INL/RPT-23-73919
Revision 0

Estimate of Gamma Dose Rates from Arrays of Fermi-1 Blanket Elements During the MEDE Process

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SUMMARY

The Enrico Fermi Atomic Power Plant Unit 1 (Fermi-1) was a sodium-cooled fast breeder reactor located in Monroe County, Michigan. The reactor was powered by a core of enriched uranium metal alloy driver fuel, which was enveloped by an axial and radial blanket material consisting of depleted uranium metal alloyed with 3 wt.% molybdenum. There are 406 axial and 559 radial irradiated sodium-bonded Fermi-1 blanket assemblies in storage at INL, totaling 34 metric tons of heavy metal.

Disposal of the Fermi-1 blanket material directly into a geological repository is prohibited due to the reactive characteristic of its bond sodium. A melt drain evaporate (MEDE) process can effectively remove bond sodium from Fermi-1 blanket material. Consequently, planning is underway to apply a MEDE process to treat the 34 metric tons of heavy metal of irradiated Fermi-1 blanket material. Given the irradiated Fermi-1 blanket material's relatively low power history and 50+ years of decay, it can be treated in a shielded glovebox. To assess the requisite shielding, the dose rates of the Fermi-1 blanket elements in various process configurations are needed.

The method to perform the dose rate calculations is to first generate an average source term and associated photon source spectra for the Fermi-1 blanket material in SCALE and then use the associated photon spectra to calculate dose rates using MCNP6.2 in seven representative geometries. Dose rates in rem/h were calculated on contact (1 cm from outer geometry surface), 30 cm away from outer geometry surface, and 1 m from outer geometry surface at axial heights spanning the length of the blanket material within the geometry.

The maximum average dose rate for the single Fermi-1 radial blanket element is ~0.60 rem/h, for the Fermi-1 radial blanket assembly ~1.10 rem/h, for the single Fermi-1 axial blanket element ~0.5 rem/h, for the Fermi-1 axial blanket assembly ~1.01 rem/h, for the MEDE can ~ 0.98 rem/h, for the Fermi Storage Canister ~ 0.83 rem/h, and for the MEDE cans in the DOE Standard Canister ~0.51 rem/h.

Based on these maximum average values, the bounding dose rates are assumed to be three times the average dose rates calculated for the axial blanket material and 5.7 times the average dose rates calculated for the radial blanket material, based on the distribution of Fermi-1 blanket material assembly burnup.

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ACRONYMS

DSC	DOE Standard Canister
EOL	end of life
FSC	Fermi-1 storage canister
INL	Idaho National Laboratory
MEDE	melt drain evaporate
MTHM	metric tons heavy metal

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Estimate of Gamma Dose Rates from Arrays of Fermi-1 Blanket Elements During the MEDE Process

1. INTRODUCTION

The Enrico Fermi Atomic Power Plant Unit 1 (Fermi-1) was a sodium-cooled fast breeder reactor in Monroe County, Michigan. The reactor was powered by a core of enriched uranium metal alloy driver fuel, which was enveloped by an axial and radial blanket material consisting of depleted uranium metal alloyed with 3 wt.% molybdenum. The blanket material was loaded into stainless-steel tubes that were filled with sodium metal and sealed to form blanket elements. The sodium metal provided a thermal bond between the depleted uranium alloy and its stainless-steel cladding.

The Fermi-1 reactor operated intermittently from 1963 to 1972, when it was decommissioned. The Fermi-1 driver fuel was transported in 1973 to the Savannah River Project facility for dispositioning. The irradiated Fermi-1 blanket material was later transported to Idaho National Laboratory in 1975 and placed in underground storage, where it currently resides.

There are 406 axial and 559 radial irradiated sodium-bonded Fermi-1 blanket assemblies in storage at Idaho National Laboratory, totaling 34 metric tons of heavy metal. The axial blanket assemblies are the remains of the original Fermi-1 core assemblies after the midsections that contained the driver fuel were removed. Consequently, the axial blanket assemblies include both upper and lower sections, each of which consists of 16 elements that are fixed adjacent to the inner wall of its square duct. The radial blanket assemblies, devoid of a fueled section, are intact and comprised of 25 elements in a 5 × 5 array within the same sized stainless-steel duct.

Disposal of the Fermi-1 blanket material directly into a geological repository is prohibited due to the reactive characteristic of its bond sodium. A melt drain evaporate (MEDE) process can effectively remove bond sodium from the Fermi-1 blanket material. Consequently, planning is underway to apply a MEDE process to treat the 34 metric tons of heavy metal of irradiated Fermi-1 blanket material. Given the irradiated Fermi-1 blanket material's relatively low power history and 50+ years of decay, it can be treated in a shielded glovebox. To assess the requisite shielding, the dose rates of the Fermi-1 blanket elements in various process configurations are needed.

2. METHODOLOGY

The method to calculate the dose rate is to first generate an average source term and associated photon source spectra for the Fermi-1 blanket material using the ORIGEN module in the SCALE code suite. (Rearden and Jessee 2018). This was based on the end of life (EOL) activities provided by the project team (see Appendix A) and then decayed 28 years to arrive at activities in 2028 when the MEDE activities are projected to be performed. Using MCNP 6.2 (Werner 2017; Werner et al. 2018), this source term is used to calculate the total dose equivalent rates from photons at various axial locations in seven geometries based on the photon spectra generated in ORIGEN and applying the ANSI/ANS-6.1.1-1977 flux-to-dose conversion factors (ANS 1977, see Appendix C). Neutron dose rates are assumed to be negligible relative to the photon dose rates and are not calculated. The calculations are performed using the ENDF/B-V continuous-energy cross section libraries at room temperature. All dose rate calculations use the average source term. The bounding dose rates are assumed to be three times the average dose rates calculated for the axial blanket material and 5.7 times the average dose rates calculated for the radial blanket material, based on the distribution of Fermi-1 blanket material assembly burnup (see Appendix B)

Dose rates in rem/h were calculated on contact (1 cm from outer geometry surface), 30 cm away from outer geometry surface, and 1 m from outer geometry surface at axial heights spanning the length of the blanket material within the geometry in 10 cm increments with 0 cm being the axial center of the geometry.

3. DESCRIPTIONS AND SCENARIOS

3.1 Fermi-1 Radial Blanket Material Element and Assembly

There are two types of Fermi-1 blanket material elements: axial and radial. Both are evaluated in this study. The radial blanket element consists of an approximately 61.75-inch-long depleted uranium-molybdenum alloy material. Between the radial blanket material and cladding is a sodium bond, which serves as a heat transfer medium between the blanket material and cladding. Above the radial blanket material is 2.5 inches of sodium followed by 6.85 inches of argon plenum. The radial blanket material, sodium bond and plenum space are encased in a stainless-steel cladding. The radial blanket elements are then bundled together in a 5 × 5 square grid within an assembly duct to form the radial blanket assembly. Above the element array is a control rod assembly and handling feature for the assembly. Below the element array are end features for locking the assembly into the reactor lower core plate. Figure 1 shows a schematic of the Fermi-1 blanket element and assembly. Figure 2 shows radial and axial views of the Fermi-1 blanket element as modeled in MCNP6. Figure 3 shows radial and axial views of the Fermi-1 blanket assembly as modeled in MCNP6. The argon gas in the plenum was not modeled, and the volume is left as a void. The upper and lower assembly features were not modeled as they will be removed prior to being introduced into the MEDE process.

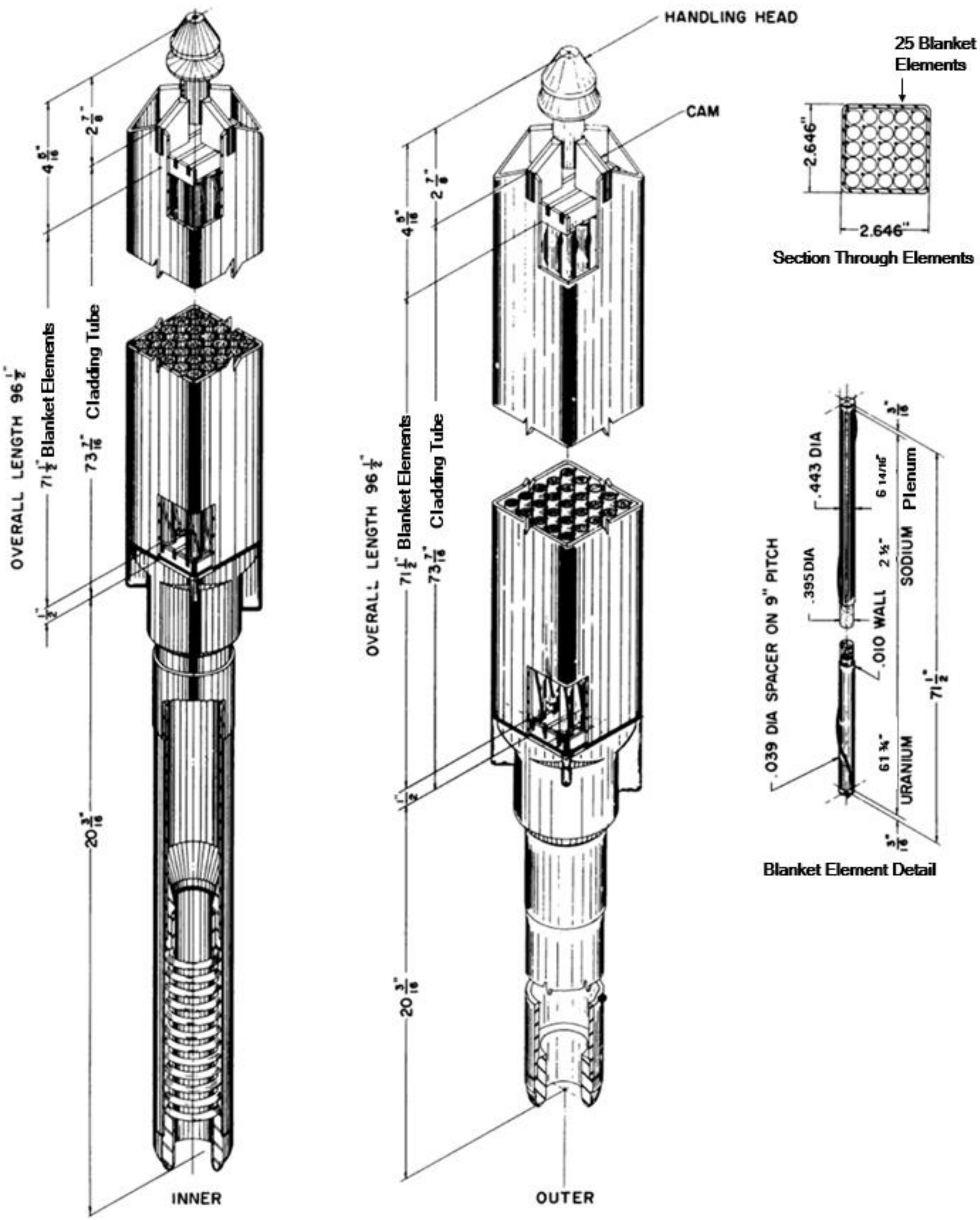

Figure 1. Fermi-1 radial blanket configuration.

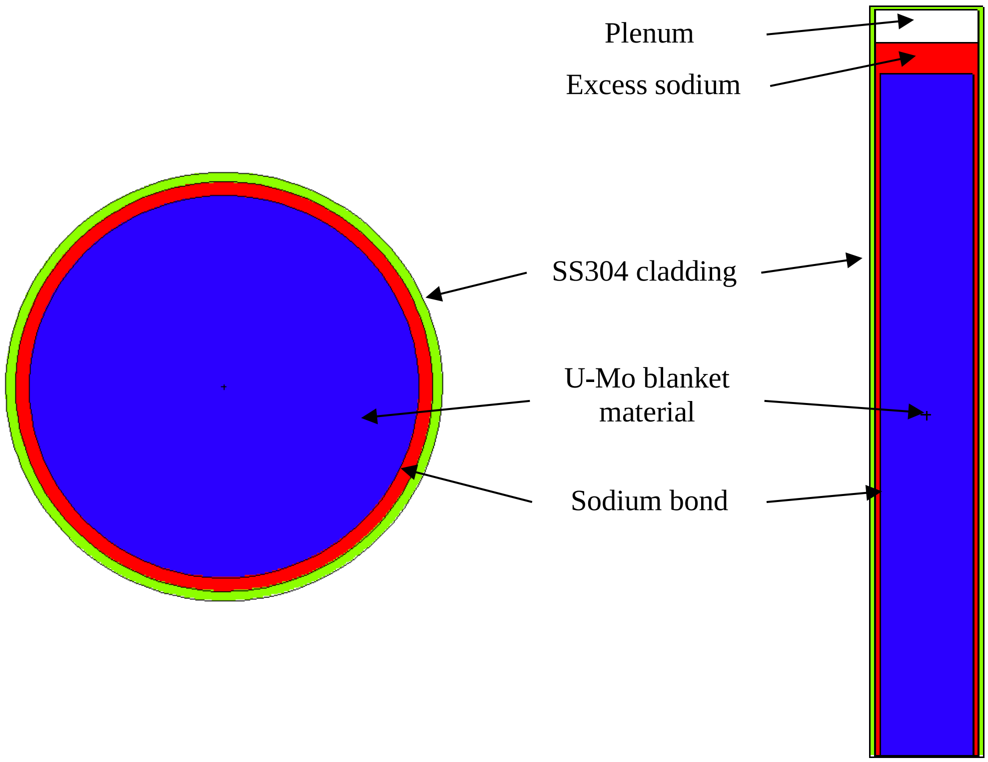

Figure 2. Fermi-1 blanket element as modeled in MCNP6.

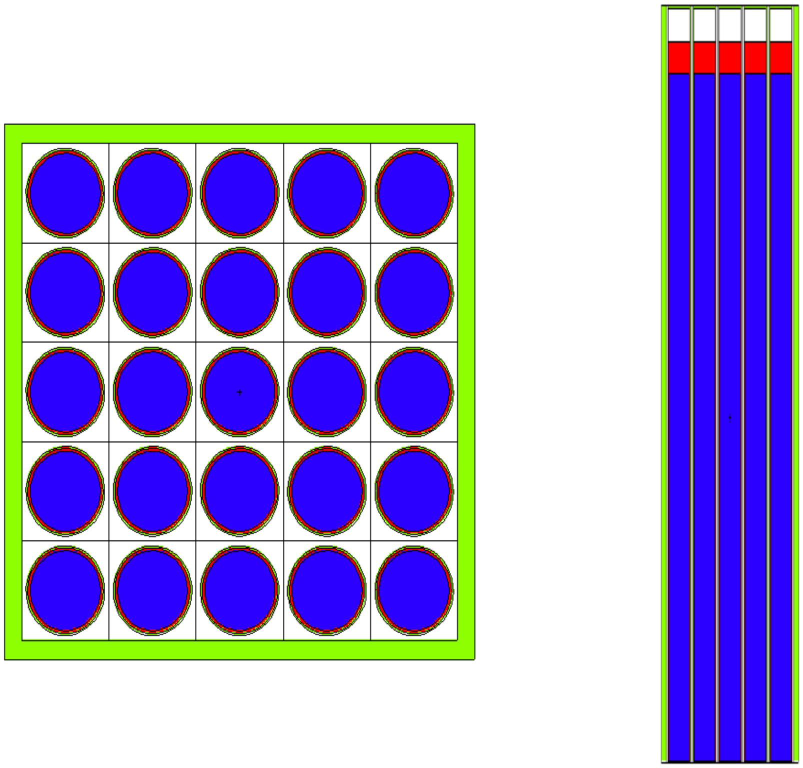

Figure 3. Fermi-1 blanket material assembly section as modeled in MCNP6.

3.2 Fermi-1 Axial Blanket Material Element and Assembly

The axial blanket material is found above and below the driver fuel assemblies. The axial blanket element consists of an approximately 14-inch-long depleted uranium-molybdenum alloy material. Between the axial blanket material and cladding is the same sodium bond. Above the axial blanket material is 1.2 inches of sodium followed by 1.9 inches of argon plenum. The blanket material, sodium bond, and plenum space are encased in a stainless-steel cladding. The axial blanket elements are then bundled together in a 5 × 5 square grid (with only the outer locations filled) within an assembly duct to form the axial blanket assembly section of the driver fuel assemblies. Above the element array is a control rod assembly and handling feature for the assembly. Below the element array are end features for locking the assembly into the reactor lower core plate. Figure 4 shows radial and axial views of the Fermi-1 axial blanket assembly sections as modeled in MCNP6. The argon gas in the plenum was not modeled, and the volume is left as a void. The upper and lower assembly features were not modeled as the will be removed prior to being introduced into the MEDE process.

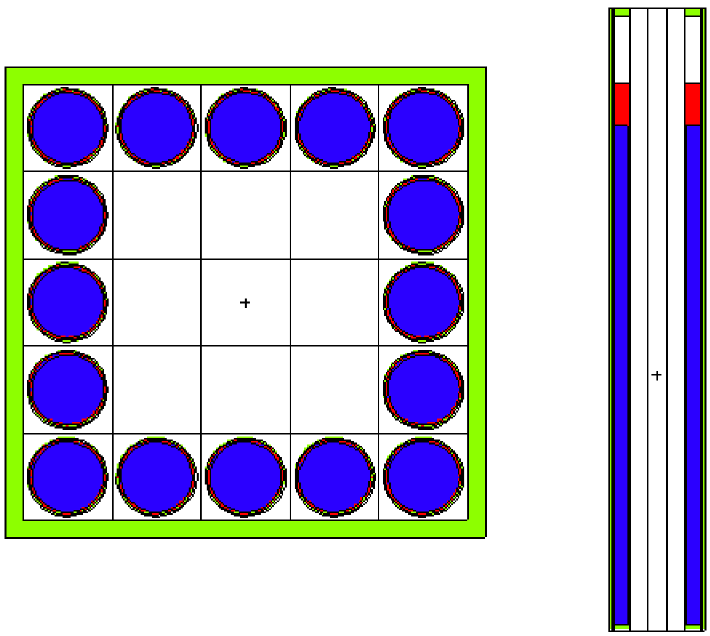

Figure 4. Fermi-1 blanket material assembly section as modeled in MCNP6.

3.3 MEDE Can

The current proposed procedure for the MEDE process is to remove the blanket elements from their assemblies and place 169 individual blanket elements inside the MEDE can. The MEDE can is a ½-inch-thick, 7.5-inch-diameter steel pipe, which is the configuration proposed for the MEDE process to remove the sodium bond from the Fermi-1 blanket material elements. This configuration allows for cutting the ends of the Fermi-1 blanket elements and performing the MEDE process. Figure 5 shows radial and axial views of 169 Fermi-1 blanket elements in the 7-inch-diameter MEDE can as modeled in MCNP6.

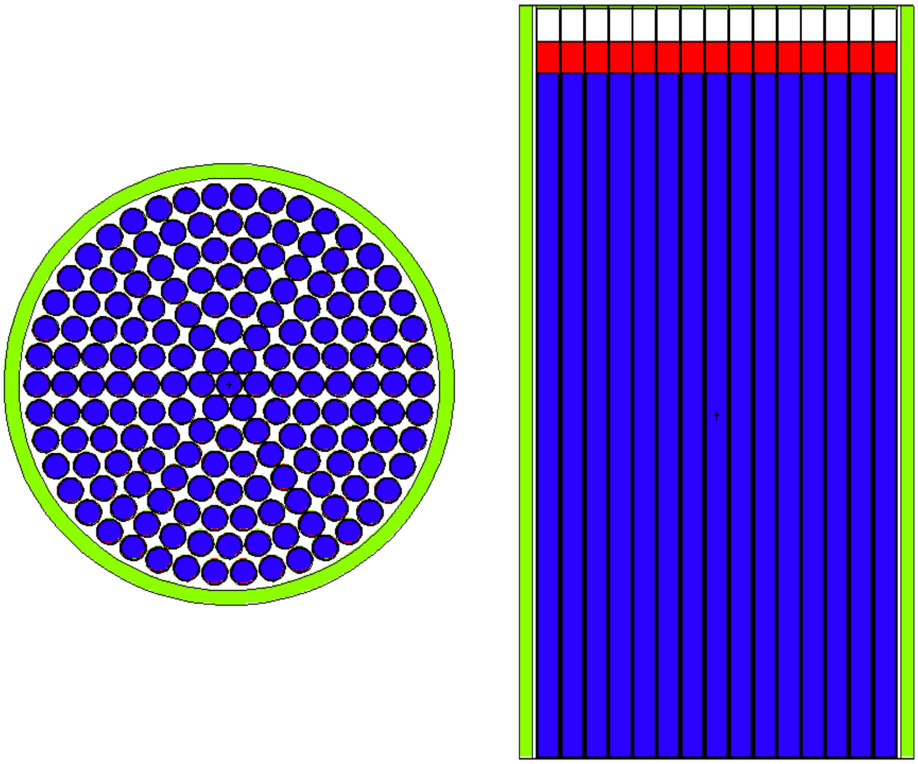

Figure 5. The 169 Fermi-1 blanket elements inside a 7-inch-diameter pipe used for the MEDE process as modeled in MCNP6.

3.4 Fermi-1 Storage Canister

The Fermi-1 assemblies are currently stored in a 25.5-inch stainless-steel canister referred to as the Fermi Storage Canister (FSC). The assemblies are placed in an array constructed from 3 × 3 × 0.83-inch square tubing. The canister itself has a maximum length of 158.5 inches and a top and bottom plate that are 0.75 inches thick. Figure 6 shows radial and axial views of the Fermi-1 radial blanket assemblies in the FSC. Ten of the 37 locations have two radial blanket assemblies, resulting in 47 assemblies stored per FSC.

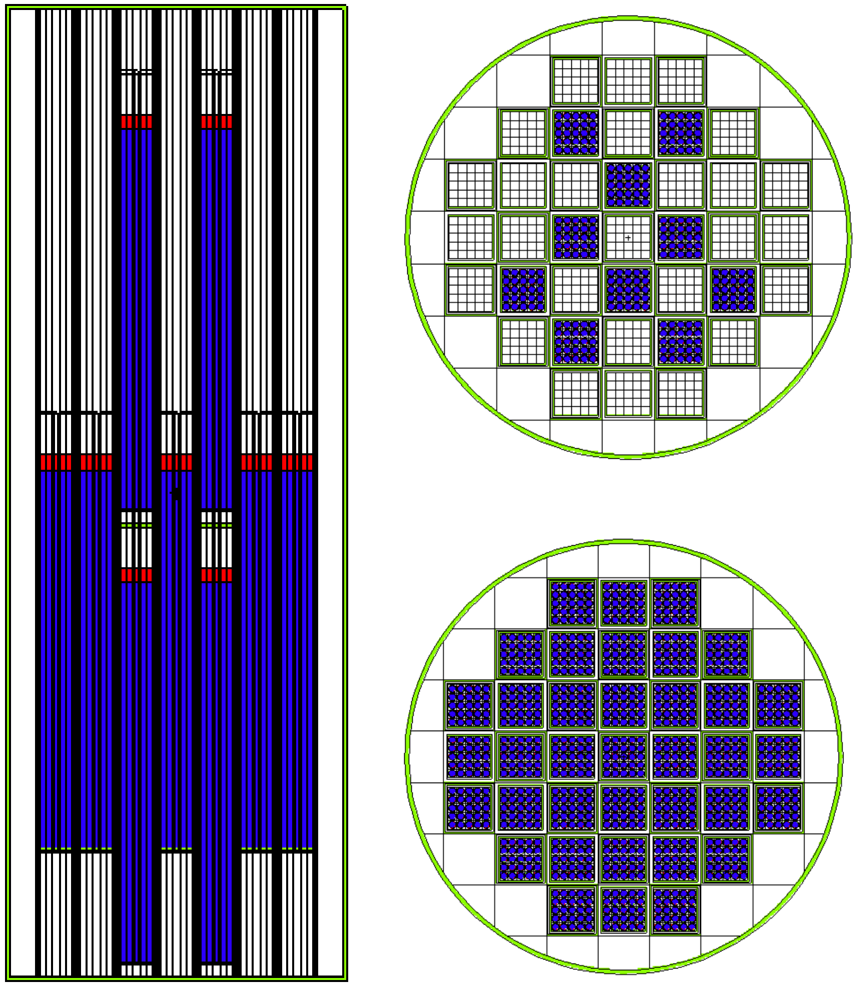

Figure 6. Fermi-1 radial blanket material in an FSC as modeled in MCNP.

3.5 DOE Standard Canister

There are four variants of the DOE Standard Canister (DSC) based on two lengths (10 and 15 ft) and two diameters (18 and 24 inch). The scenario to be investigated involves placing seven MEDE cans into one 10 × 24 DSC. The description of the 10 × 24 DSC is taken from (DOE 1999a). The DSC is a right circular cylinder made of stainless-steel pipe (Type 316L or UNS S31603) with an outside diameter of 24 inches and a wall thickness of 0.5 inches. The nominal internal length of the DSC used for fuel loading is 8.2 ft (~98 inches). The top and bottom carbon steel (Carbon Steel 516 Grade 70) impact plates are 2 inches thick at the centers. Dished heads seal the ends of the DSC. Table 1 provides a specification overview of the DSC, and Figure 7 shows an axial cross section view of the 15 ft DSC variant. Figure 8 shows radial and axial views of seven MEDE cans in a 10 × 24 DSC as modeled in MCNP6.

Table 1. DSC specification overview.

Canister Dimensions	Maximum Loaded Canister Weight	Intended Use
45.7-cm (18-inch) diameter 3.05-m (10-foot) total length	2,270-kg (5,005-lb) total weight	Shorter fuels that effectively utilize the length of a 3.05-m (10-foot) canister[a]
45.7-cm (18-inch) diameter 4.57-m. (15-foot) total length	2,721-kg (6,000-lb) total weight	Longer fuels and/or those that can be more efficiently stacked into the 4.57-m (15-foot) canister[b]
61.0-cm (24-inch) diameter 3.05-m. (10-foot) total length	4,081-kg (8,996-lb) total weight	Low-Enriched Uranium (LEU) fuels, or small quantities of canistered HEU material
61.0-cm (24-inch) diameter 4.57-m. (15-foot) total length	4,536-kg (10,000-lb) total weight	High-Enriched Uranium (HEU) High-Flux Isotope Reactor (HFIR) outer assemblies and Shippingport Light-Water Breeder Reactor (LWBR) power-flattening blanket assemblies[c]

[a] For co-disposal, the shorter fuels are reserved for the shorter canisters to match (approximately) the number of 3.05-m (10-foot) HLW canisters generated at both Savannah River and West Valley.

[b] Exceptions may occur as in the case of the much shorter Ft. St. Vrain fuels, where three-high stacked blocks in short canisters vs. five-high blocks in long canisters would cause an inordinate increase in the total number of SNF canisters generated.

[c] Both fuels contain significant quantities of fissile material, but because of their physical size, it is not possible to utilize the 45.7-cm (18-inch) canister. These fuel units also require additional poisoning internal to the fuel assemblies themselves in conjunction with their installation in the 61.0-cm (24-inch) diameter canister.

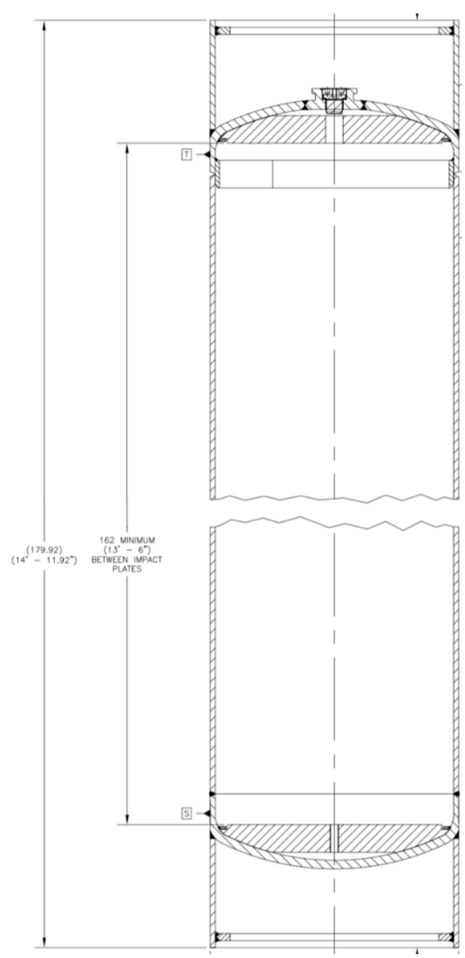

Figure 7. The DSC.

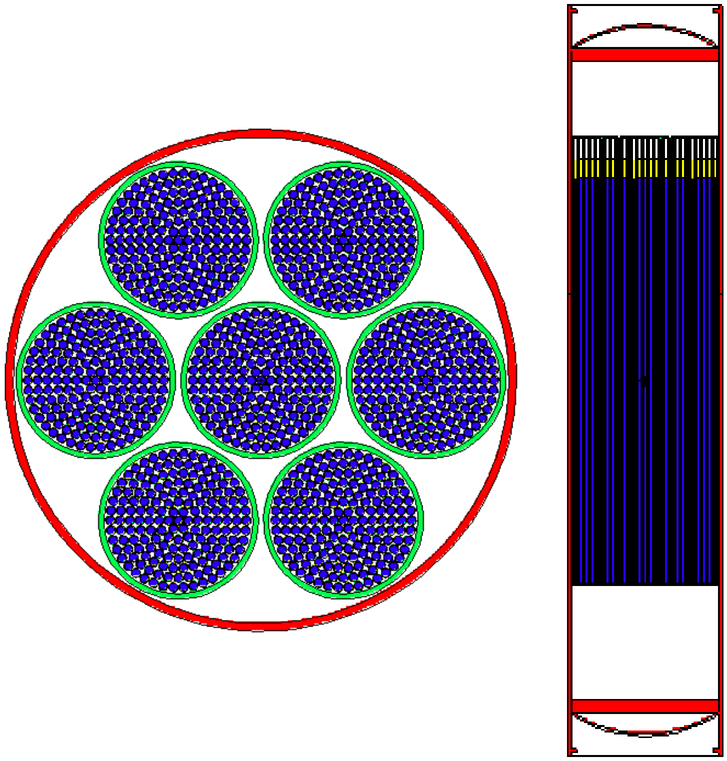

Figure 8. Seven MEDE cans of 169 Fermi-1 blanket elements each in a 10 × 24 DSC as modeled in MCNP6.

3.6 Scenarios

The following seven scenarios were considered in this analysis:

1. A single Fermi-1 radial blanket material element (active length ~157cm).
2. A single Fermi-1 radial blanket assembly (which consists of 25 radial blanket elements).
3. A single Fermi-1 axial blanket material element (active length ~35.5cm).
4. A single Fermi-1 axial blanket assembly (which consists of 16 axial blanket elements).
5. Forty-seven Fermi-1 radial blanket assemblies in the FSC.
6. One hundred sixty-nine Fermi-1 radial blanket material elements inside the MEDE can.
7. Seven such “MEDE cans” arranged inside a 10 × 24 DSC.

4. ASSUMPTIONS

1. All air volumes are modeled as void.
2. Based on the radioisotopic composition provided in Appendix A, the source from the Fe-55, Co-60, and Ni-63 originated in the stainless-steel clad, with the remainder of the source term originating from the DU-Mo blanket material.
3. The neutron contribution to dose is negligible.
4. Assemblies are modeled with end features removed as this is the proposed configuration for the MEDE process and contributions to dose from these structural pieces are negligible.
5. The Fermi-1 radial and axial blanket assembly parameters in table.

Table 2. MCNP model parameters.

Parameter	**Value**
Blanket material pellet radius	0.50165 cm
Sodium bond gap radius (clad inner radius)	0.53721 cm
Clad outer radius	0.56261 cm
Element endcap thickness	0.508 cm
Axial blanket material active length	35.56 cm
Radial blanket material active length	156.845
Height of sodium above active length	6.35 cm
Height of plenum	17.3999 cm
Assembly pin pitch	0.623316 cm
Assembly flat to flat	3.11658 cm
Assembly duct thickness	0.24384 cm

5. MATERIALS

This section provides the material compositions used in the model.

Table 3. Composition of depleted uranium-molybdenum alloy (Fermi-1 blanket material).

Element	**Composition (wt.%)**
Uranium-235	0.2395
Uranium-238	0.967605
Molybdenum	3
*Density = 18.6881 g/cm^3	

* Composition and density calculated based on 97:3 mass of U-to-Mo, and densities of U and Mo in the Pacific Northwest National Laboratory's Material Compendium Rev 2 (PNNL 2021).

Table 4. Composition of stainless steel 304 (Fermi-1 blanket clad material).

Element	Composition (at. %)
Carbon	0.3635
Manganese	1.9870
Phosphorus	0.0793
Sulphur	0.0511
Silicon	1.9434
Chromium	19.9443
Nickel	08.8343
Iron	66.7971
*Density = 8.03 g/cm^3	

* Composition and density taken from the Pacific Northwest National Laboratory's Material Compendium Rev 2 (PNNL 2021) for SS304.

Table 5. Composition of sodium (Fermi-1 blanket bond material).

Element	Composition (at. %)
Sodium	100
Density = 0.97 g/cm^3	

Table 6. Composition of stainless steel 316 (DSC material).

Element	Composition (at. %)
Carbon	0.3683
Manganese	2.0128
Phosphorus	0.0803
Sulphur	0.0517
Silicon	1.9687
Chromium	18.0771
Nickel	11.3043
Molybdenum	1.4406
Iron	64.6962
*Density = 7.98 g/cm^3	

* Composition and density based on DSC preliminary design specifications (DOE 1999b).

6. RESULTS

SCALE 6.2.3 was used to generate the photon source spectra.
Table 7 show the photon source spectra for a single Fermi-1 blanket element based on the average burnup isotopics. Using the source term generated in SCALE, the MCNP6 radiation transport code estimated the total dose equivalent rate at various locations within the geometry. Where possible, the blanket material source was started in the blanket material and the clad source term was started in the element cladding. In the MEDE can and DSC scenarios, the two sources were combined and started in the blanket material. Depending on the number of blanket elements in the geometry, the appropriate multiplier must be applied to the source term.
Table 8 shows the multiplier used for each scenario.

Table 7. Photon source term for a single Fermi-1 blanket element.

Group No.	Energy Group Upper Bound (MeV)	Energy Group Lower Bound (MeV)	Blanket Material Photon Source Intensity (photons/s)	Clad Photon Source Intensity (photons/s)
1	2.00E+01	1.00E+01	2.4823E-03	0
2	1.00E+01	8.00E+00	3.4058E-02	0
3	8.00E+00	6.50E+00	1.5961E-01	0
4	6.50E+00	5.00E+00	8.2660E-01	0
5	5.00E+00	4.00E+00	2.0484E+00	0
6	4.00E+00	3.00E+00	6.1688E+00	0
7	3.00E+00	2.50E+00	1.4088E+01	2.0618E-03
8	2.50E+00	2.00E+00	5.3043E+03	1.2371E+00
9	2.00E+00	1.66E+00	8.8568E+04	0.0000E+00
10	1.66E+00	1.33E+00	4.0762E+05	1.0307E+05
11	1.33E+00	1.00E+00	1.8833E+06	1.0293E+05
12	1.00E+00	8.00E-01	2.9267E+06	7.9084E+00
13	8.00E-01	6.00E-01	8.9591E+08	2.6182E-01
14	6.00E-01	4.00E-01	1.5319E+07	7.4044E-01
15	4.00E-01	3.00E-01	1.9786E+07	9.4959E+00
16	3.00E-01	2.00E-01	2.9627E+07	1.0805E+01
17	2.00E-01	1.00E-01	8.8022E+07	1.8691E+02
18	1.00E-01	4.50E-01	1.5922E+08	9.3894E+02
19	4.50E-02	1.00E-02	5.5195E+08	3.2236E+04

Table 8. Photon source strength multiplier.

Scenario	Number of Blanket Elements in Geometry	Photon Source Strength Multiplier
Radial blanket element	1	1.65E+09
Axial blanket element	1	3.365E+08
Radial blanket assembly	25	4.12E+10
Axial blanket assembly	16	5.40E+09
169 radial elements in MEDE can	169	2.79E+11
47 radial assemblies in FSC	1175	1.936E+12
Seven MEDE cans in DSC	1,183	1.95E+12

Dose rates in rem/h were calculated on contact (1 cm from geometry surface), 30 cm away from geometry surface, and 1 m from geometry surface spanning the length of the blanket material within the geometry in 10 cm increments with 0 cm being the axial center of the geometry.

Figure 9–Figure 15 show the axial distribution of dose rates from the scenarios. A summary of the estimated maximum dose rates is provided in Table 9. The bounding dose rates are assumed to be 3 times the average dose rates calculated for the axial blanket material and 5.7 times the average dose rates calculated for the radial blanket material, based on the distribution of Fermi-1 blanket assembly burnup (see Appendix B).

Table 9. Maximum average and bounding dose rate.

Scenario	Maximum Average Dose Rate (rem/h)	Maximum Bounding Dose Rate (rem/h)
Radial blanket element	~0.60	~3.42*
Radial blanket assembly	~1.1	~6.27*
Axial blanket element	~0.485	~1.455+
Axial blanket assembly	~1.005	~3.015+
169 elements in MEDE can	~0.98	~5.59*
47 radial assemblies in FSC	~0.83	~4.73*
Seven MEDE cans in DSC	~0.51	~2.91*

* Bounding dose rate determined by applying a factor of 5.7 to the maximum average dose rate (from radial blanket burnup distribution, see Appendix B).

+ Bounding dose rate determined by applying a factor of 3 to the maximum average dose rate (from axial blanket burnup distribution, see Appendix B).

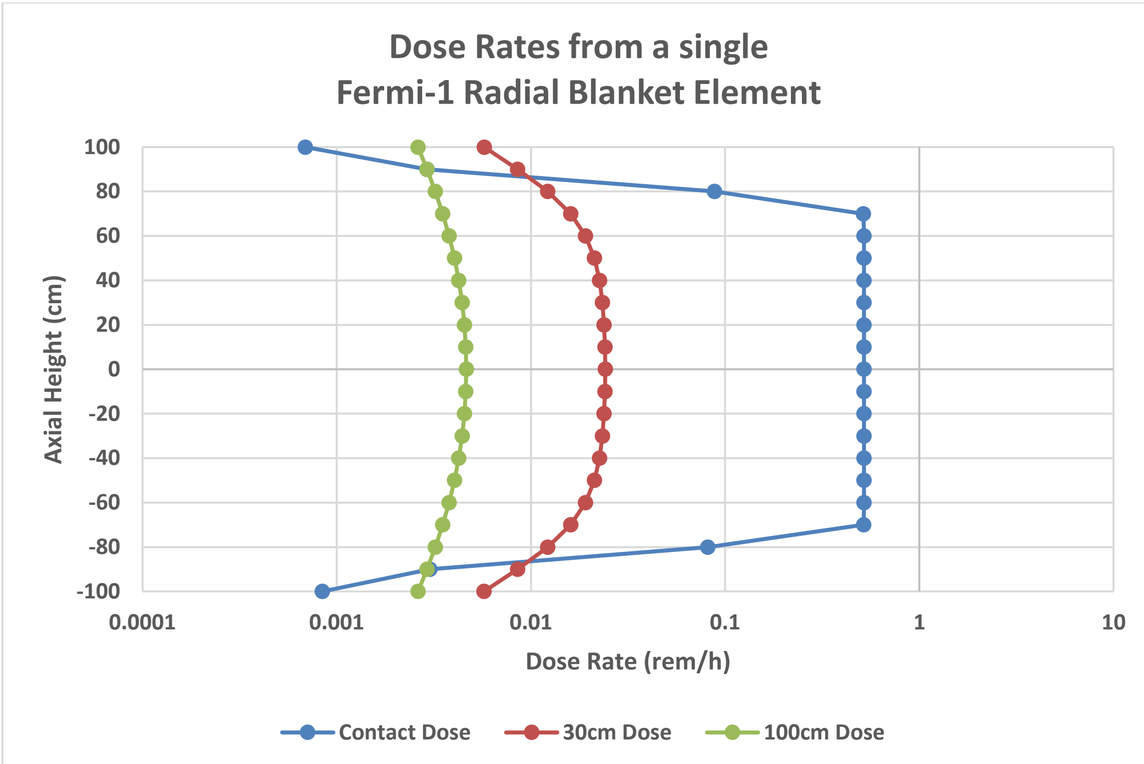

Figure 9. Dose rates from a single Fermi-1 blanket element.

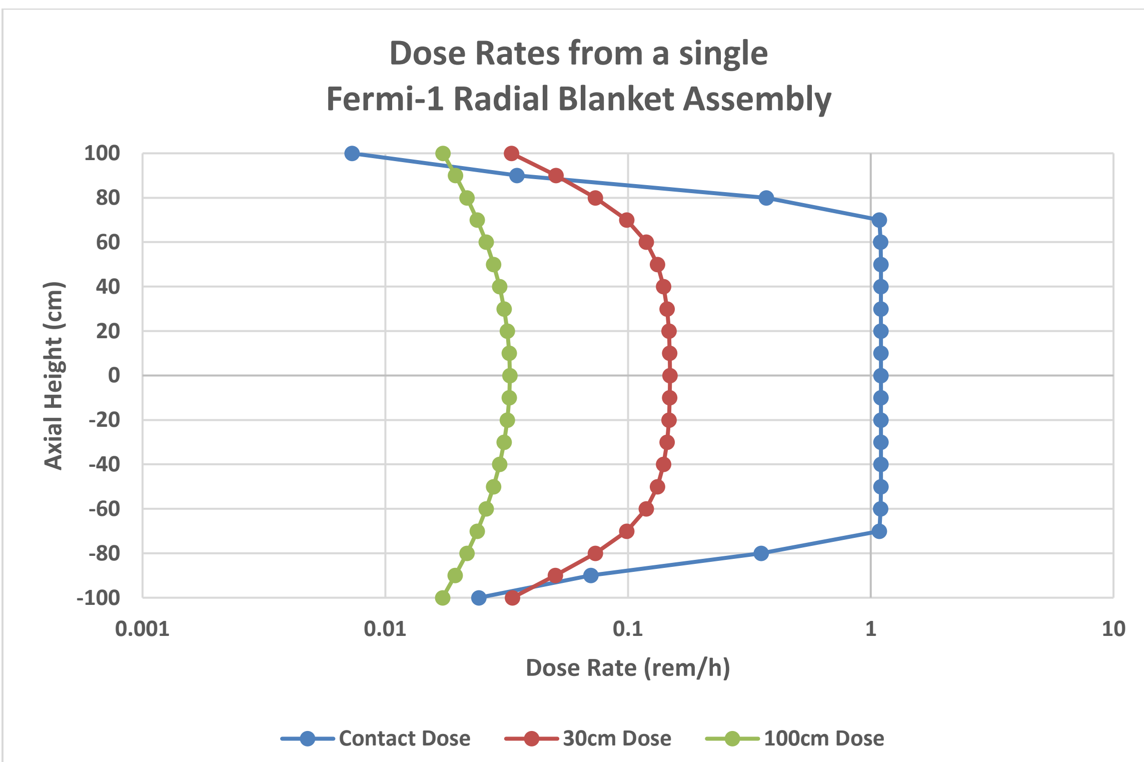

Figure 10. Dose rates from a single Fermi-1 blanket assembly.

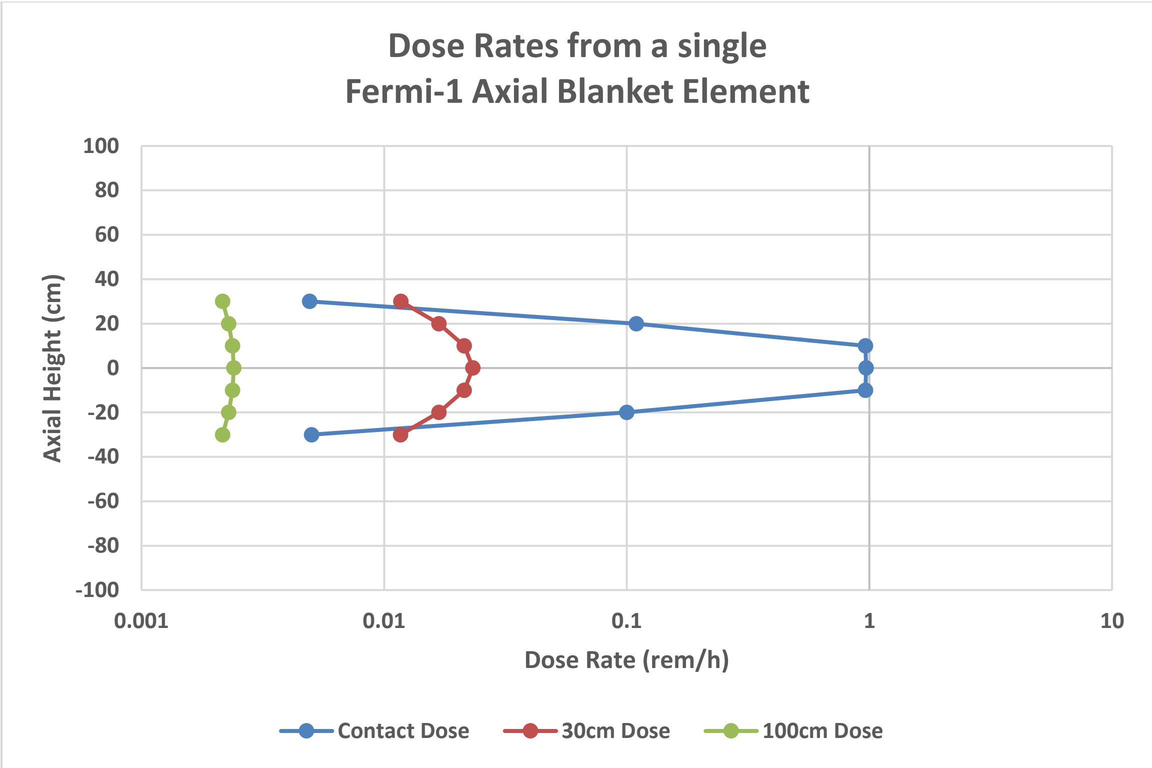

Figure 11. Dose rates from a single axial blanket element.

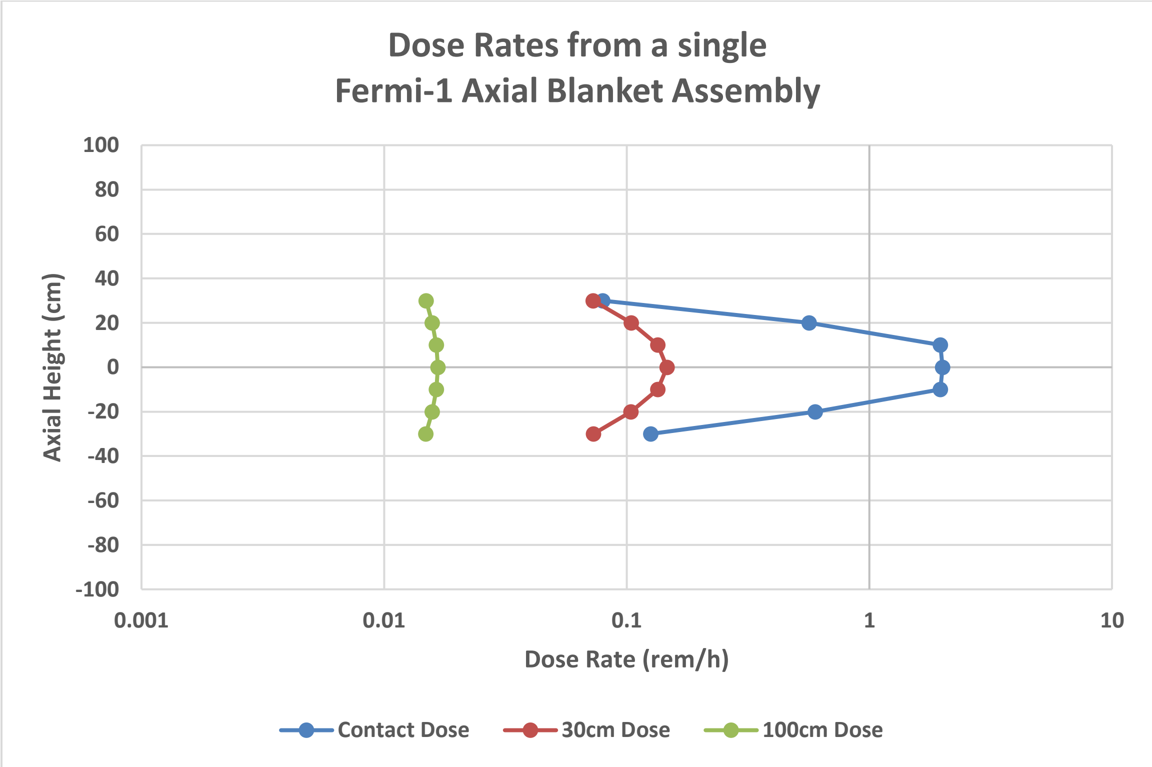

Figure 12. Dose rates from a single axial blanket assembly.

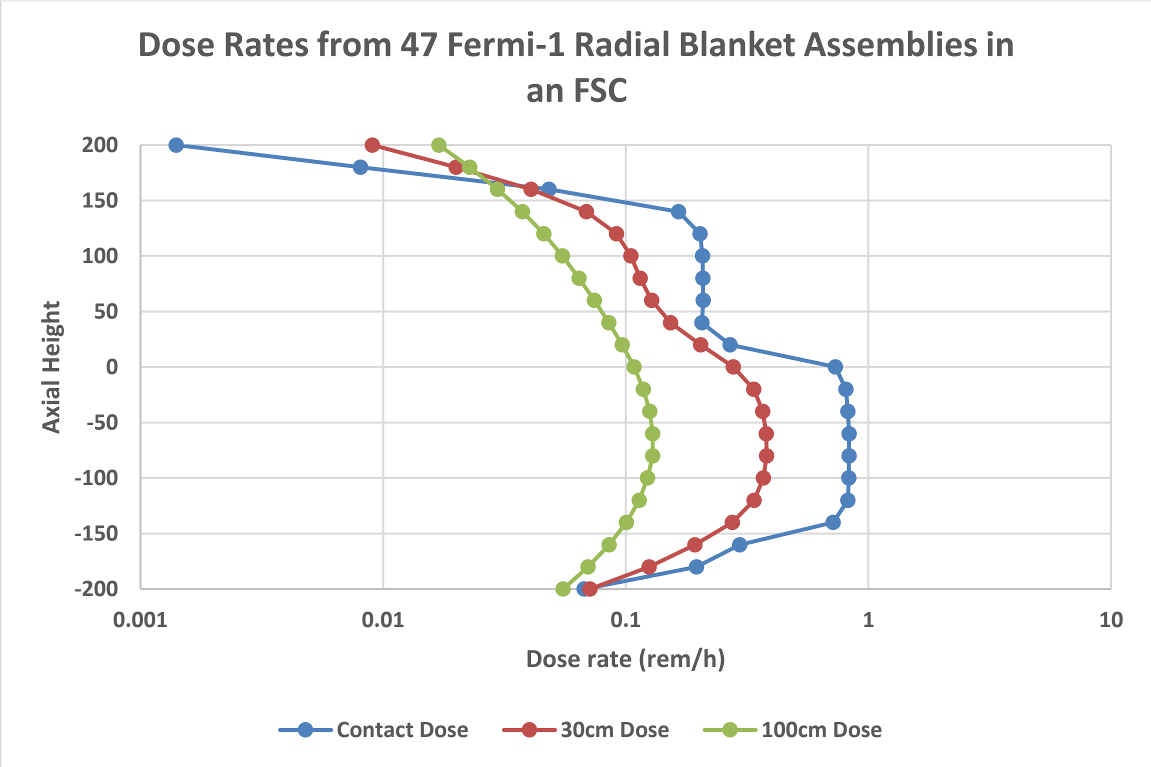

Figure 13. Dose rates from 47 Fermi-1 radial blanket assemblies in an FSC.

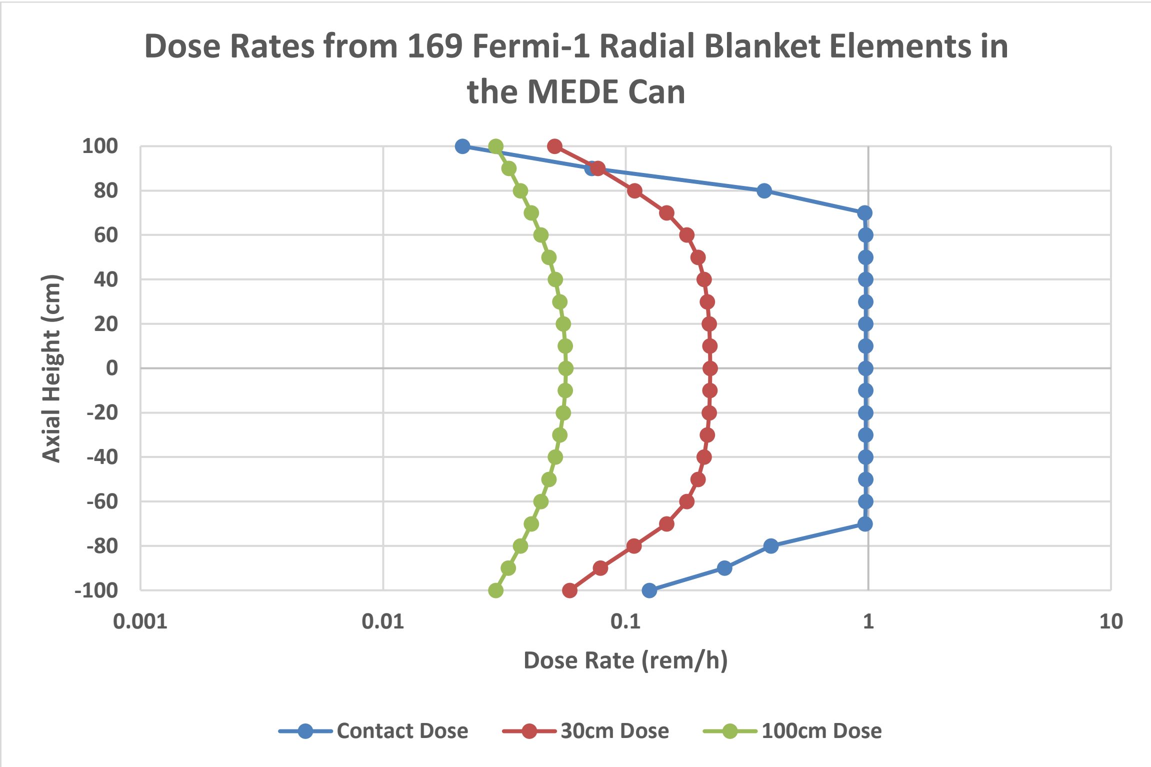

Figure 14. Dose rates from a single MEDE can with 169 Fermi-1 blanket elements.

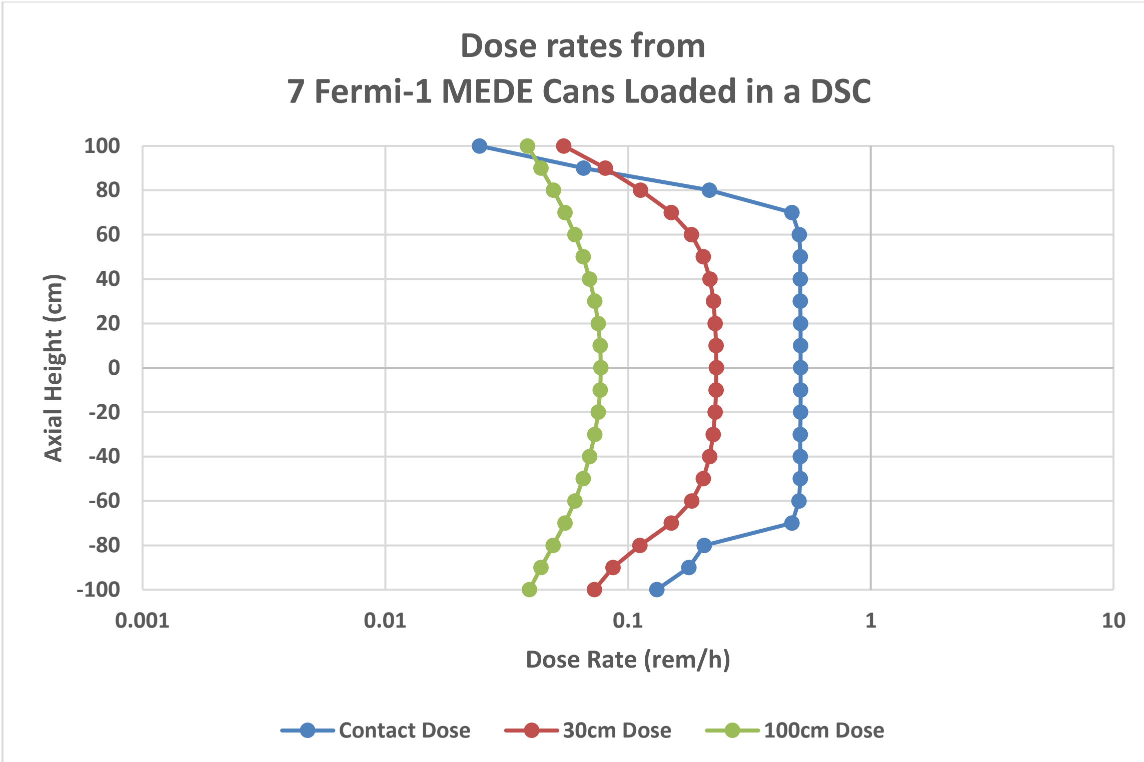

Figure 15. Dose rates from a single DSC loaded with seven MEDE cans.

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Appendix A
Radioisotopic Composition of Fermi-1 Blanket Material Circa 2000

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Appendix A – Radioisotopic Composition of Fermi-1 Blanket Material Circa 2000

Table A1. Radioisotopic composition of an average radial and an average axial blanket element

ISOTOPE	AVERAGE AXIAL BLANKET ELEMENT Activity, Ci / element	AVERAGE RADIAL BLANKET ELEMENT Activity, Ci / element
Fe 55	2.03E-04	2.43E-04
Co 60	6.10E-05	7.46E-05
Ni 63	3.02E-04	3.78E-04
Nb 93M	2.99E-05	4.11E-05
Mo 93	4.91E-05	6.74E-05
Th 234	1.66E-04	7.32E-04
Pa 234	1.66E-04	7.32E-04
U 238	1.66E-04	7.32E-04
Pu 239	7.88E-03	2.90E-02
Kr 85	5.57E-04	1.41E-03
Sr 90	1.32E-02	3.39E-02
Y 90	1.32E-02	3.39E-02
Cs 137	2.14E-02	5.02E-02
Ba 137M	2.03E-02	4.75E-02
Sm 151	1.22E-03	2.63E-03
Rh-106	1.22E-09	1.98E-09
Ce-144	1.05E-11	2.20E-11
Pr-144	1.05E-11	2.20E-11
Sb-125	3.01E-06	6.76E-06
Pm-147	8.84E-05	1.87E-04
Eu-155	7.40E-05	1.43E-04
Total	7.91E-02	2.02E-01

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Appendix B
Burnup Distribution of Fermi-1 Blanket Assemblies

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Appendix B – Burnup Distribution of Fermi-1 Blanket Assemblies

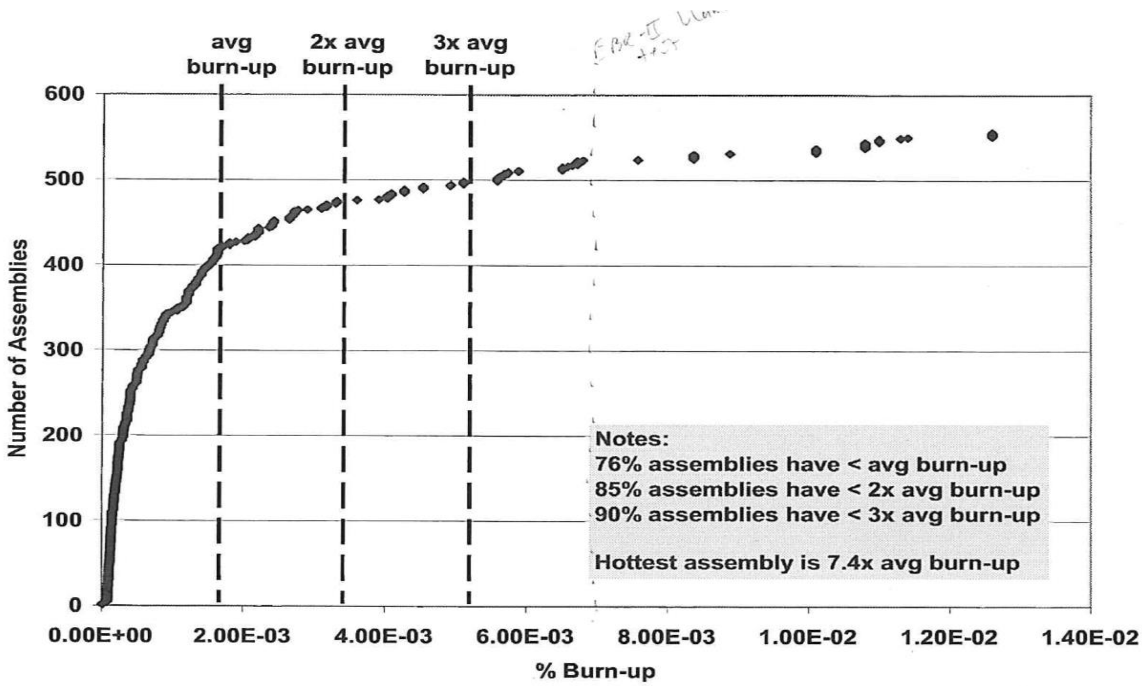

Figure B1. Burnup of inventory of Fermi-1 radial blanket material.

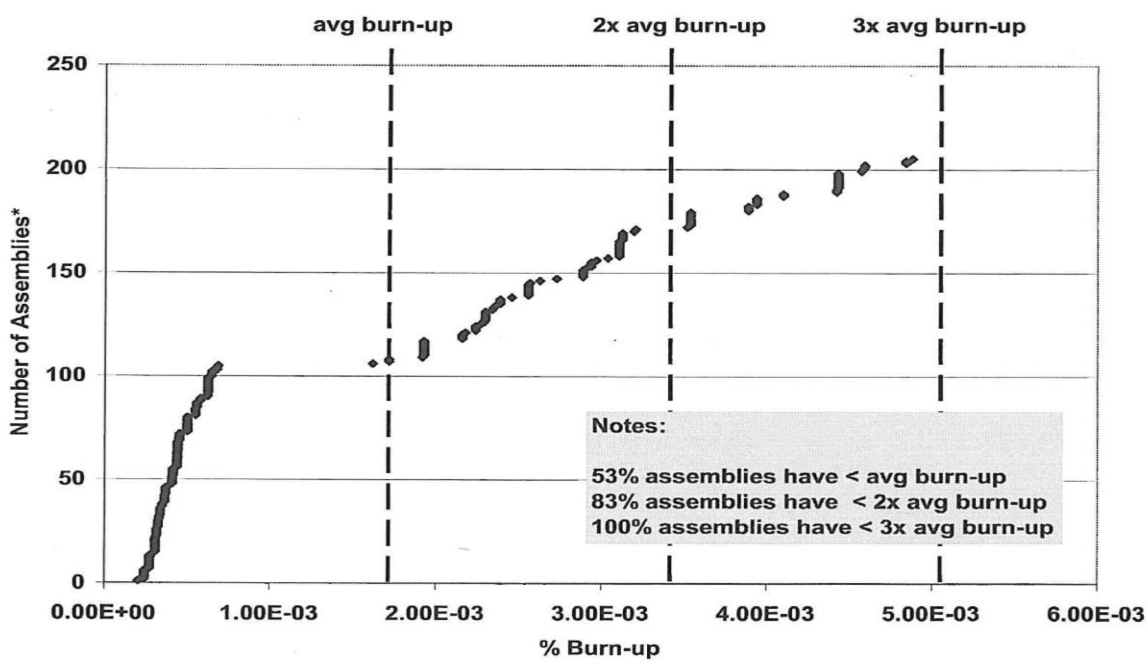

Figure B2. Burnup of inventory of Fermi-1 axial blanket material.

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Appendix C
ANSI Photon Flux-to-Dose Conversion Factors

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Appendix C – ANSI Photon Flux-to-Dose Conversion Factors

Table C1. ANSI Photon Flux to Dose Conversion Factors

Energy (MeV)	**Conversion Factor, DFn(E) (rem/h)/(n/cm2-s)**	**Energy (MeV)**	**Conversion Factor, DFn(E) (rem/h)/(n/cm2-s)**
1.00E-02	3.96E-06	1.40E+00	2.51E-06
3.00E-02	5.82E-07	1.80E+00	2.99E-06
5.00E-02	2.90E-07	2.20E+00	3.42E-06
7.00E-02	2.58E-07	2.60E+00	3.82E-06
1.00E-01	2.83E-07	2.80E+00	4.01E-06
1.50E-01	3.79E-07	3.25E+00	4.41E-06
2.00E-01	5.01E-07	3.75E+00	4.83E-06
2.50E-01	6.31E-07	4.25E+00	5.23E-06
3.00E-01	7.59E-07	4.75E+00	5.60E-06
3.50E-01	8.78E-07	5.00E+00	5.80E-06
4.00E-01	9.85E-07	5.25E+00	6.01E-06
4.50E-01	1.08E-06	5.75E+00	6.37E-06
5.00E-01	1.17E-06	6.25E+00	6.74E-06
5.50E-01	1.27E-06	6.75E+00	7.11E-06
6.00E-01	1.36E-06	7.50E+00	7.66E-06
6.50E-01	1.44E-06	9.00E+00	8.77E-06
7.00E-01	1.52E-06	1.10E+01	1.03E-05
8.00E-01	1.68E-06	1.30E+01	1.18E-05
1.00E+00	1.98E-06	1.50E+01	1.33E-05

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Appendix D
Fermi-1 Blanket Element Characteristics

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Appendix D – Fermi-1 Blanket Element Characteristics

Table D.1 Nominal characteristics of Fermi radial and axial blanket fuel elements

	RADIAL	AXIAL	NOTES
Cladding outer diameter, in	0.443	0.443	Ref. 1
Cladding wall thickness, in	0.010	0.010	Ref. 1
Sodium radial annulus thickness, in.	0.014	0.014	Ref. 1
Fuel slug diameter, in.	0.395	0.395	Ref. 1
Fuel column total length, in	61.75	14	five slugs per radial, one per axial Ref. 1
"Excess" sodium height above fuel column, in.	2.5	1.2	Axial value per X-radiograph Ref. 1
Fuel element length, in.	71.5	17.5	Ref. 1
Fuel element weight, g	2,458	569	Appendices A-3, A-1 of Ref. 2
Uranium, total g per fuel element	2,211	501	Appendices A-3, A-1 of Ref. 2
Sodium, g per fuel element	23.17 20.7	6.22 5.53	Calculated with nominal dimensions, 0.967 g/cc Appendices A-3, A-1 of Ref. 2
Uranium enrichment % (U235/U total)	0.35%	0.35%	Ref. 1
Fuel slug composition (wt. %)	U-3 Mo	U-3 Mo	Ref. 1
Fuel element cladding and hardware alloy type	304SS	304SS	Ref. 1
Fuel element spacer wire diameter / helical pitch, in.	0.039 / 9	none	Ref. 1