



# ECAR-5139 MARVEL Radiological Source Term

August 2020

*Changing the World's Energy Future*

James R Parry



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# **ECAR-5139 MARVEL Radiological Source Term**

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**August 2020**

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## MARVEL Reactor End of Life Preliminary Radiological Source Term

1. Effective Date	08/03/20	<b>Professional Engineer's Stamp</b>  <b>N/A</b>
2. Does this ECAR involve a Safety SSC?	No	
3. Safety SSC Determination Document ID	N/A	
4. SSC ID	N/A	
5. Project No.	N/A	
6. Engineering Job (EJ) No.	N/A	
7. Building	MFC-720	
8. Site Area	MFC	
9. Objective / Purpose		
<p>As part of the Microreactor Applications Research Validation and Evaluation Project (MARVEL) design effort, a preliminary end of life reactor fuel radiological source term is calculated in support of the MARVEL preliminary hazard evaluation. The source term calculation assumes a two-year uninterrupted operating life at a power of about 111 kW for a total energy of 7,000,000 MJ. A final source term for the final hazard evaluation will need to be generated or an evaluation performed to determine the applicability of the source term documented here for use in the final hazard evaluation.</p>		
10. If revision, please state the reason and list sections and/or page being affected.		
N/A		
11. Conclusion / Recommendations		
<p>The preliminary radiological source term for MARVEL has been calculated and presented. The source term assumes continuous operation for two full years for a total thermal energy generation of 7,000,000 MJ. This exceeds the planned thermal energy generation for the MARVEL reactor. This source term can be used for dose consequence analyses to support the preliminary hazard analysis for MARVEL.</p>		

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**1.0 PROJECT ROLES AND RESPONSIBILITIES**

Project Role	Name	Organization	Pages Covered (if applicable)
Performer	J. Parry	U020	See eCR 679677
Checker <sup>a</sup>	S. Morrill	U023	See eCR 679677
Independent Reviewer <sup>b</sup>	N/A	N/A	N/A
CUI Reviewer <sup>c</sup>	S. Martinson	F510	See eCR 679677
Manager <sup>d</sup>	B. Moon	U022	See eCR 679677
Requestor <sup>e,f</sup>	B. Moon	C140	See eCR 679677
Nuclear Safety <sup>f</sup>	D. Gerstner	H372/U022	See eCR 679677
Document Owner <sup>f</sup>	B. Moon	U022	See eCR 679677
Reviewer <sup>f</sup>	T. Reiss	H350	-----

**Responsibilities:**

- 
- a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
- b. Concurrence of method or approach. See definition, LWP-10106.
- c. Concurrence with the document's markings in accordance with LWP-11202.
- d. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
- e. Authorizes the commencement of work of the engineering deliverable. See Appendix A.
- f. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.
- 

**NOTE:** Delete or mark "N/A" for project roles not engaged. Include ALL personnel and their roles listed above in the eCR system. The list of the roles above is not all inclusive. If needed, the list can be extended or reduced.

## 2.0 SCOPE AND BRIEF DESCRIPTION

As part of the Microreactor Applications Research Validation and Evaluation Project (MARVEL) design effort, a preliminary end of life reactor fuel radiological source term is calculated in support of the MARVEL preliminary hazard evaluation. The source term calculation assumes a two-year uninterrupted operating life at a power of about 111 kW for a total energy of 7,000,000 MJ which exceeds the planned two-year operation at 100 kW. A final source term for the final hazard evaluation will need to be generated or an evaluation performed to determine the applicability of the source term documented here for use in the final hazard evaluation.

## 3.0 DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

Technical parameter input and sources are identified in the text as appropriate.

## 4.0 RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

References are documented in Section 8.0.

## 5.0 ASSUMPTIONS

The following assumptions were used in the calculation of the calculated source term.

- MARVEL reactor will operate at a steady power level of 100 kW
- MARVEL reactor will operate continuously for no longer than two years
- The total thermal energy generated by MARVEL will be no greater than 7,000,000 MJ (which is greater than the energy if operated for two years at 100 kW as planned.) If it is desired to exceed the total thermal energy analyzed (7,000,000 MJ) a new source term and dose consequence will need to be analyzed.
- Any changes in the reactor design will not significantly alter the source term or invalidate the source term use in preliminary dose and hazard evaluations.

## 6.0 COMPUTER CODE VALIDATION

- A. Computer type: Apple Mac Pro
- B. Operating System and Version: macOS 10.15
- C. Computer program name and revision:  
MCNP6 1.0 [1]  
SCALE 6.2 [2]
- D. Inputs (may refer to an appendix):  
MCNP6 input files are stored on the TREAT shared server at:

//fS2/Projects/PMO/Active Projects/TREAT/PERSONAL FOLDERS/Parry/MARVEL

SCALE input files are stored on the TREAT shared server at:

//fS2/Projects/PMO/Active Projects/TREAT/PERSONAL FOLDERS/Parry/MARVEL

E. Outputs (may refer to an appendix):

MCNP6 input files are stored on the TREAT shared server at:

//fS2/Projects/PMO/Active Projects/TREAT/PERSONAL FOLDERS/Parry/MARVEL

SCALE input files are stored on the TREAT shared server at:

//fS2/Projects/PMO/Active Projects/TREAT/PERSONAL FOLDERS/Parry/MARVEL

F. Evidence of, or reference to, computer program validation:

MCNP – ECAR-3846 [3]

SCALE – ECAR-3538 [4]

G. Bases supporting application of the computer program to the specific physical problem:

MCNP – ECAR-3846

SCALE – ECAR-3538

## 7.0 DISCUSSION/ANALYSIS

The calculation of the radiological source term for MARVEL proceeds in two distinct stages. The reactor is first modeled in MCNP with a neutron flux tally defined over all of the fuel cells in the model. The neutron flux tally is divided into energy bins (creating an energy spectrum) correlated to the 252-energy bin structure required in SCALE. In the next stage SCALE uses the MCNP calculated neutron spectrum to collapse the neutron reaction cross sections into problem specific one-group cross sections and irradiates the fuel at a constant power to calculate the activation and fission product inventory.

### 7.1. MCNP Model of MARVEL

The MCNP model was generated by members of the Reactor and fuels scrum team for MARVEL. The model is considered a good representation of what will be the reference design for MARVEL. To meet the schedule constraints for the MARVEL project, this model is used as is for the preliminary source term calculation. Since the thermal power of the reactor is not expected to change, the use of an early model for preliminary source term calculations is not considered to be a high technical risk.

#### 7.1.1. MARVEL Model Description

The MCNP model of MARVEL consists of 36 fuel elements in a hexagonal array housed in a single wall stainless steel core barrel with a liquid metal sodium coolant (see Figure 1). The fuel meat is composed



of U-ZrH<sub>1.7</sub> with an outer diameter of just under 3 cm and a total height of just over 51 cm. The uranium content of the fuel meat is 25 weight percent enriched to 19.75 weight percent <sup>235</sup>U. Above and below the fuel meat are beryllium reflectors, the meat and reflectors are clad in type 316 stainless steel.

cro-reactor core

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0.00000, 0.00000)

1.00000, 0.00000)

0.00, 0.00)

12.50, 12.50)

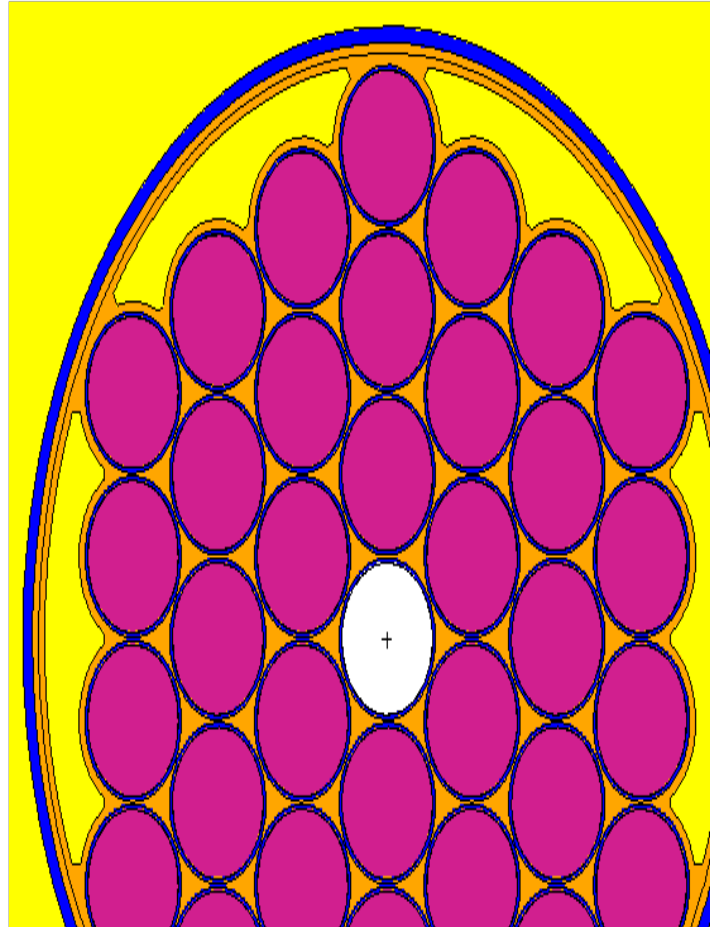


Figure 1: Radial cross section of the MARVEL core.

The core is also reflected radially with beryllium and uses four rotating drums almost 20 cm in diameter to control reactivity. The drums are beryllium with 1-cm thick 90° arc of poison on the outer radius that rotates away from the core to bring the reactor critical and rotate towards the core to shut down the reactor (see Figure 2). The empty location at the center of the core is for a shutdown rod. The rod is not modeled since it would be completely withdrawn during normal operations. The reactor model also has an upper and lower liquid sodium plenum, a sodium vapor region, and liquid metal from the sterling engines above the upper sodium plenum (see Figure 3).

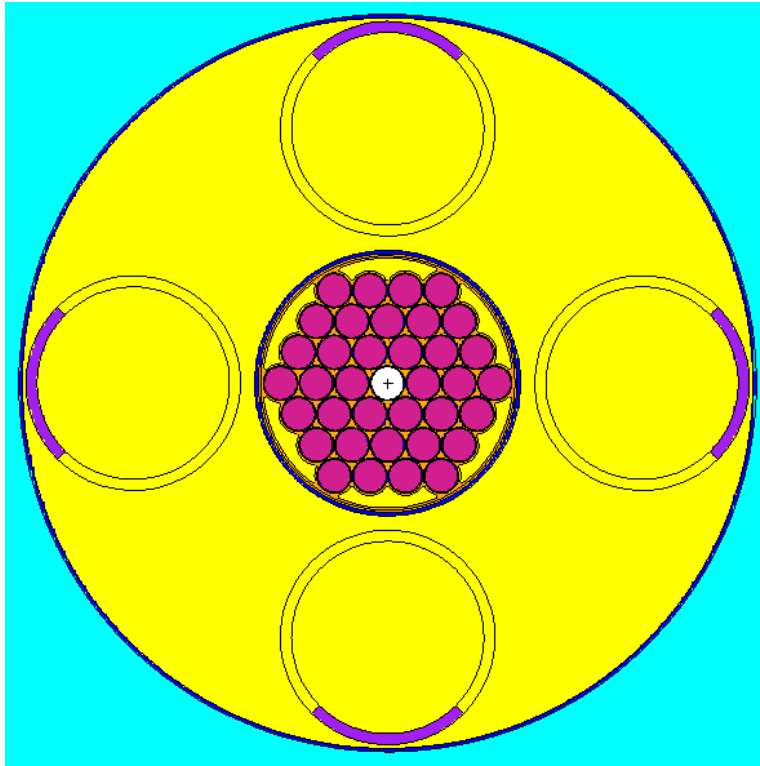


Figure 2: Radial cross section of the MARVEL reactor.

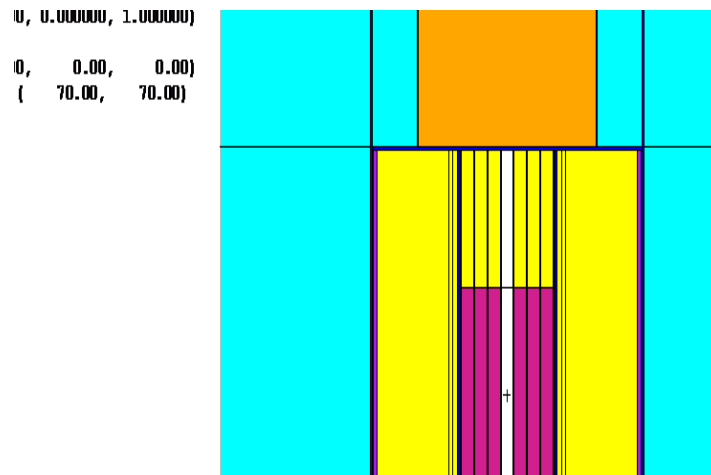


Figure 3: Axial cross section of the MARVEL reactor.

### 7.2. Analysis Details

The calculation of the source term involves calculating a problem dependent (self-shielded) neutron spectrum in MCNP to use in the COUPLE module of the SCALE code package to generate problem specific neutron interaction cross sections. Then the problem specific cross sections are used in the

ORIGEN-S module of SCALE to irradiate the fuel material and generate a source term.

### 7.2.1. MCNP Spectrum Calculation

In MCNP, a neutron flux tally (type 4 tally) was set up to include all of the cells containing fuel meat into one tally result. The tally result represents the average flux over all of the cells. To determine the neutron spectrum the tally was modified with energy breakpoints with 252 energy groups to match the 252-energy group structure used in SCALE. The MCNP results are normalized per source particle in MCNP, but since the spectrum input into the COUPLE module is a weighting function, the raw data from the MCNP tally is appropriate for use. However, the tally results in MCNP are ordered from low energy to high energy so the tally results need to be sorted from high energy to low energy before being input into COUPLE. The calculated neutron spectrum from MCNP sorted from high to low energy is provided in Table 1.

Table 1: MCNP calculated neutron energy spectrum in the MARVEL fuel sorted from high to low energy.

Energy	Neutron per Source Particle	Energy	Neutron per Source Particle	Energy	Neutron per Source Particle
2.00E+01	1.33E-09	1.88E-04	1.64E-06	2.47E-06	1.03E-06
1.73E+01	4.21E-09	1.80E-04	2.09E-06	2.38E-06	9.44E-07
1.57E+01	8.62E-09	1.70E-04	6.29E-06	2.30E-06	1.11E-06
1.46E+01	1.03E-08	1.43E-04	5.74E-06	2.21E-06	1.15E-06
1.38E+01	2.91E-08	1.22E-04	9.01E-07	2.12E-06	1.58E-06
1.28E+01	4.13E-07	1.19E-04	4.36E-07	2.00E-06	8.29E-07
1.00E+01	1.27E-06	1.18E-04	2.86E-07	1.94E-06	1.17E-06
8.19E+00	4.45E-06	1.16E-04	1.00E-06	1.86E-06	1.37E-06
6.43E+00	1.33E-05	1.13E-04	1.63E-06	1.77E-06	1.45E-06
4.80E+00	7.79E-06	1.08E-04	9.99E-07	1.68E-06	1.54E-06
4.30E+00	3.81E-05	1.05E-04	1.07E-06	1.59E-06	1.62E-06
3.00E+00	2.77E-05	1.01E-04	1.60E-06	1.50E-06	9.53E-07
2.48E+00	8.35E-06	9.70E-05	2.64E-06	1.45E-06	9.84E-07
2.35E+00	4.30E-05	9.00E-05	3.41E-06	1.40E-06	1.01E-06
1.85E+00	4.14E-05	8.17E-05	6.74E-07	1.35E-06	1.05E-06
1.50E+00	1.36E-05	8.00E-05	1.81E-06	1.30E-06	1.09E-06
1.40E+00	6.32E-06	7.60E-05	1.89E-06	1.25E-06	5.45E-07
1.36E+00	5.73E-06	7.20E-05	2.25E-06	1.23E-06	5.58E-07
1.32E+00	1.02E-05	6.75E-05	1.03E-06	1.20E-06	5.61E-07
1.25E+00	7.90E-06	6.50E-05	1.09E-06	1.18E-06	5.77E-07
1.20E+00	1.68E-05	6.30E-05	1.13E-06	1.15E-06	2.35E-07
1.10E+00	1.60E-05	6.10E-05	1.73E-06	1.14E-06	2.35E-07
1.01E+00	1.74E-05	5.80E-05	2.74E-06	1.13E-06	2.34E-07
9.20E-01	4.02E-06	5.34E-05	1.79E-06	1.12E-06	2.34E-07
9.00E-01	5.19E-06	5.06E-05	1.56E-06	1.11E-06	2.33E-07
8.75E-01	2.89E-06	4.83E-05	2.22E-06	1.10E-06	2.35E-07
8.61E-01	8.80E-06	4.52E-05	8.64E-07	1.09E-06	2.38E-07
8.20E-01	1.55E-05	4.40E-05	1.25E-06	1.08E-06	2.41E-07
7.50E-01	1.70E-05	4.24E-05	1.11E-06	1.07E-06	2.45E-07
6.79E-01	2.22E-06	4.10E-05	1.16E-06	1.06E-06	2.50E-07
6.70E-01	1.78E-05	3.96E-05	3.90E-07	1.05E-06	2.57E-07
6.00E-01	7.23E-06	3.91E-05	9.44E-07	1.04E-06	2.65E-07
5.73E-01	6.33E-06	3.80E-05	3.15E-07	1.03E-06	2.72E-07
5.50E-01	1.68E-05	3.76E-05	2.87E-07	1.02E-06	2.78E-07
4.92E-01	6.59E-06	3.73E-05	8.91E-08	1.01E-06	2.81E-07
4.70E-01	9.28E-06	3.71E-05	4.91E-08	1.00E-06	7.00E-07
4.40E-01	6.34E-06	3.70E-05	4.33E-07	9.75E-07	6.98E-07
4.20E-01	6.46E-06	3.60E-05	4.97E-07	9.50E-07	7.20E-07
4.00E-01	2.43E-05	3.55E-05	3.71E-07	9.25E-07	7.49E-07
3.30E-01	2.27E-05	3.50E-05	1.07E-06	9.00E-07	1.65E-06

## MARVEL Reactor End of Life Preliminary Radiological Source Term

Energy	Neutron per Source Particle	Energy	Neutron per Source Particle	Energy	Neutron per Source Particle
2.70E-01	2.95E-05	3.38E-05	4.40E-07	8.50E-07	1.65E-06
2.00E-01	2.53E-05	3.33E-05	1.45E-06	8.00E-07	1.83E-06
1.49E-01	1.16E-05	3.18E-05	5.19E-07	7.50E-07	2.04E-06
1.28E-01	1.78E-05	3.13E-05	1.32E-06	7.00E-07	2.11E-06
1.00E-01	1.07E-05	3.00E-05	2.84E-06	6.50E-07	1.15E-06
8.50E-02	2.32E-06	2.75E-05	3.07E-06	6.25E-07	1.28E-06
8.20E-02	5.70E-06	2.50E-05	3.27E-06	6.00E-07	2.65E-06
7.50E-02	1.61E-06	2.25E-05	1.08E-06	5.50E-07	3.02E-06
7.30E-02	1.18E-05	2.18E-05	7.41E-07	5.00E-07	3.75E-06
6.00E-02	8.09E-06	2.12E-05	3.04E-07	4.50E-07	4.18E-06
5.20E-02	2.17E-06	2.05E-05	7.06E-07	4.00E-07	2.52E-06
5.00E-02	5.80E-06	2.00E-05	8.54E-07	3.75E-07	2.94E-06
4.50E-02	2.10E-05	1.94E-05	1.28E-06	3.50E-07	3.27E-06
3.00E-02	1.97E-05	1.85E-05	2.58E-06	3.25E-07	3.45E-06
2.00E-02	7.12E-06	1.70E-05	1.83E-06	3.00E-07	3.93E-06
1.70E-02	1.26E-05	1.60E-05	3.20E-06	2.75E-07	5.09E-06
1.30E-02	1.41E-05	1.44E-05	3.30E-06	2.50E-07	6.02E-06
9.50E-03	7.18E-06	1.29E-05	2.22E-06	2.25E-07	7.04E-06
8.03E-03	1.46E-05	1.19E-05	9.14E-07	2.00E-07	7.82E-06
5.70E-03	1.59E-05	1.15E-05	4.18E-06	1.75E-07	8.49E-06
3.90E-03	1.69E-06	1.00E-05	2.76E-06	1.50E-07	1.03E-05
3.74E-03	8.72E-06	9.10E-06	3.07E-06	1.25E-07	1.25E-05
3.00E-03	6.51E-06	8.10E-06	3.66E-06	1.00E-07	5.33E-06
2.50E-03	4.58E-06	7.15E-06	5.55E-07	9.00E-08	5.18E-06
2.25E-03	1.00E-06	7.00E-06	4.37E-07	8.00E-08	5.11E-06
2.20E-03	8.82E-06	6.88E-06	2.01E-07	7.00E-08	4.85E-06
1.80E-03	6.09E-06	6.75E-06	1.83E-07	6.00E-08	4.51E-06
1.55E-03	1.15E-06	6.50E-06	7.61E-07	5.00E-08	3.84E-06
1.50E-03	1.10E-05	6.25E-06	1.02E-06	4.00E-08	3.20E-06
1.15E-03	7.56E-06	6.00E-06	2.85E-06	3.00E-08	1.20E-06
9.50E-04	1.30E-05	5.40E-06	2.12E-06	2.53E-08	2.65E-06
6.83E-04	6.71E-07	5.00E-06	1.64E-06	1.00E-08	2.17E-07
6.70E-04	7.80E-06	4.70E-06	3.78E-06	7.50E-09	1.67E-07
5.50E-04	2.24E-05	4.10E-06	2.62E-06	5.00E-09	4.67E-08
3.05E-04	2.26E-06	3.73E-06	1.68E-06	4.00E-09	3.37E-08
2.85E-04	6.66E-06	3.50E-06	2.44E-06	3.00E-09	1.78E-08
2.40E-04	3.17E-06	3.20E-06	8.50E-07	2.50E-09	1.42E-08
2.20E-04	1.81E-06	3.10E-06	8.86E-07	2.00E-09	4.86E-09
2.10E-04	2.45E-07	3.00E-06	2.74E-07	1.50E-09	4.09E-09
2.07E-04	1.06E-06	2.97E-06	9.37E-07	1.20E-09	4.34E-09
2.02E-04	1.67E-06	2.87E-06	9.74E-07	1.00E-09	1.67E-09
1.93E-04	2.72E-07	2.77E-06	1.02E-06	7.50E-10	5.83E-10
1.92E-04	3.30E-07	2.67E-06	1.06E-06	5.00E-10	9.84E-10
1.89E-04	2.36E-07	2.57E-06	1.10E-06	1.00E-10	8.28E-13
				total	1.12E-03

**7.2.2. ORIGEN-S Source Term Calculation**

ORIGEN-S is a module in SCALE that performs isotope generation and depletion calculations. Materials are irradiated with neutrons under constant power or constant flux using the ORIGEN-S neutron interaction cross sections to determine post irradiation composition. Because MARVEL is a constant power reactor the irradiation of fuel material in the model was performed under constant power. The fuel material as defined in MCNP was used as the material input for ORIGEN-S in units of atoms per barn-cm. The fuel volume was defined as one cubic cm requiring the results from ORIGEN-S to be scaled to actual fuel volume. Since the fuel volume is calculated and reported as part of the MCNP flux tally, that volume, 12818.4 cm<sup>3</sup>, was used for the scaling.

MARVEL Reactor End of Life Preliminary Radiological Source Term

Since 1 cm<sup>3</sup> of fuel was input into ORIGEN-S, the irradiation power becomes the power density of the reactor. This was determined by assuming all the thermal energy is generated in the fuel meat so the 100 kW thermal was divided by the fuel volume:

The total energy generated by fission in 1 cm<sup>3</sup> would then be:

The total reactor energy would be:

For the source term calculation, the total reactor energy was rounded up to 7 million MJ which results in a power density of:

The power density was then rounded up to 8.653 x 10<sup>-6</sup> MW/cm<sup>3</sup> or 8.653 W/cm<sup>3</sup> for the analysis. 8.653 W/cm<sup>3</sup> for 12,818.4 cm<sup>3</sup> of fuel is equivalent to MARVEL operating at 110.9 kW, therefore, this preliminary source term should be conservative for the MARVEL hazard analysis for operation of 2 years at 100 kW. The ORIGEN-S calculated source terms at the end of irradiation for 1 cm<sup>3</sup> is provided in Table 2. The source term for 1 cm<sup>3</sup> was multiplied by the core volume to calculate the source term for the whole core and is also provided in Table 2.

Table 2: End of life radiological source term for the MARVEL reactor.

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
ac-225	5.0139E-15	6.4270E-11	i-123	1.8735E-13	2.4015E-09	rh-107	1.7089E-02	2.1905E+02
ac-226	8.2977E-17	1.0636E-12	i-124	2.3769E-18	3.0468E-14	rh-108	7.8971E-03	1.0123E+02
ac-227	9.2654E-13	1.1877E-08	i-125	2.0215E-12	2.5912E-08	rh-108m	3.1912E-05	4.0906E-01
ac-228	6.6716E-13	8.5519E-09	i-126	2.8762E-09	3.6868E-05	rh-109	4.8964E-03	6.2764E+01
ag-105	5.8240E-20	7.4654E-16	i-128	3.1193E-05	3.9984E-01	rh-110	2.9756E-05	3.8142E-01
ag-105m	3.6443E-20	4.6714E-16	i-129	3.6266E-09	4.6487E-05	rh-110m	3.0331E-03	3.8879E+01
ag-106	5.7130E-15	7.3232E-11	i-130	7.8138E-05	1.0016E+00	rh-111	1.8641E-03	2.3895E+01
ag-106m	1.2902E-14	1.6538E-10	i-130m	4.3260E-05	5.5452E-01	rh-112	1.2628E-03	1.6187E+01
ag-107m	1.5191E-12	1.9472E-08	i-131	2.1310E-01	2.7316E+03	rh-113	1.1742E-03	1.5051E+01
ag-108	5.6129E-10	7.1948E-06	i-132	3.2027E-01	4.1053E+03	rh-114	6.4642E-04	8.2861E+00
ag-108m	5.3368E-13	6.8409E-09	i-132m	8.6861E-04	1.1134E+01	rh-115	3.8824E-04	4.9766E+00
ag-109m	4.9131E-03	6.2978E+01	i-133	4.9350E-01	6.3259E+03	rh-116	1.2071E-04	1.5473E+00
ag-110	8.4933E-05	1.0887E+00	i-133m	3.4927E-02	4.4771E+02	rh-117	5.7828E-05	7.4126E-01
ag-110m	2.1542E-06	2.7613E-02	i-134	5.7548E-01	7.3767E+03	rh-118	1.4236E-05	1.8248E-01
ag-111	1.8450E-03	2.3650E+01	i-134m	2.7434E-02	3.5166E+02	rh-119	3.1607E-06	4.0515E-02
ag-111m	1.8519E-03	2.3738E+01	i-135	4.6424E-01	5.9508E+03	rh-120	8.5529E-07	1.0963E-02
ag-112	1.2729E-03	1.6317E+01	i-136	1.9748E-01	2.5314E+03	rh-121	1.1645E-07	1.4927E-03
ag-113	8.2645E-04	1.0594E+01	i-136m	9.3617E-02	1.2000E+03	rh-122	1.4637E-08	1.8762E-04
ag-113m	1.2077E-03	1.5481E+01	i-137	2.2538E-01	2.8890E+03	rn-217	3.5099E-19	4.4991E-15
ag-114	1.0384E-03	1.3311E+01	i-138	1.1076E-01	1.4198E+03	rn-218	5.0256E-14	6.4420E-10
ag-115	1.0051E-03	1.2884E+01	i-139	5.7435E-02	7.3622E+02	rn-219	8.2192E-13	1.0536E-08
ag-115m	8.6935E-05	1.1144E+00	i-140	1.1718E-02	1.5021E+02	rn-220	4.8172E-11	6.1749E-07
ag-116	1.0603E-03	1.3591E+01	i-141	3.0866E-03	3.9565E+01	rn-222	1.0186E-17	1.3057E-13
ag-116m	6.2412E-05	8.0002E-01	i-142	4.5079E-04	5.7784E+00	ru-103	2.3196E-01	2.9734E+03
ag-117	8.8901E-04	1.1396E+01	i-143	6.9346E-06	8.8890E-02	ru-105	8.1136E-02	1.0400E+03
ag-117m	1.3023E-04	1.6693E+00	i-144	1.9354E-07	2.4809E-03	ru-106	2.6269E-02	3.3673E+02
ag-118	6.6123E-04	8.4759E+00	in-111	6.7415E-18	8.6415E-14	ru-107	1.6968E-02	2.1750E+02
ag-118m	3.0341E-04	3.8892E+00	in-111m	1.2986E-18	1.6646E-14	ru-108	7.8652E-03	1.0082E+02

## MARVEL Reactor End of Life Preliminary Radiological Source Term

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
ag-119	6.6061E-04	8.4680E+00	in-112	6.4177E-14	8.2265E-10	ru-109	4.7800E-03	6.1272E+01
ag-120	3.0040E-04	3.8506E+00	in-112m	5.1755E-14	6.6342E-10	ru-110	3.0033E-03	3.8498E+01
ag-120m	6.4124E-05	8.2197E-01	in-113m	5.6154E-14	7.1980E-10	ru-111	1.7230E-03	2.2086E+01
ag-121	2.4952E-04	3.1984E+00	in-114	2.0760E-09	2.6611E-05	ru-112	1.0217E-03	1.3097E+01
ag-122	4.2639E-05	5.4656E-01	in-114m	1.1984E-09	1.5362E-05	ru-113	5.7653E-04	7.3902E+00
ag-122m	4.0008E-05	5.1284E-01	in-115	3.0379E-18	3.8941E-14	ru-114	1.8683E-04	2.3949E+00
ag-123	3.6772E-05	4.7136E-01	in-115m	1.0165E-03	1.3030E+01	ru-115	3.8485E-05	4.9332E-01
ag-124	4.5400E-05	5.8196E-01	in-116	1.1140E-05	1.4280E-01	ru-116	7.2590E-06	9.3049E-02
ag-125	1.8763E-06	2.4051E-02	in-116m	1.8445E-05	2.3644E-01	ru-117	1.1592E-06	1.4859E-02
ag-126	3.7362E-07	4.7892E-03	in-117	6.5551E-04	8.4026E+00	ru-118	2.2120E-07	2.8354E-03
ag-127	5.7253E-08	7.3389E-04	in-117m	7.8782E-04	1.0099E+01	ru-119	2.2246E-08	2.8516E-04
ag-128	7.8251E-09	1.0031E-04	in-118	9.7167E-04	1.2455E+01	ru-120	2.2167E-09	2.8415E-05
ag-129	1.3102E-09	1.6795E-05	in-118m	1.5293E-07	1.9603E-03	ru-97	4.8385E-16	6.2022E-12
ag-130	4.6860E-07	6.0067E-03	in-119	4.9569E-04	6.3540E+00	sb-117	5.5878E-20	7.1627E-16
am-239	2.6245E-15	3.3642E-11	in-119m	5.9853E-04	7.6722E+00	sb-118	3.4348E-15	4.4029E-11
am-240	1.4661E-11	1.8793E-07	in-120	1.0177E-03	1.3045E+01	sb-118m	4.9569E-15	6.3540E-11
am-241	1.5316E-07	1.9633E-03	in-120m	3.3821E-05	4.3353E-01	sb-119	1.8977E-12	2.4325E-08
am-242	2.8767E-06	3.6875E-02	in-121	6.6807E-04	8.5636E+00	sb-120	2.2003E-10	2.8204E-06
am-242m	6.1647E-10	7.9022E-06	in-121m	4.0463E-04	5.1867E+00	sb-120m	1.3278E-10	1.7020E-06
am-243	6.5888E-12	8.4458E-08	in-122	1.1095E-03	1.4222E+01	sb-122	3.1901E-06	4.0892E-02
am-244	6.3454E-11	8.1338E-07	in-122m	1.4347E-04	1.8391E+00	sb-122m	2.4446E-07	3.1336E-03
am-244m	9.5050E-10	1.2184E-05	in-123	5.9870E-04	7.6744E+00	sb-124	3.1881E-06	4.0866E-02
am-245	9.3136E-17	1.1939E-12	in-123m	6.0349E-04	7.7358E+00	sb-124m	4.8709E-07	6.2437E-03
as-72	2.8255E-15	3.6218E-11	in-124	1.1442E-03	1.4667E+01	sb-125	1.0568E-03	1.3546E+01
as-73	2.0810E-13	2.6675E-09	in-124m	1.8201E-04	2.3331E+00	sb-126	6.6232E-05	8.4899E-01
as-74	1.7820E-11	2.2842E-07	in-125	6.7988E-04	8.7150E+00	sb-126m	1.2505E-04	1.6029E+00
as-76	1.2792E-07	1.6397E-03	in-125m	5.3292E-04	6.8312E+00	sb-127	1.2262E-02	1.5718E+02
as-77	6.0464E-04	7.7505E+00	in-126	7.7897E-04	9.9851E+00	sb-128	1.7862E-03	2.2896E+01
as-78	1.5686E-03	2.0107E+01	in-126m	1.9397E-04	2.4864E+00	sb-128m	2.5642E-02	3.2869E+02
as-79	3.3325E-03	4.2717E+01	in-127	3.4457E-03	4.4168E+01	sb-129	4.1487E-02	5.3180E+02
as-80	9.3781E-03	1.2021E+02	in-127m	5.6121E-04	7.1938E+00	sb-129m	8.3125E-04	1.0655E+01
as-81	1.4327E-02	1.8365E+02	in-128	1.3002E-03	1.6666E+01	sb-130	5.4262E-02	6.9555E+02
as-82	1.8808E-02	2.4109E+02	in-128m	1.0466E-03	1.3416E+01	sb-130m	7.5774E-02	9.7130E+02
as-82m	2.0996E-03	2.6914E+01	in-129	2.0959E-03	2.6866E+01	sb-131	1.8906E-01	2.4234E+03
as-83	2.3308E-02	2.9877E+02	in-129m	1.8685E-03	2.3951E+01	sb-132	1.3219E-01	1.6945E+03
as-84	1.5644E-02	2.0053E+02	in-130	6.9988E-03	8.9713E+01	sb-132m	7.5836E-02	9.7210E+02
as-85	1.4895E-02	1.9093E+02	in-130m	5.7539E-04	7.3756E+00	sb-133	1.5492E-01	1.9858E+03
as-86	4.1927E-02	5.3744E+02	in-131	9.5621E-04	1.2257E+01	sb-134	2.7323E-02	3.5024E+02
as-87	3.2306E-03	4.1411E+01	in-131m	4.2705E-04	5.4741E+00	sb-134m	2.8111E-02	3.6034E+02
as-88	9.1729E-03	1.1758E+02	in-132	4.9035E-04	6.2855E+00	sb-135	1.1357E-02	1.4558E+01
as-89	1.3755E-05	1.7632E-01	in-133	1.7895E-05	2.2939E-01	sb-136	1.0086E-03	1.2929E+01
as-90	3.1429E-07	4.0287E-03	in-134	6.2060E-07	7.9551E-03	sb-137	5.1353E-03	6.5826E+01
as-91	3.1052E-08	3.9804E-04	in-135	1.4412E-08	1.8474E-04	sb-138	6.1367E-06	7.8663E-02
as-92	1.2584E-09	1.6131E-05	kr-100	8.1152E-08	1.0402E-03	sb-139	3.4104E-07	4.3716E-03
at-217	5.0141E-15	6.4273E-11	kr-79	3.1723E-14	4.0664E-10	se-73	2.3703E-20	3.0383E-16
at-218	2.0373E-21	2.6115E-17	kr-79m	1.5863E-14	2.0334E-10	se-73m	1.4620E-20	1.8741E-16
ba-131	8.4780E-17	1.0867E-12	kr-81	1.6980E-15	2.1766E-11	se-75	1.4182E-13	1.8179E-09
ba-133	1.3923E-12	1.7847E-08	kr-81m	6.7987E-11	8.7148E-07	se-77m	2.0134E-06	2.5809E-02
ba-135m	2.3798E-08	3.0505E-04	kr-83m	3.8985E-02	4.9973E+02	se-79	1.5670E-08	2.0086E-04
ba-136m	1.1293E-04	1.4476E+00	kr-85	2.5048E-03	3.2108E+01	se-79m	3.2539E-03	4.1710E+01
ba-137m	1.9477E-02	2.4966E+02	kr-85m	9.4460E-02	1.2108E+03	se-81	1.4928E-02	1.9135E+02
ba-139	4.7034E-01	6.0290E+03	kr-87	1.8513E-01	2.3731E+03	se-81m	1.0362E-03	1.3282E+01
ba-140	4.5560E-01	5.8401E+03	kr-88	2.5645E-01	3.2873E+03	se-83	3.3398E-02	4.2811E+02
ba-141	4.2778E-01	5.4835E+03	kr-89	3.2615E-01	4.1807E+03	se-83m	3.0658E-03	3.9299E+01
ba-142	4.2061E-01	5.3915E+03	kr-90	3.3803E-01	4.3330E+03	se-84	7.0182E-02	8.9962E+02
ba-143	4.0473E-01	5.1880E+03	kr-91	2.4186E-01	3.1003E+03	se-85	7.7154E-02	9.8899E+02
ba-144	3.1979E-01	4.0992E+03	kr-92	1.2191E-01	1.5627E+03	se-86	9.8934E-02	1.2682E+03
ba-145	1.4212E-01	1.8218E+03	kr-93	3.5957E-02	4.6091E+02	se-87	5.6551E-02	7.2489E+02
ba-146	6.7816E-02	8.6929E+02	kr-94	6.7800E-03	8.6909E+01	se-88	2.5665E-02	3.2898E+02
ba-147	1.8249E-02	2.3392E+02	kr-95	6.2717E-04	8.0393E+00	se-89	3.8051E-03	4.8775E+01

## MARVEL Reactor End of Life Preliminary Radiological Source Term

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
ba-148	1.7975E-03	2.3041E+01	kr-96	2.7576E-03	3.5348E+01	se-90	9.7648E-04	1.2517E+01
ba-149	1.1138E-04	1.4277E+00	kr-97	5.4539E-06	6.9910E-02	se-91	6.2273E-05	7.9824E-01
ba-150	7.8195E-06	1.0023E-01	kr-98	1.1843E-04	1.5181E+00	se-92	4.5244E-06	5.7996E-02
ba-151	7.8064E-07	1.0007E-02	kr-99	1.7260E-08	2.2125E-04	se-93	2.7118E-07	3.4761E-03
ba-152	1.2572E-08	1.6115E-04	la-135	6.2587E-13	8.0227E-09	se-94	6.6272E-09	8.4950E-05
ba-153	5.5665E-10	7.1354E-06	la-137	6.6172E-14	8.4822E-10	sm-145	1.1513E-11	1.4758E-07
bi-210	1.4081E-15	1.8050E-11	la-138	3.0832E-17	3.9522E-13	sm-146	2.1052E-16	2.6985E-12
bi-211	8.2192E-13	1.0536E-08	la-140	4.6941E-01	6.0171E+03	sm-147	4.5736E-13	5.8626E-09
bi-212	4.8172E-11	6.1749E-07	la-141	4.2920E-01	5.5017E+03	sm-148	4.4098E-19	5.6527E-15
bi-213	5.0137E-15	6.4268E-11	la-142	4.2787E-01	5.4846E+03	sm-151	4.2215E-04	5.4113E+00
bi-214	1.0187E-17	1.3058E-13	la-143	4.3346E-01	5.5563E+03	sm-153	1.3354E-02	1.7118E+02
br-77	5.3163E-14	6.8146E-10	la-144	3.9890E-01	5.1133E+03	sm-155	2.6825E-03	3.4385E+01
br-77m	4.1036E-14	5.2602E-10	la-145	2.8111E-01	3.6034E+03	sm-156	1.3236E-03	1.6966E+01
br-78	5.8711E-12	7.5258E-08	la-146	1.2234E-01	1.5682E+03	sm-157	5.8763E-04	7.5325E+00
br-79m	3.8215E-10	4.8986E-06	la-146m	5.4485E-02	6.9841E+02	sm-158	3.0215E-04	3.8731E+00
br-80	1.9024E-08	2.4386E-04	la-147	6.6753E-02	8.5567E+02	sm-159	9.1618E-05	1.1744E+00
br-80m	1.1779E-08	1.5099E-04	la-148	2.7830E-02	3.5674E+02	sm-160	2.6018E-05	3.3351E-01
br-82	2.1997E-05	2.8197E-01	la-149	6.4903E-03	8.3195E+01	sm-161	4.4097E-06	5.6525E-02
br-82m	1.6662E-05	2.1358E-01	la-150	9.3308E-04	1.1961E+01	sm-162	5.7591E-07	7.3822E-03
br-83	3.8995E-02	4.9985E+02	la-151	1.0973E-04	1.4066E+00	sm-163	8.6159E-08	1.1044E-03
br-84	7.1545E-02	9.1709E+02	la-152	7.8282E-06	1.0034E-01	sm-164	1.4090E-08	1.8061E-04
br-84m	1.2752E-03	1.6346E+01	la-153	6.0175E-07	7.7135E-03	sm-165	1.6921E-09	2.1690E-05
br-85	9.4177E-02	1.2072E+03	la-154	2.2839E-08	2.9276E-04	sn-113	1.6961E-15	2.1741E-11
br-86	1.3147E-01	1.6852E+03	la-155	6.2741E-10	8.0424E-06	sn-113m	1.9303E-15	2.4743E-11
br-87	1.4776E-01	1.8940E+03	lu-171	2.4379E-20	3.1250E-16	sn-117m	2.2855E-06	2.9296E-02
br-88	1.2724E-01	1.6310E+03	lu-172	3.7130E-15	4.7595E-11	sn-119m	2.9956E-05	3.8399E-01
br-89	7.9888E-02	1.0240E+03	lu-172m	3.2029E-15	4.1056E-11	sn-121	1.0198E-03	1.3072E+01
br-90	4.1052E-02	5.2622E+02	lu-173	2.0424E-11	2.6180E-07	sn-121m	2.3858E-06	3.0582E-02
br-91	1.6519E-02	2.1175E+02	lu-174	8.4573E-13	1.0841E-08	sn-123	9.1278E-05	1.1700E+00
br-92	2.0912E-03	2.6806E+01	lu-174m	1.1115E-12	1.4248E-08	sn-123m	1.2129E-03	1.5547E+01
br-93	3.2339E-04	4.1453E+00	lu-176	2.1630E-19	2.7726E-15	sn-125	1.0733E-03	1.3758E+01
br-94	2.2226E-05	2.8490E-01	lu-176m	2.8530E-08	3.6571E-04	sn-125m	1.6690E-03	2.1394E+01
br-95	2.8646E-07	3.6720E-03	lu-177	1.4841E-09	1.9024E-05	sn-126	2.6400E-08	3.3841E-04
br-96	1.6341E-07	2.0947E-03	lu-177m	9.3038E-13	1.1926E-08	sn-127	7.4510E-03	9.5510E+01
br-97	7.0521E-10	9.0397E-06	mn-66	3.4997E-10	4.4861E-06	sn-127m	4.2918E-03	5.5014E+01
cd-107	2.2613E-17	2.8986E-13	mn-67	2.9122E-10	3.7330E-06	sn-128	2.5089E-02	3.2160E+02
cd-109	2.0888E-12	2.6775E-08	mn-68	5.9020E-11	7.5654E-07	sn-128m	1.1954E-02	1.5323E+02
cd-111m	3.0544E-10	3.9153E-06	mn-69	7.9183E-12	1.0150E-07	sn-129	2.2186E-02	2.8439E+02
cd-113	9.7394E-20	1.2484E-15	mo-100	8.8226E-20	1.1309E-15	sn-129m	1.4665E-02	1.8798E+02
cd-113m	6.1881E-07	7.9322E-03	mo-101	3.8319E-01	4.9119E+03	sn-130	4.5528E-02	5.8360E+02
cd-115	1.0165E-03	1.3030E+01	mo-102	3.1990E-01	4.1006E+03	sn-130m	4.4409E-02	5.6925E+02
cd-115m	5.8107E-05	7.4484E-01	mo-103	2.2648E-01	2.9031E+03	sn-131	3.4971E-02	4.4827E+02
cd-117	8.5718E-04	1.0988E+01	mo-104	1.4049E-01	1.8009E+03	sn-131m	3.3448E-02	4.2875E+02
cd-117m	2.1504E-04	2.7565E+00	mo-105	7.5129E-02	9.6303E+02	sn-132	4.4153E-02	5.6597E+02
cd-118	9.7121E-04	1.2449E+01	mo-106	3.2325E-02	4.1435E+02	sn-133	8.0236E-03	1.0285E+02
cd-119	6.6068E-04	8.4689E+00	mo-107	1.1023E-02	1.4130E+02	sn-134	1.3953E-03	1.7886E+01
cd-119m	3.7174E-04	4.7651E+00	mo-108	3.0106E-03	3.8591E+01	sn-135	6.0113E-05	7.7055E-01
cd-120	1.0008E-03	1.2829E+01	mo-109	1.3162E-03	1.6872E+01	sn-136	2.2054E-06	2.8270E-02
cd-121	5.5832E-04	7.1568E+00	mo-110	3.3686E-04	4.3180E+00	sn-137	1.3562E-06	1.7384E-02
cd-121m	2.9184E-04	3.7409E+00	mo-111	3.1366E-05	4.0206E-01	sr-100	2.9309E-03	3.7569E+01
cd-122	1.0331E-03	1.3243E+01	mo-112	2.7897E-06	3.5759E-02	sr-101	3.5574E-04	4.5600E+00
cd-123	8.2880E-04	1.0624E+01	mo-113	2.7078E-07	3.4710E-03	sr-102	1.7163E-05	2.2000E-01
cd-124	9.6217E-04	1.2333E+01	mo-114	1.1632E-08	1.4910E-04	sr-103	2.7583E-07	3.5357E-03
cd-125	3.9853E-04	5.1085E+00	mo-115	9.4112E-10	1.2064E-05	sr-104	2.5286E-08	3.2413E-04
cd-126	5.8466E-04	7.4944E+00	mo-93	5.0757E-15	6.5062E-11	sr-105	3.0836E-09	3.9527E-05
cd-127	5.7253E-04	7.3389E+00	mo-93m	5.3712E-13	6.8850E-09	sr-83	1.8496E-15	2.3709E-11
cd-128	2.5211E-04	3.2316E+00	mo-99	4.4991E-01	5.7671E+03	sr-85	2.0216E-11	2.5914E-07
cd-129	9.4487E-07	1.2112E-02	nb-100	4.3575E-01	5.5856E+03	sr-85m	1.1898E-11	1.5251E-07
cd-130	6.1502E-03	7.8836E+01	nb-100m	2.3536E-02	3.0169E+02	sr-87m	6.6920E-06	8.5781E-02
cd-131	1.1334E-03	1.4528E+01	nb-101	3.6983E-01	4.7406E+03	sr-89	3.4321E-01	4.3994E+03

## MARVEL Reactor End of Life Preliminary Radiological Source Term

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
cd-132	1.3870E-07	1.7779E-03	nb-102	2.1161E-01	2.7125E+03	sr-90	1.9776E-02	2.5350E+02
ce-137	1.4276E-13	1.8300E-09	nb-102m	5.9441E-02	7.6194E+02	sr-91	4.2215E-01	5.4113E+03
ce-139	9.0100E-08	1.1549E-03	nb-103	1.4660E-01	1.8792E+03	sr-92	4.3125E-01	5.5279E+03
ce-139m	4.3171E-08	5.5338E-04	nb-104	2.9577E-02	3.7913E+02	sr-93	4.5386E-01	5.8178E+03
ce-141	4.2828E-01	5.4899E+03	nb-104m	2.2631E-02	2.9009E+02	sr-94	4.4095E-01	5.6523E+03
ce-143	4.3573E-01	5.5854E+03	nb-105	2.0467E-02	2.6235E+02	sr-95	3.8424E-01	4.9253E+03
ce-144	3.3461E-01	4.2892E+03	nb-106	1.7021E-03	2.1818E+01	sr-96	2.7606E-01	3.5386E+03
ce-145	2.8782E-01	3.6894E+03	nb-107	3.0964E-04	3.9691E+00	sr-97	1.2887E-01	1.6519E+03
ce-146	2.1977E-01	2.8171E+03	nb-108	2.4616E-05	3.1554E-01	sr-98	6.0465E-02	7.7506E+02
ce-147	1.4002E-01	1.7948E+03	nb-109	3.7246E-05	4.7743E-01	sr-99	1.0875E-02	1.3940E+02
ce-148	1.1697E-01	1.4994E+03	nb-110	1.3070E-06	1.6754E-02	ta-178	4.4430E-18	5.6952E-14
ce-149	5.7826E-02	7.4124E+02	nb-111	2.3166E-07	2.9695E-03	ta-179	2.8209E-14	3.6159E-10
ce-150	3.0635E-02	3.9269E+02	nb-112	2.6826E-09	3.4387E-05	ta-180	3.7634E-11	4.8241E-07
ce-151	7.7553E-03	9.9411E+01	nb-113	4.8934E-10	6.2726E-06	ta-182	4.7848E-07	6.1333E-03
ce-152	1.6521E-03	2.1177E+01	nb-90	2.6933E-21	3.4524E-17	ta-182m	6.6286E-11	8.4968E-07
ce-153	1.6842E-04	2.1589E+00	nb-91	1.3550E-16	1.7369E-12	ta-183	1.0134E-07	1.2990E-03
ce-154	1.2928E-05	1.6572E-01	nb-91m	5.7601E-19	7.3835E-15	tb-155	7.5106E-15	9.6274E-11
ce-155	8.4418E-07	1.0821E-02	nb-92	2.9902E-19	3.8330E-15	tb-156	4.6699E-13	5.9861E-09
ce-156	4.6721E-08	5.9889E-04	nb-92m	3.4854E-14	4.4677E-10	tb-156m	4.7280E-14	6.0605E-10
ce-157	1.7636E-09	2.2607E-05	nb-93m	1.9216E-08	2.4632E-04	tb-157	1.3425E-13	1.7209E-09
cm-240	2.7772E-16	3.5599E-12	nb-94	2.9994E-12	3.8448E-08	tb-158	9.6271E-13	1.2340E-08
cm-241	6.8978E-14	8.8419E-10	nb-94m	3.0176E-08	3.8681E-04	tb-158m	3.6437E-11	4.6706E-07
cm-242	9.6014E-07	1.2307E-02	nb-95	4.9987E-01	6.4075E+03	tb-160	6.3399E-07	8.1267E-03
cm-243	6.2874E-12	8.0594E-08	nb-95m	5.4058E-03	6.9294E+01	tb-161	1.5522E-05	1.9897E-01
cm-244	1.2853E-11	1.6475E-07	nb-96	1.6157E-04	2.0711E+00	tb-162	5.4579E-06	6.9962E-02
cm-245	4.1467E-17	5.3154E-13	nb-97	4.8079E-01	6.1630E+03	tb-163	2.3199E-06	2.9737E-02
cm-246	7.7439E-20	9.9264E-16	nb-97m	4.5616E-01	5.8472E+03	tb-164	9.0688E-07	1.1625E-02
co-65	3.8076E-11	4.8807E-07	nb-98	4.2399E-01	5.4349E+03	tb-165	4.1082E-07	5.2661E-03
co-66	1.3266E-08	1.7005E-04	nb-98m	2.7713E-03	3.5524E+01	tb-166	1.9563E-07	2.5077E-03
co-67	4.2996E-08	5.5114E-04	nb-99	2.7194E-01	3.4858E+03	tb-167	8.0662E-08	1.0340E-03
co-68	4.9214E-08	6.3084E-04	nb-99m	1.7815E-01	2.2836E+03	tb-168	3.2939E-08	4.2223E-04
co-69	5.0630E-08	6.4900E-04	nd-140	3.9209E-15	5.0260E-11	tb-169	1.4518E-08	1.8610E-04
co-70	3.3552E-08	4.3008E-04	nd-141	1.5421E-10	1.9767E-06	tb-170	4.5936E-09	5.8883E-05
co-71	2.0251E-08	2.5959E-04	nd-141m	3.0407E-11	3.8977E-07	tb-171	1.2279E-09	1.5740E-05
co-72	7.8531E-09	1.0066E-04	nd-144	1.3151E-16	1.6857E-12	tc-100	2.2527E-03	2.8876E+01
co-73	3.0749E-09	3.9415E-05	nd-147	1.6511E-01	2.1164E+03	tc-101	3.8322E-01	4.9123E+03
co-74	4.4677E-10	5.7269E-06	nd-149	8.0312E-02	1.0295E+03	tc-102	3.2062E-01	4.1098E+03
co-75	6.0976E-11	7.8161E-07	nd-150	8.5830E-21	1.1002E-16	tc-102m	7.2610E-04	9.3074E+00
cr-66	2.3137E-12	2.9658E-08	nd-151	3.1609E-02	4.0518E+02	tc-103	2.3242E-01	2.9793E+03
cr-67	6.2176E-13	7.9700E-09	nd-152	2.0145E-02	2.5823E+02	tc-104	1.4790E-01	1.8958E+03
cs-129	6.4083E-21	8.2144E-17	nd-153	1.1452E-02	1.4680E+02	tc-105	8.1043E-02	1.0388E+03
cs-131	1.1252E-10	1.4423E-06	nd-154	4.9266E-03	6.3151E+01	tc-106	3.7198E-02	4.7682E+02
cs-132	1.2968E-07	1.6623E-03	nd-155	1.4887E-03	1.9083E+01	tc-107	1.5622E-02	2.0025E+02
cs-134	9.4142E-04	1.2067E+01	nd-156	4.1007E-04	5.2564E+00	tc-108	5.8021E-03	7.4374E+01
cs-134m	3.2598E-04	4.1785E+00	nd-157	5.2802E-05	6.7684E-01	tc-109	3.0475E-03	3.9064E+01
cs-135	2.7384E-07	3.5102E-03	nd-158	6.9759E-06	8.9420E-02	tc-110	1.3411E-03	1.7191E+01
cs-135m	2.7635E-05	3.5424E-01	nd-159	5.1975E-07	6.6624E-03	tc-111	4.2673E-04	5.4700E+00
cs-136	1.0147E-03	1.3007E+01	nd-160	3.6819E-08	4.7196E-04	tc-112	8.5113E-05	1.0910E+00
cs-136m	2.8177E-04	3.6118E+00	nd-161	1.6391E-09	2.1011E-05	tc-113	2.0480E-05	2.6252E-01
cs-137	2.0549E-02	2.6341E+02	ni-65	3.8078E-11	4.8810E-07	tc-114	2.8877E-06	3.7016E-02
cs-138	4.9254E-01	6.3136E+03	ni-66	1.4376E-08	1.8428E-04	tc-115	4.3525E-07	5.5792E-03
cs-138m	1.6790E-02	2.1522E+02	ni-67	5.3829E-08	6.9000E-04	tc-116	4.3123E-08	5.5277E-04
cs-139	4.6516E-01	5.9626E+03	ni-68	9.6652E-08	1.2389E-03	tc-117	1.9374E-09	2.4834E-05
cs-140	4.1872E-01	5.3673E+03	ni-69	1.7368E-07	2.2263E-03	tc-118	4.6127E-10	5.9127E-06
cs-141	3.0662E-01	3.9304E+03	ni-70	3.1655E-07	4.0577E-03	tc-95	9.9936E-21	1.2810E-16
cs-142	1.9923E-01	2.5538E+03	ni-71	4.3465E-07	5.5715E-03	tc-96	2.8476E-17	3.6502E-13
cs-143	1.0662E-01	1.3667E+03	ni-72	6.7600E-07	8.6652E-03	tc-97	1.1934E-17	1.5297E-13
cs-144	3.1881E-02	4.0866E+02	ni-73	6.2654E-07	8.0312E-03	tc-97m	2.2189E-11	2.8443E-07
cs-145	5.9379E-03	7.6114E+01	ni-74	3.7942E-07	4.8636E-03	tc-98	3.6830E-14	4.7210E-10
cs-146	6.4713E-04	8.2952E+00	ni-75	1.2821E-07	1.6434E-03	tc-99	2.9303E-06	3.7562E-02



## MARVEL Reactor End of Life Preliminary Radiological Source Term

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
cs-147	1.7131E-04	2.1959E+00	ni-76	4.2383E-08	5.4328E-04	tc-99m	3.9542E-01	5.0687E+03
cs-148	2.8359E-06	3.6352E-02	ni-77	5.0957E-09	6.5319E-05	te-119	1.0104E-20	1.2952E-16
cs-149	6.0680E-08	7.7782E-04	ni-78	5.2694E-10	6.7545E-06	te-121	6.2371E-13	7.9950E-09
cs-150	3.8435E-09	4.9268E-05	np-234	8.6372E-19	1.1072E-14	te-121m	2.7380E-13	3.5097E-09
cs-151	6.4595E-10	8.2800E-06	np-235	3.8614E-12	4.9497E-08	te-123m	1.8311E-09	2.3472E-05
cu-66	1.4387E-08	1.8442E-04	np-236	2.3251E-15	2.9804E-11	te-125m	2.2068E-04	2.8288E+00
cu-67	5.4037E-08	6.9267E-04	np-236m	2.5151E-09	3.2240E-05	te-127	1.2147E-02	1.5571E+02
cu-68	9.8363E-08	1.2609E-03	np-237	5.0412E-09	6.4620E-05	te-127m	1.9422E-03	2.4896E+01
cu-68m	1.4586E-09	1.8697E-05	np-238	1.4970E-04	1.9189E+00	te-128	4.1385E-21	5.3049E-17
cu-69	1.8992E-07	2.4345E-03	np-239	2.7557E+00	3.5324E+04	te-129	3.9595E-02	5.0754E+02
cu-70	3.6388E-07	4.6644E-03	np-240	4.4756E-05	5.7370E-01	te-129m	6.9709E-03	8.9356E+03
cu-70m	6.1278E-08	7.8549E-04	np-240m	7.6172E-05	9.7640E-01	te-131	1.9128E-01	2.4519E+03
cu-71	7.9230E-07	1.0156E-02	np-241	3.7939E-13	4.8632E-09	te-131m	3.1376E-02	4.0219E+02
cu-72	1.8610E-06	2.3855E-02	pa-229	3.4180E-15	4.3813E-11	te-132	3.1865E-01	4.0846E+03
cu-73	4.6014E-06	5.8983E-02	pa-230	6.7025E-13	8.5915E-09	te-133	2.4845E-01	3.1847E+03
cu-74	5.8388E-06	7.4844E-02	pa-231	2.9893E-11	3.8318E-07	te-133m	2.7560E-01	3.5328E+03
cu-75	7.9849E-06	1.0235E-01	pa-232	2.3626E-08	3.0285E-04	te-134	5.1018E-01	6.5397E+03
cu-76	6.5549E-06	8.4023E-02	pa-233	6.8957E-09	8.8392E-05	te-135	2.4573E-01	3.1499E+03
cu-77	3.4831E-06	4.4648E-02	pa-234	7.3832E-10	9.4641E-06	te-136	1.0082E-01	1.2924E+03
cu-78	8.7733E-07	1.1246E-02	pa-234m	4.5966E-07	5.8921E-03	te-137	3.0566E-02	3.9181E+02
cu-79	3.1334E-08	4.0165E-04	pa-235	8.7297E-08	1.1190E-03	te-138	5.2527E-03	6.7331E+01
cu-80	6.6636E-09	8.5417E-05	pb-207m	4.1358E-18	5.3014E-14	te-139	5.7117E-04	7.3215E+00
dy-157	9.6726E-20	1.2399E-15	pb-209	5.0182E-15	6.4325E-11	te-140	1.2102E-03	1.5513E+01
dy-159	3.2523E-13	4.1689E-09	pb-210	1.4379E-15	1.8432E-11	te-141	6.4369E-06	8.2511E-02
dy-165	4.7282E-07	6.0608E-03	pb-211	8.2192E-13	1.0536E-08	te-142	2.1825E-07	2.7976E-03
dy-165m	3.1582E-08	4.0483E-04	pb-212	4.8172E-11	6.1749E-07	th-226	5.0255E-14	6.4419E-10
dy-166	2.2466E-07	2.8798E-03	pb-214	1.0184E-17	1.3054E-13	th-227	8.4797E-13	1.0870E-08
dy-167	1.0063E-07	1.2899E-03	pd-101	7.1413E-17	9.1540E-13	th-228	4.9158E-11	6.3013E-07
dy-168	4.6237E-08	5.9268E-04	pd-103	4.3189E-10	5.5361E-06	th-229	5.6675E-16	7.2648E-12
dy-169	2.4936E-08	3.1964E-04	pd-107	3.1073E-09	3.9831E-05	th-230	3.5968E-14	4.6105E-10
dy-170	1.1617E-08	1.4891E-04	pd-107m	1.3111E-07	1.6806E-03	th-231	7.1121E-07	9.1166E-03
dy-171	5.4920E-09	7.0399E-05	pd-109	4.9154E-03	6.3008E+01	th-232	1.3352E-16	1.7115E-12
dy-172	6.2311E-09	7.9873E-05	pd-109m	4.2195E-07	5.4087E-03	th-233	2.3934E-09	3.0680E-05
er-163	7.4941E-19	9.6062E-15	pd-111	1.8649E-03	2.3905E+01	th-234	4.5965E-07	5.8920E-03
er-165	1.4403E-13	1.8462E-09	pd-111m	5.3561E-07	6.8657E-03	tl-206	2.1856E-21	2.8016E-17
er-167m	1.2551E-08	1.6088E-04	pd-112	1.2728E-03	1.6315E+01	tl-207	8.1965E-13	1.0507E-08
er-169	2.6144E-08	3.3512E-04	pd-113	1.2609E-03	1.6163E+01	tl-208	1.7313E-11	2.2192E-07
er-171	7.0507E-09	9.0379E-05	pd-114	9.7347E-04	1.2478E+01	tl-209	1.1030E-16	1.4139E-12
er-172	9.5825E-09	1.2283E-04	pd-115	9.7093E-04	1.2446E+01	tl-210	2.1405E-21	2.7438E-17
eu-149	1.6622E-13	2.1307E-09	pd-116	7.1378E-04	9.1495E+00	tm-166	1.3158E-20	1.6866E-16
eu-152	1.4044E-06	1.8002E-02	pd-117	7.5500E-04	9.6779E+00	tm-167	1.1837E-16	1.5173E-12
eu-152m	2.2318E-05	2.8608E-01	pd-118	3.1321E-04	4.0149E+00	tm-168	1.7773E-14	2.2782E-10
eu-154	2.6045E-05	3.3386E-01	pd-119	7.6046E-05	9.7479E-01	tm-170	5.0175E-10	6.4316E-06
eu-154m	5.6735E-06	7.2725E-02	pd-120	2.1255E-04	2.7246E+00	tm-171	3.5445E-09	4.5435E-05
eu-155	5.4185E-04	6.9457E+00	pd-121	1.1125E-05	1.4260E-01	tm-172	9.6530E-09	1.2374E-04
eu-156	2.0637E-03	2.6453E+01	pd-122	2.6194E-06	3.3577E-02	tm-173	1.7894E-17	2.2937E-13
eu-157	5.9994E-04	7.6903E+00	pd-123	5.2752E-07	6.7620E-03	u-230	5.0168E-14	6.4307E-10
eu-158	3.2013E-04	4.1036E+00	pd-124	1.0139E-07	1.2997E-03	u-231	1.6462E-14	2.1102E-10
eu-159	1.1425E-04	1.4645E+00	pm-143	5.5617E-20	7.1292E-16	u-232	2.3945E-10	3.0694E-06
eu-160	4.0498E-05	5.1912E-01	pm-144	9.1178E-16	1.1688E-11	u-233	5.2879E-12	6.7782E-08
eu-161	1.2694E-05	1.6272E-01	pm-145	9.0584E-12	1.1611E-07	u-234	3.9055E-09	5.0062E-05
eu-162	2.8430E-06	3.6443E-02	pm-146	1.2927E-08	1.6570E-04	u-235	7.1115E-07	9.1158E-03
eu-163	7.8610E-07	1.0077E-02	pm-147	6.5751E-02	8.4282E+02	u-235m	4.8915E-06	6.2701E-02
eu-164	1.7483E-07	2.2410E-03	pm-148	2.3540E-03	3.0175E+01	u-236	1.0122E-07	1.2975E-03
eu-165	4.5051E-08	5.7748E-04	pm-148m	1.7223E-03	2.2077E+01	u-237	1.2347E-02	1.5827E+02
eu-166	1.0393E-08	1.3322E-04	pm-149	8.0396E-02	1.0305E+03	u-238	4.5964E-07	5.8918E-03
eu-167	2.1347E-09	2.7363E-05	pm-150	1.1062E-04	1.4180E+00	u-239	2.7555E+00	3.5321E+04
fe-65	3.8076E-11	4.8807E-07	pm-151	3.1670E-02	4.0596E+02	w-181	7.8260E-14	1.0032E-09
fe-66	6.9696E-09	8.9339E-05	pm-152	2.0230E-02	2.5932E+02	w-183m	5.3614E-09	6.8725E-05
fe-67	1.2835E-08	1.6452E-04	pm-152m	1.3614E-04	1.7451E+00	w-185	1.5780E-14	2.0227E-10

## MARVEL Reactor End of Life Preliminary Radiological Source Term

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
fe-68	7.6391E-09	9.7921E-05	pm-153	1.2188E-02	1.5623E+02	w-185m	6.0467E-17	7.7509E-13
fe-69	2.6248E-09	3.3646E-05	pm-154	5.3863E-03	6.9044E+01	w-187	1.7688E-20	2.2673E-16
fe-70	7.2397E-10	9.2801E-06	pm-154m	4.6002E-04	5.8967E+00	xe-125	1.1745E-16	1.5055E-12
fe-71	1.2503E-10	1.6027E-06	pm-155	2.5500E-03	3.2687E+01	xe-125m	3.1210E-17	4.0006E-13
fe-72	1.8112E-11	2.3217E-07	pm-156	1.0354E-03	1.3272E+01	xe-127	3.9949E-12	5.1208E-08
fr-221	5.0141E-15	6.4273E-11	pm-157	3.2787E-04	4.2028E+00	xe-127m	7.6539E-13	9.8111E-09
fr-222	4.9786E-21	6.3818E-17	pm-158	7.8276E-05	1.0034E+00	xe-129m	6.3932E-10	8.1951E-06
fr-223	1.2786E-14	1.6390E-10	pm-159	1.4067E-05	1.8032E-01	xe-131m	2.3222E-03	2.9767E+01
ga-67	6.1977E-19	7.9445E-15	pm-160	1.6443E-06	2.1077E-02	xe-133	4.7344E-01	6.0687E+03
ga-68	1.7741E-14	2.2741E-10	pm-161	1.7736E-07	2.2735E-03	xe-133m	1.4240E-02	1.8253E+02
ga-70	8.5624E-11	1.0976E-06	pm-162	1.2909E-08	1.6547E-04	xe-134m	2.6215E-03	3.3603E+01
ga-72	2.4521E-06	3.1432E-02	pm-163	1.2898E-09	1.6533E-05	xe-135	4.5532E-01	5.8365E+03
ga-72m	8.9861E-08	1.1519E-03	po-210	8.1516E-16	1.0449E-11	xe-135m	8.8239E-02	1.1311E+03
ga-73	8.6169E-06	1.1045E-01	po-211	2.2685E-15	2.9079E-11	xe-137	4.5078E-01	5.7783E+03
ga-74	2.6089E-05	3.3442E-01	po-212	3.0859E-11	3.9556E-07	xe-138	4.6086E-01	5.9075E+03
ga-74m	6.5448E-07	8.3894E-03	po-213	4.9038E-15	6.2859E-11	xe-139	3.6743E-01	4.7099E+03
ga-75	8.1360E-05	1.0429E+00	po-214	5.0266E-14	6.4433E-10	xe-140	2.6593E-01	3.4088E+03
ga-76	2.3015E-04	2.9502E+00	po-215	8.2192E-13	1.0536E-08	xe-141	9.2214E-02	1.1820E+03
ga-77	5.4815E-04	7.0264E+00	po-216	4.8172E-11	6.1749E-07	xe-142	3.2775E-02	4.2012E+02
ga-78	1.0271E-03	1.3166E+01	po-218	1.0187E-17	1.3058E-13	xe-143	3.1678E-03	4.0606E+01
ga-79	1.3779E-03	1.7662E+01	pr-139	1.3147E-11	1.6852E-07	xe-144	5.2225E-04	6.6944E+00
ga-80	8.8125E-04	1.1296E+01	pr-140	8.7466E-08	1.1212E-03	xe-145	1.5853E-05	2.0321E-01
ga-81	6.0199E-04	7.7165E+00	pr-142	2.6404E-04	3.3846E+00	xe-146	1.4967E-06	1.9185E-02
ga-82	4.5325E-04	5.8099E+00	pr-142m	9.1913E-05	1.1782E+00	xe-147	1.4165E-07	1.8157E-03
ga-83	1.7128E-05	2.1955E-01	pr-143	4.2041E-01	5.3890E+03	y-100	5.0124E-02	6.4251E+02
ga-84	8.0288E-04	1.0292E+01	pr-144	3.3469E-01	4.2902E+03	y-101	2.1452E-02	2.7498E+02
ga-85	1.1934E-07	1.5297E-03	pr-144m	3.2398E-03	4.1529E+01	y-102	2.0595E-02	2.6399E+02
ga-86	2.3109E-06	2.9622E-02	pr-145	2.8785E-01	3.6898E+03	y-103	2.9154E-04	3.7371E+00
gd-151	1.2256E-12	1.5710E-08	pr-146	2.2006E-01	2.8208E+03	y-104	5.3006E-05	6.7945E-01
gd-152	7.3469E-20	9.4176E-16	pr-147	1.6519E-01	2.1175E+03	y-105	2.7246E-06	3.4925E-02
gd-153	8.1289E-08	1.0420E-03	pr-148	1.2019E-01	1.5406E+03	y-106	5.4626E-09	7.0022E-05
gd-159	1.1603E-04	1.4873E+00	pr-148m	3.2437E-03	4.1579E+01	y-107	1.2317E-09	1.5788E-05
gd-161	1.5567E-05	1.9954E-01	pr-149	7.9695E-02	1.0216E+03	y-108	4.9482E-12	6.3428E-08
gd-162	5.3439E-06	6.8500E-02	pr-150	4.6557E-02	5.9679E+02	y-87	5.2872E-12	6.7773E-08
gd-163	2.1345E-06	2.7361E-02	pr-151	2.5570E-02	3.2777E+02	y-87m	5.2639E-16	6.7475E-12
gd-164	7.5445E-07	9.6708E-03	pr-152	9.5490E-03	1.2240E+02	y-88	2.6074E-08	3.3423E-04
gd-165	2.6710E-07	3.4238E-03	pr-153	3.0881E-03	3.9585E+01	y-89m	1.7765E-04	2.2772E+00
gd-166	1.0071E-07	1.2909E-03	pr-154	4.5901E-04	5.8838E+00	y-90	2.0381E-02	2.6125E+02
gd-167	3.2374E-08	4.1498E-04	pr-155	7.5151E-05	9.6332E-01	y-90m	5.2576E-05	6.7394E-01
gd-168	9.8242E-09	1.2593E-04	pr-156	7.3886E-06	9.4710E-02	y-91	4.2145E-01	5.4023E+03
gd-169	2.1669E-09	2.7776E-05	pr-157	6.9865E-07	8.9556E-03	y-91m	2.4840E-01	3.1841E+03
ge-69	8.0890E-19	1.0369E-14	pr-158	4.0686E-08	5.2153E-04	y-92	4.3631E-01	5.5928E+03
ge-71	4.7826E-13	6.1305E-09	pr-159	1.8453E-09	2.3654E-05	y-93	4.6154E-01	5.9162E+03
ge-71m	1.8372E-13	2.3550E-09	pu-236	2.1306E-10	2.7311E-06	y-93m	1.5854E-01	2.0322E+03
ge-73m	8.4898E-06	1.0883E-01	pu-237	4.4171E-10	5.6620E-06	y-94	4.7013E-01	6.0263E+03
ge-75	8.1872E-05	1.0495E+00	pu-237m	9.9952E-11	1.2812E-06	y-95	4.6556E-01	5.9677E+03
ge-75m	3.4414E-06	4.4113E-02	pu-238	9.5485E-07	1.2240E-02	y-96	2.9533E-01	3.7857E+03
ge-77	5.9829E-04	7.6691E+00	pu-239	1.5030E-04	1.9266E+00	y-96m	1.4450E-01	1.8523E+03
ge-77m	7.2447E-06	9.2865E-02	pu-240	9.8798E-06	1.2664E-01	y-97	2.2478E-01	2.8813E+03
ge-78	1.5576E-03	1.9966E+01	pu-241	1.9036E-04	2.4401E+00	y-97m	1.3396E-01	1.7172E+03
ge-79	2.2254E-03	2.8526E+01	pu-242	3.7710E-11	4.8338E-07	y-98	1.4602E-01	1.8717E+03
ge-79m	9.4192E-04	1.2074E+01	pu-243	1.7060E-07	2.1868E-03	y-98m	8.5067E-02	1.0904E+03
ge-80	8.3432E-03	1.0695E+02	pu-245	9.3136E-17	1.1939E-12	y-99	1.5543E-01	1.9924E+03
ge-81	9.5932E-03	1.2297E+02	ra-222	5.0256E-14	6.4420E-10	yb-169	9.4518E-17	1.2116E-12
ge-81m	2.4969E-04	3.2006E+00	ra-223	8.2192E-13	1.0536E-08	yb-169m	1.1566E-17	1.4826E-13
ge-82	9.5781E-03	1.2278E+02	ra-224	4.8171E-11	6.1748E-07	yb-175	1.7270E-11	2.2137E-07
ge-83	2.3561E-03	3.0201E+01	ra-225	5.2898E-15	6.7807E-11	yb-177	2.1581E-11	2.7663E-07
ge-84	2.1308E-03	2.7313E+01	ra-226	1.0418E-17	1.3354E-13	zn-69	1.9025E-07	2.4387E-03
ge-85	1.7809E-04	2.2828E+00	ra-227	7.3193E-17	9.3822E-13	zn-69m	2.6978E-10	3.4581E-06
ge-86	4.2557E-02	5.4551E+02	ra-228	1.4763E-17	1.8924E-13	zn-71	8.0108E-07	1.0269E-02

## MARVEL Reactor End of Life Preliminary Radiological Source Term

Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci	Isotope	Ci per cm <sup>3</sup>	Total Core Ci
ge-87	1.5430E-04	1.9779E+00	rb-100	2.9238E-03	3.7478E+01	zn-71m	4.0173E-08	5.1495E-04
ge-88	3.6908E-06	4.7310E-02	rb-101	1.4814E-07	1.8989E-03	zn-72	2.4441E-06	3.1329E-02
ge-89	3.6501E-09	4.6788E-05	rb-102	4.4543E-09	5.7097E-05	zn-73	8.4844E-06	1.0876E-01
h-3	7.9873E-05	1.0238E+00	rb-81	1.0898E-14	1.3969E-10	zn-74	2.4945E-05	3.1975E-01
hf-171	1.3182E-21	1.6897E-17	rb-83	8.3419E-11	1.0693E-06	zn-75	6.6145E-05	8.4787E-01
hf-172	3.0721E-15	3.9379E-11	rb-84	3.3824E-09	4.3357E-05	zn-76	1.4926E-04	1.9133E+00
hf-173	3.2181E-11	4.1251E-07	rb-86	1.2038E-05	1.5431E-01	zn-77	2.3789E-04	3.0494E+00
hf-174	2.0878E-19	2.6762E-15	rb-86m	1.8154E-06	2.3271E-02	zn-78	2.6300E-04	3.3712E+00
hf-175	4.7197E-06	6.0499E-02	rb-87	5.3805E-12	6.8969E-08	zn-79	1.2081E-04	1.5486E+00
hf-177m	9.7986E-08	1.2560E-03	rb-88	2.5817E-01	3.3093E+03	zn-80	1.8656E-05	2.3914E-01
hf-178m	3.1355E-08	4.0192E-04	rb-89	3.4140E-01	4.3762E+03	zn-81	3.6278E-07	4.6503E-03
hf-179m	1.0404E-03	1.3336E+01	rb-90	3.4941E-01	4.4789E+03	zn-82	8.4007E-07	1.0768E-02
hf-180m	2.2729E-06	2.9135E-02	rb-90m	6.4341E-02	8.2475E+02	zn-83	1.2181E-08	1.5614E-04
hf-181	6.7216E-05	8.6160E-01	rb-91	4.0321E-01	5.1685E+03	zr-100	4.1386E-01	5.3050E+03
hf-182	1.2993E-14	1.6655E-10	rb-92	3.4901E-01	4.4737E+03	zr-101	2.2785E-01	2.9207E+03
ho-159	3.4892E-21	4.4726E-17	rb-93	2.5848E-01	3.3133E+03	zr-102	1.5224E-01	1.9515E+03
ho-161	5.1165E-15	6.5585E-11	rb-94	1.2174E-01	1.5605E+03	zr-103	4.0258E-02	5.1604E+02
ho-161m	2.6983E-17	3.4588E-13	rb-95	5.7180E-02	7.3296E+02	zr-104	6.8722E-03	8.8091E+01
ho-162	8.9979E-14	1.1534E-09	rb-96	1.5723E-02	2.0154E+02	zr-105	8.2774E-03	1.0610E+02
ho-162m	8.6108E-14	1.1038E-09	rb-97	2.8173E-03	3.6113E+01	zr-106	2.9784E-06	3.8178E-02
ho-163	2.8401E-16	3.6406E-12	rb-98	3.4952E-04	4.4803E+00	zr-107	5.0021E-07	6.4119E-03
ho-163m	2.3903E-13	3.0640E-09	rb-99	1.7042E-05	2.1845E-01	zr-108	2.5814E-08	3.3089E-04
ho-164	1.2423E-11	1.5924E-07	re-186	7.9900E-17	1.0242E-12	zr-109	3.0344E-08	3.8896E-04
ho-164m	8.6782E-12	1.1124E-07	rh-101	3.1727E-12	4.0669E-08	zr-110	8.1102E-10	1.0396E-05
ho-166	2.2939E-07	2.9404E-03	rh-101m	7.0517E-12	9.0392E-08	zr-88	4.7619E-14	6.1040E-10
ho-166m	2.3415E-13	3.0014E-09	rh-102	1.3138E-08	1.6841E-04	zr-89	1.3474E-04	1.7272E+00
ho-167	1.0139E-07	1.2997E-03	rh-102m	1.9936E-09	2.5555E-05	zr-89m	1.8256E-05	2.3401E-01
ho-168	4.7007E-08	6.0255E-04	rh-103m	2.2937E-01	2.9402E+03	zr-90m	1.8331E-04	2.3497E+00
ho-169	2.6128E-08	3.3492E-04	rh-104	4.2146E-03	5.4024E+01	zr-93	4.7084E-07	6.0354E-03
ho-170	1.2164E-08	1.5592E-04	rh-104m	3.2051E-04	4.1084E+00	zr-95	5.0025E-01	6.4124E+03
ho-170m	5.4711E-10	7.0131E-06	rh-105	8.1038E-02	1.0388E+03	zr-96	2.7613E-17	3.5395E-13
ho-171	6.9425E-09	8.8992E-05	rh-105m	2.2997E-02	2.9478E+02	zr-97	4.7973E-01	6.1494E+03
ho-172	9.3287E-09	1.1958E-04	rh-106	2.6358E-02	3.3787E+02	zr-98	4.1592E-01	5.3314E+03
i-121	1.6665E-21	2.1362E-17	rh-106m	9.7801E-06	1.2537E-01	zr-99	4.1655E-01	5.3395E+03
						totals	4.8739E+01	6.2476E+05

## 8.0 CONCLUSION

The preliminary radiological source term for MARVEL has been calculated and presented. The source term assumes continuous operation for two full years for a total thermal energy generation of 7,000,000 MJ. This exceeds the planned thermal energy generation for the MARVEL reactor. This source term can be used for dose consequence analyses to support the preliminary hazard analysis for MARVEL.

## 9.0 REFERENCES

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