
92234.50C	3.8752E-05			6.3722E-06	5.8030E-06	4.9235E-06		**4.7472E-06**
92235.50C	3.6079E-03			5.9327E-04	5.4027E-04	4.5839E-04		**4.4198E-04**
92238.50C	2.0955E-04			3.4457E-05	3.1380E-05	2.6624E-05		**2.5670E-05**
5010.50C							5.1188E-04	**9.1634E-06**
5011.56C							2.1208E-03	**3.7966E-05**
6000.50C							1.1853E-04	**2.1219E-06**
7014.50C							3.3891E-04	**6.0670E-06**
12000.50C		6.7211E-04		1.2157E-04	1.7075E-04	1.4487E-04		**1.3968E-04**
13027.50C	1.5235E-02	5.9272E-02		1.3226E-02	1.7339E-02	1.4711E-02		**1.4185E-02**
14000.50C		3.4898E-04		6.3123E-05	8.8657E-05	7.5220E-05	1.2673E-03	**9.5214E-05**
15031.50C							6.8948E-05	**1.2343E-06**
16032.50C							4.4530E-05	**7.9716E-07**
24000.50C		7.8542E-05		1.4207E-05	1.9953E-05	1.6929E-05	1.7342E-02	**3.2677E-04**
25055.50C							1.7277E-03	**3.0929E-05**
26000.50C							5.2215E-02	**9.3473E-04**
28000.50C							1.0913E-02	**1.9536E-04**
29000.50C		6.4267E-05		1.1625E-05	1.6327E-05	1.3852E-05		**1.3356E-05**
1001.50C	4.2490E-02		6.6878E-02	5.0771E-02	4.6236E-02	4.9364E-02		**4.7597E-02**
8016.50C	2.1245E-02		3.3439E-02	2.5385E-02	2.3118E-02	2.4682E-02		**2.3798E-02**
42000.50C							1.2366E-03	**2.2137E-05**
Totals:	8.2826E-02	6.0436E-02	1.0032E-01	9.0227E-02	8.7566E-02	8.9499E-02	8.7905E-02	**8.7868E-02**

Homogenized MIT Fuel Assembly
Homogenized Fuel + Water in Basket Holes

Volume Fractions for Codisposal Basket:

Water	0.1648147
Fuel	0.6155381
Basket	0.2196472

Number Densities in Homogenized Fuel including Side Plates

	Water	**Cell**	**Cell+Basket**
92234.50C		4.923E-06	**3.031E-06**
92235.50C		4.5839E-04	**0.0002822**
92238.50C		2.6624E-05	**1.639E-05**
13027.50C		1.4711E-02	**0.0090554**
14000.50C		7.5220E-05	**4.63E-05**
24000.50C		1.6929E-05	**1.042E-05**
12000.50C		1.4487E-04	**8.917E-05**
29000.50C		1.3852E-05	**8.527E-06**
1001.50C	6.6878E-02	4.9364E-02	**0.0414081**
8016.50C	3.3439E-02	2.4682E-02	**0.0207041**
Total:	1.0032E-01	8.9499E-02	**7.1624E-02**

Homogenized MIT Fuel Assembly
Fuel Plates + Moderator + Side Plates + Surrounding Water Layer

Fuel Plate Homogenization Calculations

	Fuel Meat	Clad (Al)	Moderator	Cell
PX	0.03810	0.08001	0.23170	
Thickness	0.07620	0.08382	0.30338	0.4634044
Vol. Fractions	0.16444	0.18088	0.65469	1.00000

Addition of Side Plate Aluminum Into Homogenized Assembly

	Plate Array		Side Plates		Top/Bottom
Base	6.79562		0.12905	(Two each)	7.05372
Height	5.70230		5.70230		0.16510
Area	38.75066		1.47176		2.32914
	Total Area of Side Plates:		3.80090		
	Total Area of Assembly:		42.55157		
Vol. Fractions		Plate Array:	0.91068	AL Sides:	0.08932

Addition of Water Layer Surrounding Assembly to Homogenized Assembly

	Assembly		Cell		Water Layer
Base	7.05372		7.64989		
Height	6.03250		6.55600		
Area	42.55157		50.15268		7.60111
Vol. Fractions	0.84844		1.00000		0.15156

Number Densities in Homogenized Fuel Including Side Plates

	Fuel Meat	Aluminum	Water	Plate Array	Assembly	Cell
92234.50C	3.8752E-05			6.3722E-06	5.8030E-06	4.923E-06
92235.50C	3.6079E-03			5.9327E-04	5.4027E-04	4.5839E-04
92238.50C	2.0955E-04			3.4457E-05	3.1380E-05	2.6624E-05
13027.50C	1.5235E-02	5.9272E-02		1.3226E-02	1.7339E-02	1.4711E-02
14000.50C		3.4898E-04		6.3123E-05	8.8657E-05	7.5220E-05
24000.50C		7.8542E-05		1.4207E-05	1.9953E-05	1.6929E-05
12000.50C		6.7211E-04		1.2157E-04	1.7075E-04	1.4487E-04
29000.50C		6.4267E-05		1.1625E-05	1.6327E-05	1.3852E-05
1001.50C	4.2490E-02		6.6878E-02	5.0771E-02	4.6236E-02	4.9364E-02
8016.50C	2.1245E-02		3.3439E-02	2.5385E-02	2.3118E-02	2.4682E-02
			Total:	9.0227E-02	8.7566E-02	8.9499E-02

N(Homogenized) = N(fuel)*V.F.(fuel) + N(clad)*V.F.(clad) + N(mod)*V.F.(mod)

Effective-k	0.63481

Plate								
	vf	density						
fuel	0.16444	2.188	g/cc		0.359784	g/cc	0.47619	1.041905
clad	0.18088	2.699	g/cc		0.488192	g/cc	0.52381	1.413762
solid density	0.34531				0.847976	g/cc		2.455667
Assembly								
Plate	0.91068	0.847976	g/cc		0.772231	g/cc		2.236315
Al Sides	0.08932	2.699	g/cc		0.241087	g/cc		0.241087
					1.013318	g/cc		2.477402
Assembly + Water Layer								
Assembly	0.84844	1.013318			0.85974	g/cc		34.70%
Assembly + Water Layer + B-SS								
Assembly	0.964197	0.85974			0.828959	g/cc		
B-SS	0.017902	7.86			0.140706	g/cc		
					0.969665	g/cc		

Homogenized MIT Fuel Assembly
Fuel Plates + Moderator + Side Plates

	Fuel Plate Homogenization Calculations				
	Fuel Meat	Clad (Al)	Moderator	Cell	
PX	0.03810	0.08001	0.23170		
Thickness	0.07620	0.08382	0.30338	0.4634044	
Volume Fraction	0.16444	0.18088	0.65469	1.00000	
Addition of Side Plate Aluminum into Homogenized Assembly					
	Plate Array		Side Plates		Top/Bottom
Base	6.79562		0.12905	(Two each)	7.05372
Height	5.70230		5.70230		0.16510
Area	38.75066		1.47176		2.32914
	Total Area of Side Plates:		3.80090		
	Total Area of Assembly:		42.55157		
Volume Fractions		Plate Array:	0.91068	AL Sides:	0.08932
Number Densities in Homogenized Fuel including Side Plates					
	Fuel Meat	Aluminum	Water	Plate Array	Assembly
92234.50C	3.8752E-05			6.3722E-06	5.8030E-06
92235.50C	3.6079E-03			5.9327E-04	5.4027E-04
92238.50C	2.0955E-04			3.4457E-05	3.1380E-05
13027.50C	1.5235E-02	5.9272E-02		1.3226E-02	1.7339E-02
14000.50C		3.4898E-04		6.3123E-05	8.8657E-05
24000.50C		7.8542E-05		1.4207E-05	1.9953E-05
12000.50C		6.7211E-04		1.2157E-04	1.7075E-04
29000.50C		6.4267E-05		1.1625E-05	1.6327E-05
1001.50C	4.2490E-02		6.6878E-02	5.0771E-02	4.6236E-02
8016.50C	2.1245E-02		3.3439E-02	2.5385E-02	2.3118E-02
			Total:	9.0227E-02	8.7566E-02

N(Homogenized) = N(fuel)*V.F.(fuel) + N(clad)*V.F.(clad) + N(mod)*V.F.(mod)

Homogenized MIT Fuel Assembly
Fuel Plates + Moderator, Intact Side Plates

	Fuel Meat	Clad	Moderator	Cell
PX	0.03810	0.08001	0.23170	
Thickness	0.07620	0.08382	0.30338	0.4634044
Volume Fraction	0.16444	0.18088	0.65469	1.00000
Number Densities in Homogenized Fuel/Moderator Cell				
92234.50C	3.8752E-05			6.3722E-06
92235.50C	3.6079E-03			5.9327E-04
92238.50C	2.0955E-04			3.4457E-05
13027.50C	1.5235E-02	5.9272E-02		1.3226E-02
14000.50C		3.4898E-04		6.3123E-05
24000.50C		7.8542E-05		1.4207E-05
12000.50C		6.7211E-04		1.2157E-04
29000.50C		6.4267E-05		1.1625E-05
1001.50C	4.2490E-02		6.6878E-02	5.0771E-02
8016.50C	2.1245E-02		3.3439E-02	2.5385E-02
			Total:	9.0227E-02

N(Homogenized) = N(fuel)*V.F.(fuel) + N(clad)*V.F.(clad) + N(mod)*V.F.(mod)

Homogenized ORR Fuel Plates and Water
(Water-Logged Fuel Meat)

Note: all lengths, widths, and heights are in cm, and all volumes are in cm^3

Active Fuel Length	60.9450				
Assembly OD	7.6100	8.357	(Width and Height)		
Assembly Volume	3875.9051				
Fuel Meat Volumes				**Comb Plates**	
Inner Meat Volume	24.9589	17	Each	Thickness	0.475
Outer Meat Volume	24.9998	2	Each	Height	8.049
Total Meat Volume	**474.3009**			Total Volume	**466.0189898**
Clad/Meat Ratio	1.6000	(0.051-.020)/.020		**Water**	
Total Clad Volume	**758.88144**			Total Volume	**2176.7038**
Total Plate Volume	1233.1823				
	Fuel Meat	Cladding	Comb Plate	Water	Assembly
Volume Fractions	0.1224	0.1958	0.1202	0.5616	1.0000
Number Densities					**Assembly**
	Fuel Meat	Cladding	Comb Plate	Water	**Homogenized**
U-235	1.875E-03				**2.294E-04**
U-238	7.153E-03				**8.753E-04**
Al	1.680E-02	6.022E-02	6.022E-02		**2.109E-02**
Si	6.018E-03				**7.365E-04**
H	2.718E-02			6.694E-02	**4.092E-02**
O	1.359E-02			3.347E-02	**2.046E-02**

Number Densities	Assembly Homogenized
92235.50C	2.294E-04
92238.50C	8.753E-04
13027.50C	2.109E-02
14000.50C	7.365E-04
1001.50C	4.092E-02
8016.50C	2.046E-02
	8.431E-02

Homogenized ORR Fuel Cell
(Water-Logged Fuel Meat)

Active Fuel Length	60.9450										
Assembly OD	7.6100	8.357	(Width and Height)								
Assembly Volume	3875.9051										
Fuel Meat Volumes				**Comb Plates**							
Inner Meat Volume	24.9589	17	Each	Thickness	0.475						
Outer Meat Volume	24.9998	2	Each	Height	8.049						
Total Meat Volume	**474.3009**			Total Volume	**466.0189898**						
Clad/Meat Ratio	1.6000	(0.051-.020)/.020		**Water**							
Total Clad Volume	**758.88144**			Total Volume	**2176.7038**						
Total Plate Volume	1233.1823										
Assembly	Fuel Meat	Cladding	Comb Plate	Water	Assembly						
Volume Fractions	0.1224	0.1958	0.1202	0.5616	1.0000						
Fuel Cell											
Width	8.1180	Height	8.8640	Volume	4385.4774	solids	vf				
Water Layer Vol.	509.5722					meat	0.1082	7.8552	0.849561	0.279132	2.192635
Cell	Fuel Meat	Cladding	Comb Plate	Water	Assembly	cladding	0.1730	2.699	0.467046	0.446611	1.205402
Volume Fractions	0.1082	0.1730	0.1063	0.6125	1.0000	comb	0.1063	2.699	0.286807	0.274258	0.740221
							0.3875		1.603414	1	4.138259
Number Densities					**Assembly**						
	Fuel Meat	Cladding	Comb Plate	Water	**Homogenized**					38.75%	
U-235	1.875E-03				**2.028E-04**						
U-238	7.153E-03				**7.736E-04**						
Al	1.680E-02	6.022E-02	6.022E-02		**1.864E-02**						
Si	6.018E-03				**6.509E-04**						
H	2.718E-02			6.694E-02	**4.394E-02**						
O	1.359E-02			3.347E-02	**2.197E-02**						

Number Densit	Assembly Homogenized
92235.50C	2.028E-04
92238.50C	7.736E-04
13027.50C	1.864E-02
14000.50C	6.509E-04
1001.50C	4.394E-02
8016.50C	2.197E-02
	8.618E-02

Homogenized ORR Basket
(Water-Logged Fuel Meat)

Active Fuel Length	60.9450					
Assembly OD	7.6100	8.357	(Width and Height)			
Assembly Volume	3875.9051					
Fuel Meat Volumes				**Comb Plates**		
Inner Meat Volume	24.9589	17	Each	Thickness	0.475	
Outer Meat Volume	24.9998	2	Each	Height	8.049	
Total Meat Volume	**474.3009**			Total Volume	**466.0189898**	
Clad/Meat Ratio	1.6000	(0.051-.020)/.020		**Water**		
Total Clad Volume	**758.88144**			Total Volume	**2176.7038**	
Total Plate Volume	1233.1823					
Assembly	Fuel Meat	Cladding	Comb Plate	Water	Assembly	
Volume Fractions	0.1224	0.1958	0.1202	0.5616	1.0000	
Fuel Cell						
Width	8.1180	Height	8.8640	Volume	4385.4774	
Water Layer Vol.	**509.5722**					
Steel Tube Wall						
Width	8.3680	Height	9.1140	Volume	4648.0284	
Steel Layer Vol.	**262.5511**					
Cell	Fuel Meat	Cladding	Comb Plate	Water	Basket Steel	Total
Volume Fractions	0.1020	0.1633	0.1003	0.5779	0.0565	1.0000
Number Densities					Basket	**Basket**
	Fuel Meat	Cladding	Comb Plate	Water	Structure	**Homogenized**
92235.50C	1.875E-03					**1.913E-04**
92238.50C	7.153E-03					**7.299E-04**
6000.50C					1.19E-04	**6.712E-06**
7014.50C					3.40E-04	**1.919E-05**
13027.50C	1.680E-02	6.022E-02	6.022E-02			**1.758E-02**
14000.50C	6.018E-03				1.27E-03	**6.859E-04**
15031.50C					6.91E-05	**3.905E-06**
16032.50C					4.46E-05	**2.522E-06**
24000.50C					1.56E-02	**8.787E-04**
25055.50C					1.73E-03	**9.784E-05**
26000.50C					5.58E-02	**3.154E-03**
28000.50C					9.72E-03	**5.493E-04**
42000.50C					1.24E-03	**7.003E-05**
1001.50C	2.718E-02			6.694E-02		**4.146E-02**
8016.50C	1.359E-02			3.347E-02		**2.073E-02**

Number Densitie	Basket Homogenized
92235.50C	1.913E-04
92238.50C	7.299E-04
6000.50C	6.712E-06
7014.50C	1.919E-05
13027.50C	1.758E-02
14000.50C	6.859E-04
15031.50C	3.905E-06
16032.50C	2.522E-06
24000.50C	8.787E-04
25055.50C	9.784E-05
26000.50C	3.154E-03
28000.50C	5.493E-04
42000.50C	7.003E-05
1001.50C	4.146E-02
8016.50C	2.073E-02
	8.616E-02

Homogenized ORR Cylinder
(Water-Logged Fuel Meat)

Active Fuel Length	60.9450					
Assembly OD	7.6100	8.357	(Width and Height)			
Assembly Volume	3875.9051					
Fuel Meat Volumes				**Comb Plates**		
Inner Meat Volume	24.9589	17	Each	Thickness	0.475	
Outer Meat Volume	24.9998	2	Each	Height	8.049	
Total Meat Volume	**474.3009**			Total Volume	**466.0189898**	
Clad/Meat Ratio	1.6000	(0.051-.020)/.020		**Water**		
Total Clad Volume	**758.88144**			Total Volume	**2176.7038**	
Total Plate Volume	1233.1823					
Assembly	Fuel Meat	Cladding	Comb Plate	Water	Assembly	
Volume Fractions	0.1224	0.1958	0.1202	0.5616	1.0000	
Fuel Cell						
Width	8.1180	Height	8.8640	Volume	4385.4774	
Water Layer Vol.	**509.5722**					
Steel Tube Wall						
Width	8.3680	Height	9.1140	Volume	4648.0284	
Steel Layer Vol.	**262.5511**		Total Basket Volume		46480.28445	
Water in Cylinder						
Cyl. Inner Radius	20.4650		Cylinder	Volume	80188.38345	
Water Volume	33708.0990					
Cell	Fuel Meat	Cladding	Comb Plate	Water	Basket Steel	Basket Supports
Volume Fractions	0.0591	0.0946	0.0581	0.3350	0.0327	0.4204
					Total =	1.0000
Number Densities					Basket	**Cylinder**
	Fuel Meat	Cladding	Comb Plate	Water	Structure	**Homogenized**
92235.50C	1.875E-03					**1.109E-04**
92238.50C	7.153E-03					**4.231E-04**
6000.50C					1.19E-04	**6.888E-06**
7014.50C					3.40E-04	**1.969E-05**
13027.50C	1.680E-02	6.022E-02	6.022E-02			**1.019E-02**
14000.50C	6.018E-03				1.27E-03	**4.296E-04**
15031.50C					6.91E-05	**4.007E-06**
16032.50C					4.46E-05	**2.588E-06**
24000.50C					1.56E-02	**9.017E-04**
25055.50C					1.73E-03	**1.004E-04**
26000.50C					5.58E-02	**3.237E-03**
28000.50C					9.72E-03	**5.637E-04**
42000.50C					1.24E-03	**7.186E-05**
1001.50C	2.718E-02			6.694E-02		**5.048E-02**
8016.50C	1.359E-02			3.347E-02		**2.524E-02**

Note: Basket Supports are assumed to be solid steel blocks surrounding basket tube array.

note that basket
supports are assumed to be
6% of the volume outside
of the basket with the remainder
being water. this is based on the fact that
5.6% of the homogenized basket
volume was steel

Number Densities	Cylinder Homogenized
92235.50C	1.109E-04
92238.50C	4.231E-04
6000.50C	6.888E-06
7014.50C	1.969E-05
13027.50C	1.019E-02
14000.50C	4.296E-04
15031.50C	4.007E-06
16032.50C	2.588E-06
24000.50C	9.017E-04
25055.50C	1.004E-04
26000.50C	3.237E-03
28000.50C	5.637E-04
42000.50C	7.186E-05
1001.50C	5.048E-02
8016.50C	2.524E-02
	9.179E-02

7.3.2-1: ORR Degraded Fuel - In CoDisposal Basket

NO BORON		k-caculated	sigma	k-effective
ORRHASBL	Homogenized Assembly	0.84944	0.00138	0.87220
ORRSAB1	Homogenized Water Gap	0.87496	0.00142	0.89780
ORRSAB2	Homogenized Basket Steel	0.93429	0.00144	0.95717
ORRSAB3	Homogenized Cylinder	0.41517	0.00108	0.43733
Axial Boron Divider Plates				
ORR1	Homogenized Assembly	0.77988	0.00139	0.80266
ORR2	Homogenized Water Gap	0.80703	0.00151	0.83005
ORR3	Homogenized Basket Steel	0.87177	0.00153	0.89483
ORR4	Homogenized Cylinder	0.38910	0.00098	0.41106

7.3.2-1: ORR Intact Fresh Fuel in DHLW Five Pack

Case Name	Percent H2O* in Fuel Me	k-calculated	sigma	k-effective
ORR10E	0	0.84389	0.00150	0.86689
ORR10G	25	0.85397	0.00149	0.87695
ORR10H	50	0.86274	0.00151	0.88576
ORR10I	75	0.86317	0.00118	0.88553
ORR10J	95	0.87276	0.00156	0.89588
ORR10F	100	0.87355	0.00152	0.89659

* Percentage of maximum of volume percent water in fuel meat.

```
HOMOGENIZED MIT CELL inc. WATER LAYER, SS/B Dividers, 1.5 cm XM-19, Detailed
C    DHLW Canisters Dropped to Bottom
C      DHLW CANISTER
1     3  -2.85   -1 -3 4   IMP:N=1 U=1 $ DHLW GLASS
2     5  -7.9    1  -3 4 IMP:N=1 U=1 $ SS304L CANISTER WALL
3     5  -7.9    3     IMP:N=1 U=1 $ SS304L CANISTER TOP
4     5  -7.9   -4     IMP:N=1 U=1 $ SS304L CANISTER TOP
C     GLASS LOGS
11    1  1.0032-1  -2  -5 6  FILL=1 TRCL=(-8. 47.7 0) IMP:N=1   $ DHLW GLASS
12    LIKE 11 BUT TRCL=(55.2 9. 0)
13    LIKE 11 BUT TRCL=(30.5 -46.9 0)
14    LIKE 11 BUT TRCL=(-30.5 -46.9 0)
15    LIKE 11 BUT TRCL=(-55.2 9. 0)
C
C    ARRAY OF PLATES IS HOMOGENIZED
C
20   2  8.9482-2          -80 81 -53 54    IMP:N=1  U=3  $ HOMOGENIZED FUEL PLATES
C
21   1  1.0032-1          -80 81 53        IMP:N=1  U=3  $ water above Assembly (Z)
22   1  1.0032-1          -80 81 -54       IMP:N=1  U=3  $ Water below Assembly (Z)
C
23   8  8.8111-2  -81                      IMP:N=1  U=3  $ steel left Assembly
24   8  8.8111-2   80                      IMP:N=1  U=3  $ steel right Assembly
C
25   9  8.5935-2   108                     IMP:N=1  U=4  $ Steel/water Universe for padding ends of arrays
26   1  1.0032-1  109 -108                IMP:N=1  U=4
27   9  8.5935-2   -109                    IMP:N=1  U=4  $ Steel/water Universe for padding ends of arrays
C
C
C
C    SET UP UNIVERSES CONTAINING FUEL ASSEMBLIES
28   1  1.0032-1 -100 101  -40 41   u=5 imp:n=1 lat=1    $ array for right group of two assemblies
     fill=-3:3 -1:1 -1:1
     4 4 4 4 4 4 4  4 4 4 4 4 4 4  4 4 4 4 4 4 4
     4 4 4 4 4 4 4  4 4 3 3 4 4 4  4 4 4 4 4 4 4
     4 4 4 4 4 4 4  4 4 4 4 4 4 4  4 4 4 4 4 4 4
      trcl=(6.20 0 0)
29   LIKE 28 BUT TRCL=(-14.100 0 0) U=6                 $ array for left group of two assemblies
C
35   1  1.0032-1 -100 101  -40 41   u=7 imp:n=1 lat=1    $ array for lower group of four assemblies
     fill=-3:3 -1:1 -1:1
     4 4 4 4 4 4 4  4 4 4 4 4 4 4  4 4 4 4 4 4 4
     4 4 4 4 4 4 4  4 3 3 3 3 4 4  4 4 4 4 4 4 4
     4 4 4 4 4 4 4  4 4 4 4 4 4 4  4 4 4 4 4 4 4
     trcl=(-2.58 -7.654 0)
36   LIKE 35 BUT TRCL=(-4.5 7.654 0)  U=8                $ array for upper group of four assemblies
C
37   LIKE 28 BUT TRCL=(-6.179 15.05 0)  U=9              $ array for TOP ROW - Left
C
38   LIKE 28 BUT TRCL=(6.179 14.92 0  -1 0 0  0 1 0  0 0 1) U=10 $ array for TOP ROW - Right
C
39   LIKE 28 BUT TRCL=( 6.179 -15.06 0) U=11             $ array for bottom group of TWO assemblies
C
40   LIKE 28 BUT TRCL=(-6.179 -15.05 0  1 0 0  0 -1 0  0 0 1) U=12 $ array for TOP group of TWO assemblies
C
C
C    THE FUEL ASSEMBLIES ARE CONSTRUCTED.  NOW CONSTRUCT THE FUEL BASKET AND INSERT THE ASSEMBLIES
C
41   0             -106 95  -102 103  -200 210 IMP:N=1  FILL=5 U=13 $  Center right two assemblies
C
42   0              107 -96 -102 103  -200 210 IMP:N=1  FILL=6 U=13 $  Center left two assemblies
C
43   9  8.5935-2  -95 96   -102 103  -200 210      IMP:N=1  U=13 $ Steel Divider between Center asbl groups
44   9  8.5935-2  -300 106  -102 103  -200 210     IMP:N=1  U=13 $ Steel to right of Center asbl groups
46   9  8.5935-2  -300 -107  -102 103  -200 210    IMP:N=1  U=13 $ Steel to left of Center asbl groups
C      Now insert steel above (X,Y) and below the central row of four assemblies
54   9  8.5935-2  -300 -103 111 -200 210         IMP:N=1 U=13  $ Steel plate Below Central Row of Four
55   8  8.8111-2  113 -114 -111 112  -200 210    IMP:N=1 U=13  $ SS316B2A below steel plate
56   9  8.5935-2  114 -300 -111 112  -200 210    IMP:N=1 U=13  $ Steel to right of SS316B2A
57   9  8.5935-2 -113 -300 -111 112  -200 210    IMP:N=1 U=13  $ Steel to left of SS316B2A
```

```
c
60   9  8.5935-2  -300 102 -120 -200 210         IMP:N=1 U=13  $ Steel plate Above Central Row of Four
c      The lower middle row of four assemblies are separated by a thin steel plate
70   0        104  -300 -112 115  -200 210      IMP:N=1  FILL=7 U=13 $  Lower Middle Row
71   9  8.5935-2   105 -104 -300 -112 115 -200 210  IMP:N=1 U=13    $ Steel vertical bar to left of lower middle row
72   1  1.0032-1 -300 -105 -112 115 -200 210  IMP:N=1  U=13  $ Water to left of Steel vertical bar
c
75   9  8.5935-2  -300 -115 116  -200 210      IMP:N=1  U=13  $ Steel below Lower Middle Row
c
c
c    The instructions below describe the boron stainless plate above the center row of assemblies
81   8  8.8111-2  123 -124  120 -122  -200 210     IMP:N=1  U=13  $ SS316B2A above steel plate
82   9  8.5935-2  124 -300  120 -122  -200 210     IMP:N=1  U=13  $ Steel to right of SS316B2A
83   9  8.5935-2 -123 -300  120 -122  -200 210     IMP:N=1  U=13  $ Steel to left of SS316B2A
c      The upper middle row of four assemblies are created below
90   0     -130     -300  122 -125  -200 210      IMP:N=1  FILL=8 U=13 $  Upper Middle Row
91   9  8.5935-2    130 -131   -300 122 -125 -200 210  IMP:N=1 U=13 $ Steel vertical bar to right of upper middle row
92   1  1.0032-1   -300  131  122 -125 -200 210   IMP:N=1 U=13 $ Water to right of Steel vertical bar
95   9  8.5935-2  -300  125 -126  -200 210        IMP:N=1 U=13 $ Steel above Upper Middle Row
c
c
c     The cell cards below construct the uppermost row of two assemblies
100   9  8.5935-2    96  -95  126 -147  -200 210     IMP:N=1  U=13  $ Steel center bar
101   9  8.5935-2    95  -141 126 -140  -200 210     IMP:N=1  U=13 $ Steel on right side
102   8  8.8111-2   141  -142 126 -140  -200 210     IMP:N=1  U=13 $ SS316B2A
103   9  8.5935-2   142  -300 126 -140  -200 210     IMP:N=1  U=13 $ Steel on right side
104   9  8.5935-2  -96    143 126 -140  -200 210     IMP:N=1  U=13 $ Steel on left side
105   8  8.8111-2 -143    144 126 -140  -200 210     IMP:N=1  U=13 $ SS316B2A
106   9  8.5935-2 -144  -300 126 -140  -200 210     IMP:N=1  U=13 $ Steel on left side
c
c     The following cell cards construct the steel angles to left and right of the center bar
107   1  1.0032-1       -96  -145 140 -147  -200 210  IMP:N=1 U=13 $ Water to left of Steel vertical bar
108   9  8.5935-2  -96    145 -146 140 -147  -200 210  IMP:N=1 U=13 $ Steel to left of center
110   1  1.0032-1         95  -149 140 -147  -200 210  IMP:N=1 U=13 $ Water to right of Steel vertical bar
111   9  8.5935-2   95    149 -150 140 -147  -200 210  IMP:N=1 U=13 $ Steel to right of center
c
112   9  8.5935-2  -96    151 -152 140 -147  -200 210  IMP:N=1 U=13 $ Steel at left side
113   1  1.0032-1  -96    152 -300 140 -147  -200 210  IMP:N=1 U=13 $ Water at left
114   9  8.5935-2   95    153 -154 140 -147  -200 210  IMP:N=1 U=13 $ Steel at right
115   1  1.0032-1   95    154 -300 140 -147  -200 210  IMP:N=1 U=13 $ Water at right
c
c     Left Top Assembly
120  0     -96  146 -151 140 -147  -200 210 IMP:N=1  FILL=9 U=13 $  Center left assembly
121  0      95  150 -153 140 -147  -200 210 IMP:N=1  FILL=10 U=13 $  Center right assembly
c
129   9  8.5935-2  -300       147 -148  -200 210    IMP:N=1 U=13 $ Horizontal Steel Above Top Row
c
130   1  1.0032-1  -300  148            -200 210    IMP:N=1 U=13 $ Water above Upper Middle Row
c
c     The cell cards below construct the bottommost row of two assemblies
140   9  8.5935-2    96  -95  -116  177  -200 210     IMP:N=1  U=13  $ Steel center bar
141   9  8.5935-2    95  -171 -116  170  -200 210     IMP:N=1  U=13  $ Steel on right side
142   8  8.8111-2   171  -172 -116  170  -200 210     IMP:N=1  U=13  $ SS316B2A
143   9  8.5935-2   172  -300 -116  170  -200 210     IMP:N=1  U=13  $ Steel on right side
144   9  8.5935-2  -96    173 -116  170  -200 210     IMP:N=1  U=13  $ Steel on left side
145   8  8.8111-2 -173    174 -116  170  -200 210     IMP:N=1  U=13  $ SS316B2A
146   9  8.5935-2 -174  -300 -116  170  -200 210     IMP:N=1  U=13  $ Steel on left side
c
c     The following cell cards construct the steel angles to left and right of the center bar
147   1  1.0032-1       -96   175 -170  177  -200 210  IMP:N=1 U=13 $ Water to left of Steel vertical bar
148   9  8.5935-2  -96  -175   176 -170  177  -200 210  IMP:N=1 U=13 $ Steel to left of center
150   1  1.0032-1         95   179 -170  177  -200 210  IMP:N=1 U=13 $ Water to right of Steel vertical bar
151   9  8.5935-2   95  -179   180 -170  177  -200 210  IMP:N=1 U=13 $ Steel to right of center
c
152   9  8.5935-2  -96  -181   182 -170  177  -200 210  IMP:N=1 U=13 $ Steel at left side
153   1  1.0032-1  -96  -182  -300 -170  177  -200 210  IMP:N=1 U=13 $ Water at left
154   9  8.5935-2   95  -183   184 -170  177  -200 210  IMP:N=1 U=13 $ Steel at right
155   1  1.0032-1   95  -184  -300 -170  177  -200 210  IMP:N=1 U=13 $ Water at right
c
c     Bottom Assemblies
```

```
160  0    -96  -176  181 -170  177  -200 210 IMP:N=1  FILL=12 U=13 $  Center left assembly
161  0     95  -180  183 -170  177  -200 210 IMP:N=1  FILL=11 U=13 $  Center right assembly
c
169   9  8.5935-2  -300     -177 178  -200 210     IMP:N=1 U=13 $ Horizontal Steel Above Top Row
c
170   1  1.0032-1  -300  -178            -200 210      IMP:N=1 U=13 $ Water above Upper Middle Row
c
c
c
200   8  8.8111-2  -300  200 -220            IMP:N=1  U=13  $ SS316B2A above Assemblies in Z-direction
201   8  8.8111-2  -300 -210  230            IMP:N=1  U=13  $ SS316B2A above Assemblies (Z)
210   1  1.0032-1  -300  220                 IMP:N=1  U=13  $ Water above
211   1  1.0032-1  -300 -230                 IMP:N=1  U=13  $ Water above
c
c
250   0  -320 321 -322 323 -225 235  LAT=1  U=14 IMP:N=1
      FILL=0:0 0:0 -3:3  13 13 13 13 13 13 13 TRCL=(0 0 32.5) $ Stack of fuel basket segments
c
c
300  0  -36  -24  25 U=2  FILL=14 IMP:N=1   $  FUEL ASSEMBLIES & BASKET
c
301   6  -7.88       36  -24  25 U=2  IMP:N=1       $ Steel Codisposal Tube Wall
302   6  -7.88           24      U=2  IMP:N=1       $ Steel Codisposal Tube Wall
303   6  -7.88               -25 U=2  IMP:N=1       $ Steel Codisposal Tube Wall
305   0               -37 -26  27   FILL=2 TRCL=(0 -4.2 0) IMP:N=1   $ Codisposal Canister
C     INSIDE CONTAINER
360    1    1.0032-1 -10 -14 15  #11 #12 #13 #14 #15 #305 IMP:N=1
C     WP
361    4    -8.4425    10 -11 -14 15  IMP:N=1 $ INNER BARRIER SIDE
362    4    -8.4425    -11  14 -16 IMP:N=1    $ INNER BARRIER TOP
363    4    -8.4425    -11 -15  17  IMP:N=1   $ INNER BARRIER BOTTOM
364    7    -7.832    11 -12 -16 17  IMP:N=1 $ OUTER BARRIER SIDE
365    7    -7.832    -12  16 -18 IMP:N=1    $ OUTER BARRIER TOP
366    7    -7.832    -12 -17  19  IMP:N=1   $ OUTER BARRIER BOTTOM
367    1    1.0032-1  12 -13 -18 19  IMP:N=1 $ REFLECTOR SIDE
368    1    1.0032-1  -13  18 -20 IMP:N=1    $ REFLECTOR TOP
369    1    1.0032-1  -13 -19  21  IMP:N=1   $ REFLECTOR BOTTOM
C     OUTSIDE WORLD
381    0  13:20:-21   IMP:N=0

C     SURFACE SPECIFICATIONS
1     CZ 29.528
2     CZ 30.48
3     PZ  137.13
4     PZ -137.13
5     PZ  138.7175
6     PZ -138.7175
C     CELL FILL CARDS
7     CZ 31
8     PZ  140
9     PZ -140
10    CZ  86.5    $  IR of WP
11    CZ  88.5    $  OUTSIDE OF WASTE INNER BARRIER WALL
12    CZ  98.5    $  OUTSIDE OF WASTE OUTER BARRIER WALL
13    CZ  113.5   $  AIR REFLECTOR OUTSIDE CONTAINER
14    PZ  152     $ INNER HEIGHT OF CONTAINER
15    PZ -152
16    PZ  154.5   $ TOP OF INNER BARRIER LID
17    PZ -154.5
18    PZ  165.5   $ TOP OF OUTER BARRIER LID
19    PZ -165.5
20    PZ  180.5   $ TOP OF AIR REFLECTOR
21    PZ -180.5
c
24    PZ  129.9  $ TOP OF STACK OF FOUR ASSEMBLIES
25    PZ -129.9  $ TOP OF STACK OF FOUR ASSEMBLIES
26    PZ  131.4  $ TOP OF CANISTER LID
27    PZ -131.4  $ TOP OF CANISTER LID
c
36  CZ  20.465   $ Inner Radius of Codisposal Tube Wall
```

```
37  CZ  21.965   $ Outer Radius of Codisposal Tube Wall
c
c
40   PY  3.278  $ Top of Assembly Array (INCLUDING WATER LAYER)
41   PY -3.278  $ Bottom of Assembly Array
c    Fuel Plate Dimensions
51   PZ  28.8925  $ Max Length of Fuel
52   PZ -28.8925
53   PZ  29.2100  $ Fuel Plate Length
54   PZ -29.2100
55   PY  2.76479  $ Max Width of Fuel
56   PY -2.76479
57   PY  4.  $ Fuel Plate Width   3.24104 actual
58   PY -4.
59   PX  0.03810  $ Max Fuel Thickness
60   PX -0.03810
61   PX  0.08001  $ Minimum Clad Thickness
62   PX -0.08001
63   P  -1.732051 1. 0. -0.40132    $ Water Gap  0.20066 translated
64   P  -1.732051 1. 0.  0.40132
c    Assembly Dimensions
c    PLATE DIMENSIONS FIRST
70   P  -0.57735 1. 0. -2.931473  $ Slot gap
71   P  -0.57735 1. 0.  2.931473
72   PY  2.85115 $ Top of Array
73   PY -2.85115 $ Bottom of Array
74   PY  3.01625 $ Top of Assembly
75   PY -3.01625 $ Bottom of Assembly
c    PLATE ARRAY DIMENSIONS
76   P  -1.732051 1. 0.  5.88518 $ right Side of Plate Array
77   P  -1.732051 1. 0. -5.88518 $ left Side of Plate Array
78   P  -1.732051 1. 0.  6.1087 $ right Side of Assembly
79   P  -1.732051 1. 0. -6.1087 $ left Side of Assembly
80   P  -1.732051 1. 0.  6.6250 $ right Inside of steel divider plate
81   P  -1.732051 1. 0. -6.6250 $ left Inside of steel divider plate
c    Assembly Array
c
95   PX  .452    $ Right side of vertical bar between groups of two assemblies
96   PX  -.452   $ Left side of vertical bar
c
100  P  -1.732051 1. 0.  6.871  $ right Side of Assembly Array
101  P  -1.732051 1. 0. -6.871  $ left Side of Assembly Array
102  PY  3.278  $ Top of Assembly Array (INCLUDING WATER LAYER)
103  PY -3.278  $ Bottom of Assembly Array
c
104  PX -16.634    $ Right side of vertical bar to left of Lower Middle Assembly array
105  PX -17.600    $ Left Side of vertical bar
c
106  PX  19.605 $ right Side steel of middle assembly layer
107  PX -19.605 $ left Side  steel
c
108  P  -1.732051 1. 0.  5.00  $ right Side of steel filler block
109  P  -1.732051 1. 0. -5.00  $ left Side of steel filler block
c
111  PY  -4.13  $  Lower Boundary of steel plate below central row of four assemblies
112  PY  -4.384 $  Lower Boundary of boron stainless (thickness= 0.100 inches or 2.54 mm)
113  PX  -12.19 $  LEFT corner of boron stainless plate
114  PX   18.904 $ RIGHT corner of boron stainless plate (yes, it is offset)
115  PY  -10.940 $ Bottom of lower middle layer of four fuel assemblies
116  PY  -11.665 $ Bottom of steel below middle layer of four fuel assemblies
c
120  PY   4.13  $  Upper Boundary of steel plate below central row of four assemblies
c
122  PY   4.384 $  Boundary of boron stainless (thickness= 0.100 inches or 2.54 mm)
123  PX   -18.19 $  LEFT corner of boron stainless plate
124  PX   12.980 $ RIGHT corner of boron stainless plate (yes, it is offset)
125  PY   10.940 $ Top of upper middle layer of four fuel assemblies
126  PY   11.665 $ Top of steel above upper middle layer of four fuel assemblies
130  PX  16.634    $ Left side of vertical bar to right of Upper Middle Assembly array
131  PX  17.600    $ Right Side of vertical bar
```

```
c
c    The following surfaces are related to the top and bottom rows of two each
140  PY  11.919     $ Top of stainless/boron layer
141  PX  4.45       $ Left corner of ss/b for right side
142  PX  11.4       $ Right corner of ss/b for right side
143  PX  -4.45       $ Left corner of ss/b for right side
144  PX  -11.4       $ Right corner of ss/b for right side
145  P  -1.732051 1. 0.  17.345  $ Left Side Central Bar - inner edge
146  P  -1.732051 1. 0.  18.940  $ Left Side Central Bar - outer edge
147  PY  18.275      $ Bottom Edge of Horizontal Steel for upper row of two assemblies
148  PY  19.275      $ Upper Edge of Horizontal Steel for upper row of assemblies
149  P    1.732051 1. 0.  17.345  $ Right Side Central Bar - inner edge
150  P    1.732051 1. 0.  18.940  $ Right Side Central Bar- outer edge
c
151  P  -1.732051 1. 0.  32.222  $ Left Side Steel - inner edge
152  P  -1.732051 1. 0.  33.707  $ Left Side Steel - outer edge
153  P    1.732051 1. 0.  32.222  $ Right Side Steel - inner edge
154  P    1.732051 1. 0.  33.707  $ Right Side Steel - outer edge
c
c
c    The following surfaces are related to the top and bottom rows of two each
170  PY  -11.919     $ Top of stainless/boron layer
171  PX  4.45       $ Left corner of ss/b for right side
172  PX  11.4       $ Right corner of ss/b for right side
173  PX  -4.45       $ Left corner of ss/b for right side
174  PX  -11.4       $ Right corner of ss/b for right side
175  P    1.732051 1. 0.  -17.345  $ Left Side Central Bar - inner edge
176  P    1.732051 1. 0.  -18.940  $ Left Side Central Bar - outer edge
177  PY  -18.275      $ Bottom Edge of Horizontal Steel for upper row of two assemblies
178  PY  -19.275      $ Upper Edge of Horizontal Steel for upper row of assemblies
179  P    -1.732051 1. 0.  -17.345  $ Right Side Central Bar - inner edge
180  P    -1.732051 1. 0.  -18.940  $ Right Side Central Bar- outer edge
c
181  P     1.732051 1. 0.  -32.222  $ Left Side Steel - inner edge
182  P     1.732051 1. 0.  -33.707  $ Left Side Steel - outer edge
183  P    -1.732051 1. 0.  -32.222  $ Right Side Steel - inner edge
184  P    -1.732051 1. 0.  -33.707  $ Right Side Steel - outer edge
c
c
c    TOP AND BOTTOM ENDS OF A MIT FUEL ASBL AND THE BASKET SEGMENT
200  PZ  32     $ Boundary of water layer above fuel
210  PZ -32     $ Boundary of water layer below fuel
220  PZ  33.   $ Reflected Halfway through SS316B2A plate
225  PZ  32.5  $ Reflected Halfway through SS316B2A plate
230  PZ -33.   $ Reflected Halfway through SS316B2A plate
235  PZ -32.5  $ Reflected Halfway through SS316B2A plate
c
300  CZ  25.       $ DUMMY Inner Radius of Codisposal Tube Wall for universe nesting
c
320    PX   30.   $  DUMMY COORDINATES FOR AXIAL STACKING
321    PX  -30.
322    PY   30.
323    PY  -30.

MODE N
KCODE 3500 1.0 20 120
c      SDEF  RAD=D1  EXT=D2 ERG=D3 AXS 0 0 1
c      SI1  0. 20.4
c      SI2  129.
c      SP3   -3
c
c       MATERIAL SPECIFICATIONS
M1     1001.50C 6.6878-2  $ WATER
       8016.50C 3.3439-2
MT1     LWTR.01T
M2    92234.50C          4.9235-06  $ Homogenized Fuel (INCLUDING Side Plates)
      92235.50C          4.5839-04
      92238.50C          2.6624-05
      13027.50C          1.4650-02
      14000.50C          7.5220-05
```

```
     24000.50C         1.6929-05
     12000.50C         1.4487-04
     29000.50C         1.3852-05
     1001.50C          4.9394-02
     8016.50C          2.4697-02
MT2    LWTR.01T
C    DHLW Glass
M3     3006.50C -1.080-1   3007.55C -1.332     5010.50C -6.234-1 $ DHLW GLASS
       5011.56C -2.509     8016.50C  -4.4102+1  9019.50C -3.108-2
      11023.50C -8.233    12000.50C -8.046-1  13027.50C -2.057
      14000.50C -2.1967+1 16032.50C -1.263-1  19000.50C -2.916
      20000.50C -6.458-1  22000.50C -5.823-1  25055.50C -1.520
      26000.55C -7.211    28000.50C -7.170-1  15031.50C -1.372-2
      24000.50C -8.055-2 29000.50C  -1.489-1  47109.50C -4.906-2
      56138.50C -8.083-2 82000.50C -5.948-2   17000.50C -1.131-1
      90232.50C -1.811-1  62149.50C -4.411-4  92233.50C -9.727-9
      92234.50C -3.261-4  92236.50C -1.036-3  93237.55C -7.509-4
      92235.50C -1.734-2  92238.50C -3.674    94238.50C -5.153-3
      94239.55C -1.234-2  94240.50C -2.265-3  94241.50C -9.631-4
      94242.50C -1.906-4  95241.50C -1.908-4  95242.50C -8.847-8
      95243.50C -1.725-6  96245.35C -2.325-9
C        INCOLOY ALLOY 825
M4      6000.50C  -0.05  13027.50C  -0.20  14000.50C  -0.50
     16032.50C  -0.03  22000.50C  -0.90  24000.50C -21.50
     25055.50C  -1.00  26000.55C -28.57  28000.50C -42.00
     29000.50C  -2.25  42000.50C  -3.00
C        SS304L D=7.9 G/CC
M5      6000.50C  -0.030 7014.50C  -0.100 14000.50C -0.75
     15031.50C  -0.045 16032.50C  -0.030 24000.50C -19.000
     25055.50C  -2.000 26000.55C -68.045 28000.50C -10.000
M6      6000.50C  -.06  7014.50C  -.3 14000.50C -.75  $ XM-19 SS
     15031.50C  -.04 16032.50C  -.03 24000.50C -22
     25055.50C  -5. 26000.55C -57.07 28000.50C -12.5
     42000.50C  -2.25
C        A 516 CARBON STEEL
M7      6000.50C  -0.22   25055.50C  -0.90   14000.50C  -0.275  $ A516
     16032.50C  -0.035  15031.50C  -0.035  26000.55C  -98.535 $ 7.832 g/cc
M8      5010.50C  5.5313-4  5011.56C 3.0557-3  $ Borated Stainless SS316B3A@75%B-10
        6000.50C  1.1778-4  7014.50C  3.3676-4 14000.50C 1.2592-3
     15031.50C  6.8511-5 16032.50C  4.4248-5 24000.50C 1.7232-2
     25055.50C  1.7167-3 26000.55C 5.1655-2 28000.50C 1.0843-2
     42000.50C  1.2388-3
M9      6000.50C  1.1883-4  7014.50C  3.3977-4 14000.50C 1.2705-3  $ 316L SS
     15031.50C  6.9123-5 16032.50C  4.4643-5 24000.50C 1.5556-2
     25055.50C  1.7321-3 26000.55C 5.5840-2 28000.50C 9.7247-3
     42000.50C  1.2398-3
C
C
PRINT
```

```
orroz3 - HOMO ORR CELL inc. WATER LAYER, SS/B Dividers, 1.5 cm XM-19, Detailed
C    DHLW Canisters Dropped to Bottom
C      DHLW CANISTER
1     3  -2.85    -1 -3 4   IMP:N=1 U=1 $ DHLW GLASS
2     5  -7.9     1  -3 4 IMP:N=1 U=1 $ SS304L CANISTER WALL
3     5  -7.9     3     IMP:N=1 U=1 $ SS304L CANISTER TOP
4     5  -7.9    -4     IMP:N=1 U=1 $ SS304L CANISTER TOP
C     GLASS LOGS
11    1  1.0032-1  -2  -5 6  FILL=1 TRCL=(-8. 47.7 0) IMP:N=1   $ DHLW GLASS
12    LIKE 11 BUT TRCL=(55.2 9. 0)
13    LIKE 11 BUT TRCL=(30.5 -46.9 0)
14    LIKE 11 BUT TRCL=(-30.5 -46.9 0)
15    LIKE 11 BUT TRCL=(-55.2 9. 0)
C
C     HOMOGENIZED CELL SPECIFICATIONS
C
100    2   8.618-2 -141 142 -143 144  190 -191 IMP:N=1 U=3  $ HOMOG. FUEL
101    1   1.0032-1 -141 142 -143 144 -190  192 IMP:N=1 U=3  $ Water Below FUEL
102    1   1.0032-1 -141 142 -143 144  191 -193 IMP:N=1 U=3  $ Water Below FUEL
C
103    9   -7.9497 (141:-142:143:-144) 192 -193  IMP:N=1 U=3  $ STEEL Basket
C
104   8  8.8111-2  -192  IMP:N=1  U=3 $ STEEL/BORON BOTTOM
105   8  8.8111-2   193  IMP:N=1  U=3 $ STEEL/BORON TOP
C
110    1   1.0032-1  -141 142 -143 144  192 -193    IMP:N=1 U=2 $ WATER
111    9   -7.9497 (141:-142:143:-144)  192 -193   IMP:N=1 U=2  $ More Water
C
112   8  8.8111-2  -192  IMP:N=1  U=2 $ STEEL/BORON BOTTOM
113   8  8.8111-2   193  IMP:N=1  U=2 $ STEEL/BORON TOP
C
C
C
150   0   -151 +152 -153 +154 194 -195 IMP:N=1   LAT=1
     TRCL=(-1.80 0.295 35.4489) U=14
      FILL -3:3  -2:2  -2:3
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 3 3 3 2 2
      2 2 3 3 3 3 2
      2 2 3 3 3 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 3 3 3 2 2
      2 2 3 3 3 3 2
      2 2 3 3 3 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 3 3 3 2 2
      2 2 3 3 3 3 2
      2 2 3 3 3 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 3 3 3 2 2
      2 2 3 3 3 3 2
      2 2 3 3 3 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
      2 2 2 2 2 2 2
C
C
C
300  0  -36  -24  25 U=4  FILL=14 IMP:N=1   $  FUEL ASSEMBLIES & BASKET
```

```
c
301   6  -7.88      36  -24  25 U=4  IMP:N=1       $ Steel Codisposal Tube Wall
302   6  -7.88           24     U=4  IMP:N=1       $ Steel Codisposal Tube Wall
303   6  -7.88               -25 U=4  IMP:N=1       $ Steel Codisposal Tube Wall
305   0              -37 -26  27   FILL=4 TRCL=(0 -4.2 0) IMP:N=1   $ Codisposal Canister
c     INSIDE CONTAINER
360    1   1.0032-1 -10 -14 15  #11 #12 #13 #14 #15 #305 IMP:N=1
c     WP
361    4   -8.4425   10 -11 -14 15  IMP:N=1 $ INNER BARRIER SIDE
362    4   -8.4425   -11  14 -16 IMP:N=1    $ INNER BARRIER TOP
363    4   -8.4425   -11 -15  17  IMP:N=1   $ INNER BARRIER BOTTOM
364    7   -7.832   11 -12 -16 17  IMP:N=1 $ OUTER BARRIER SIDE
365    7   -7.832   -12  16 -18 IMP:N=1     $ OUTER BARRIER TOP
366    7   -7.832   -12 -17  19  IMP:N=1   $ OUTER BARRIER BOTTOM
367    1   1.0032-1  12 -13 -18 19  IMP:N=1 $ REFLECTOR SIDE
368    1   1.0032-1  -13  18 -20 IMP:N=1    $ REFLECTOR TOP
369    1   1.0032-1  -13 -19  21  IMP:N=1   $ REFLECTOR BOTTOM
c     OUTSIDE WORLD
381    0  13:20:-21   IMP:N=0

c     SURFACE SPECIFICATIONS
1     CZ 29.528
2     CZ 30.48
3     PZ  137.13
4     PZ -137.13
5     PZ  138.7175
6     PZ -138.7175
c     CELL FILL CARDS
7     CZ 31
8     PZ  140
9     PZ -140
10    CZ  86.5    $  IR of WP
11    CZ  88.5    $  OUTSIDE OF WASTE INNER BARRIER WALL
12    CZ  98.5    $  OUTSIDE OF WASTE OUTER BARRIER WALL
13    CZ  113.5   $  AIR REFLECTOR OUTSIDE CONTAINER
14    PZ  152     $ INNER HEIGHT OF CONTAINER
15    PZ -152
16    PZ  154.5   $ TOP OF INNER BARRIER LID
17    PZ -154.5
18    PZ  165.5   $ TOP OF OUTER BARRIER LID
19    PZ -165.5
20    PZ  180.5   $ TOP OF AIR REFLECTOR
21    PZ -180.5
c
24    PZ  143.297  $ TOP OF STACK OF FOUR ASSEMBLIES
25    PZ -143.795  $ TOP OF STACK OF FOUR ASSEMBLIES
26    PZ  144.8  $ TOP OF CANISTER LID
27    PZ -145.3  $ BOTTOM OF CANISTER LID
c
36  CZ  20.465   $ Inner Radius of Codisposal Tube Wall
37  CZ  21.965   $ Outer Radius of Codisposal Tube Wall
c
c
c      ASSEMBLY OUTER DIMENSIONS
131    PX   3.805   $ RIGHT COMB PLATE OD (2.996" from Appendix A)
132    PX  -3.805   $ LEFT COMB PLATE OD
133    PY   3.756   $ TOP OF COMB PLATE  (center -0.422 cm) (3.29")
134    PY  -4.600   $ BOTTOM OF COMB PLATE (center +0.422 cm)
c
c      WATER GAP SURROUNDING FUEL ELEMENT
141    PX   4.059   $ RIGHT WATER LAYER (2.996"+0.200" outer boundary)
142    PX  -4.059   $ LEFT WATER LAYER (0.100" on a side)
143    PY   4.137   $ TOP WATER LAYER  (center -0.422 cm-.127) (3.29"+0.200")
144    PY  -4.727   $ BOTTOM WATER LAYER (center +0.422 cm -.127)
c
c
151    PX   4.309   $ RIGHT STEEL ID (STEEL IS 5 mm TOTAL THICKNESS)
152    PX  -4.309   $ LEFT STEEL ID  (SO ADD 2.5 mm TO OUTER EDGES)
153    PY   4.387   $ TOP OF STEEL ID
154    PY  -4.977   $ BOTTOM OF STEEL
```

```
C
C      Core Boundaries
C
190    PZ  -34.449  $ BOTTOM OF FUEL ELEMENT
191    PZ   34.449  $ TOP OF FUEL ELEMENT
192    PZ  -35.449  $ Water Below Fuel
193    PZ   35.449  $ Water Above Fuel
194    PZ  -35.949  $ Water Below Fuel
195    PZ   35.949  $ Water Above Fuel
C

MODE N
KCODE 3500 1.0 20 120
C     SDEF  RAD=D1  EXT=D2 ERG=D3 AXS 0 0 1
C     SI1  0. 20.4
C     SI2  129.
C     SP3   -3
C
C      MATERIAL SPECIFICATIONS
M1    1001.50C 6.6878-2  $ WATER
      8016.50C 3.3439-2
MT1    LWTR.01T
C      20. w/o URANIUM ALUMINUM ALLOY Homogenized
M2     92235.50C        2.028E-04
       92238.50C        7.736E-04
       13027.50C        1.864E-02
       14000.50C        6.509E-04
       1001.50C         4.394E-02
       8016.50C         2.197E-02
MT2    LWTR.01T
C    DHLW Glass
M3     3006.50C -1.080-1   3007.55C -1.332     5010.50C -6.234-1 $ DHLW GLASS
       5011.56C -2.509     8016.50C  -4.4102+1  9019.50C -3.108-2
      11023.50C -8.233    12000.50C -8.046-1  13027.50C -2.057
      14000.50C -2.1967+1 16032.50C -1.263-1  19000.50C -2.916
      20000.50C -6.458-1  22000.50C -5.823-1  25055.50C -1.520
      26000.55C -7.211    28000.50C -7.170-1  15031.50C -1.372-2
      24000.50C -8.055-2 29000.50C  -1.489-1  47109.50C -4.906-2
      56138.50C -8.083-2 82000.50C -5.948-2   17000.50C -1.131-1
      90232.50C -1.811-1  62149.50C -4.411-4  92233.50C -9.727-9
      92234.50C -3.261-4  92236.50C -1.036-3  93237.55C -7.509-4
      92235.50C -1.734-2  92238.50C -3.674    94238.50C -5.153-3
      94239.55C -1.234-2  94240.50C -2.265-3  94241.50C -9.631-4
      94242.50C -1.906-4  95241.50C -1.908-4  95242.50C -8.847-8
      95243.50C -1.725-6  96245.35C -2.325-9
C        INCOLOY ALLOY 825
M4     6000.50C  -0.05  13027.50C  -0.20  14000.50C  -0.50
     16032.50C  -0.03  22000.50C  -0.90  24000.50C -21.50
     25055.50C  -1.00  26000.55C -28.57  28000.50C -42.00
     29000.50C  -2.25  42000.50C  -3.00
C        SS304L D=7.9 G/CC
M5     6000.50C  -0.030 7014.50C  -0.100 14000.50C -0.75
     15031.50C  -0.045 16032.50C  -0.030 24000.50C -19.000
     25055.50C  -2.000 26000.55C -68.045 28000.50C -10.000
M6     6000.50C  -.06  7014.50C  -.3 14000.50C -.75  $ XM-19 SS
     15031.50C  -.04 16032.50C  -.03 24000.50C -22
     25055.50C  -5. 26000.55C -57.07 28000.50C -12.5
     42000.50C  -2.25
C        A 516 CARBON STEEL
M7     6000.50C  -0.22   25055.50C  -0.90   14000.50C  -0.275  $ A516
     16032.50C  -0.035  15031.50C  -0.035  26000.55C  -98.535 $ 7.832 g/cc
M8     5010.50C  5.5313-4  5011.56C 3.0557-3  $ Borated Stainless SS316B3A@75%B-10
       6000.50C  1.1778-4  7014.50C  3.3676-4 14000.50C 1.2592-3
     15031.50C  6.8511-5 16032.50C  4.4248-5 24000.50C 1.7232-2
     25055.50C  1.7167-3 26000.55C 5.1655-2 28000.50C 1.0843-2
     42000.50C  1.2388-3
M9     6000.50C  1.1883-4  7014.50C  3.3977-4 14000.50C 1.2705-3  $ 316L SS
     15031.50C  6.9123-5 16032.50C  4.4643-5 24000.50C 1.5556-2
     25055.50C  1.7321-3 26000.55C 5.5840-2 28000.50C 9.7247-3
     42000.50C  1.2398-3
```

```
C
C
PRINT
```

```
=sas2h    parm='skipshipdata'
MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU, 5 Year Decay
238group    latticecell
'
'  mixtures of fuel-plate-unit-cell:
arbmualx 2.188 4 0 1 0 92235 0.935 92234 0.01 92238 0.055
 13027 3.9509 1 1 500 end
arbmal 2.64 1 0 0 0 13027 100. 2 1 500 end
h2o       3 den=1. 1 400 end
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'  fuel-plate-cell geometry:
'
symmslabcell  0.40132  0.0762 1 3 0.16002 2 end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'
'  assembly and cycle parameters:
' volume normalized to provide 8100 MWD/MTU
ncycles=4 nlib/cyc=4  npin/assm=1 fuelngth=57.785
printlevel=6 lightel=0   volfueltot=6.64E+5  end
power=9.68 burn=209.2 down=554.4 end
power=9.68 burn=209.2 down=554.4  end
power=9.68 burn=209.2 down=554.4  end
power=9.68 burn=209.2 down=1826.25  end
end


1                        gamma source spectrum for gamma lines (sas2)
0                                              1826.25  day time of the requested nuclides
0                             energy interval in mev        photons / second      mev / second
0
                         1.0000E-02 to      5.0000E-02        5.6907E+14        1.7072E+13
                         5.0000E-02 to      1.0000E-01        1.6948E+14        1.2711E+13
                         1.0000E-01 to      2.0000E-01        1.2203E+14        1.8304E+13
                         2.0000E-01 to      3.0000E-01        3.5823E+13        8.9557E+12
                         3.0000E-01 to      4.0000E-01        2.6161E+13        9.1564E+12
                         4.0000E-01 to      6.0000E-01        2.6078E+13        1.3039E+13
                         6.0000E-01 to      8.0000E-01        6.9410E+14        4.8587E+14
                         8.0000E-01 to      1.0000E+00        4.2129E+12        3.7916E+12
                         1.0000E+00 to      1.3300E+00        2.7098E+12        3.1570E+12
                         1.3300E+00 to      1.6600E+00        8.6390E+11        1.2915E+12
                         1.6600E+00 to      2.0000E+00        1.4871E+11        2.7214E+11
                         2.0000E+00 to      2.5000E+00        7.5465E+11        1.6980E+12
                         2.5000E+00 to      3.0000E+00        4.4580E+09        1.2259E+10
                         3.0000E+00 to      4.0000E+00        4.8433E+08        1.6952E+09
                         4.0000E+00 to      5.0000E+00        1.6927E+02        7.6171E+02
                         5.0000E+00 to      6.5000E+00        5.5653E+01        3.2001E+02
                         6.5000E+00 to      8.0000E+00        8.7613E+00        6.3520E+01
                         8.0000E+00 to      1.0000E+01        1.5467E+00        1.3920E+01
0                        totals                               1.6514E+15        5.7533E+14
0
0                        total energy from nuclides with spectrum data    =   5.7533E+14
0                        total energy from nuclides with no spectrum data =   1.9246E+08
1
1
                    total (alpha-n plus spon. fission) neutron source spectrum as a function of time
```

```
                               (using reaction spectra for uranium dioxide)
0
                                 mit 36.8 g u235/plate, ualx fuel 8100 mwd/mtu, 5 year decay
                                        neutron spectra, neutrons/sec/basis
                                          basis = single reactor assembly

     boundaries, mev      initial    304.4 d    608.8 d    913.1 d   1217.5 d   1521.9 d   1826.3 d

  1 6.43E+00 - 2.00E+01 1.903E+01 1.899E+01 1.898E+01 1.898E+01 1.898E+01 1.898E+01 1.898E+01
  2 3.00E+00 - 6.43E+00 6.871E+03 6.704E+03 6.657E+03 6.644E+03 6.640E+03 6.639E+03 6.639E+03
  3 1.85E+00 - 3.00E+00 1.837E+04 1.842E+04 1.844E+04 1.844E+04 1.844E+04 1.844E+04 1.844E+04
  4 1.40E+00 - 1.85E+00 4.940E+03 4.998E+03 5.015E+03 5.019E+03 5.021E+03 5.021E+03 5.021E+03
  5 9.00E-01 - 1.40E+00 2.870E+03 2.912E+03 2.924E+03 2.927E+03 2.928E+03 2.928E+03 2.928E+03
  6 4.00E-01 - 9.00E-01 9.767E+02 9.905E+02 9.944E+02 9.955E+02 9.958E+02 9.959E+02 9.959E+02
  7 1.00E-01 - 4.00E-01 1.609E+02 1.629E+02 1.635E+02 1.637E+02 1.637E+02 1.637E+02 1.637E+02
  8 1.70E-02 - 1.00E-01  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
  9 3.00E-03 - 1.70E-02  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 10 5.50E-04 - 3.00E-03  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 11 1.00E-04 - 5.50E-04  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 12 3.00E-05 - 1.00E-04  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 13 1.00E-05 - 3.00E-05  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 14 3.05E-06 - 1.00E-05  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 15 1.77E-06 - 3.05E-06  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 16 1.30E-06 - 1.77E-06  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 17 1.13E-06 - 1.30E-06  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 18 1.00E-06 - 1.13E-06  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 19 8.00E-07 - 1.00E-06  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 20 4.00E-07 - 8.00E-07  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 21 3.25E-07 - 4.00E-07  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 22 2.25E-07 - 3.25E-07  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 23 1.00E-07 - 2.25E-07  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 24 5.00E-08 - 1.00E-07  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 25 3.00E-08 - 5.00E-08  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 26 1.00E-08 - 3.00E-08  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 27 1.00E-11 - 1.00E-08  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
0                       3.421E+04 3.421E+04 3.421E+04 3.421E+04 3.421E+04 3.421E+04 3.421E+04
1
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=origens
0$$  a8 26 a11 71 e
1$$ 1  1t
 MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU
3$$ 21 0 1 e
2t
35$$ 0  t
56$$ 0 10 a13 -1 5 3 0 4 e   5t
Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU
per MTU (for per assembly divide by 1818.18)
60**  .1 .2 .3 .4 .5 .6 .7 .8 .9 1.
65$$ a12 1 a33 1 a54 1 e
6t
56$$ 0 10 a10 10 a14 5 a17 4 e  57** 1.  e  5t
60**  2 3 4 5 6 7 8 9 10 20
65$$ a12 1 a33 1 a54 1 e
6t
56$$ 0 10 a10 10 a14 5 a17 4 e  57** 20  e  5t
60**  30 40 50 60 70 80 90 100 200 300
65$$ a12 1 a33 1 a54 1 e
6t
56$$ 0 10 a10 10 a14 5 a17 4 e  57** 300  e  5t
60**  400 500 600 700 800 900 1+3 2+3 5+3 1+4
65$$ a12 1 a33 1 a54 1 e
6t
56$$ f0  t
end
     Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                             light elements        page   15
0                        element thermal power, watts
                         basis =per MTU (for per assembly divide by 1818
              charge  discharge      .2 yr      .4 yr      .6 yr      .8 yr     1.0 yr
       h     2.69E-07  2.69E-07  2.66E-07  2.63E-07  2.60E-07  2.57E-07  2.55E-07
      na     1.17E+01  1.17E+01  7.28E-20  6.90E-20  6.54E-20  6.20E-20  5.88E-20
      mg     2.23E+01  2.23E+01   .00E+00   .00E+00   .00E+00   .00E+00   .00E+00
      al     1.62E+03  1.62E+03   .00E+00   .00E+00   .00E+00   .00E+00   .00E+00
      si     1.43E-15  1.43E-15  5.50E-28  5.50E-28  5.49E-28  5.49E-28  5.49E-28
       p     1.81E-21  1.81E-21  5.20E-23  1.50E-24  4.83E-26  6.77E-27  5.58E-27
   totals    1.65E+03  1.65E+03  2.66E-07  2.63E-07  2.60E-07  2.57E-07  2.55E-07
     Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                                  actinides        page   19
0                        element thermal power, watts
                         basis =per MTU (for per assembly divide by 1818
              charge  discharge      .2 yr      .4 yr      .6 yr      .8 yr     1.0 yr
      tl     1.73E-06  1.73E-06  1.88E-06  2.02E-06  2.15E-06  2.27E-06  2.39E-06
      pb     4.79E-07  4.79E-07  5.18E-07  5.55E-07  5.91E-07  6.24E-07  6.55E-07
      bi     4.52E-06  4.52E-06  4.89E-06  5.23E-06  5.56E-06  5.87E-06  6.17E-06
      po     1.64E-05  1.64E-05  1.79E-05  1.92E-05  2.04E-05  2.16E-05  2.26E-05
      at     8.81E-11  8.81E-11  8.40E-11  8.78E-11  9.24E-11  9.70E-11  1.02E-10
      rn     8.83E-06  8.83E-06  9.57E-06  1.03E-05  1.09E-05  1.15E-05  1.21E-05
      fr     1.11E-09  1.11E-09  1.16E-09  1.23E-09  1.30E-09  1.36E-09  1.43E-09
      ra     7.92E-06  7.92E-06  8.59E-06  9.22E-06  9.80E-06  1.04E-05  1.09E-05
      ac     1.48E-08  1.48E-08  1.56E-08  1.65E-08  1.74E-08  1.84E-08  1.93E-08
      th     3.02E-03  3.02E-03  2.31E-03  2.31E-03  2.31E-03  2.32E-03  2.32E-03
      pa     2.99E-04  2.99E-04  1.03E-04  1.03E-04  1.04E-04  1.04E-04  1.04E-04
       u     8.90E+01  8.90E+01  1.84E+00  1.83E+00  1.83E+00  1.83E+00  1.83E+00
      np     7.86E+01  7.86E+01  1.53E-05  1.53E-05  1.53E-05  1.53E-05  1.53E-05
      pu     6.42E-02  6.42E-02  6.45E-02  6.45E-02  6.45E-02  6.45E-02  6.45E-02
      am     9.99E-06  9.99E-06  1.01E-05  1.13E-05  1.26E-05  1.38E-05  1.50E-05
      cm     1.53E-05  1.53E-05  1.13E-05  8.30E-06  6.09E-06  4.47E-06  3.28E-06
      bk     7.37E-32  7.37E-32  4.08E-32  3.49E-32  2.98E-32  2.54E-32  2.18E-32
      cf     5.95E-33  5.95E-33  9.47E-33  1.19E-32  1.45E-32  1.62E-32  1.80E-32
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   totals   1.68E+02  1.68E+02  1.90E+00  1.90E+00  1.90E+00  1.90E+00  1.90E+00
0                       element thermal power, watts
                        basis =per MTU (for per assembly divide by 1818
              charge discharge     .2 yr     .4 yr     .6 yr     .8 yr    1.0 yr
        h   3.26E-03  3.26E-03  3.23E-03  3.19E-03  3.15E-03  3.12E-03  3.08E-03
       be   8.96E-10  8.96E-10  8.96E-10  8.96E-10  8.96E-10  8.96E-10  8.96E-10
        c   8.83E-09  8.83E-09  8.83E-09  8.83E-09  8.83E-09  8.83E-09  8.83E-09
       ni   9.68E-02  9.68E-02  2.18E-17  4.72E-27   .00E+00   .00E+00   .00E+00
       cu   1.68E+00  1.68E+00  6.07E-16  7.23E-25  1.89E-33   .00E+00   .00E+00
       zn   2.42E+01  2.42E+01  1.53E-14  6.84E-26   .00E+00   .00E+00   .00E+00
       ga   2.19E+02  2.19E+02  2.77E-13  1.23E-24   .00E+00   .00E+00   .00E+00
       ge   7.91E+02  7.91E+02  1.85E-17  2.21E-19  2.64E-21  3.15E-23  3.76E-25
       as   3.56E+03  3.56E+03  2.77E-14  7.10E-28   .00E+00   .00E+00   .00E+00
       se   8.20E+03  8.20E+03  5.59E-06  5.59E-06  5.59E-06  5.59E-06  5.59E-06
       br   2.44E+04  2.44E+04  1.42E-16  1.60E-31   .00E+00   .00E+00   .00E+00
       kr   3.21E+04  3.21E+04  3.95E+00  3.90E+00  3.85E+00  3.80E+00  3.75E+00
       rb   6.26E+04  6.26E+04  7.72E-04  5.10E-05  3.37E-06  2.26E-07  1.81E-08
       sr   4.91E+04  4.91E+04  5.18E+02  2.09E+02  9.52E+01  5.33E+01  3.79E+01
        y   6.69E+04  6.69E+04  8.32E+02  4.31E+02  2.62E+02  1.90E+02  1.60E+02
       zr   2.89E+04  2.89E+04  1.11E+03  5.04E+02  2.28E+02  1.04E+02  4.70E+01
       nb   5.17E+04  5.17E+04  1.61E+03  8.87E+02  4.39E+02  2.08E+02  9.63E+01
       mo   1.44E+04  1.44E+04  2.02E-05  2.01E-13  1.99E-21  1.97E-29   .00E+00
       tc   1.53E+04  1.53E+04  1.97E-03  1.96E-03  1.96E-03  1.96E-03  1.96E-03
       ru   1.59E+03  1.59E+03  2.27E+02  6.30E+01  1.77E+01  5.22E+00  1.73E+00
       rh   6.26E+02  6.26E+02  1.34E+02  1.08E+02  9.19E+01  7.95E+01  6.92E+01
       pd   7.62E+01  7.62E+01  1.58E-07  1.58E-07  1.58E-07  1.58E-07  1.58E-07
       ag   1.66E+02  1.66E+02  6.82E-03  2.14E-03  1.74E-03  1.42E-03  1.16E-03
       cd   1.48E+02  1.48E+02  4.69E-02  1.66E-02  6.87E-03  3.72E-03  2.69E-03
       in   1.24E+03  1.24E+03  5.60E-06  1.92E-06  6.57E-07  2.26E-07  7.81E-08
       sn   4.34E+03  4.34E+03  2.39E-01  1.43E-01  9.68E-02  6.56E-02  4.45E-02
       sb   1.81E+04  1.81E+04  2.15E+00  2.04E+00  1.94E+00  1.84E+00  1.75E+00
       te   2.25E+04  2.25E+04  1.21E+01  3.45E+00  1.28E+00  6.38E-01  3.94E-01
        i   5.10E+04  5.10E+04  1.54E+00  2.83E-03  8.17E-06  2.98E-06  2.97E-06
       xe   2.87E+04  2.87E+04  1.47E-01  1.57E-03  2.24E-05  3.18E-07  4.51E-09
       cs   4.45E+04  4.45E+04  3.02E+01  2.99E+01  2.96E+01  2.94E+01  2.92E+01
       ba   2.77E+04  2.77E+04  1.24E+02  9.51E+01  9.41E+01  9.37E+01  9.32E+01
       la   4.60E+04  4.60E+04  1.92E+02  3.62E+00  6.83E-02  1.29E-03  2.43E-05
       ce   1.07E+04  1.07E+04  2.66E+02  1.30E+02  8.95E+01  7.08E+01  5.84E+01
       pr   1.36E+04  1.36E+04  1.35E+03  1.11E+03  9.31E+02  7.79E+02  6.52E+02
       nd   1.46E+03  1.46E+03  4.53E+00  4.50E-02  4.47E-04  4.44E-06  4.41E-08
       pm   7.63E+02  7.63E+02  2.04E+01  1.88E+01  1.76E+01  1.67E+01  1.58E+01
       sm   4.60E+01  4.60E+01  6.61E-02  6.60E-02  6.59E-02  6.58E-02  6.57E-02
       eu   1.89E+01  1.89E+01  9.75E-01  5.37E-01  5.08E-01  4.95E-01  4.82E-01
       gd   2.38E-01  2.38E-01  7.90E-06  6.40E-06  5.19E-06  4.21E-06  3.41E-06
       tb   3.53E-02  3.53E-02  4.03E-04  1.97E-04  9.77E-05  4.85E-05  2.41E-05
       dy   3.63E-04  3.63E-04  3.39E-12  1.16E-18  3.94E-25  1.34E-31   .00E+00
       ho   3.75E-05  3.75E-05  9.96E-10  9.78E-10  9.78E-10  9.78E-10  9.78E-10
       er   2.79E-07  2.79E-07  3.40E-11  1.56E-13  7.12E-16  3.26E-18  1.49E-20
       tm   1.96E-07  1.96E-07  1.57E-09  1.46E-09  1.36E-09  1.26E-09  1.17E-09
   totals   6.31E+05  6.31E+05  6.44E+03  3.60E+03  2.30E+03  1.64E+03  1.27E+03
    Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                         light elements         page   52
0                       element thermal power, watts
                        basis =per MTU (for per assembly divide by 1818
             initial    3.0 yr    5.0 yr    7.0 yr    9.0 yr   20.0 yr
        h   2.55E-07  2.27E-07  2.03E-07  1.82E-07  1.62E-07  8.75E-08
       na   5.88E-20  3.45E-20  2.03E-20  1.19E-20  6.98E-21  3.72E-22
       si   5.49E-28  5.44E-28  5.40E-28  5.35E-28  5.31E-28  5.08E-28
        p   5.58E-27  5.50E-27  5.45E-27  5.41E-27  5.37E-27  5.13E-27
   totals   2.55E-07  2.27E-07  2.03E-07  1.82E-07  1.62E-07  8.75E-08
    Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                         actinides              page   56
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0                         element thermal power, watts
                          basis =per MTU (for per assembly divide by 1818
              initial     3.0 yr     5.0 yr     7.0 yr     9.0 yr    20.0 yr
      tl     2.39E-06   3.18E-06   3.57E-06   3.77E-06   3.88E-06   4.27E-06
      pb     6.55E-07   9.04E-07   1.07E-06   1.21E-06   1.34E-06   2.18E-06
      bi     6.17E-06   8.60E-06   1.03E-05   1.18E-05   1.32E-05   2.27E-05
      po     2.26E-05   3.05E-05   3.49E-05   3.78E-05   4.01E-05   5.31E-05
      at     1.02E-10   1.50E-10   1.97E-10   2.43E-10   2.89E-10   5.45E-10
      rn     1.21E-05   1.65E-05   1.92E-05   2.11E-05   2.28E-05   3.30E-05
      fr     1.43E-09   2.22E-09   3.13E-09   4.16E-09   5.31E-09   1.34E-08
      ra     1.09E-05   1.48E-05   1.71E-05   1.88E-05   2.03E-05   2.90E-05
      ac     1.93E-08   2.99E-08   4.24E-08   5.66E-08   7.25E-08   1.85E-07
      th     2.32E-03   2.36E-03   2.39E-03   2.43E-03   2.46E-03   2.64E-03
      pa     1.04E-04   1.07E-04   1.09E-04   1.12E-04   1.14E-04   1.29E-04
       u     1.83E+00   1.83E+00   1.83E+00   1.83E+00   1.83E+00   1.83E+00
      np     1.53E-05   1.53E-05   1.53E-05   1.53E-05   1.53E-05   1.53E-05
      pu     6.45E-02   6.45E-02   6.45E-02   6.45E-02   6.44E-02   6.44E-02
      am     1.50E-05   2.63E-05   3.66E-05   4.59E-05   5.43E-05   8.78E-05
      cm     3.28E-06   1.63E-07   2.32E-08   1.69E-08   1.64E-08   1.55E-08
      bk     2.18E-32   4.46E-33   9.47E-34   1.35E-34    .00E+00    .00E+00
      cf     1.80E-32   2.54E-32   2.72E-32   2.72E-32   2.72E-32   2.64E-32
  totals     1.90E+00   1.90E+00   1.90E+00   1.90E+00   1.90E+00   1.90E+00
   Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                        fission products        page   74
0                         element thermal power, watts
                          basis =per MTU (for per assembly divide by 1818
              initial     3.0 yr     5.0 yr     7.0 yr     9.0 yr    20.0 yr
       h     3.08E-03   2.76E-03   2.46E-03   2.20E-03   1.97E-03   1.06E-03
      be     8.96E-10   8.96E-10   8.96E-10   8.96E-10   8.96E-10   8.96E-10
       c     8.83E-09   8.82E-09   8.82E-09   8.82E-09   8.82E-09   8.81E-09
      ge     3.76E-25    .00E+00    .00E+00    .00E+00    .00E+00    .00E+00
      se     5.59E-06   5.59E-06   5.59E-06   5.59E-06   5.59E-06   5.59E-06
      kr     3.75E+00   3.30E+00   2.90E+00   2.55E+00   2.24E+00   1.10E+00
      rb     1.81E-08   3.42E-09   3.42E-09   3.42E-09   3.42E-09   3.42E-09
      sr     3.79E+01   2.76E+01   2.63E+01   2.50E+01   2.38E+01   1.82E+01
       y     1.60E+02   1.32E+02   1.25E+02   1.19E+02   1.14E+02   8.66E+01
      zr     4.70E+01   1.73E-02   4.76E-05   4.13E-05   4.13E-05   4.13E-05
      nb     9.63E+01   3.74E-02   3.27E-05   2.27E-05   2.60E-05   4.00E-05
      tc     1.96E-03   1.96E-03   1.96E-03   1.96E-03   1.96E-03   1.96E-03
      ru     1.73E+00   1.10E-01   2.81E-02   7.19E-03   1.84E-03   1.02E-06
      rh     6.92E+01   1.77E+01   4.53E+00   1.16E+00   2.97E-01   1.66E-04
      pd     1.58E-07   1.58E-07   1.58E-07   1.58E-07   1.58E-07   1.58E-07
      ag     1.16E-03   1.53E-04   2.01E-05   2.66E-06   3.53E-07   3.79E-09
      cd     2.69E-03   2.01E-03   1.82E-03   1.65E-03   1.50E-03   8.72E-04
      in     7.81E-08   2.16E-12   3.00E-15   2.93E-15   2.93E-15   2.93E-15
      sn     4.45E-02   1.17E-03   2.59E-04   2.29E-04   2.23E-04   2.06E-04
      sb     1.75E+00   1.05E+00   6.34E-01   3.82E-01   2.30E-01   1.49E-02
      te     3.94E-01   7.08E-02   4.12E-02   2.48E-02   1.49E-02   9.12E-04
       i     2.97E-06   2.97E-06   2.97E-06   2.97E-06   2.97E-06   2.97E-06
      xe     4.51E-09   1.32E-19   1.20E-25   1.09E-31    .00E+00    .00E+00
      cs     2.92E+01   2.73E+01   2.58E+01   2.45E+01   2.33E+01   1.80E+01
      ba     9.32E+01   8.90E+01   8.50E+01   8.12E+01   7.75E+01   6.01E+01
      la     2.43E-05   3.27E-13   3.27E-13   3.27E-13   3.27E-13   3.27E-13
      ce     5.84E+01   9.83E+00   1.66E+00   2.81E-01   4.76E-02   2.71E-06
      pr     6.52E+02   1.10E+02   1.87E+01   3.16E+00   5.34E-01   3.04E-05
      nd     4.41E-08   3.88E-12   3.93E-12   3.94E-12   3.94E-12   3.94E-12
      pm     1.58E+01   9.30E+00   5.49E+00   3.23E+00   1.91E+00   1.04E-01
      sm     6.57E-02   6.47E-02   6.37E-02   6.27E-02   6.18E-02   5.67E-02
      eu     4.82E-01   3.70E-01   2.86E-01   2.22E-01   1.73E-01   4.83E-02
      gd     3.41E-06   4.20E-07   5.16E-08   6.34E-09   7.79E-10   1.07E-14
      tb     2.41E-05   2.19E-08   1.99E-11   1.81E-14   1.64E-17   4.06E-34
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        ho      9.78E-10  9.77E-10  9.76E-10  9.74E-10  9.73E-10  9.67E-10
        er      1.49E-20   .00E+00   .00E+00   .00E+00   .00E+00   .00E+00
        tm      1.17E-09  5.70E-10  2.77E-10  1.35E-10  6.54E-11  1.23E-12
    totals      1.27E+03  4.28E+02  2.97E+02  2.61E+02  2.44E+02  1.84E+02
      Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                              light elements        page   89
0                             element thermal power, watts
                              basis =per MTU (for per assembly divide by 1818
                 initial   40.0 yr   60.0 yr   80.0 yr  100.0 yr  300.0 yr
         h      8.75E-08  2.84E-08  9.23E-09  3.00E-09  9.74E-10  1.27E-14
        na      3.72E-22  1.81E-24  8.76E-27  4.25E-29  2.06E-31   .00E+00
        si      5.08E-28  4.69E-28  4.32E-28  3.99E-28  3.68E-28  1.64E-28
         p      5.13E-27  4.74E-27  4.37E-27  4.03E-27  3.72E-27  1.66E-27
    totals      8.75E-08  2.84E-08  9.23E-09  3.00E-09  9.74E-10  1.27E-14
      Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                   actinides        page   93
0                             element thermal power, watts
                              basis =per MTU (for per assembly divide by 1818
                 initial   40.0 yr   60.0 yr   80.0 yr  100.0 yr  300.0 yr
        tl      4.27E-06  5.43E-06  7.04E-06  8.93E-06  1.10E-05  3.44E-05
        pb      2.18E-06  4.45E-06  7.46E-06  1.10E-05  1.50E-05  7.37E-05
        bi      2.27E-05  4.74E-05  7.86E-05  1.14E-04  1.52E-04  6.27E-04
        po      5.31E-05  9.14E-05  1.46E-04  2.16E-04  2.98E-04  1.72E-03
        at      5.45E-10  1.01E-09  1.48E-09  1.95E-09  2.43E-09  7.32E-09
        rn      3.30E-05  6.07E-05  9.71E-05  1.40E-04  1.87E-04  8.50E-04
        fr      1.34E-08  3.35E-08  5.78E-08  8.43E-08  1.12E-07  3.99E-07
        ra      2.90E-05  5.27E-05  8.39E-05  1.21E-04  1.61E-04  7.34E-04
        ac      1.85E-07  4.68E-07  8.10E-07  1.18E-06  1.57E-06  5.63E-06
        th      2.64E-03  2.98E-03  3.32E-03  3.67E-03  4.02E-03  7.51E-03
        pa      1.29E-04  1.54E-04  1.80E-04  2.06E-04  2.31E-04  4.87E-04
         u      1.83E+00  1.83E+00  1.83E+00  1.83E+00  1.83E+00  1.83E+00
        np      1.53E-05  1.53E-05  1.53E-05  1.53E-05  1.53E-05  1.53E-05
        pu      6.44E-02  6.42E-02  6.41E-02  6.40E-02  6.39E-02  6.33E-02
        am      8.78E-05  1.15E-04  1.23E-04  1.23E-04  1.21E-04  8.88E-05
        cm      1.55E-08  1.40E-08  1.27E-08  1.15E-08  1.05E-08  3.91E-09
        cf      2.64E-32  2.46E-32  2.38E-32  2.30E-32  2.22E-32  1.45E-32
    totals      1.90E+00  1.90E+00  1.90E+00  1.90E+00  1.90E+00  1.91E+00
      Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                            fission products        page  111
0                             element thermal power, watts
                              basis =per MTU (for per assembly divide by 1818
                 initial   40.0 yr   60.0 yr   80.0 yr  100.0 yr  300.0 yr
         h      1.06E-03  3.44E-04  1.12E-04  3.63E-05  1.18E-05  1.54E-10
        be      8.96E-10  8.96E-10  8.96E-10  8.96E-10  8.96E-10  8.96E-10
         c      8.81E-09  8.79E-09  8.76E-09  8.74E-09  8.72E-09  8.51E-09
        se      5.59E-06  5.59E-06  5.59E-06  5.59E-06  5.59E-06  5.59E-06
        kr      1.10E+00  3.01E-01  8.27E-02  2.27E-02  6.23E-03  1.51E-08
        rb      3.42E-09  3.42E-09  3.42E-09  3.42E-09  3.42E-09  3.42E-09
        sr      1.82E+01  1.11E+01  6.78E+00  4.15E+00  2.53E+00  1.84E-02
         y      8.66E+01  5.29E+01  3.23E+01  1.98E+01  1.21E+01  8.77E-02
        zr      4.13E-05  4.13E-05  4.13E-05  4.13E-05  4.13E-05  4.13E-05
        nb      4.00E-05  5.33E-05  5.89E-05  6.13E-05  6.23E-05  6.31E-05
        tc      1.96E-03  1.96E-03  1.96E-03  1.96E-03  1.96E-03  1.96E-03
        ru      1.02E-06  1.24E-12  1.50E-18  1.81E-24  2.19E-30   .00E+00
        rh      1.66E-04  6.12E-09  4.97E-11  4.17E-13  3.50E-15   .00E+00
        pd      1.58E-07  1.58E-07  1.58E-07  1.58E-07  1.58E-07  1.58E-07
        ag      3.79E-09  3.39E-09  3.04E-09  2.73E-09  2.45E-09  8.21E-10
        cd      8.72E-04  3.26E-04  1.22E-04  4.57E-05  1.71E-05  9.18E-10
        in      2.93E-15  2.93E-15  2.93E-15  2.93E-15  2.93E-15  2.93E-15
        sn      2.06E-04  1.80E-04  1.60E-04  1.44E-04  1.32E-04  9.34E-05
        sb      1.49E-02  9.87E-04  9.00E-04  8.99E-04  8.99E-04  8.98E-04
        te      9.12E-04  5.68E-06  3.54E-08  2.20E-10  1.37E-12  3.65E-22
         i      2.97E-06  2.97E-06  2.97E-06  2.97E-06  2.97E-06  2.97E-06
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       cs    1.80E+01  1.13E+01  7.14E+00  4.50E+00  2.84E+00  2.80E-02
       ba    6.01E+01  3.79E+01  2.38E+01  1.50E+01  9.46E+00  9.31E-02
       la    3.27E-13  3.27E-13  3.27E-13  3.27E-13  3.27E-13  3.27E-13
       ce    2.71E-06  5.18E-14  9.93E-22  1.90E-29   .00E+00   .00E+00
       pr    3.04E-05  5.82E-13  1.11E-20  2.13E-28   .00E+00   .00E+00
       nd    3.94E-12  3.94E-12  3.94E-12  3.94E-12  3.94E-12  3.94E-12
       pm    1.04E-01  5.28E-04  2.69E-06  1.71E-08  1.44E-09  5.21E-13
       sm    5.67E-02  4.86E-02  4.17E-02  3.57E-02  3.06E-02  6.57E-03
       eu    4.83E-02  7.51E-03  1.76E-03  4.99E-04  1.54E-04  3.89E-09
       gd    1.07E-14  3.33E-15  3.44E-15  3.48E-15  3.49E-15  3.50E-15
       ho    9.67E-10  9.56E-10  9.45E-10  9.34E-10  9.23E-10  8.23E-10
       tm    1.23E-12  9.02E-16  6.60E-19  4.83E-22  3.54E-25   .00E+00
   totals    1.84E+02  1.14E+02  7.03E+01  4.35E+01  2.70E+01  2.37E-01
     Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                       light elements        page  126
0                        element thermal power, watts
                         basis =per MTU (for per assembly divide by 1818
              initial  500.0 yr  700.0 yr  900.0 yr 2000.0 yr10000.0 yr
        h    1.27E-14  1.67E-19  2.18E-24  2.85E-29   .00E+00   .00E+00
       si    1.64E-28  7.35E-29  3.28E-29  1.47E-29  1.74E-31   .00E+00
        p    1.66E-27  7.42E-28  3.32E-28  1.48E-28  1.76E-30   .00E+00
   totals    1.27E-14  1.67E-19  2.18E-24  1.91E-28  1.94E-30   .00E+00
     Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                            actinides        page  130
0                        element thermal power, watts
                         basis =per MTU (for per assembly divide by 1818
              initial  500.0 yr  700.0 yr  900.0 yr 2000.0 yr10000.0 yr
       tl    3.44E-05  5.88E-05  8.34E-05  1.08E-04  2.44E-04  1.12E-03
       pb    7.37E-05  1.62E-04  2.78E-04  4.19E-04  1.55E-03  1.56E-02
       bi    6.27E-04  1.23E-03  1.96E-03  2.79E-03  8.98E-03  7.83E-02
       po    1.72E-03  4.15E-03  7.48E-03  1.16E-02  4.67E-02  4.95E-01
       at    7.32E-09  1.25E-08  1.79E-08  2.35E-08  5.88E-08  4.78E-07
       rn    8.50E-04  1.80E-03  3.01E-03  4.46E-03  1.59E-02  1.54E-01
       fr    3.99E-07  6.87E-07  9.73E-07  1.26E-06  2.86E-06  1.33E-05
       ra    7.34E-04  1.56E-03  2.61E-03  3.87E-03  1.38E-02  1.34E-01
       ac    5.63E-06  9.69E-06  1.37E-05  1.78E-05  4.02E-05  1.85E-04
       th    7.51E-03  1.10E-02  1.45E-02  1.79E-02  3.69E-02  1.67E-01
       pa    4.87E-04  7.42E-04  9.96E-04  1.25E-03  2.62E-03  1.17E-02
        u    1.83E+00  1.83E+00  1.83E+00  1.83E+00  1.82E+00  1.78E+00
       np    1.53E-05  1.53E-05  1.53E-05  1.53E-05  1.53E-05  1.53E-05
       pu    6.33E-02  6.29E-02  6.25E-02  6.21E-02  6.01E-02  4.74E-02
       am    8.88E-05  6.44E-05  4.68E-05  3.39E-05  5.82E-06  2.02E-11
       cm    3.91E-09  1.46E-09  5.47E-10  2.05E-10  9.18E-13  8.76E-19
       cf    1.45E-32  1.01E-32  6.76E-33  4.19E-33  8.12E-34   .00E+00
   totals    1.91E+00  1.92E+00  1.92E+00  1.93E+00  2.01E+00  2.89E+00
     Part B MIT 36.8 g U235/Plate, UAlx Fuel 8100 MWD/MTU                                     fission products        page  148
0                        element thermal power, watts
                         basis =per MTU (for per assembly divide by 1818
              initial  500.0 yr  700.0 yr  900.0 yr 2000.0 yr10000.0 yr
        h    1.54E-10  2.02E-15  2.64E-20  3.46E-25   .00E+00   .00E+00
       be    8.96E-10  8.96E-10  8.96E-10  8.96E-10  8.95E-10  8.92E-10
        c    8.51E-09  8.31E-09  8.11E-09  7.92E-09  6.93E-09  2.63E-09
       se    5.59E-06  5.59E-06  5.59E-06  5.58E-06  5.57E-06  5.48E-06
       kr    1.51E-08  3.40E-13  3.03E-13  3.03E-13  3.02E-13  2.94E-13
       rb    3.42E-09  3.42E-09  3.42E-09  3.42E-09  3.42E-09  3.42E-09
       sr    1.84E-02  1.34E-04  9.69E-07  7.04E-09  1.21E-20   .00E+00
        y    8.77E-02  6.37E-04  4.62E-06  3.36E-08  5.77E-20   .00E+00
       zr    4.13E-05  4.13E-05  4.13E-05  4.13E-05  4.12E-05  4.11E-05
       nb    6.31E-05  6.31E-05  6.31E-05  6.30E-05  6.30E-05  6.28E-05
       tc    1.96E-03  1.96E-03  1.96E-03  1.96E-03  1.95E-03  1.90E-03
       pd    1.58E-07  1.58E-07  1.58E-07  1.58E-07  1.58E-07  1.58E-07
       ag    8.21E-10  2.76E-10  9.25E-11  3.10E-11  7.67E-14  8.25E-33
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      cd    9.18E-10  4.94E-14  8.77E-17  8.50E-17  8.50E-17  8.50E-17
      in    2.93E-15  2.93E-15  2.93E-15  2.93E-15  2.93E-15  2.93E-15
      sn    9.34E-05  9.02E-05  8.98E-05  8.97E-05  8.90E-05  8.42E-05
      sb    8.98E-04  8.97E-04  8.95E-04  8.94E-04  8.87E-04  8.40E-04
      te    3.65E-22  3.65E-22  3.65E-22  3.65E-22  3.65E-22  3.65E-22
       i    2.97E-06  2.97E-06  2.97E-06  2.97E-06  2.97E-06  2.97E-06
      cs    2.80E-02  3.96E-04  1.24E-04  1.22E-04  1.22E-04  1.21E-04
      ba    9.31E-02  9.16E-04  9.01E-06  8.87E-08  8.10E-19   .00E+00
      la    3.27E-13  3.27E-13  3.27E-13  3.27E-13  3.27E-13  3.27E-13
      nd    3.94E-12  3.94E-12  3.94E-12  3.94E-12  3.94E-12  3.94E-12
      pm    5.21E-13  2.07E-16  8.20E-20  3.25E-23   .00E+00   .00E+00
      sm    6.57E-03  1.41E-03  3.01E-04  6.46E-05  5.21E-08  3.86E-08
      eu    3.89E-09  1.00E-12  1.84E-14  3.83E-16  2.16E-25   .00E+00
      gd    3.50E-15  3.50E-15  3.50E-15  3.50E-15  3.50E-15  3.50E-15
      ho    8.23E-10  7.33E-10  6.53E-10  5.82E-10  3.08E-10  3.03E-12
  totals    2.37E-01  6.55E-03  3.50E-03  3.24E-03  3.16E-03  3.06E-03
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GLASS, Homogenized MIT Cylinder, Shielding Model, Source in Glass Logs Only
C       DHLW CANISTER
1     3  -2.85    -1 -3 4   IMP:P=1 U=1 $ DHLW GLASS
2     5  -7.9     1 -2 -3 4 IMP:P=1 U=1 $ SS304L CANISTER WALL
3     5  -7.9    -5  3 -2   IMP:P=1 U=1 $ SS304L CANISTER TOP
4     5  -7.9     6 -4 -2   IMP:P=1 U=1 $ SS304L CANISTER TOP
5     1  5.1373-5  2 -5 6 IMP:P=1 U=1  $ AIR AROUND CANISTER
6     1  5.1373-5   5    IMP:P=1 U=1  $ AIR ABOVE CANISTER
7     1  5.1373-5   -6   IMP:P=1 U=1  $ AIR ABOVE CANISTER
C     GLASS LOGS
41    1  5.1373-5   -7  -8 9  FILL=1 TRCL=(0 55 0) IMP:P=1   $ DHLW GLASS
42    LIKE 41 BUT TRCL=(52. 17. 0)
43    LIKE 41 BUT TRCL=(33 -43.5 0)
44    LIKE 41 BUT TRCL=(-33 -43.5 0)
45    LIKE 41 BUT TRCL=(-52. 17. 0)
C    EVERYTHING IN CODISPOSAL CYLINDER IS HOMOGENIZED
C
50   2  2.885-02  -36  -24  25 U=2  IMP:P=1       $ HOMOGENIZED FUELCYLINDER
C
51   6  -7.88       36  -24  25 U=2  IMP:P=1       $ Steel Codisposal Tube Wall
52   6  -7.88            24     U=2  IMP:P=1       $ Steel Codisposal Tube Wall
53   6  -7.88                -25 U=2  IMP:P=1       $ Steel Codisposal Tube Wall
55   0            -37 -26  27   FILL=2  IMP:P=1       $ Steel Codisposal Tube Wall
C     INSIDE CONTAINER
60    1   5.1373-5  -10 -14 15  #41 #42 #43 #44 #45 #55 IMP:P=1
C     WP
61    4    -8.4425   10 -11 -14 15  IMP:P=1 $ INNER BARRIER SIDE
62    4    -8.4425   -11  14 -16 IMP:P=1    $ INNER BARRIER TOP
63    4    -8.4425   -11 -15  17  IMP:P=1   $ INNER BARRIER BOTTOM
64    7    -7.832   11 -12 -16 17  IMP:P=1 $ OUTER BARRIER SIDE
65    7    -7.832   -12  16 -18 IMP:P=1    $ OUTER BARRIER TOP
66    7    -7.832   -12 -17  19  IMP:P=1   $ OUTER BARRIER BOTTOM
67    1    5.1373-5   12 -13 -18 19  IMP:P=1 $ REFLECTOR SIDE
68    1    5.1373-5   -13  18 -20 IMP:P=1    $ REFLECTOR TOP
69    1    5.1373-5   -13 -19  21  IMP:P=1   $ REFLECTOR BOTTOM
C     OUTSIDE WORLD
81    0  13:20:-21   IMP:P=0

C     SURFACE SPECIFICATIONS
1     CZ 29.528
2     CZ 30.48
3     PZ  137.13
4     PZ -137.13
5     PZ  138.7175
6     PZ -138.7175
C     CELL FILL CARDS
7     CZ 31
8     PZ  140
9     PZ -140
10    CZ  86.5    $  IR of WP
11    CZ  88.5    $  OUTSIDE OF WASTE INNER BARRIER WALL
12    CZ  98.5    $  OUTSIDE OF WASTE OUTER BARRIER WALL
13    CZ  113.5   $  AIR REFLECTOR OUTSIDE CONTAINER
14    PZ  152     $ INNER HEIGHT OF CONTAINER
15    PZ -152
16    PZ  154.5   $ TOP OF INNER BARRIER LID
17    PZ -154.5
18    PZ  165.5   $ TOP OF OUTER BARRIER LID
19    PZ -165.5
20    PZ  180.5   $ TOP OF AIR REFLECTOR
21    PZ -180.5
C
24    PZ  129.9  $ TOP OF STACK OF FOUR ASSEMBLIES
25    PZ -129.9  $ TOP OF STACK OF FOUR ASSEMBLIES
26    PZ  131.4  $ TOP OF CANISTER LID
27    PZ -131.4  $ TOP OF CANISTER LID
C
36  CZ  20.465   $ Inner Radius of Codisposal Tube Wall
37  CZ  21.965   $ Outer Radius of Codisposal Tube Wall
C
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C      Tally Segmenting Surfaces
361  PZ  5
362  PZ -5
363  PZ  10
364  PZ -10
365  PZ  20
366  PZ -20
367  PZ  40
368  PZ -40
369  PZ  80
370  PZ -80
380  PX  5
381  PX -5
382  PY  0

MODE   P
C      SOURCE
SDEF    POS=D1 RAD=D2 EXT=D3  ERG=D4 AXS= 0 0 1
C       Glass Log Gamma Source
SI1     L  0. 55. 0.  52. 17. 0.  33. -43.5 0.
            -33. -43.5 0.  -52. 17. 0.
SP1       .2 .2 .2 .2 .2
SI2       0 29.527
SI3     137.1
SI4     H  .40 .60 .80 1.00 1.33 1.66 2.00 2.50
         3.00 4.00 5.00 6.50 8.00 10.00
SP4      0. 5.90E-2 9.03E-1 1.43E-2 1.98E-2 4.30E-3 3.44E-4 1.97E-3 1.37E-5
           1.53E-6 3.52E-10 1.41E-10 2.75E-11 5.85E-12
C      TALLY SPECIFICATIONS
F2:P    11 12 16 17 18 19
FM2      7.5E15
FC2     Normalized and flux-to-dose conversion factor applied
DE2     .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 .7 .8
        1.0 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 5.75 6.25
        6.75 7.5 9.0 11.0 13.0 15.0
DF2     3.96-6 5.82-7 2.90-7 2.58-7 2.83-7 3.79-7 5.01-7 6.31-7 7.59-7
        8.78-7 9.85-7 1.08-6 1.17-6 1.27-6 1.36-6 1.44-6 1.52-6 1.68-6
        1.98-6 2.51-6 2.99-6 3.42-6 3.82-6 4.01-6 4.41-6 4.83-6 5.23-6
        5.60-6 5.80-6 6.01-6 6.37-6 6.74-6 7.11-6 7.66-6 8.77-6 1.03-5
        1.18-5 1.33-5
F12:P   (2 < 41) (2 < 42) (2 < 43) (2 < 44) (2 < 45)  T
FS12    369 -370  367 -368 365 -366  363 -364  361 -362 T
F22:P   12
FM22    7.5E15
FC22    Normalized and flux-to-dose conversion factor applied
DE22    .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 .7 .8
        1.0 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 5.75 6.25
        6.75 7.5 9.0 11.0 13.0 15.0
DF22    3.96-6 5.82-7 2.90-7 2.58-7 2.83-7 3.79-7 5.01-7 6.31-7 7.59-7
        8.78-7 9.85-7 1.08-6 1.17-6 1.27-6 1.36-6 1.44-6 1.52-6 1.68-6
        1.98-6 2.51-6 2.99-6 3.42-6 3.82-6 4.01-6 4.41-6 4.83-6 5.23-6
        5.60-6 5.80-6 6.01-6 6.37-6 6.74-6 7.11-6 7.66-6 8.77-6 1.03-5
        1.18-5 1.33-5
FS22    369 -370  367 -368 365 -366  363 -364  361 -362 T
F32:P    12
FS32     367 -368 -382 380 -381 T
SD32      7.7674+4 7.7674+4  2.4756+4 1.1978+4 1.1978+4 8.0060+2 2.04853+5
FM32      7.5E15
FC32     Normalized and flux-to-dose conversion factor applied
DE32     .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 .7 .8
        1.0 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 5.75 6.25
        6.75 7.5 9.0 11.0 13.0 15.0
DF32     3.96-6 5.82-7 2.90-7 2.58-7 2.83-7 3.79-7 5.01-7 6.31-7 7.59-7
        8.78-7 9.85-7 1.08-6 1.17-6 1.27-6 1.36-6 1.44-6 1.52-6 1.68-6
        1.98-6 2.51-6 2.99-6 3.42-6 3.82-6 4.01-6 4.41-6 4.83-6 5.23-6
        5.60-6 5.80-6 6.01-6 6.37-6 6.74-6 7.11-6 7.66-6 8.77-6 1.03-5
        1.18-5 1.33-5
E0:P 0.4 0.6 0.8 1.0 1.33 1.66 2.0 2.5 3.0 4.0 5.0 6.5 8.00 10.00 T
C
C       MATERIAL SPECIFICATIONS
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M1     7000.01P  4.2148-5  $ AIR
       8000.01P  9.2249-6
M2     92000.01P    2.585-4     $ homogenized fuel, water removed
       5000.01P     5.072-5
       6000.01P     2.838-05
       7000.01P     8.116-05
       12000.01P    7.783-05
       13000.01P    7.885-03
       14000.01P    3.439-04
       15000.01P    1.651-05
       16000.01P    1.066-05
       24000.01P    3.760-03
       25000.01P    4.137-04
       26000.01P    1.327-02
       28000.01P    2.346-03
       29000.01P    7.442-06
       42000.01P    2.961-04
C    DHLW Glass
M3      3000.01P -1.44       5000.01P -3.132 $ DHLW GLASS
        8000.01P  -4.4102+1  9000.01P -3.108-2
       11000.01P -8.233     12000.01P -8.046-1  13000.01P -2.057
       14000.01P -2.1967+1 16000.01P -1.263-1  19000.01P -2.916
       20000.01P -6.458-1  22000.01P -5.823-1  25000.01P -1.520
       26000.01P -7.211    28000.01P -7.170-1  15000.01P -1.372-2
       24000.01P -8.055-2 29000.01P  -1.489-1  47000.01P -4.906-2
       56000.01P -8.083-2 82000.01P -5.948-2   17000.01P -1.131-1
       90000.01P -1.811-1  62000.01P -4.411-4  92000.01P -3.693
       94000.01P -2.091-2
C          INCOLOY ALLOY 825
M4     6000.01P  -0.05  13000.01P  -0.20  14000.01P  -0.50  $ Alloy 825
      16000.01P  -0.03  22000.01P  -0.90  24000.01P -21.50  $ 8.14 g/cc
      25000.01P  -1.00  26000.01P -28.57  28000.01P -42.00
      29000.01P  -2.25  42000.01P  -3.00
C          SS304L D=7.9 G/CC
M5     6000.01P  -0.030 7014.01P  -0.100 14000.01P -0.75
      15031.01P  -0.045 16032.01P  -0.030 24000.01P -19.000
      25055.01P  -2.000 26000.01P -68.045 28000.01P -10.000
M6     6000.01P  -.06  7014.01P  -.3 14000.01P -.75  $ XM-19 SS
      15031.01P  -.04 16032.01P  -.03 24000.01P -22
      25055.01P  -5. 26000.01P -57.07 28000.01P -12.5
      42000.01P  -2.25
C          A 516 CARBON STEEL
M7     6000.01P  -0.22  14000.01P  -0.275  15031.01P  -0.035
      16032.01P  -0.035  25055.01P  -0.90
      26000.01P -98.535
C
NPS  30000000
PRINT
PRDMP 2000000
```