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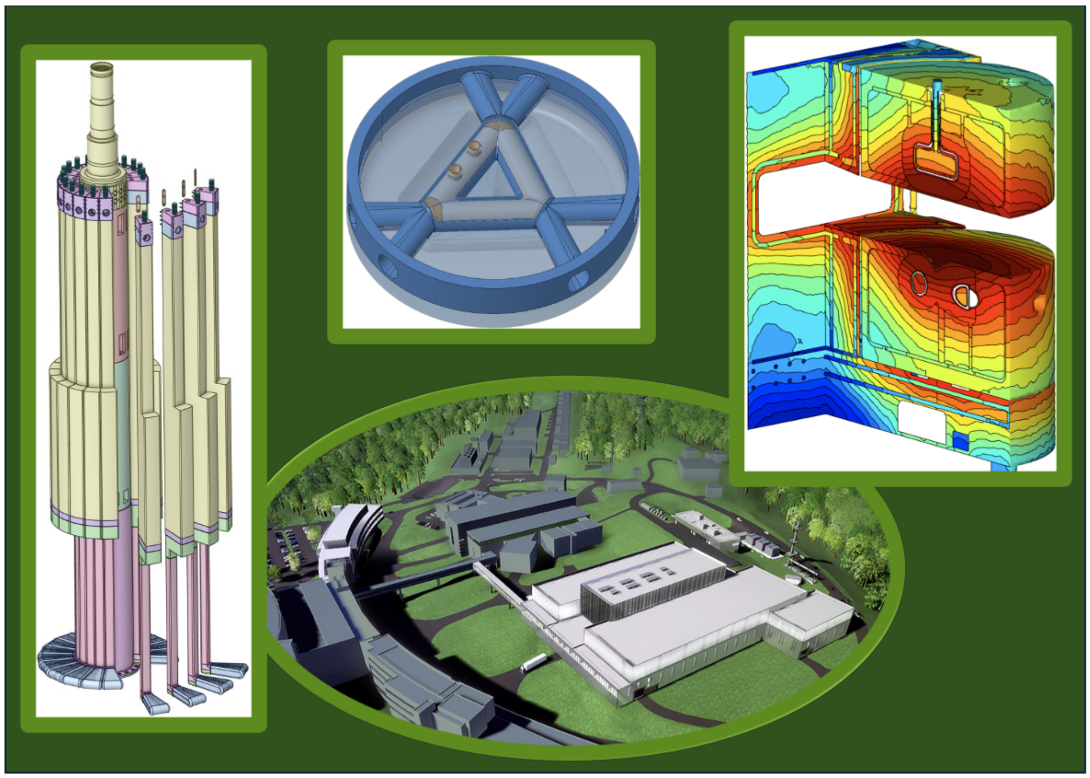
Oak Ridge National Laboratory Second Target Station Target and MRA Radionuclide Inventories and Decay Heat



Tucker McClanahan, Ph.D.

August 2026

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Second Target Station Project

Oak Ridge National Laboratory
Second Target Station Target and MRA Radionuclide Inventories and Decay Heat

Tucker McClanahan, Ph.D.

August 2026

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Primary Author						

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00	Initial Release
01	Updated for Final Design

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ABBREVIATIONS

MRA	Moderator Reflector Assembly
ORNL	Oak Ridge National Laboratory
SNS	Spallation Neutron Source
STS	Second Target Station
TDR	Target Drive Room
TVP	Target Viewing Periscope

EXECUTIVE SUMMARY

This report evaluates radionuclide inventories, decay heat, and photoneutron emission rates for target segments and the moderator reflector assembly (MRA) of the Oak Ridge National Laboratory (ORNL) Spallation Neutron Source (SNS) Second Target Station (STS). The analysis supports evaluations of component maintenance temperatures, waste classification and disposal, and transportation in shipping casks.

For target segments, a single segment meets the 3-60B A2 criterion after 1 year of decay. Two target segments meet that criterion after 2 years of decay. Calculated decay heat is below the applicable 500 W cask limit for the evaluated target-segment and MRA cases. The target segment produces a nonzero photoneutron source term that is inconsistent with the current 3-60B safety analysis report assumptions and requires further cask-authorization evaluation. The MRA photoneutron source term falls below the TN-RAM evaluated source strength of 1×10^6 n/s after approximately 1.5 years of decay.

1 SCOPE

This report presents the radionuclide inventory and decay heat for the target segments along with the moderator reflector assembly (MRA) at the Oak Ridge National Laboratory (ORNL) Spallation Neutron Source (SNS) Second Target Station (STS). The results discussed in this report evaluate or support the requirements listed in Section 2. The decay heat results support calculations of target and MRA maintenance temperatures during beam off conditions, and evaluations of accident scenarios that could cause component overheating. The radionuclide inventories support waste characterization, disposal path evaluation, and transportation planning. A partial evaluation of transportation-cask requirements indicates that the nonzero photoneutron source term from a target segment is not consistent with the current 3-60B cask safety analysis report assumptions. Additional cask-specific evaluation, amendment, or an alternative transportation package may therefore be required. The MRA photoneutron source term is below the TN-RAM evaluated neutron source strength after 2 years of decay.

2 ACCEPTANCE CRITERIA

Requirements that are evaluated are as follows:

1. Requirement S.03.02.03-10222 - Transportation in 3-60B
   - "Perishable components shall be capable of transportation within the Energy Solutions 3-60B transportation cask."

Requirements that are supported but not evaluated are as follows:

2. Requirement S.03.04-2335 - MRA Shipping Requirement
   - "The MRA shall meet the radiological requirements for shipping in the TN-RAM cask after operation and decay time of 2 years or less."
3. Requirement S.03.02.03-1570 - Maintenance Temperatures
   - "The surface temperature with the beam off after 10 years of operation and the following flow parameters shall not exceed 150°C.
     - Flow Rate: 1 L/min
     - Inlet Flow Temperature: 33°C
     - Cooldown time before maintenance starts: 8 Hours

     NOTE: The target segment must remain cool to avoid additional stress from differential thermal expansion rates within the target segment. The secondary flow rate should maintain the target below the indicated temperature."
4. Requirement S.03.02-1449 - Disposal Path
   - "All items with lifetime less than the facility shall include a removal and replacement scheme and be capable of shipping to and disposal at a waste facility."
5. Requirement S.03.02-10213 - Disposal Preparation and Transportation
   - "All perishable components shall be capable of transportation with a certified Type B container which has been approved by the DOE for consignment of radioactive material. NOTE: The STS Project has selected the Energy Solutions 3-60B as the basis of design for target assembly/component waste disposal & transportation."
6. Requirement S.03.04-2332 - MRA Disposal Requirement
   - "The MRA shall be capable of shipping to and disposal at a waste facility at the end of life."
7. Requirement S.03.04-2322 - MRA Disposal Classification Requirement
   - "The MRA shall meet the waste acceptance criteria for Nevada National Security Site after operation and decay time of 1 year or less."

3 ASSUMPTIONS AND LIMITATIONS

The main assumptions associated with the generation of the target and MRA radionuclide inventories and decay heat data detailed in McClanahan's paper are also applicable to this report [1]. The radionuclide inventories and decay heat are calculated using neutron fluxes and spallation products computed assuming a 700 kW, 1.3 GeV proton beam resulting in 3.36×10^{15} protons per second incident on the target in a nominal 60 cm^2 beam area. These neutron fluxes and spallation products were used to generate the radionuclide inventories and decay heat data assuming an operational year is defined as 2500 hours of beam on, 1880 hours beam off, 2500 hours beam on, and 1880 hours of beam off.

The target segment is assumed to operate for 10 years, and the MRA is assumed to operate for 6 years.

Water is within the target and MRA during the photoneutron emission calculations to provide a conservative estimate for the photoneutron emission rates. Also, the hydrogen has been left in the MRA to provide a conservative estimate for the photoneutron emission rates.

When calculating decay heat, CINDER2008 assumes that all energy emitted by decaying radionuclides is deposited locally in the material.

4 METHODOLOGY AND MODELS

Two general methodologies are utilized in the analysis detailed in this report. The first general methodology is applied to generate the radionuclide inventories and decay heat described in Section 4.1, and the second general methodology is used in the transport of the decay gamma sources to calculate photoneutron emission rates as described in Section 4.2.

4.1 GENERATION OF RADIONUCLIDE INVENTORIES AND DECAY HEAT

The basis of the methodology for generating the radionuclide inventories, decay gamma spectra, decay heat data for the target and MRA is detailed in McClanahan's paper [1]. MCNP® Version 6.2 with ADVANTG Version 3.2.0 along with CINDER2008 from the AARE Version 1.0 package are used in the methodology workflow in McClanahan's paper [2, 3, 4]. Further improvements in the methodology have been implemented in McClanahan's recent report by using conservative flux and reaction rate values, and by rigorously monitoring flux convergence in each cell [5]. The MCNP output files generated in McClanahan's report are used in this report as input to the CINDER2008 calculations to calculate the radionuclide inventories and decay heat data [5].

A Python script using the ACTIUM Python package processes the *table_by_nuclide* files generated by CINDER2008 and produces radionuclide inventory spreadsheets and target segment decay heat plots [6].

The decay gamma spectra used in Section 4.2 are based on the 7428-group CINDER2008 spectrum rather than the 25-group spectrum used in McClanahan's report. The integrals of the decay gamma spectra are the same between the 7428-group and 25-group spectra but the higher resolution energy bins allow for better calculation of the photoneutrons produced by the MRA and Target. With the 25-group energy bin structure, some gamma emissions were effectively represented at energies above their physical energies to energies above the photonuclear threshold for several isotopes due to the relatively large energy bin widths. For example, ^{60}Co emits a 1.332 MeV gamma with every decay. This gamma is binned to the energy group between 1.33 - 1.66 MeV via the 25-group structure. At 1.332 MeV, the photonuclear cross section for ^{9}Be is 7.6×10^{-9} b whereas at 1.66 MeV, the photonuclear cross section for ^{9}Be is 2.8×10^{-4} b. In this relatively small energy bin, the photonuclear cross section for ^{9}Be increases by a factor of 37000.

4.2 TRANSPORT OF DECAY GAMMA SOURCES

Various components of the methodology for transporting the decay gamma sources from McClanahan's report to compute photoneutron emission rates are detailed in the sections below [5]. Section 4.2.1 describes the geometry used in the decay gamma transport for both the MRA and target segment and drive. Section 4.2.2 details the isotopic composition of the materials used in the geometry. Section 4.2.3 shows the decay gamma sources used to compute the photoneutron emission rates. Section 4.2.4 describes the method used to transport the sources throughout the target or MRA.

4.2.1 Geometry

The target segment and MRA geometries used to calculate the photoneutron emission rate are discussed in this section. Figure 1 shows a cross section view of the single target segment geometry along the proton beam. Water has been left in the model to add a conservative estimation of the photoneutron production because ^{2}H is a contributor to the photoneutron emission from the target. The target segment is completely surrounded by void in all directions. Figure 2 shows a plan view of the target foot geometry at the proton beam elevation showing the wedge geometrical nature of the target foot.

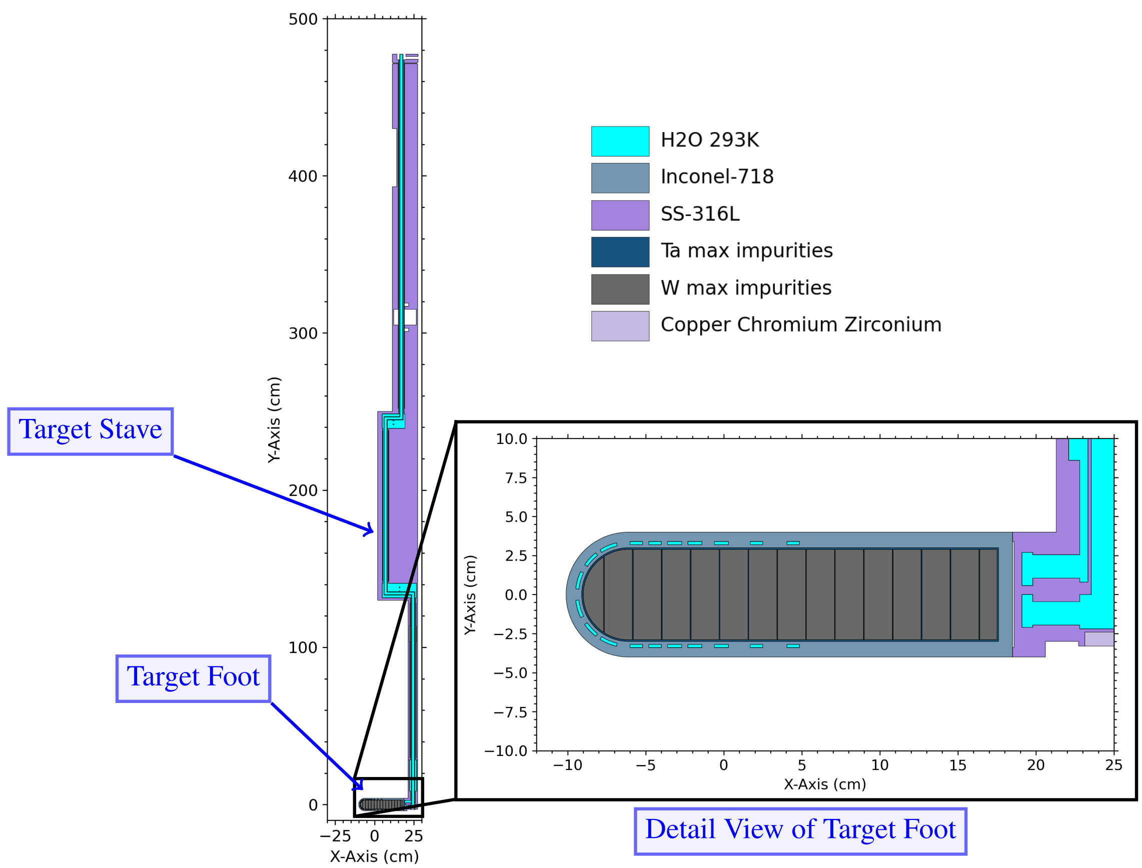

Figure 1. Cross section view of the geometry of a single target segment along the proton beam (Z=0.01 cm).

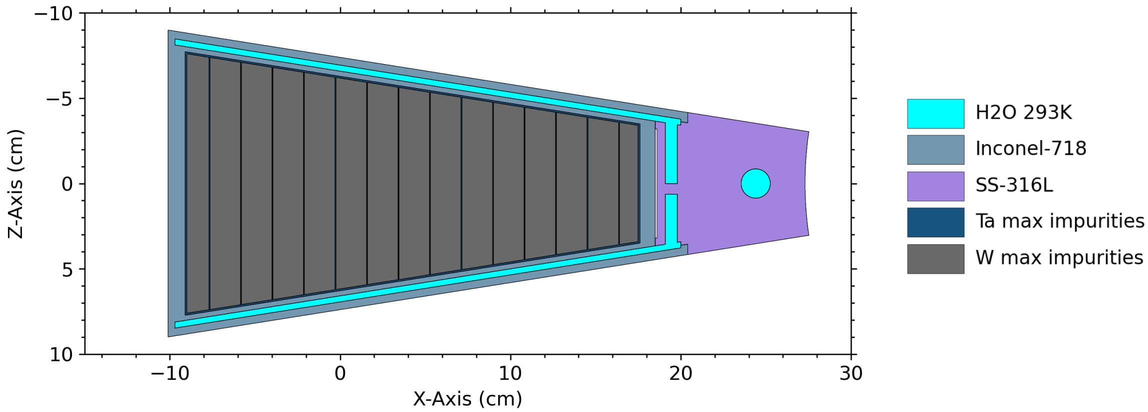

Figure 2. Plan view of the target foot geometry at the proton beam elevation (Y=0.0 cm).

Figure 3 shows a cross section view of the MRA geometry along the proton beam. Like the target geometry, the MRA is completely surrounded by void and the water is left in the MRA. In addition to the water being left in the MRA for this analysis, the hydrogen has also been left in the MRA to provide a conservative estimate for the amount of photoneutrons emitted from the MRA.

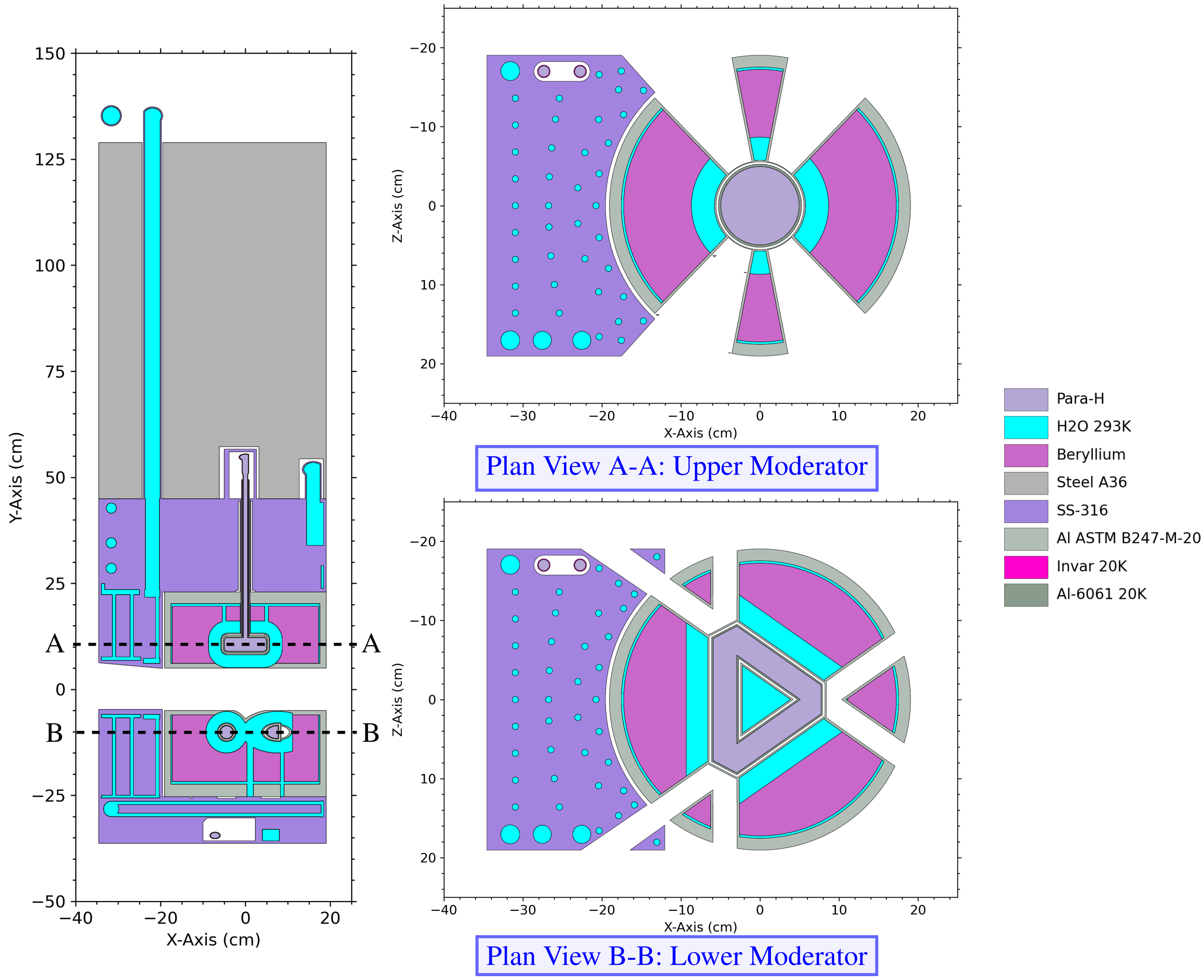

Figure 3. Cross section view of the MRA geometry along the proton beam (Z=0.01 cm) along with plan views of the upper and lower moderators.

4.2.2 Materials

The materials used in the analysis described in this report are detailed in tables included in Appendix D. During the Monte Carlo transport runs where the photoneutron emission rates are tallied, ENDF/B-VII.1 cross sections supplemented by TENDL 2021 cross sections are used [7, 8].

4.2.3 Decay Gamma Source

The decay gamma source intensities calculated using the methodology described in Section 4.1 are shown in the figures of this section. The most intense sources of decay gammas are in the target foot and backbone of the MRA. The target segment and MRA have been subdivided to spatially resolve the decay gamma source. If a space is white in the figures, that region's decay gamma source term was not included in the analysis of this report.

Figure 4 shows a cross section view of the 1 year decay gamma source for a single target segment. The detail view of the target foot has a separate colorbar from the main figure of the entire segment. The decay gamma source intensity decreases as the subdivisions of the segment are further away from the beam-on-target location (Y=0.0 cm). The detail view of the target foot shows that the thin layer of tantalum is the most intense gamma emitter in the target segment.

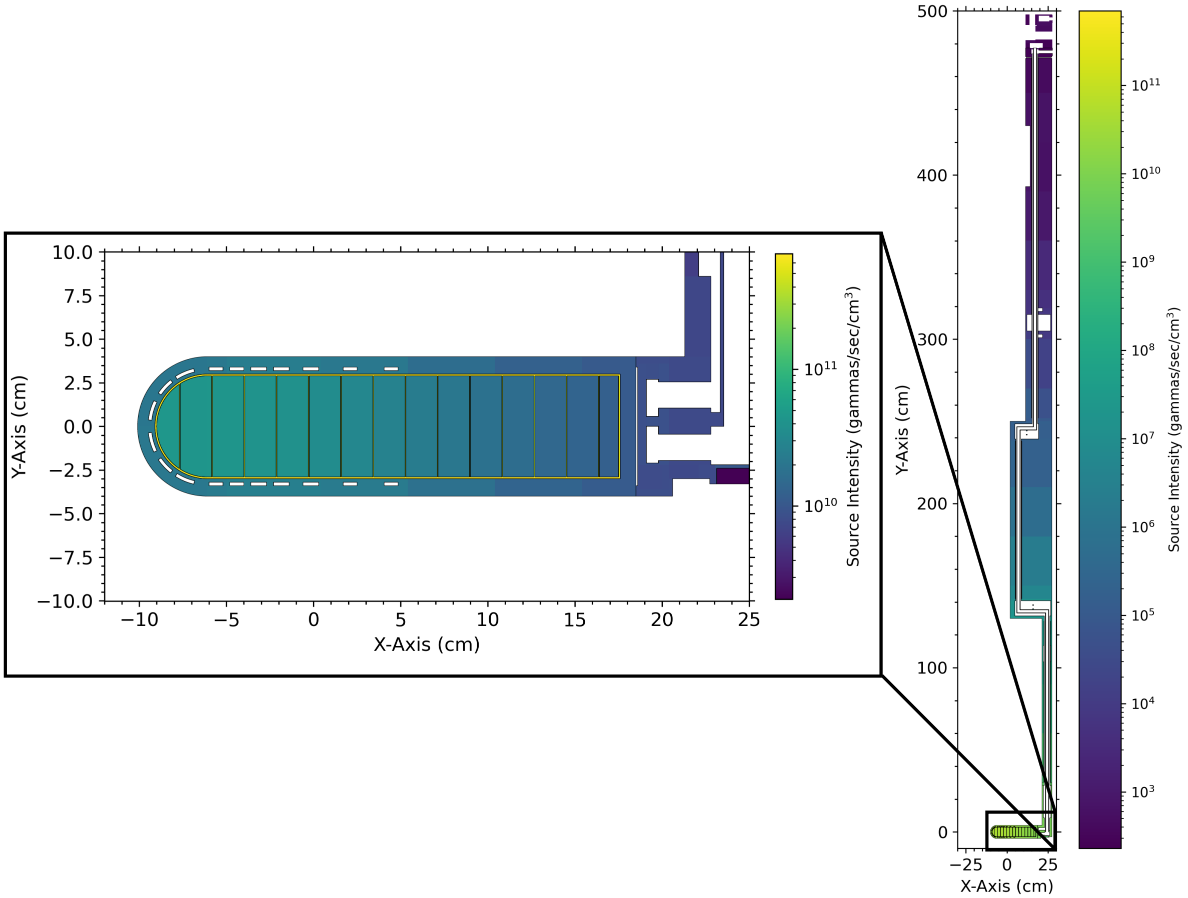

Figure 4. Cross section view of 1 year decay gamma source for a single target segment along the proton beam (Z=0.01 cm).

Section 5.3 contains photoneutron emission rates for the MRA at various decay times. Figure 5 shows an example of one of the decay gamma sources at 1 year of decay. The most intense gamma emitter of the MRA at 1 year of decay is the stainless steel backbone shown in Figure 5.

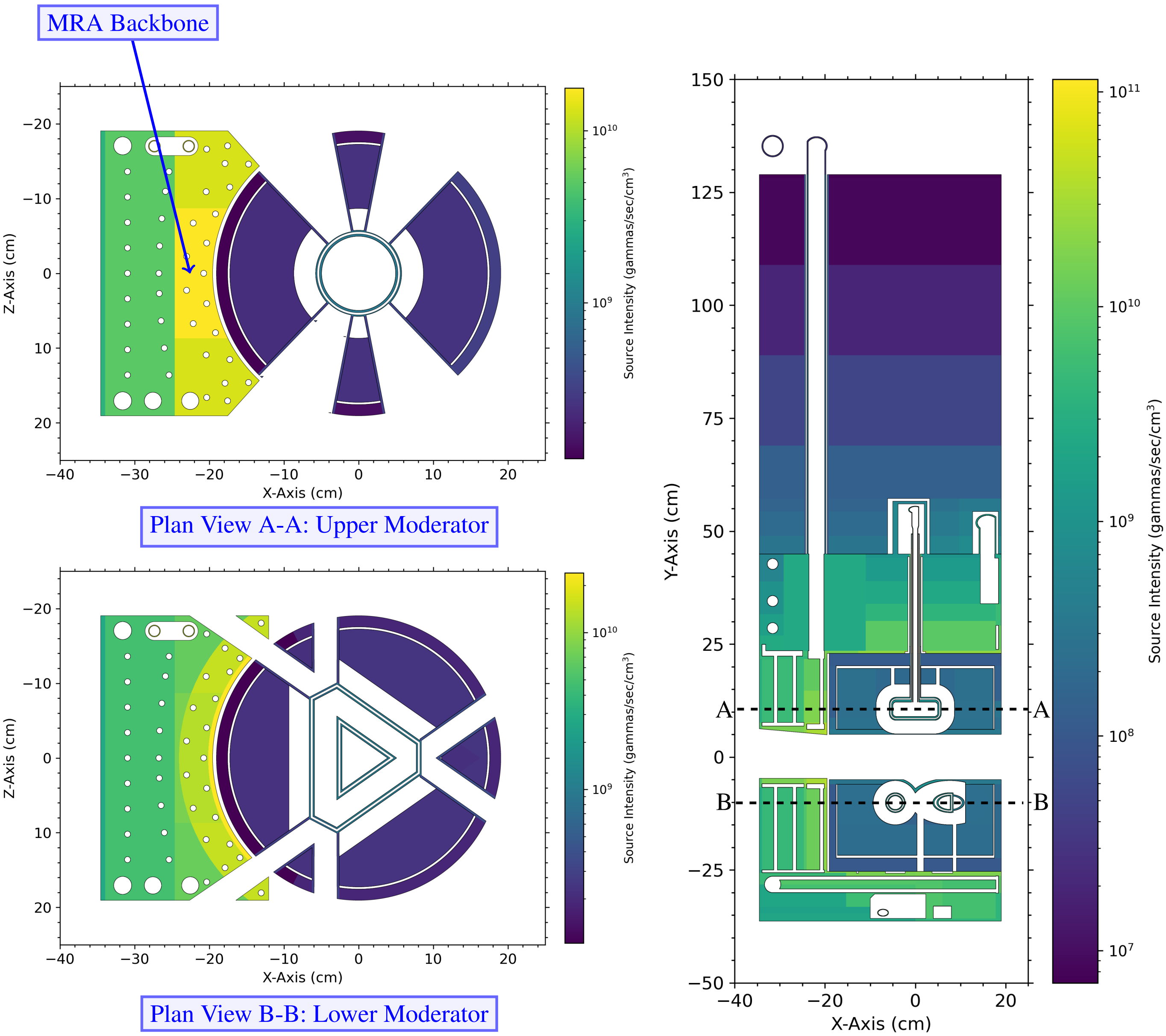

Figure 5. Cross section view of the MRA 1 year decay gamma source along the proton beam (Z=0.01 cm) along with plan views of the upper and lower moderators.

4.2.4 Particle Transport

MCNP® Code Version 6.3.0 is used to transport the decay gamma sources for the target segment and MRA shown in Section 4.2.3 to generate the photoneutron emission rates [9]. The photoneutron emission rates are tallied with a surface crossing tally (F1) on a copy of the bounding surface of the calculation moved inward 1 cm as to not tally on a surface that is the zero importance boundary. The void that completely surrounds the target segment or MRA geometries allows the neutrons that exit the geometry, to immediately ray-trace to the surface crossing tally leading to an efficient calculation.

To aid in convergence of the surface crossing tally, a simple source biasing scheme was used where if the source probability is greater than zero, the source biasing parameter was set to unity. Along with the source biasing, biased photonuclear physics is employed by setting the fourth entry of the *phys:p* card to 1. In order to have a more efficient calculation, a photon cutoff energy of 1.0 MeV is used because no neutrons will be generated from a 1.0 MeV or less photon interaction.

4.2.5 Post Processing

A Python script was written to process the photoneutron emission rates from 8 target segment and 60 MRA Monte Carlo runs using the MCNPTools Package [10]. Each run has a unique decay gamma source. This script loads in the mctal file from each MCNP® run and sums the respective sources together for either the target segment or MRA for each decay timestep. The geometry, and source intensity plots are generated using the RTPlotter Python suite of tools developed by Joel Risner, Wouter de Wet and Tucker McClanahan.

5 ANALYSIS AND RESULTS

This section presents the results of the radionuclide inventories, decay heat data, and photoneutron emission rates in the target segment and MRA. The following subsections provide detailed descriptions of the calculated quantities. Section 5.1 describes the radionuclide inventories for the target segment and MRA. Section 5.2 shows the decay heat of the target segment foot over time. Section 5.3 discusses the photoneutron emission rates from the target segment and MRA.

5.1 RADIONUCLIDE INVENTORIES

The radionuclide inventories for the target segment and MRA are discussed in this section. The radionuclide inventories are electronically attached to this document and are available by using a PDF viewer that supports PDF attachment such as Adobe Acrobat, Adobe Reader, Firefox etc. These radionuclide inventories are included in this report to support Requirements 1-2, and 3-7 outlined in Section 2.

5.1.1 Target Segment Radionuclide Inventory

The attached *Single Target Segment Radionuclide Inventory 1 Year Decay* contains the radionuclide inventory for a single target segment operated for 10 years and allowed to decay 1 year. The total activity is calculated to be 3701 Ci, with an A2 sum of fractions of 2356. This value is determined by calculating the ratio of the target segment activity to the A2 limit provided in 10CFR71 Section V.b Appendix A Tables 1 and 3 and summing all ratios. The A2 sum of fractions is often included in cask certificates of compliance as a requirement.The A2 fraction for a single target segment (2356) is below the A2 limit for the Model 3-60B Type B shipping cask (3000) [11]. The dominant contributor to the A2 sum of fractions is ^{151}Gd, with an A2 fraction of 1975, accounting for approximately 84% of the overall A2 sum of fractions. Furthermore, the decay heat of a single target segment after 1 year of decay is 13.69 W, which is below the 3-60B cask limit of 500 W.

However, the STS project plans to ship two target segments in the same shipment. After 1 year of decay, the A2 fraction for two target segments is calculated to be 4712, exceeding the 3-60B cask A2 limit. To address this, a 2-year decay time is also considered in this report. The attached *Single Target Segment Radionuclide Inventory* contains the radionuclide inventory for a single target segment operated for 10 years and allowed to decay 2 years. For two target segments, the total activity is 3802 Ci, and the A2 sum of fractions is 999.14. This value satisfies the A2 limit requirement of the 3-60B cask. The A2 sum of fractions for two target segments after 2 years of decay is driven by multiple isotopes, with the top three contributors being ^{151}Gd (A2 fraction of 534), ^{148}Gd (A2 fraction of 222), and ^{172m}Lu (A2 fraction of 203). Additionally, the decay heat for two target segments after 2 years of decay is 9.508 W, which is below the 3-60B cask limit for decay heat.

5.1.2 MRA Radionuclide Inventory

The attached *MRA Radionuclide Inventory* contains the radionuclide inventory for a MRA operated for 6 years and allowed to decay 1 year. For a MRA, the total activity is 17366 Ci and the A2 sum of fraction is 484.66. The TN-RAM safety analysis report states a limit of 3000 A2 and the MRA after 1 year of decay is below this limit [12]. The A2 sum of fractions for the MRA after 1 year of decay is primarily driven by ^{60}Co with an A2 fraction of 400.18 contributing 83% to the overall A2 sum of fractions. The decay heat for the MRA is 74.236 W after 1 year of decay and meets the TN-RAM cask requirement of a maximum of 500 W [12].

5.2 TARGET SEGMENT DECAY HEAT

The decay heat for the target segment foot is used to support Requirements 1, and 3-5 in Section 2. The target segment foot is the lowest portion of the target segment including the tungsten and tantalum spallation package wrapped in water-cooled inconel. The foot stops 4 cm up the target segment stave. A detail view of the foot is shown in Figures 1 & 2.

The attached *Single Target Segment Foot Decay Heat* contains the decay heat data for a single target segment foot separated by material for decay times from 0 to 214 days in 1 hour increments up to 2 days of decay and then 24 hour increments after 2 days of decay.

Figure 6 shows the decay heat over time for a single target segment foot operated for 10 years. Tungsten dominates the decay heat for the first two hours of decay and then Tantalum takes over as the dominant contributor to the decay heat for the remainder of decay time.

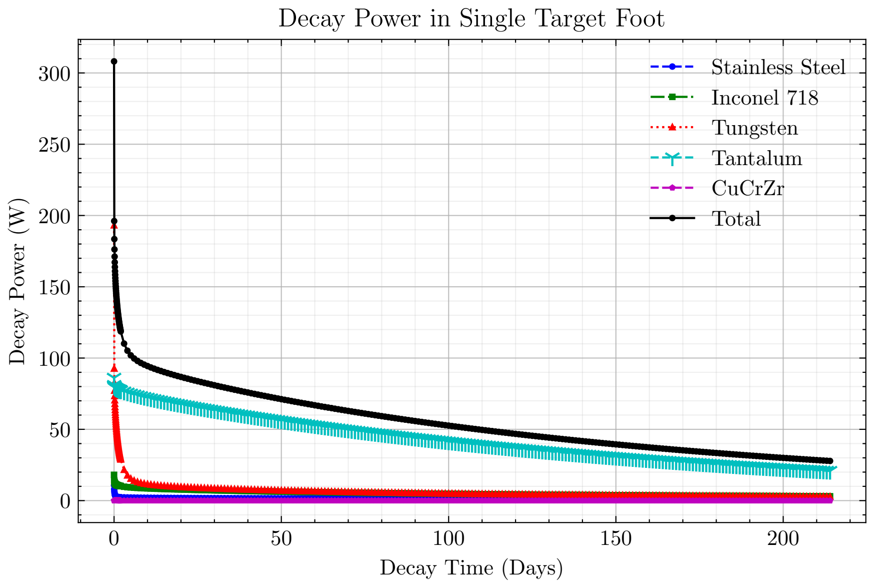

Figure 6. Single target segment foot decay heat over time after 10 years of operation.

5.3 PHOTONEUTRON EMISSIONS

As a part of evaluating Requirements 1 & 2, the shipping casks have requirements on the amount of neutrons emitting from the waste package. For both the target segment and the MRA, neutrons are emitted by photonuclear reactions where a decay gamma with energy above the photonuclear energy threshold interacts with an atom and produces a neutron via (γ,n) reaction. The photonuclear energy threshold varies among the isotopes. ^{9}Be has the lowest photonuclear energy threshold at 1.67 MeV and ^{2}H also has a low photonuclear threshold at 2.22 MeV [13]. The target segment neutron emissions are discussed in Section 5.3.1. The MRA photoneutron emissions are discussed in Section 5.3.2.

5.3.1 Target Segment Photoneutron Emissions

The 3-60B safety analysis report states, "There are no sources of neutron radiation in the radioactive materials to be carried in the 3-60B cask" [11]. However, a single target segment emits $(1.97 \pm 0.09) \times 10^2$ n/s after 10 years of operation followed by 1 year of decay. Therefore, Requirement 1 in Section 2 is failed. Even if the target segments were allowed to decay 2 years, the neutron emission from them would not be zero, and would still fail Requirement 1. Figure 7 shows the energy differential photoneutron emission spectrum for a single target segment after 10 years of operation and 1 year of decay for the most intense decay gamma source out of the 8 decay gamma sources. This most intense decay gamma source contributes 84% of the total amount of photoneutron emissions. The cumulative percent of integral curve, shown in Figure 7, indicates that 80% of the neutron emissions are below 1×10^{-7} MeV and 20% is from 0.1-1 MeV. Most of the photoneutrons in the target segment are due to Mo impurity in the metal components.

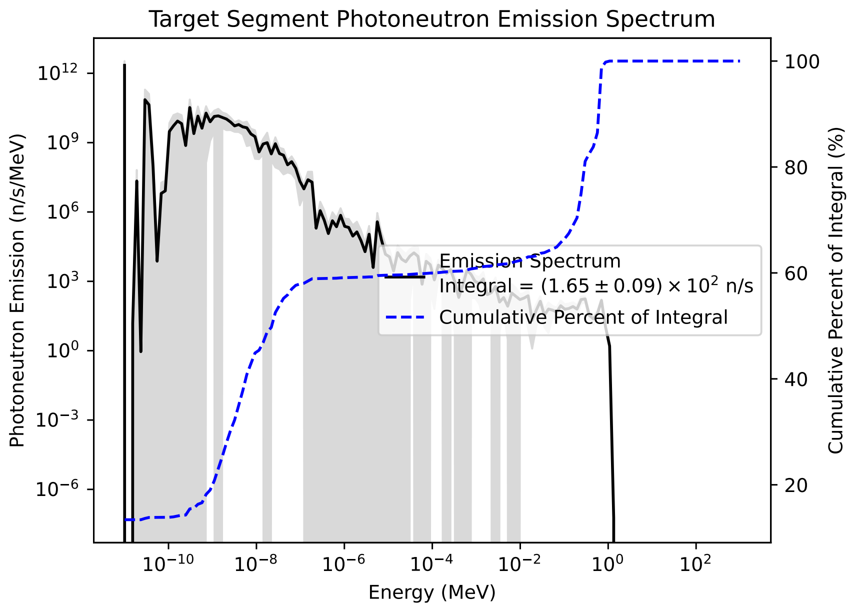

Figure 7. Single Target Segment 1 Year Decay Photoneutron emission spectrum.

Figure 8 illustrates the split between the population of neutrons emitted below $1{\times}10^{-7}$ MeV and the population of neutrons emitted between 0.1-1 MeV by plotting the neutron emission per unit lethargy. The two peaks in Figure 8 illustrate the two populations relative to one another.

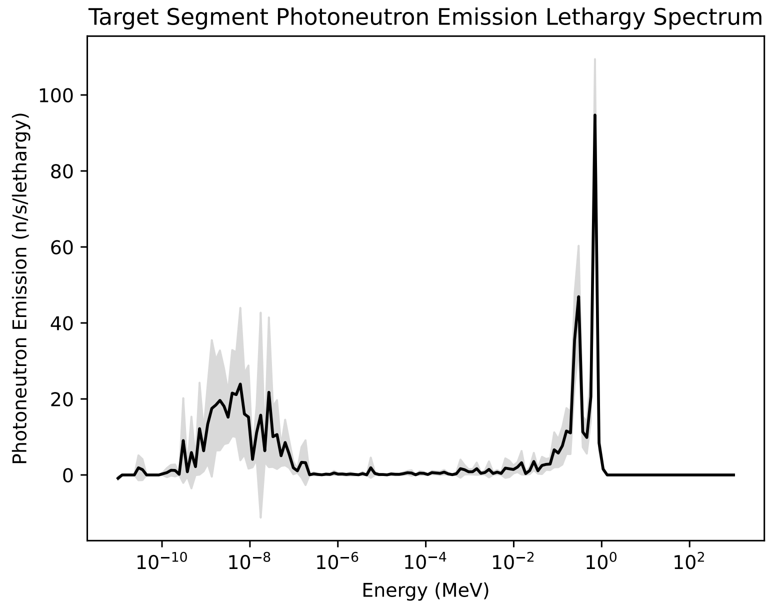

Figure 8. Single Target Segment 1 Year Decay Photoneutron emission lethargy spectrum.

The total number of neutrons emitted by a single target segment after 10 years of operation and 1 year of decay is negligible. To demonstrate how the neutron emission is negligible, consider the neutron emissions from the target segment were condensed to a point source, and all of the neutrons emitted from the point source are 1 MeV for conservatism. The effective tissue dose 1 m away from the unshielded point source is $(1.57 \pm 0.07) \times 10^{-4}$ mrem/hr. The average person living in the United States receives on the order of 7.07×10^{-2} mrem/hr [14]. The dose from the single target segment neutron emission rate is a factor of 441 lower than the dose rate of an average person living in the United States. The flux 1 m away from the point source is also very low at $(1.57 \pm 0.07) \times 10^{-3}$ n/cm^2/sec.

5.3.2 MRA Photoneutron Emissions

The TN-RAM cask safety analysis report states, "No neutron generating source material beyond an inconsequential amount as a result of surface contamination is to be transported. However, a source of 1×10^6 neutrons per second is evaluated" [12]. The MRA emits $(5.6 \pm 0.2) \times 10^5$ n/s after 6 years of operation followed by 2 years of decay. Figure 9 shows the MRA total neutron emission over time where the blue dashed line is the 1×10^6 n/s TN-RAM cask limit. The MRA photoneutron source term falls below the 1×10^6 n/s evaluated source strength after approximately 1.5 years of decay. The errors shown as shading around the black line in Figure 9 show 2 σ error above and below the line.

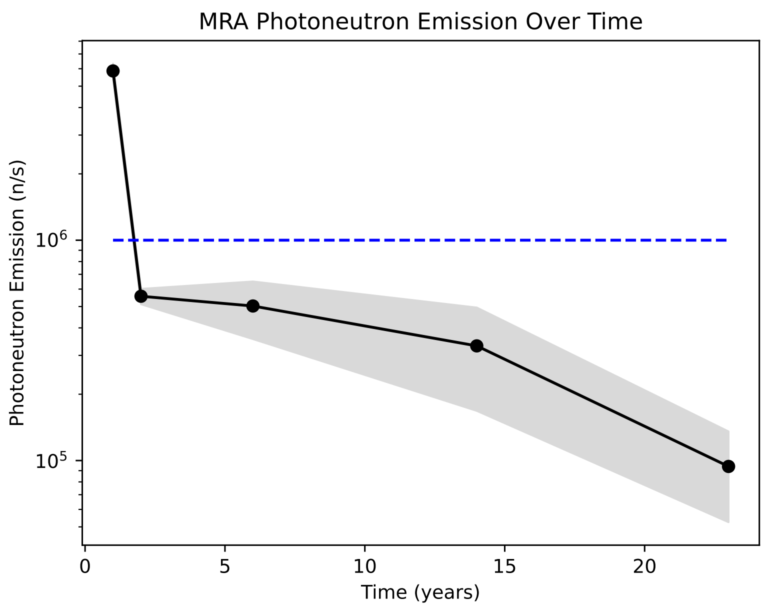

Figure 9. MRA photoneutron emission over time. The blue dashed line is the TN-RAM cask neutron emission limit.

Figure 10 shows the energy differential photoneutron emission spectrum for the MRA's most intense decay gamma sources after 6 years of operation and 1 year of decay. The total amount of neutrons emitted by this source contributes 95% of the total neutron emission by the MRA. The cumulative percent of integral curve in Figure 10 indicates a majority of the neutrons emitted from the MRA are between 1×10^{-7}-0.1 MeV. Figure 11 shows the photoneutron emission spectrum per unit lethargy to better illustrate that most of the neutrons emitted from the MRA are between 1×10^{-7}-0.1 MeV. Most of the photoneutrons emitted from the MRA are born in the beryllium reflector. Most of the gammas that drive the photoneutron come from ^{56}Co in the stainless steel backbone of the MRA.

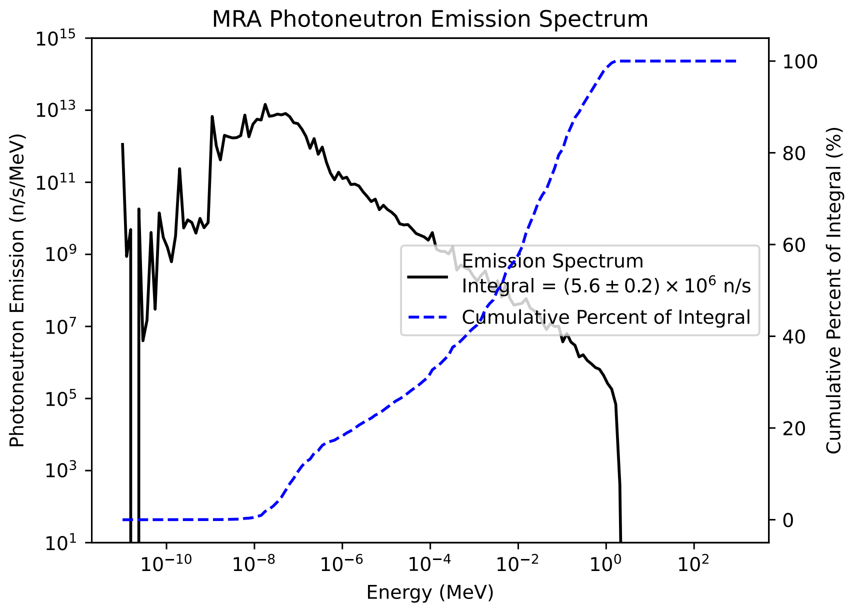

Figure 10. MRA photoneutron emission spectrum after 6 years of operation and 1 year of decay.

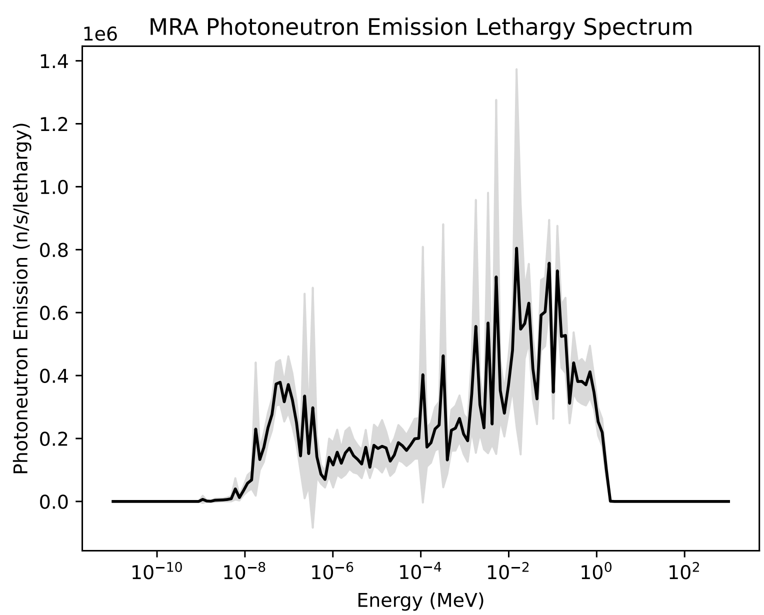

Figure 11. MRA photoneutron emission spectrum per unit lethargy after 6 years of operation and 1 year of decay.

6 CONCLUSIONS

This analysis generated radionuclide inventories, decay heat values, and photoneutron emission rates for the STS target segments and MRA to support transportation, disposal, maintenance, and waste characterization evaluations.

For target segment transportation, one target segment meets the 3-60B A2 limit after 1 year of decay. Two target segments exceed the 3-60B limit after 1 year of decay but meet the limit after 2 years of decay. The calculated decay heat for the evaluated target segment cases is below the 3-60B cask limit of 500 W.

For the MRA, the calculated A2 value and decay heat after 1 year of decay are below the TN-RAM limits identified in this report. The calculated MRA photoneutron emission falls below the TN-RAM evaluated neutron source strength of 1×10^6 n/s after approximately 1.5 years of decay.

Although the photoneutron emission from a target segment is negligible, it is nonzero and is therefore noncompliant with the 3-60B safety analysis report statement. These results provide the radionuclide inventories needed for subsequent cask qualification, waste acceptance, disposal-path, maintenance temperature, and accident evaluations.

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APPENDIX A. COMPUTER HARDWARE AND SOFTWARE

APPENDIX A. COMPUTER HARDWARE AND SOFTWARE

A local Mac was used in this analysis. The unmodified code from LANL was used for MCNP® and the ACTIUM package was used for the activation.

APPENDIX B. LOCATION OF COMPUTATIONAL INPUT AND OUTPUT FILES

APPENDIX B. LOCATION OF COMPUTATIONAL INPUT AND OUTPUT FILES

The computational input and output files are located in the sts_archive located at:

/home/sts_archive/S.03.12_Neutronics/S.03.12.01_Neutronics_Analysis_Support/S03120100-TRT10026_STS_Target_MRA_Radionuclides

This directory contains the following two folders:

- Radionuclide_Inventories_and_Decay_Heat
  - This folder contains the inputs and outputs for the radionuclide inventory and decay heat calculations
  - Inside of each component folder is the input scripts need to reproduce the radionuclide inventories and decay heat data.
- Photoneutron_Emissions
  - This folder contains the inputs and outputs for generating the decay gamma sources and the photoneutron emission calculation inputs and outputs.
    - CINDER2008/
      - This folder contains the CINDER2008 calculations for each major component groups.
    - MCNP/
      - This folder contains the MCNP calculations for each major component group for the photoneutron emission calculations.
    - Post_Processing/
      - This folder contains the post processing scripts that generated the data and plots in this report.
- Generating_Figures
  - This folder contains plotting scripts used to generate the figures in this document.
  - The script that generates all figures in this report is generate_plots.py

APPENDIX C. TECHNICAL REVIEW DOCUMENTATION

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TECHNICAL REVIEW CHECKLIST

	Yes	No	N/A
Is the calculation well organized, legible, and complete?			
If excerpts from other sources are included in the calculation package, are the excerpts legible and properly referenced?			
Do the calculations cover the expressed purpose?			
Are all necessary elements included?			
Is the method used appropriate considering the purpose and type of analysis and the use and acceptability of the results (i.e. margin to limits)?			
Is the method in accordance with codes, standards, and regulatory requirements?			
Has the method been employed similarly elsewhere in industry?			
Are assumptions necessary to perform the analysis adequately described, justified, and reasonable?			
Are there any Unverified Assumptions (UVAs)?			
Were UVAs justified?			
Are the inputs sufficiently documented considering the purpose of the analysis?			
Is all the software used identified correctly (name, version, manual reference, OS, and compilers are documented)?			
Are the computer codes suitable for the present analysis?			
Does the model adequately represent the physical systems?			
Is the magnitude of the result reasonable?			
Are the directions of trends reasonable?			

Additional comments:

Technical Reviewer Date

ADVANCED REVIEW CHECKLIST

Method of Advanced Review used

____ In-Depth Calculation Review

____ Alternate Calculation

____ Qualification Test

Supporting Material: (Title, number of pages)

Independent Review Verification

	Yes	No
Did you perform the original calculation?		
Did you specify a single analytical approach?		
Did you rule out certain analytical considerations?		
Did you establish any input to the calculation being verified?		

Justification for any "Yes" to a question above:

Does the independent review support the calculation findings? What differences were observed?

Additional comments:

Reviewer Date

APPENDIX D. MATERIAL DEFINITION

APPENDIX D. MATERIAL DEFINITION

Table D.1. Para-H Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{4}H	1.0000E+00	1.0000E+00
Density (g/cm^3)	0.0729194	

Table D.2. H2O 293K Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{1}H	1.1190E-01	6.6659E-01
^{2}H	2.5720E-05	7.6667E-05
^{16}O	8.8772E-01	3.3321E-01
^{17}O	3.5865E-04	1.2667E-04
Density (g/cm^3)	1.0	

Table D.3. Inconel-718 Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{10}B	1.1059E-05	6.3593E-05
^{11}B	4.8941E-05	2.5597E-04
^{0}C	8.0000E-04	3.8351E-03
^{27}Al	8.0000E-03	1.7072E-02
^{28}Si	3.2153E-03	6.6175E-03
^{29}Si	1.6918E-04	3.3617E-04
^{30}Si	1.1550E-04	2.2187E-04
^{31}P	1.5000E-04	2.7885E-04
^{32}S	1.4207E-04	2.5586E-04
^{33}S	1.1568E-06	2.0202E-06

Table D.3 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{34}S	6.7534E-06	1.1448E-05
^{36}S	1.6826E-08	2.6936E-08
^{46}Ti	9.1081E-04	1.1413E-03
^{47}Ti	8.3924E-04	1.0292E-03
^{48}Ti	8.4922E-03	1.0198E-02
^{49}Ti	6.3620E-04	7.4839E-04
^{50}Ti	6.2156E-04	7.1658E-04
^{50}Cr	8.7647E-03	1.0104E-02
^{52}Cr	1.7577E-01	1.9485E-01
^{53}Cr	2.0314E-02	2.2095E-02
^{54}Cr	5.1521E-03	5.4998E-03
^{55}Mn	3.5000E-03	3.6683E-03
^{54}Fe	6.7092E-03	7.1619E-03
^{56}Fe	1.0922E-01	1.1243E-01
^{57}Fe	2.5674E-03	2.5964E-03
^{58}Fe	3.4766E-04	3.4554E-04
^{59}Co	2.5000E-03	2.4426E-03
^{58}Ni	3.6959E-01	3.6732E-01
^{60}Ni	1.4727E-01	1.4149E-01
^{61}Ni	6.5085E-03	6.1505E-03
^{62}Ni	2.1091E-02	1.9610E-02
^{64}Ni	5.5448E-03	4.9942E-03
^{63}Cu	2.0544E-03	1.8797E-03
^{65}Cu	9.4562E-04	8.3860E-04
^{93}Nb	5.4500E-02	3.3777E-02
^{92}Mo	4.6693E-03	2.9253E-03
^{94}Mo	2.9814E-03	1.8281E-03
^{95}Mo	5.1906E-03	3.1491E-03
^{96}Mo	5.5025E-03	3.3036E-03
^{97}Mo	3.1867E-03	1.8934E-03

Table D.3 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{98}Mo	8.1464E-03	4.7910E-03
^{100}Mo	3.3231E-03	1.9152E-03
^{181}Ta	5.0000E-04	1.5910E-04
Density (g/cm^3)	8.19	

Table D.4. Beryllium Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{6}Li	3.8068E-06	5.7596E-06
^{7}Li	5.4060E-05	7.0124E-05
^{9}Be	9.8503E-01	9.9471E-01
^{10}B	1.5608E-06	1.4186E-06
^{11}B	6.9076E-06	5.7101E-06
^{0}C	9.5117E-04	7.2071E-04
^{16}O	6.1391E-03	3.4930E-03
^{17}O	2.4854E-06	1.3306E-06
^{24}Mg	4.0007E-04	1.5180E-04
^{25}Mg	5.2761E-05	1.9218E-05
^{26}Mg	6.0408E-05	2.1159E-05
^{27}Al	6.4155E-04	2.1639E-04
^{28}Si	3.5362E-04	1.1503E-04
^{29}Si	1.8606E-05	5.8438E-06
^{30}Si	1.2702E-05	3.8567E-06
^{54}Fe	4.7084E-05	7.9441E-06
^{56}Fe	7.6647E-04	1.2471E-04
^{57}Fe	1.8018E-05	2.8800E-06
^{58}Fe	2.4399E-06	3.8328E-07
^{103}Rh	2.7292E-04	2.4136E-05

Table D.4 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{107}Ag	1.9123E-04	1.6280E-05
^{109}Ag	1.8100E-04	1.5125E-05
^{106}Cd	3.1430E-07	2.7008E-08
^{108}Cd	2.2801E-07	1.9230E-08
^{110}Cd	3.2590E-06	2.6987E-07
^{111}Cd	3.3703E-06	2.7657E-07
^{112}Cd	6.4108E-06	5.2137E-07
^{113}Cd	3.2756E-06	2.6403E-07
^{114}Cd	7.7693E-06	6.2076E-07
^{116}Cd	2.0610E-06	1.6183E-07
^{113}In	4.1028E-06	3.3071E-07
^{115}In	9.3155E-05	7.3782E-06
^{142}Nd	4.6057E-04	2.9537E-05
^{143}Nd	2.0804E-04	1.3249E-05
^{144}Nd	4.0869E-04	2.5845E-05
^{145}Nd	1.4352E-04	9.0135E-06
^{146}Nd	2.9947E-04	1.8678E-05
^{148}Nd	1.0060E-04	6.1897E-06
^{150}Nd	1.0018E-04	6.0815E-06
^{144}Sm	4.7125E-07	2.9801E-08
^{147}Sm	2.3491E-06	1.4551E-07
^{148}Sm	1.7733E-06	1.0911E-07
^{149}Sm	2.1952E-06	1.3415E-07
^{150}Sm	1.1801E-06	7.1640E-08
^{152}Sm	4.3347E-06	2.5967E-07
^{154}Sm	3.7351E-06	2.2084E-07
^{151}Eu	9.4735E-06	5.7127E-07
^{153}Eu	1.0478E-05	6.2359E-07
^{152}Gd	3.9667E-09	2.3763E-10
^{154}Gd	4.3806E-08	2.5901E-09

Table D.4 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{155}Gd	2.9934E-07	1.7584E-08
^{156}Gd	4.1668E-07	2.4321E-08
^{157}Gd	3.2062E-07	1.8594E-08
^{158}Gd	5.1213E-07	2.9513E-08
^{160}Gd	4.5641E-07	2.5972E-08
^{156}Dy	5.5191E-08	3.2213E-09
^{158}Dy	9.4828E-08	5.4647E-09
^{160}Dy	2.3543E-06	1.3397E-07
^{161}Dy	1.9214E-05	1.0866E-06
^{162}Dy	2.6074E-05	1.4654E-06
^{163}Dy	2.5639E-05	1.4321E-06
^{164}Dy	2.9282E-05	1.6256E-06
^{162}Er	8.2284E-07	4.6246E-08
^{164}Er	9.5945E-06	5.3266E-07
^{166}Er	2.0322E-04	1.1146E-05
^{167}Er	1.3956E-04	7.6087E-06
^{168}Er	1.6562E-04	8.9757E-06
^{170}Er	9.2627E-05	4.9606E-06
^{169}Tm	2.8158E-04	1.5169E-05
^{175}Lu	7.2313E-04	3.7619E-05
^{176}Lu	1.9337E-05	1.0003E-06
^{174}Hf	3.7713E-07	1.9732E-08
^{176}Hf	1.2540E-05	6.4866E-07
^{177}Hf	4.4598E-05	2.2938E-06
^{178}Hf	6.5781E-05	3.3643E-06
^{179}Hf	3.3027E-05	1.6797E-06
^{180}Hf	8.5540E-05	4.3262E-06
^{191}Ir	8.7890E-05	4.1887E-06
^{193}Ir	1.4929E-04	7.0412E-06
^{197}Au	3.4086E-04	1.5749E-05

Table D.4 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{196}Hg	4.7456E-07	2.2039E-08
^{198}Hg	3.1865E-05	1.4649E-06
^{199}Hg	5.4189E-05	2.4786E-06
^{200}Hg	7.4575E-05	3.3940E-06
^{201}Hg	4.2763E-05	1.9365E-06
^{202}Hg	9.7364E-05	4.3872E-06
^{204}Hg	2.2623E-05	1.0094E-06
^{234}U	1.7031E-09	6.6227E-11
^{235}U	2.2819E-07	8.8352E-09
^{238}U	3.1848E-05	1.2176E-06
Density (g/cm^3)	1.82922	

Table D.5. Steel A36 Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{0}C	2.6000E-03	1.1921E-02
^{28}Si	3.6747E-03	7.2333E-03
^{29}Si	1.9335E-04	3.6746E-04
^{30}Si	1.3200E-04	2.4251E-04
^{31}P	4.0000E-04	7.1119E-04
^{32}S	4.7358E-04	8.1572E-04
^{33}S	3.8560E-06	6.4405E-06
^{34}S	2.2511E-05	3.6496E-05
^{36}S	5.6085E-08	8.5874E-08
^{55}Mn	1.2000E-02	1.2029E-02
^{54}Fe	5.5214E-02	5.6371E-02
^{56}Fe	8.9880E-01	8.8491E-01
^{57}Fe	2.1128E-02	2.0436E-02

Table D.5 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{58}Fe	2.8611E-03	2.7197E-03
^{59}Co	5.0000E-04	4.6723E-04
^{63}Cu	1.3696E-03	1.1985E-03
^{65}Cu	6.3042E-04	5.3471E-04
Density (g/cm^3)	7.85	

Table D.6. SS-316 Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{0}C	7.9073E-04	3.6489E-03
^{28}Si	9.1866E-03	1.8200E-02
^{29}Si	4.8336E-04	9.2456E-04
^{30}Si	3.2999E-04	6.1020E-04
^{31}P	4.5000E-04	8.0525E-04
^{32}S	2.8415E-04	4.9259E-04
^{33}S	2.3136E-06	3.8892E-06
^{34}S	1.3507E-05	2.2040E-05
^{36}S	3.3651E-08	5.1857E-08
^{50}Cr	7.5126E-03	8.3368E-03
^{52}Cr	1.5066E-01	1.6077E-01
^{53}Cr	1.7412E-02	1.8229E-02
^{54}Cr	4.4161E-03	4.5378E-03
^{55}Mn	2.0000E-02	2.0178E-02
^{54}Fe	3.4802E-02	3.5761E-02
^{56}Fe	5.6653E-01	5.6137E-01
^{57}Fe	1.3318E-02	1.2965E-02
^{58}Fe	1.8034E-03	1.7253E-03
^{59}Co	2.0000E-03	1.8810E-03

Table D.6 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{58}Ni	9.4077E-02	9.0002E-02
^{60}Ni	3.7486E-02	3.4668E-02
^{61}Ni	1.6567E-03	1.5070E-03
^{62}Ni	5.3688E-03	4.8051E-03
^{64}Ni	1.4114E-03	1.2237E-03
^{92}Mo	4.2448E-03	2.5599E-03
^{94}Mo	2.7103E-03	1.5997E-03
^{95}Mo	4.7187E-03	2.7558E-03
^{96}Mo	5.0023E-03	2.8910E-03
^{97}Mo	2.8970E-03	1.6569E-03
^{98}Mo	7.4059E-03	4.1926E-03
^{100}Mo	3.0210E-03	1.6760E-03
Density (g/cm^3)	8.0	

Table D.7. SS-316L Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{0}C	2.9652E-04	1.3708E-03
^{28}Si	9.1866E-03	1.8232E-02
^{29}Si	4.8336E-04	9.2621E-04
^{30}Si	3.2999E-04	6.1129E-04
^{31}P	4.5000E-04	8.0669E-04
^{32}S	2.8415E-04	4.9347E-04
^{33}S	2.3136E-06	3.8962E-06
^{34}S	1.3507E-05	2.2079E-05
^{36}S	3.3651E-08	5.1949E-08
^{50}Cr	7.5126E-03	8.3517E-03
^{52}Cr	1.5066E-01	1.6106E-01

Table D.7 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{53}Cr	1.7412E-02	1.8262E-02
^{54}Cr	4.4161E-03	4.5459E-03
^{55}Mn	2.0000E-02	2.0214E-02
^{54}Fe	3.4830E-02	3.5854E-02
^{56}Fe	5.6699E-01	5.6283E-01
^{57}Fe	1.3328E-02	1.2998E-02
^{58}Fe	1.8049E-03	1.7299E-03
^{59}Co	2.0000E-03	1.8843E-03
^{58}Ni	9.4077E-02	9.0163E-02
^{60}Ni	3.7486E-02	3.4730E-02
^{61}Ni	1.6567E-03	1.5097E-03
^{62}Ni	5.3688E-03	4.8137E-03
^{64}Ni	1.4114E-03	1.2259E-03
^{92}Mo	4.2448E-03	2.5645E-03
^{94}Mo	2.7103E-03	1.6026E-03
^{95}Mo	4.7187E-03	2.7607E-03
^{96}Mo	5.0023E-03	2.8961E-03
^{97}Mo	2.8970E-03	1.6599E-03
^{98}Mo	7.4059E-03	4.2001E-03
^{100}Mo	3.0210E-03	1.6790E-03
Density (g/cm^3)	8.0	

Table D.8. Ta max impurities Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{1}H	1.4999E-05	2.6692E-03
^{2}H	3.4474E-09	3.0698E-07
^{0}C	9.8854E-05	1.4761E-03

Table D.8 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{14}N	9.9622E-05	1.2760E-03
^{15}N	3.8987E-07	4.6615E-06
^{16}O	1.4961E-04	1.6776E-03
^{17}O	6.0569E-08	6.3904E-07
^{28}Si	4.5938E-05	2.9450E-04
^{29}Si	2.4171E-06	1.4961E-05
^{30}Si	1.6501E-06	9.8735E-06
^{46}Ti	7.9210E-06	3.0915E-05
^{47}Ti	7.2986E-06	2.7880E-05
^{48}Ti	7.3854E-05	2.7625E-04
^{49}Ti	5.5328E-06	2.0273E-05
^{50}Ti	5.4055E-06	1.9411E-05
^{54}Fe	5.6463E-06	1.8774E-05
^{56}Fe	9.1913E-05	2.9471E-04
^{57}Fe	2.1606E-06	6.8062E-06
^{58}Fe	2.9257E-07	9.0576E-07
^{58}Ni	6.7206E-05	2.0805E-04
^{60}Ni	2.6779E-05	8.0140E-05
^{61}Ni	1.1835E-06	3.4837E-06
^{62}Ni	3.8353E-06	1.1107E-05
^{64}Ni	1.0083E-06	2.8289E-06
^{93}Nb	1.0001E-03	1.9307E-03
^{92}Mo	2.8302E-05	5.5230E-05
^{94}Mo	1.8071E-05	3.4514E-05
^{95}Mo	3.1462E-05	5.9456E-05
^{96}Mo	3.3353E-05	6.2373E-05
^{97}Mo	1.9315E-05	3.5748E-05
^{98}Mo	4.9378E-05	9.0454E-05
^{100}Mo	2.0142E-05	3.6159E-05
^{181}Ta	9.9759E-01	9.8878E-01

Table D.8 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{180}W	5.8736E-07	5.8541E-07
^{182}W	1.3115E-04	1.2928E-04
^{183}W	7.1211E-05	6.9810E-05
^{184}W	1.5331E-04	1.4947E-04
^{186}W	1.4380E-04	1.3869E-04
Density (g/cm^3)	16.65	

Table D.9. W max impurities Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{0}C	9.8843E-05	1.5059E-03
^{14}N	9.9611E-05	1.3017E-03
^{15}N	3.8982E-07	4.7555E-06
^{16}O	9.9730E-05	1.1409E-03
^{17}O	4.0374E-08	4.3461E-07
^{28}Si	9.1867E-05	6.0087E-04
^{29}Si	4.8336E-06	3.0525E-05
^{30}Si	3.2999E-06	2.0146E-05
^{54}Fe	5.6456E-06	1.9153E-05
^{56}Fe	9.1903E-05	3.0065E-04
^{57}Fe	2.1604E-06	6.9435E-06
^{58}Fe	2.9254E-07	9.2402E-07
^{58}Ni	6.7198E-05	2.1225E-04
^{60}Ni	2.6776E-05	8.1756E-05
^{61}Ni	1.1834E-06	3.5540E-06
^{62}Ni	3.8348E-06	1.1331E-05
^{64}Ni	1.0082E-06	2.8859E-06
^{180}W	1.1739E-03	1.1937E-03

Table D.9 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{182}W	2.6211E-01	2.6361E-01
^{183}W	1.4232E-01	1.4235E-01
^{184}W	3.0640E-01	3.0480E-01
^{186}W	2.8739E-01	2.8281E-01
Density (g/cm^3)	19.25	

Table D.10. Al ASTM B247-M-20 Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{24}Mg	9.3540E-03	1.0623E-02
^{25}Mg	1.2336E-03	1.3449E-03
^{26}Mg	1.4124E-03	1.4807E-03
^{27}Al	9.6000E-01	9.6919E-01
^{28}Si	7.3493E-03	7.1557E-03
^{29}Si	3.8669E-04	3.6352E-04
^{30}Si	2.6399E-04	2.3991E-04
^{46}Ti	1.1880E-04	7.0422E-05
^{47}Ti	1.0947E-04	6.3511E-05
^{48}Ti	1.1077E-03	6.2930E-04
^{49}Ti	8.2983E-05	4.6181E-05
^{50}Ti	8.1073E-05	4.4217E-05
^{50}Cr	1.4608E-04	7.9670E-05
^{52}Cr	2.9295E-03	1.5364E-03
^{53}Cr	3.3858E-04	1.7421E-04
^{54}Cr	8.5868E-05	4.3365E-05
^{55}Mn	1.5000E-03	7.4374E-04
^{54}Fe	3.9519E-04	1.9957E-04
^{56}Fe	6.4331E-03	3.1329E-03

Table D.10 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{57}Fe	1.5123E-04	7.2354E-05
^{58}Fe	2.0478E-05	9.6286E-06
^{63}Cu	2.7392E-03	1.1857E-03
^{65}Cu	1.2608E-03	5.2896E-04
^{64}Zn	1.1794E-03	5.0254E-04
^{66}Zn	7.0491E-04	2.9126E-04
^{67}Zn	1.0493E-04	4.2707E-05
^{68}Zn	4.9390E-04	1.9807E-04
^{70}Zn	1.6864E-05	6.5695E-06
Density (g/cm^3)	2.7	

Table D.11. Copper Chromium Zirconium Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{28}Si	9.1867E-04	2.0801E-03
^{29}Si	4.8336E-05	1.0567E-04
^{30}Si	3.2999E-05	6.9741E-05
^{50}Cr	5.0084E-04	6.3523E-04
^{52}Cr	1.0044E-02	1.2250E-02
^{53}Cr	1.1608E-03	1.3890E-03
^{54}Cr	2.9440E-04	3.4576E-04
^{54}Fe	4.5164E-05	5.3042E-05
^{56}Fe	7.3521E-04	8.3265E-04
^{57}Fe	1.7283E-05	1.9229E-05
^{58}Fe	2.3404E-06	2.5591E-06
^{63}Cu	6.7329E-01	6.7776E-01
^{65}Cu	3.0991E-01	3.0237E-01
^{90}Zr	1.5212E-03	1.0718E-03

Table D.11 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{91}Zr	3.3543E-04	2.3374E-04
^{92}Zr	5.1834E-04	3.5728E-04
^{94}Zr	5.3673E-04	3.6207E-04
^{96}Zr	8.8314E-05	5.8332E-05
Density (g/cm^3)	8.89	

Table D.12. EPDM Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{1}H	1.4111E-01	6.6190E-01
^{2}H	3.2435E-05	7.6127E-05
^{0}C	8.5886E-01	3.3803E-01
Density (g/cm^3)	0.9	

Table D.13. Invar 20K Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{0}C	1.4827E-03	6.9470E-03
^{28}Si	3.6748E-03	7.3922E-03
^{29}Si	1.9335E-04	3.7553E-04
^{30}Si	1.3200E-04	2.4784E-04
^{31}P	2.5001E-04	4.5426E-04
^{32}S	2.3679E-04	4.1680E-04
^{33}S	1.9280E-06	3.2909E-06
^{34}S	1.1255E-05	1.8648E-05
^{36}S	2.8043E-08	4.3879E-08
^{50}Cr	1.0435E-04	1.1758E-04

Table D.13 – continued from previous page

Nuclide	Mass Fraction	Atom Fraction
^{52}Cr	2.0926E-03	2.2673E-03
^{53}Cr	2.4185E-04	2.5710E-04
^{54}Cr	6.1337E-05	6.3997E-05
^{55}Mn	6.0002E-03	6.1466E-03
^{54}Fe	3.5031E-02	3.6550E-02
^{56}Fe	5.7025E-01	5.7375E-01
^{57}Fe	1.3405E-02	1.3251E-02
^{58}Fe	1.8153E-03	1.7634E-03
^{59}Co	5.0002E-03	4.7749E-03
^{58}Ni	2.4192E-01	2.3500E-01
^{60}Ni	9.6397E-02	9.0522E-02
^{61}Ni	4.2603E-03	3.9349E-03
^{62}Ni	1.3806E-02	1.2546E-02
^{64}Ni	3.6295E-03	3.1952E-03
Density (g/cm^3)	8.051	

Table D.14. Al-6061 20K Material Definition

Nuclide	Mass Fraction	Atom Fraction
^{24}Mg	9.3540E-03	1.0623E-02
^{25}Mg	1.2336E-03	1.3449E-03
^{26}Mg	1.4124E-03	1.4807E-03
^{27}Al	9.6000E-01	9.6919E-01
^{28}Si	7.3493E-03	7.1557E-03
^{29}Si	3.8669E-04	3.6352E-04
^{30}Si	2.6399E-04	2.3991E-04
^{46}Ti	1.1880E-04	7.0422E-05
^{47}Ti	1.0947E-04	6.3511E-05

Nuclide	Mass Fraction	Atom Fraction
^{48}Ti	1.1077E-03	6.2930E-04
^{49}Ti	8.2983E-05	4.6181E-05
^{50}Ti	8.1073E-05	4.4217E-05
^{50}Cr	1.4608E-04	7.9670E-05
^{52}Cr	2.9295E-03	1.5364E-03
^{53}Cr	3.3858E-04	1.7421E-04
^{54}Cr	8.5868E-05	4.3365E-05
^{55}Mn	1.5000E-03	7.4374E-04
^{54}Fe	3.9519E-04	1.9957E-04
^{56}Fe	6.4331E-03	3.1329E-03
^{57}Fe	1.5123E-04	7.2354E-05
^{58}Fe	2.0478E-05	9.6286E-06
^{63}Cu	2.7392E-03	1.1857E-03
^{65}Cu	1.2608E-03	5.2896E-04
^{64}Zn	1.1794E-03	5.0254E-04
^{66}Zn	7.0491E-04	2.9126E-04
^{67}Zn	1.0493E-04	4.2707E-05
^{68}Zn	4.9390E-04	1.9807E-04
^{70}Zn	1.6864E-05	6.5695E-06
Density (g/cm^3)	2.7	