Pebble Bed Reactor Domestic Safeguards

FY21 Summary Report

Prepared for
US Department of Energy

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Oak Ridge National Laboratory

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Nuclear Security Sciences Directorate

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ABBREVIATIONS

ARDP	Advanced Reactor Demonstration Program
ARS	Advanced Reactor Safeguards
DOE	US Department of Energy
FHS	fuel handling system
FNMC	Fundamental Nuclear Material Control
HALEU	high-assay low-enriched uranium
HTGR	high-temperature gas-cooled nuclear reactor
LWR	light water reactor
MBA	material balance area
MC&A	material control and accounting
NMMSS	Nuclear Materials Management and Safeguards System
NRC	US Nuclear Regulatory Authority
ORNL	Oak Ridge National Laboratory
PBMR	pebble bed modular reactor
PBR	pebble bed reactor
RZ	radial zone
SNL	Sandia National Laboratories
SNM	special nuclear material
TRISO	tristructural isotropic

ABSTRACT

This report provides the work done under the US Department of Energy NE-5 Advanced Reactor Safeguards program for FY21. It focuses on material control and accounting (MC&A) for pebble bed reactors (PBR) and addresses some of the main challenges in which current PBR MC&A approaches are still evolving, allowing for possible safeguards and security by design efforts. In FY21, efforts focused on continued vendor interactions, the impact to MC&A from the use of high-assay low enriched uranium, reporting challenges, and projected special nuclear material content of spent fuel for MC&A purposes using the PBMR-400 as an example.

1. SCOPE OF WORK

1.1 INTRODUCTION

This report summarizes work done under the US Department of Energy NE-5 Advanced Reactor Safeguards (ARS) program for FY21 on the topic of material control and accounting (MC&A) for pebble bed reactors (PBRs).

As background, Title 10 of the US Code of Federal Regulations (CFR) Part 74 defines MC&A requirements for special nuclear material (SNM). MC&A requirements are defined based on the strategic significance of the SNM. Light water reactor (LWR) fuel used in US commercial nuclear reactors is less than 10% enriched in the isotope ^{235}U,[1] which is the lowest category.

Also, even though there is Pu in LWR spent nuclear fuel,[2] LWR fuel assemblies are large, heavy, and highly radioactive, which significantly decreases the likelihood of theft. Because of this, the US Nuclear Regulatory Authority (NRC) only requires LWRs to meet the sabotage design basis threat and not the theft/diversion design basis threat based on the thinking that theft/diversion is bounded by controls to mitigate sabotage. Therefore, the NRC's MC&A regulations for LWRs are less stringent and do not require the full implementation of Category I and Category II MC&A requirements when compared with other fuel cycle facilities relying more heavily on physical security.

This will not be the case with PBRs in which the portability of spheres at certain points in the process is a key difference, albeit the SNM content per sphere is small. Also, enrichment levels will exceed 10%, which moves into Category II MC&A requirements. Therefore, PBR designs will require different nuclear MC&A methods than the existing fleet of LWRs that are currently licensed in the United States.

The main differences stem from the movable nature of the fuel spheres (i.e., pebbles) during normal reactor operations. Spheres are continuously inserted and withdrawn from the reactor core and are moved throughout the reactor and associated systems via pneumatic or hydraulic pressure tubes, as well as other mechanical means. This is in notable contrast to LWRs in which the fuel bundles are fixed during the operations cycle and the reactor must be shut down and the reactor head removed to insert, remove, or shuffle the fuel.

Additionally, the several hundred fuel bundles at an LWR are uniquely identified, whereas the fuel spheres in most proposed designs will not be. A PBR will have an inventory consisting of hundreds of

[1] 10,000 g or more of ^{235}U enriched to less than 10% is defined as Category III, SNM of low strategic significance (Nuclear Regulatory Commission 2017).
[2] The presence of Pu would typically cause SNM to be categorized as Category I, strategic SNM (Nuclear Regulatory Commission 2017).

thousands of fuel spheres, and during the operational lifetime, it may encounter millions of spheres that arrive as fresh fuel and are ultimately dispositioned as spent fuel. The number of spheres and their portability constitute the key differences as they relate to MC&A and security. The concept of item control or monitoring as defined in 10 CFR 74 will apply as one of the key approaches to manage this large number of spheres.

Even so, certain aspects of current LWR approaches were found to be applicable for fresh and spent fuel, as discussed in an Oak Ridge National Laboratory (ORNL) report to the NRC [1]. This is true for fresh and spent fuel. However, the report notes that MC&A approaches currently in use for fuel cycle facilities are more closely aligned with anticipated PBR designs instead of LWR approaches—specifically those MC&A approaches required for facilities handling SNM of moderate strategic significance (i.e., Category II) when it comes to the reactor vessel and recycle loops.

The low SNM content per sphere must also be balanced with the radiological aspects resulting from the theft of a single spent sphere. Considering only bulk amounts or groups does not address the potential consequence of the loss of an individual pebble if used in a radiological exposure device or a radiological dispersion device. A spent tristructural isotropic (TRISO) pebble will have radiation levels equivalent to a Category 1 or 2 radiological source [2].

Current PBR MC&A approaches are still evolving as vendors continue to work on plant layouts and designs for the fuel handling systems. This allows for the possible consideration of safeguards and security in the designs of these facilities.

This report focuses on fuel categorization considerations, MC&A requirements/plans, and inventory reporting and contains a more detailed analysis of fuel composition based on a PBMR-400 example. As with last year, this effort builds on the MC&A domestic safeguards challenges for PBRs as identified in the aforementioned ORNL report [1]. The referenced report was completed for the NRC in response to the emergence of this non-LWR design to analyze current policy and technical guidance.

1.2 INDUSTRY PARTNERSHIPS AND NATIONAL LABORATORIES

The results of the work being done by this project are intended to be applicable to any PBR design. The industry partnerships described in this report are providing important examples of leading PBR conceptual designs and, as such, it is useful to use them in considering possible MC&A approaches because they provide some detailed design information. Any results from this report should be applicable to any PBR design within the given general reactor design characteristics and can be used by any vendors or designers considering MC&A approaches for PBRs.

1.2.1 X-energy: Activities in FY21

In October 2020, X-energy was selected as one of two recipients for DOE's Advanced Reactor Demonstration Program (ARDP). The cooperative agreement between DOE and X-energy was signed on March 1, 2021. As part of that agreement, ORNL and Sandia National Laboratories (SNL) are partnering with X-energy on domestic safeguards and security. Since March 2021, efforts have focused on obtaining the appropriate nondisclosure agreements, work packages, and supplier agreements to support the work. No funding has been allocated from the ARDP to either national lab as of September 30, 2021.

Separate from the ARDP, technical consultations occurred throughout the year on burnup measurements, reactor modeling, and spent fuel plutonium declarations. These discussions were useful in informing the work and planning reflected in this report.

Discussions on the MC&A accounting system are expected in FY22 in parallel to the general efforts on this project. An MC&A accounting system does not yet exist in the marketplace for the PBR technology. Continued discussions on measurement and statistical methods to be used in accounting for the Pu production and U depletion in the spent fuel are also expected.

1.2.2 Kairos Power: Activities in FY21

The project met with Kairos Power on August 3–5, 2021, at the company's Alameda, California headquarters for working meetings related to MC&A approaches for PBRs. Topics included the following:

- Kairos Power fluoride salt-cooled high temperature reactor design overview
- Hermes plant layout
- General MC&A overview
- Testing lab tour
- NRC regulations overview
- Inventory flows and accounting
- Item vs. bulk accounting
- Core design
  - Pebble types
  - Composition over time
- Pebble handling and storage system
- Physical security design considerations
- Fresh and spent fuel handling and storage
- Waste handling

There were two objectives for these meetings. One was for the ARS program project team to better understand Kairos Power fluoride salt-cooled high temperature reactor and Hermes design and current needs at Kairos. The second was for the lab experts to provide additional background on work done to date at the national labs under this and other projects related to PBRs to assist their design team in understanding and provide contacts/resources that could be of assistance. These types of interactions are expected to continue into FY22.

1.2.3 National Laboratories

The project team continued coordination with the following national laboratories: SNL, Brookhaven National Laboratory, Argonne National Laboratory, and Idaho National Laboratory. Each national laboratory brings unique skills and experiences. In FY22, collaboration across the labs will continue as part of the ARS program.

2. FY21 FOCUS AREAS AND TASKS

2.1 FY21 OVERVIEW

In FY21, work focused on the impact of the use of high-assay low-enriched uranium (HALEU), as discussed in Section 2.2. Also in FY21, investigations continued on the implementation of 10 CFR 74 and the requirements for the Fundamental Nuclear Material Control (FNMC) plan, as discussed in Section 2.3. The project also looked at MC&A reporting and the impact of hundreds of thousands small objects at or below reportable quantities, as discussed in Section 2.4. Section 2.5 discusses MC&A approaches for fresh fuel receipts. Sections 2.6 discusses work done on the inventory approach for the reactor and fuel handling system. Section 2.7 provides examples of a burnup analysis based on the PBMR-400.

2.2 PBR SAFEGUARDS AND SECURITY CATEGORIZATION

In FY21, investigations continued about the impact that the use of HALEU will have on the PBR MC&A programs with the concern being the potential cost impact of additional requirements. Presentations were given on this topic during the April 2021 stakeholder's meeting for the ARS program, and this project participated in a panel discussion on the same topic during the American Nuclear Society June 2021 meetings.

As background, the categorization determines the requirements in 10 CFR 74 that the facility must meet during the MC&A licensing process. The emerging designs for PBRs will be Category II based on fuel enrichment (>10% and <20%) and quantities. LWRs are treated as Category III, which is a lower category, because of their lower enrichments.

Although not necessarily true for physical security, for MC&A, the most common conclusion to date is that the increase from Category III to Category II is not very significant because the MC&A requirements that change going from Category III to Category II are mainly inventory frequency and detection thresholds. Inventory frequency changes from annually to every 9 months, and detection thresholds are lower. Specifically on detection thresholds for Category II facilities, the NRC states that the licensee shall establish and maintain an item control program that can meet these requirements established in 10 CFR 74.43(b)(5):

> …be capable of detecting unauthorized removal of 200 grams or more of plutonium (Pu) or uranium-233 (U-233), or 300 grams or more of uranium-235 (U-235), as one or more whole items and/or as special nuclear material (SNM) removed from containers with high probability (typically defined as 95%).

As noted in the aforementioned ORNL report [1], these detection thresholds are likely easily achievable because of the dilute nature of the fuel and hence the large numbers of pebbles needed to obtain any significant quantity of SNM. Using the PBMR-400 as an example, this translates to a detection threshold of:

- 300 pebbles (^{235}U) for unirradiated pebbles with a gross weight approximately 80 kg or
- 1,000–2,000 pebbles (Pu) for irradiated pebbles with a gross weight over 500 kg. (There is some variability in published Pu content ranging from just over 0.1 to 0.2 g of Pu per pebble, depending on the burnup study referenced).

Recalling the capacity of the fresh fuel containers (Versa-Pac VP55 ~350 pebbles) and the spent fuel containers (~2,000 pebbles), these detection thresholds approach the level of an entire container.

2.2.1 What about Fuel Portability?

The portability of pebbles compared with LWR fuel assemblies was evaluated. Although the pebbles themselves are technically man-portable, for most of the SNM material flow at the reactor, design options exist for them to either be in containers or the reactor/fuel handling system where they would not be man-portable. For MC&A and security, the general rule in the case of closed containers of SNM pieces is that provisions should be made to assure that the removal of contents would be observable.

Therefore, there are only two likely material handling steps in which the pebbles become more susceptible to diversion because of their portability: the loading and unloading processes to and from the reactor. The unloading or spent fuel part of the process is probably subject to debate because it will be done remotely in a hot cell-type containment, and the fuel is highly radioactive at that point, making diversion even less credible.

For MC&A and security, addressing the fuel portability question focus should be directed to the material control features at the fresh fuel loading point in the process. Again, this is similar to the thinking used in LWRs during *reconstitution*, which is a term used to describe the process by which fuel assemblies are dissembled and modified (e.g., pin changes).

This fresh fuel loading transfer step is show in Figure 1 circled in red. Options for control could be multiple persons involved in the activity (e.g., two-person rule) or other means to confirm successful transfer of the pebbles from the VP55 through any intermediate steps (e.g., fuel conditioning) and into the reactor fuel handling system. Approaches for documentation for both MC&A and operations are analogous to approaches used in LWRs for reconstitution. The objective is an MC&A process that provides high confidence that no pebbles are stolen or diverted during this step, addressing the requirements established in 10 CFR 74.43(b)(5).

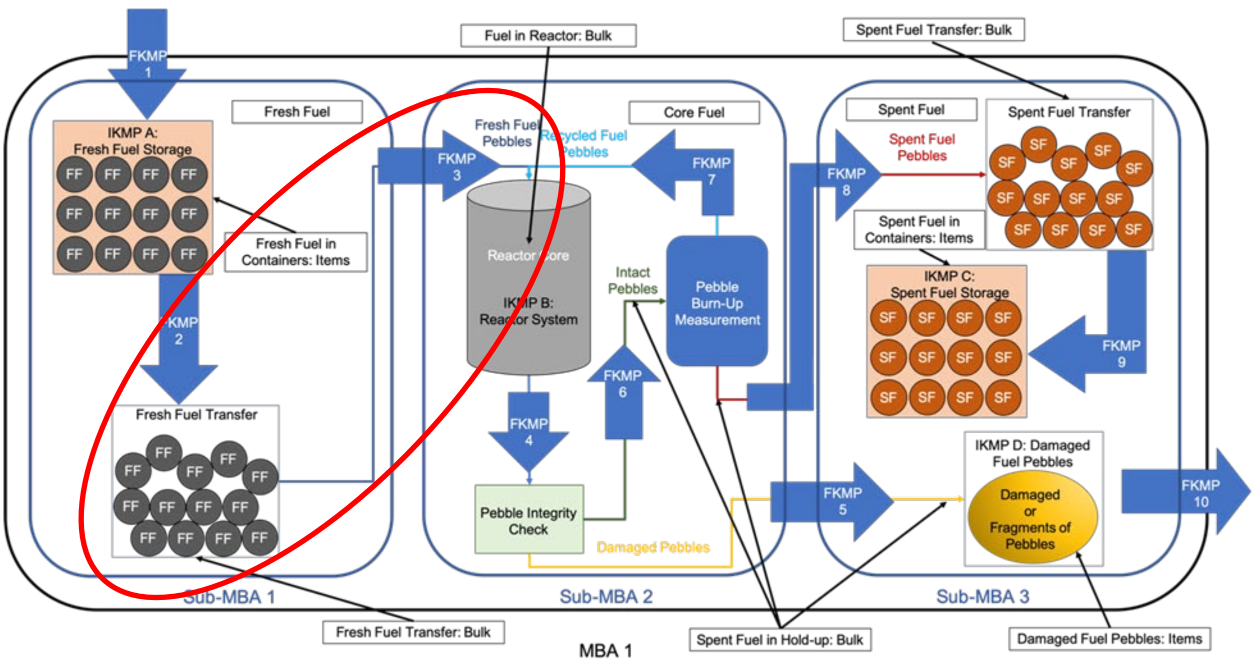

Figure 1. Process overview fuel portability.

2.2.2 Summary

For MC&A categorizing, a PBR at Category II is unlikely to result in overly burdensome additional MC&A requirements. The increased physical inventory frequency from annually to every 9 months given some thought to facility layout and the inventory approach (e.g., automation) can be minimal. The lower Category II detection thresholds are likely to be easily achievable because of the fuel diluteness and large numbers of pebbles it represents. Target quantities and volume are close to entire containers. MC&A material control focus is most needed at the point in the process in which the fuel will be transition from the fresh fuel container to the reactor fuel handling system. At that point, the portability represents the most credible location for potential theft or diversion. For other parts of the process where there are closed containers of SNM pieces, provisions should be made to assure that removal of contents would be observable.

2.3 FUNDAMENTAL NUCLEAR MATERIAL CONTROL PLAN

Another question is whether PBRs should be exempt from 10 CFR 74 Subparts D and E, like LWRs. The NRC has noted during several public meetings that this is unlikely because PBRs have aspects more like fuel cycle facilities and thus do not meet the intent behind this exemption, particularly in regard to the bulk nature of fuel handling for the reactor.

Instead of discussing whether the exemption should apply, it may be more useful to consider what really changes with respect to what must be done by the licensee in developing and documenting the PBR MC&A program. In reality, nothing changes because the overall scope and intent of an MC&A program is very consistent, regardless of the facility category or even at an LWR.

Also, whether or not the NRC has to approve the FNMC plan, even with LWRs during the NRC inspection the NRC reviews and assesses the adequacy of the MC&A program in meeting performance objectives established in 10 CFR 74.

2.3.1 FNMC Plan Comparison: How Different Are They Based on Facility Type or Category?

In September 2021, the NRC released Revision 1 of NUREG-2159 for public comment. NUREG-2159 [3], which is for Category II facilities, will likely be used for PBRs. Although there has been some anticipation about what would be in the document, MC&A plans are generally reasonably consistent in format, content, and intent across categories of material. It is not until Category I, the highest category, that there are significant additional requirements. As an illustration, Figure 2 shows content side by side to include ANSI N15.8-2009 [4], which is the template used in LWRs.

Current LWR Plan ANSI N15.8-2009	Category III SNM NUREG-1065	Category II SNM NUREG-2159	Category I SNM NUREG-1280
Organization Requirements MC&A Program	Management Structure	Management Structure	Management Structure
SNM Calculations	Measurements Measurement Control Statistics	Measurements Measurement Control Statistics	Measurements Measurement Control Statistics
Physical Inventory	Physical Inventories	Physical Inventories	Physical Inventories
Internal Control	Item Control	Item Control	Process Monitoring Item Monitoring Alarm Resolution Scrap Control
Input Control Output Control	Shipper-Receiver Comparisons	Shipper-Receiver Comparisons	Shipments and Receipts
Assessments	Assessments	Assessments	Assessments
Addressed in Internal Control	Tamper-Safing	Tamper-Safing	Tamper-Safing
Note: Implied	Resolving Anomalies Information to Assist in Recover	Resolving Anomalies Information to Assist in Recover	Resolving Anomalies Information to Assist in Recover
Addressed in Organization Requirements	Designation of MBAs, ICAs, and Custodians	*Addressed in Management Structure*	Designation of MBAs, ICAs, and Custodians
Records and Reports	Recording Keeping	Recording Keeping	Recording Keeping

Figure 2. FNMC plan comparison.

In Figure 2, the areas of the MC&A plan that are most likely to be different for PBRs with respect to LWRs are circled in red. These are also the areas in which they will behave more like fuel cycle facilities. These differences only apply to the reactor vessel and fuel handling system. Fresh and spent fuel (spent fuel containers – analogous to fuel assemblies) will be very much like LWRs in approaches and concepts. Figure 3 shows the process overview and inventory focus.

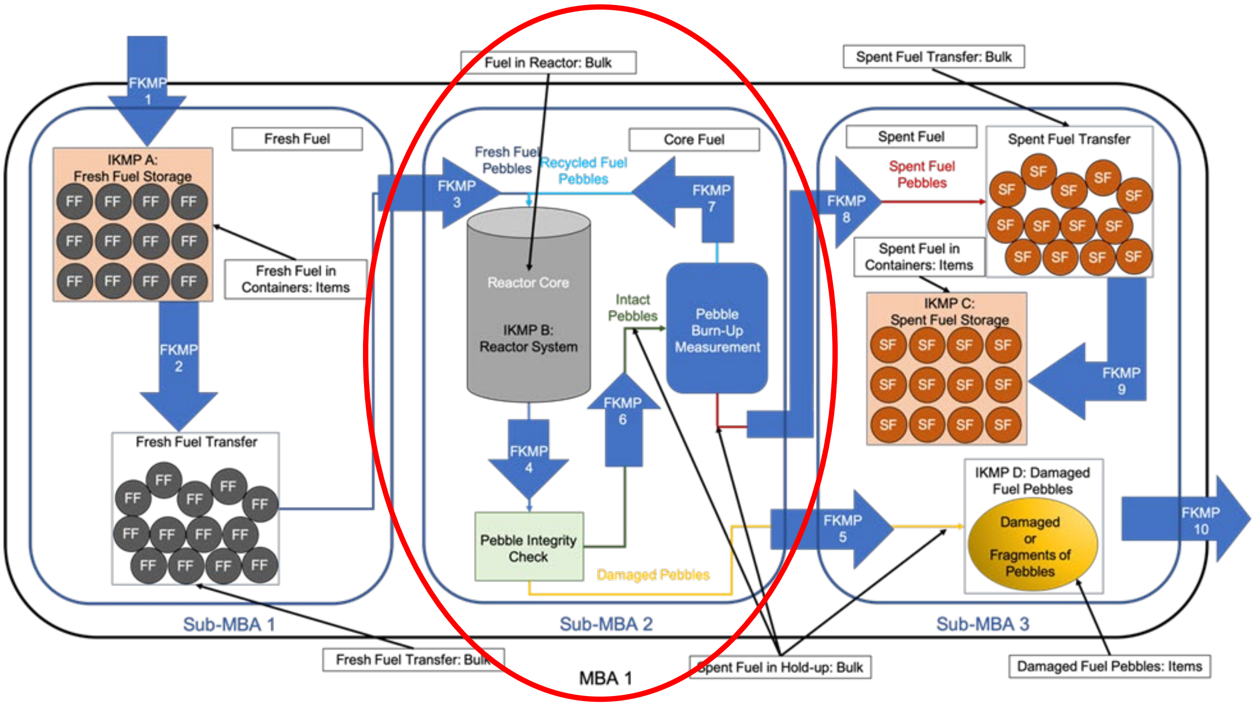

Figure 3. Process overview: inventory focus.

In FY22, this project will continue to focus on potential approaches that address the differences covering both inventory and statistical aspects. Based on discussions during FY21, if there were one recommendation that could be made regarding this area, it is in the interest of all (e.g., vendors, NRC, and DOE) to continue detailed discussions and work toward a consensus on approaches in this area. In most cases, designs in this area are still being developed; therefore, this is the optimum time to address the MC&A requirements, minimizing their impact and cost to operations.

2.4 MATERIAL ACCOUNTING AND ROUNDING CHALLENGES: REPORTING

PBRs have many discrete objects (i.e., pebbles) at small values, which will require special considerations designed into the MC&A accounting system to handle rounding for inventory and transaction reporting. This should not be construed as an issue for MC&A or security from a theft/diversion perspective because all work to date has focused on balancing around numbers of pebbles. It is simply an accounting and reporting nuance due to large numbers of small items that must be addressed for periodic MC&A reporting.

This becomes an issue in reporting to the Nuclear Materials Management and Safeguards System (NMMSS) because of reporting units (i.e., number of decimal places) and different methods of data grouping used inventory and transaction reporting. Appendix A discusses in more detail items that are considered in licensee MC&A systems for NMMSS reporting and applicable regulatory references.

2.4.1 Rounding Guidance for Reporting

Although many facility MC&A systems may—and many do—carry additional decimal places, for transaction and inventory reporting purposes to NMMSS, reporting units for enriched U and Pu are constrained to the nearest gram. Normal U is rounded to the nearest kilogram.

For both the NRC and DOE, the guidance for rounding is:

- quantities equal to or greater than 0.5 of the reporting unit are rounded up to the next whole reporting unit, and quantities less are rounded down; and

- transfers of multiple discrete items of 0.5 of a reporting unit or less but of the same material type (e.g., U, Pu) are typically summed to a total weight of that material type before applying rounding criteria. (This guidance is very applicable for handling the Pu content, which is very small.)

The following sections provide an overview of the types of differences that might be observed, depending on choices in grouping, rounding, and summing of nuclear material weights for MC&A reporting.

2.4.2 Uranium Example Using PBMR-400

Assuming that a loading 15,000 TRISO particle loading in a 15% enriched pebble and a reactor vessel containing 452,000 pebbles, gram quantities are shown in Table 1.

Table 1. Unrounded pebbles and reactor U values (grams).

	Unrounded Uranium in Pebble	Unrounded Uranium in Reactor
U234	0.012	5,424
U235	1.363	616,076
U236	0.006	2,712
U238	7.705	3,482,660
Total U	9.086	4,106,872

2.4.3 Rounding Based on Two Example Groupings: Pebble and VP55 Fresh Fuel Container (~350 Pebbles)

There are multiple groups that could be used to receive and transfer fuel into the reactor. For the example shown in Table 2, a single pebble and a VP55 (fresh fuel container) are compared to illustrate the impact of rounding and summing by these two potential groupings. The first column shows the actual U content in the reactor vessel. Rounding and summing at the pebble level are shown in the second column with the difference from actual show in the fourth column. Rounding and summing at the VP55 level are shown in the third column, and with the difference is shown in the fifth column.

Table 2. Rounding at various groupings and differences.

	Unrounded Uranium Numbers in Reactor	452000 Pebbles		1291.428571 VP55s	
		Rounded at the Pebble Level and summed	Rounded at VP55 Level and Summed by Reactor (~1292 VP55s)	Difference if rounded at Pebble Level	Difference if rounded at VP55 Level
U234	5,424	0	5,166	(5,424)	(258)
U235	616,076	445,000	616,011	(164,076)	(65)
U236	2,712	0	2,583	(2,712)	(129)
U238	3,482,660	3,616,000	3,482,983	133,340	323
Total U	4,106,872	4,068,000	4,106,743	(38,872)	(129)

Numbers in "(red)" indicate negative numbers

Although the differences are much smaller when rounding at the container level, any difference will result in a discrepancy to be resolved with NMMSS during the reconciliation process. This is due to how values are grouped and summed for reporting. Periodic rounding adjustments by the process outlined in NRC regulations will be necessary to balance licensee records with NMMSS.

2.4.4 Spent Fuel Containers and Plutonium Content

The difference becomes much more pronounced when the Pu content in the spent fuel is considered because of the small amount in each pebble, which is about 0.25 g. Using the PBMR-400 and assuming a burnup of 160 GWd/MTU and a spent fuel container of 2,000 pebbles, the differences are shown in Table 3. Individually, each pebble will round to zero. The total Pu content in the 2,000 pebble group rounded at the pebble level is zero; however, the actual content in the container is 484 g. Therefore, declaring Pu production and rounding at the spent fuel container level is a more reasonable and accurate approach.

Table 3. Pu rounding spent fuel.

	Unrounded Pu in a pebble (g)	Rounded at the pebble level and summed (g)	Rounded at the spent fuel container (g)
Pu238	0.006864	0	14
Pu239	0.08863	0	177
Pu240	0.06077	0	122
Pu241	0.04683	0	94
Pu242	0.03914	0	78
Total Pu	0.242234	0	484

2.4.5 Rounding Summary

Approaches to handle rounding adjustments are common in MC&A systems, especially fuel cycle facilities. Although not prevalent in LWRs, PBRs will behave more like fuel cycle facilities with respect to rounding. The basis and approach for rounding adjustments should be covered in the facility's FNMC plan, which should describe how rounding adjustments are captured within the MC&A accounting system and subsequently reported to NMMSS. Appendix A provides additional information on the NMMSS reporting process and types of groupings, physical and accounting, that will be encountered in PBRs.

2.5 FRESH FUEL CONTAINERS: INVENTORY AND RECEIPT VERIFICATION

X-energy and Kairos both plan to use fuel of varying enrichments, as well as graphite-only spheres. Visually, they cannot be distinguished from one another. The MC&A system must identify an approach that clearly distinguishes different levels of enrichments and also precludes non-SNM items from being mistaken for SNM items (Section 7.4 of ANSI N15.8-2009 [4]).

2.5.1 Fresh Fuel Container and Process

As reported last year, the main candidate for use as fresh fuel containers is the Versa-Pac VP55.* The VP55 is a specially configured 55 gal package for shipping uranium oxides, uranium metal, uranyl nitrate crystals, and other U compounds (e.g., uranium carbides, uranyl fluorides and uranyl carbonates, uranium hexafluoride in the special cylinders, and TRISO fuel). In this configuration, the VP55 would contain

* https://rampac.energy.gov/docs/default-source/certificates/1039342.pdf

approximately 350 pebbles with a total heavy metal (U) weight of 3 kg and a fissile content of less than 400 g ^{235}U. Some key design characteristics are shown in Figure 4.

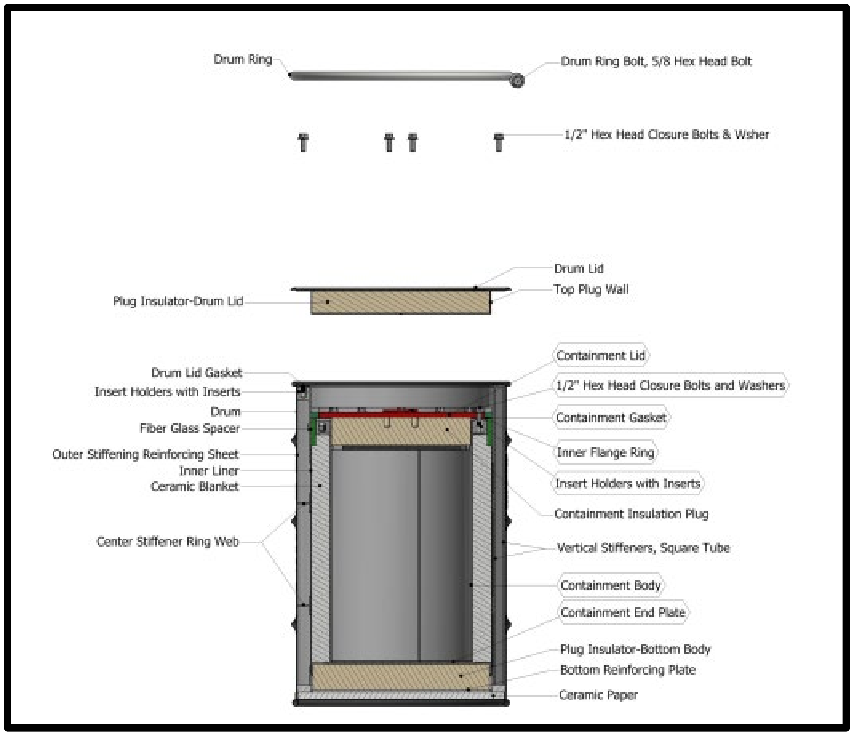

Figure 4. Versa-Pac VP55 fresh fuel container.

Each container is assumed to be sealed after it is filled with fuel spheres and before shipment from the fuel fabrication facility to the reactor. Once the containers are received at the reactor, they are placed into the fresh fuel storage area in an operating facility. The loaded and sealed VP55 containers are shown in Figure 5.

Figure 5. VP55 containers loaded and sealed.

2.5.2 MC&A Approach: Fresh Fuel

The MC&A approach for fresh fuel is not difficult and has numerous existing acceptable parallels within other types of facilities. As noted in Section 2.2, the general rule is that provisions should be made for closed containers of SNM pieces to assure that the removal of contents would be observable. Again, based on the diluteness of the SNM in the pebble, 10 CFR 74 required detection thresholds for Category II approach an entire VP55 container that would have to be compromised.

In addition to this general concept, during the licensing process, the NRC looks at how the following areas are addressed in the FNMC plan and operating procedures:

- Current knowledge of items: 10 CFR 74.43(b)(5)(i) and 10 CFR 74.43(c)(1)
- Tamper-safing: 10 CFR 74.43(c)(3)
- Receipt, shipment, and transfer of SNM: 10 CFR 74.43(c)(2)
- Item storage and handling: 10 CFR 74.43(b)(5)(ii)
- Item monitoring: 10 CFR 74.43(b)(5)(ii)

Particular to VP55s for PBRs is the fact that there will be containers of differing enrichments and non-SNM (i.e., moderator) pebbles. Handling and inventory procedures should clearly state how these are identified, stored, and managed for operations and inventory.

Receipt verification is also straightforward with several potential options shown from easiest to more difficult, which include:

- verifying the container and tamper-indicating device's (TID) serial number;
- opening the container and counting the pebbles;
- opening the container, counting the pebbles, and measuring a sample; and
- opening the container and individually measuring each pebble.

The first, least rigorous option is defined as "unopened receipts" in 10 CFR 74, which states: "Unopened receipts means receipts not opened by the licensee, including receipts of sealed sources, and receipts opened only for sampling and subsequently maintained under tamper-safing."

If there is high confidence in the transfer process, then an acceptable MC&A approach would be the first option, which includes confirming the container's and TID's serial number and inspecting the tamper-safing upon receipt and for inventory. This may be coupled with a weight measurement or quick enrichment measurement to confirm differing enrichments and non-SNM bearing containers.

High confidence means that no credible diversion strategies during transfer and storage processes were identified. This term also assumes that the processes implemented by the fuel fabricator and reactor operator for transfers and receipts have a low probability of discrepancies, which would affect MC&A, operations, and safety.

If gross weight and the container/tamper-indicating device's serial number verification are used for verification, then the numbers of pebbles and the SNM content within those pebbles would be placed into inventory based on the shipper's values and maintained until the container is opened for the fuel pebbles to be fed into the reactor.

This approach may be acceptable even for cases that have low confidence in the transfer process and fresh fuel with a short residence time in the receipt area. This is because opening the container for fuel loading shortly after receipt provides another potentially equally acceptable opportunity for verifying the SNM received within acceptable time lines for loss detection.

For cases with lower confidence from either credible diversion scenarios or performance violations in the transfer and storage processes, additional rigor in receipt and inventory checks may be warranted. These efforts could range from random sampling of containers and application of independent measurements up to 100% verification. This is not an ideal approach because of the labor-intensive nature of these checks,

2.6 PHYSICAL INVENTORY OF REACTOR VESSEL

Investigations continued on physical inventory approaches for the reactor vessel. Last year, the project hoped focus on more detail in this area. However, because of COVID-19 restrictions and because vendors are still in early design and testing of the fuel handling systems, no investigations were in detail. Therefore, there has not been convergence on a physical inventory approach for the reactor vessel.

Remaining work for both operational and MC&A performance considerations include establishing performance criteria for the pebble counting/indexing systems and discussing how core monitoring could be used to inform MC&A. Both will be part of the licensing reviews as vendors and the NRC review approaches proposed to monitor the core inventory.

This is also an integration point with safety because the reactor core fissile material inventory directly impacts reactivity, and monitoring reactivity is a primary safety function. Regulatory Guide 1.2325 (ML17325A611), Advanced Reactor Design Criterion 13, “Instrumentation and control,” requires monitoring of the reactor core [5].

From an MC&A perspective, this is the most challenging—although not necessarily the most difficult—aspect of PBR technology. This is the part of the process in which a PBR diverges from approaches used in LWRs and behaves more like fuel cycle facilities.

Although a convergence on an approach has not occurred yet, work on technical aspects that will inform an approach was performed in FY21. For example, modeling and statistical analyses for burnup and production in a spent pebble based on likely pathways through the reactor were completed for the PBMR-400 and Xe-100. The results for the PBMR-400 are provided in Section 2.7. The Xe-100 analysis, which is not included in this report, was performed under a nondisclosure agreement between X-energy and ORNL.

Using this analysis, FY22 plans include developing example statistical approaches that could be used to monitor the actual vs. expected fissile content in the spent fuel. Monitoring this could inform both operations and MC&A that the reactor is operating normally. These processes are what would be documented in the FNMC plan and facility procedures and are integration points with operations, safety, and MC&A.

2.6.1 Other Potentially Useful Studies

Other potential items to be considered that would support both domestic and international safeguards are sensitivity studies on changes in core composition. For example, for the South African Pebble Bed Modular Reactor design [6], a sensitivity study was performed to detect fertile targets inserted for a single pass in the core.

This study assessed the effect of introducing target pebbles loaded with natural U particles to normal fuel. Target pebbles were loaded and mixed with the fuel pebbles to obtain a homogenous distribution in the core. Calculations were performed for two densities of target pebbles: one that represents an additional U mass of 0.1% (in natural U) to the total enriched U mass of the fuel core and one that represents an additional mass of 0.4%. The added natural U increases the number of neutron captures in the core, which must be compensated by increasing the number of normal fuel pebbles added every day—and, consequently, sending the same increased number of spent fuel pebbles in a spent fuel bin—to keep the same reactivity margin as in the initial core so that it could continue operation sustainably.

The result of the calculation was that the daily number of fresh fuel pebbles must be increased by 21% in the first case and by 95% in the second case. Moreover, the quantity of Pu produced in the target pebbles was very low. In the first case, it would take 92 years to achieve significant quantity, and in the second case, it would take 23 years.

This is another example of the kind of study that shows how the introduction of target pebbles would be easily detected by the fresh fuel consumption. There would also be abnormal signals for the core flux and burnup measurements, but their sensitivity was not determined in this study. However, the PBR core flux would be very sensitive to changes in fuel composition and feed rates, and process monitoring of the reactor power levels and fuel pebble feed rates could inform MC&A and security.

2.7 BURNUP ANALYSIS CALCULATIONS BASED ON PBMR-400

To estimate the isotopic compositions in discharged pebbles to assist MC&A analysis at ORNL and burnup measurement analysis at SNL and others, burnup analysis calculations were performed in this work based on PBMR-400 because of its publicly available reactor design and operation information [7]. For a typical burnup analysis calculation, the required input includes (1) the initial fuel mass and composition, (2) the irradiation neutron spectra, (3) the irradiation power, (4) the final burnup value, and (5) the cooling time after the fuel is finally discharged. The final burnup value is a product of irradiation power and irradiation time. In this work, each pebble was assumed to contain 15,000 TRISO particles [7], each of which had a kernel diameter of 500 μm. The kernel was assumed to be filled with UO_2 with 15 wt% ^{235}U enrichment, which amounts to 9.09 g of U in each fresh pebble. The final burnup was assumed to be 160 GWd/MTU. The irradiation power was assumed to be 97.4 W/gU, which was derived from PBMR-400 core power and total fuel pebble loading [7]. The cooling time is specified later in this section.

In regard to the irradiation neutron spectra, this work leveraged the work performed by Skutnik et al. [8] at ORNL that modeled the PBMR-400 in detail using SCALE [9] for reactor physics studies. Figure 6 shows the 3D SCALE model for the PBMR-400 reactor [8]. The fuel compositions used in this model were for equilibrium-core fuel compositions specified in the ND-Set3 [7]. An equilibrium core is when a reactor core reaches a condition in which the average fuel compositions remain largely the same from one cycle to another; therefore, based on equilibrium core fuel compositions, this model can provide neutron spectra that are representative to the fuel cycle of PBMR-400. Note the center graphite reflector, the annular core filled with pebbles, and the side graphite reflector included in the model. Figure 2 shows the fast-to-thermal neutron flux spectral ratios of five radial zones (RZs), indicated by their distances from the core center, for the equilibrium core as functions of the core elevation. The divisions of the five RZs are made consistent with what were used in Ref. [7], and they are used only to facilitate analysis because there are no physical barriers between two adjacent zones. The higher the ratio, the harder the spectrum is considered to be. Harder spectra usually lead to greater accumulations of transuranic nuclides, including Pu under irradiation. As shown, the RZs 100–110 cm and 161–185 cm have the softest neutron spectra (i.e., lowest fast-to-thermal ratio) because of their proximities to either the center or side graphite reflectors shown in Figure 6 because graphite is a neutron moderator and thus turns fast neutrons into thermal neutrons. RZ 127–144 cm has the hardest neutron spectrum because it is farthest away from both reflectors. The remaining two RZ have relatively hard spectra compared with the two zones that are adjacent to the reflectors. Given the known influence of neutron spectra on the isotopic accumulations in fuel under irradiation, it is important to consider the variations of neutron spectra among the RZs. As to the axial variation of the neutron spectra, the spectra around the mid-height of the core are near the average spectra for each RZ.

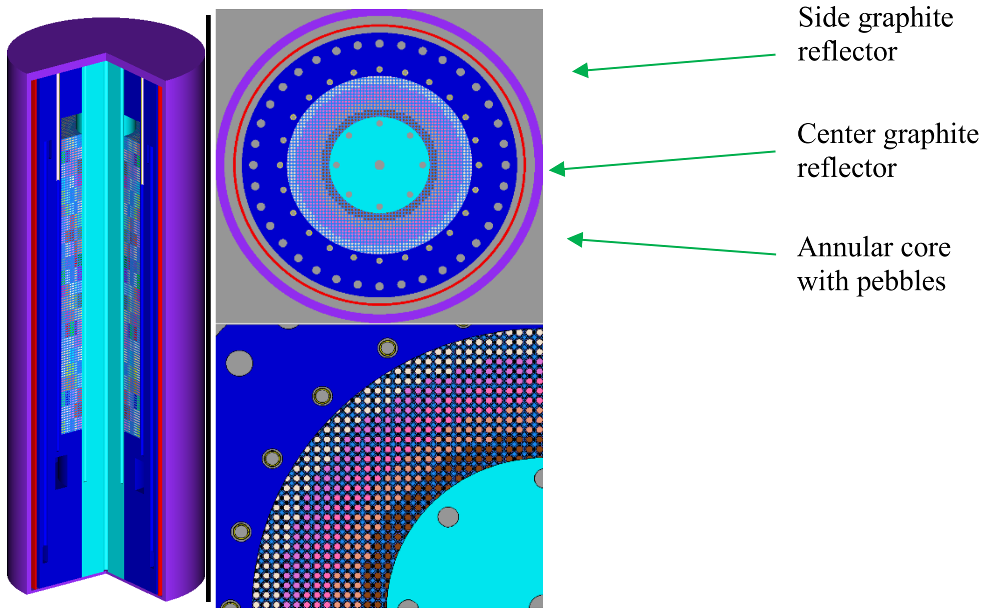

Figure 6. SCALE model for the PBMR-400 equilibrium-composition core [2]: (left) axial cutaway view and (right) horizontal cut plane view at *z* = 100 cm.

To accurately calculate the isotopic composition in a particular discharged pebble, the exact route this pebble has traveled through the core in its multiple passes (e.g., going different RZs at various core elevations) must be known. However, such information is usually unavailable because the pebbles were not individually tracked in a PBR fuel cycle. The goal of this project is not to calculate the exact isotopic composition of a particular pebble but rather to identify the range of the isotopic compositions, especially the Pu quantities, for a typical discharged pebble after it reach Radial zone (RZ) erefore, the isotopic compositions of five representative pebbles were calculated in this work, and each pebble was assumed to go through multiple passes through each of the five RZs until the specified final burnup (i.e., 160 GWd/MTU) is reached. For example, pebble 1 is assumed to always go through RZ1 in the core. The neutron spectra from each of the five RZs shown in Figure 7, together with relevant information described in the beginning of this section, were used in each of the SCALE/ORIGEN [9] calculations to calculate the isotopic compositions for each of the five representative pebbles.

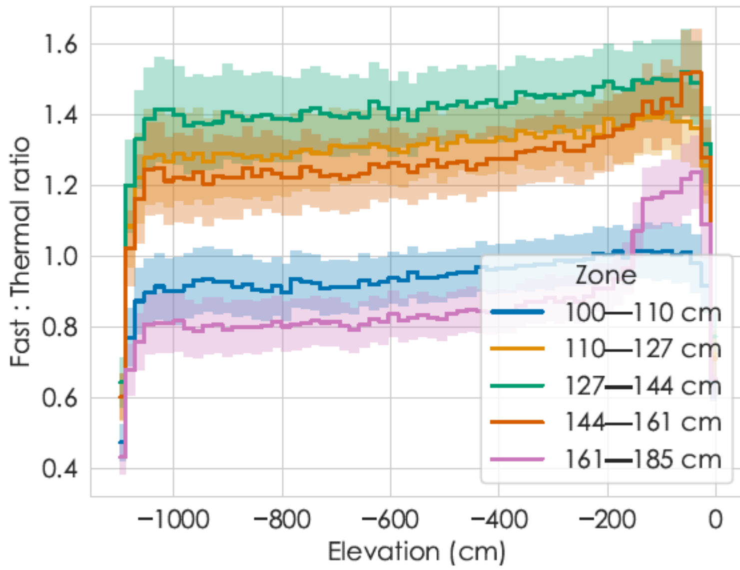

Figure 7. Spectral ratio (fast: thermal flux) for the equilibrium-composition core along the elevation of the core [2]. The thermal-fast boundary is defined at $E = 1.86$ eV. $z = 0$ cm indicates the top of the active fuel zone.

Table 4 shows the U isotopic compositions, in the unit of grams per pebble, in a fresh pebble and in the five representative discharged pebbles. The mean and standard deviation of the U isotope masses among the five pebbles from the different RZs are also included. The U isotope masses in the fresh pebble were calculated based on the assumption that each pebble contains 15,000 TRISO particles with UO_2 kernels of 500 µm in diameter and that the ^{235}U enrichment was 15 wt %. In reality, each pebble may contain a different number of TRISO particles, and the characteristics of the particles may vary from one to another. Information on such variations is unavailable to this project, and the impacts of such variations on the final Pu inventory can be assessed in the future when the relevant information becomes available. The U isotopic masses in the discharged pebbles were calculated based on the assumptions that each of the five pebbles reached a final burnup of 160 GWd/MTU and that the cooling time was 0 immediately after being discharged from the core. ^{235}U has higher fission and absorption cross sections in a softer neutron spectrum, whereas ^{238}U has higher fission and absorption cross sections in a harder neutron spectrum. Such cross section characteristics can explain why there were less ^{235}U and more ^{238}U in RZ1 and RZ5 than in the other three RZs, given that RZ1 and RZ5 had softer neutron spectra than others (Figure 7). On average, there are approximately 0.25, 6.87, and 7.31 g total of ^{235}U, ^{238}U, and U, respectively, remaining in a discharged pebble with an initial enrichment of 15% and a burnup of 160 GWd/MTU.

Table 4. U isotopic compositions (grams per pebble) of a fresh pebble with 15% ^{235}U enrichment and of five discharged pebbles irradiated in five different RZs with a final burnup of 160 GWd/MTU. The mean and standard deviation among the five pebbles are also included.

Isotope	Fresh pebble (g/pebble)	Discharged pebble with a burnup of 160 GWd/MTU (g/pebble)						
		RZ1	RZ2	RZ3	RZ4	RZ5	Mean	Std. dev.
^{234}U	0.0121	0.0072	0.0072	0.0072	0.0072	0.0072	0.0072	1.96E-06
^{235}U	1.3630	0.2386	0.2614	0.2668	0.2615	0.2423	0.2541	0.0114
^{236}U	0.0063	0.1797	0.1779	0.1774	0.1778	0.1794	0.1784	0.0009
^{238}U	7.7052	6.8940	6.8570	6.8480	6.8570	6.8880	6.8688	0.0185
U total	9.0866	7.3195	7.3035	7.2994	7.3035	7.3169	7.3085	0.0081

Table 5 shows the Pu isotopic compositions, in the unit of grams per pebble, of the five representative discharged pebbles. The mean and standard deviation of the Pu isotope masses among the five pebbles are also included. Greater Pu isotopic accumulations are generally expected in harder neutron spectra mainly because of higher ^{238}U absorption cross sections in harder neutron spectra, which explains why there were higher Pu isotopic masses in RZ2, RZ3, and RZ4 than in the other two RZs, given that the neutron spectra were harder in RZ2, RZ3, and RZ4 (Figure 6). On average, there are approximately 0.089, 0.061, and 0.24 g total of ^{239}Pu, ^{240}Pu, and Pu, respectively, remaining in a discharged pebble with an initial enrichment of 15% and a burnup of 160 GWd/MTU. Figure 3 visualizes the Pu mass values contained in Table 5. These calculations were performed based on the assumptions that each of the five pebbles reached an exact final burnup of 160 GWd/MTU. In reality, discharged pebbles may have different final burnups than each other because a pebble's burnup accumulated during its final pass through the core will vary, depending on the exact route it takes, assuming its burnup from a previous pass was determined to be below certain safety threshold by the burnup measurement system. The impact of such variations on the Pu quantities is recommended for future investigation when the relevant information becomes available.

Table 5. Pu isotopic compositions (grams per pebble) of five discharged pebbles irradiated in five different RZs with a final burnup of 160 GWd/MTU. The mean and standard deviation of Pu isotopic masses among the five pebbles are also included.

Isotope	RZ1	RZ2	RZ3	RZ4	RZ5	Mean	Std. dev.
^{238}Pu	0.0067	0.0069	0.0070	0.0069	0.0067	0.0069	0.0001
^{239}Pu	0.0824	0.0916	0.0938	0.0916	0.0838	0.0886	0.0046
^{240}Pu	0.0599	0.0613	0.0615	0.0612	0.0600	0.0608	0.0007
^{241}Pu	0.0437	0.0483	0.0494	0.0483	0.0444	0.0468	0.0023
^{242}Pu	0.0387	0.0394	0.0395	0.0394	0.0388	0.0391	0.0004
Pu total	0.2247	0.2405	0.2443	0.2404	0.2270	**0.2354**	**0.0079**

Table 6 shows the mean and standard deviation values of Pu mass in two hypothesized discharged pebble containers, one of which contains 2,000 pebbles and the other of which contains 10,000 pebbles. The mean values for the containers were based on the mean "Pu total" value for a pebble shown in Table 4, and the standard deviation values for the containers were derived using uncertainty propagation methods based on the Pu variation in a pebble among the five different RZs shown in Table 4. On average, a 2,000 pebble container is estimated to contain 471 g of Pu with a standard deviation of 0.36 g, whereas a 10,000 pebble container is estimated to contain 2,354 g of Pu with a standard deviation of 0.79 g. The last column of Table 5 shows the percentage of 2 standard deviations in the mean Pu mass. The Pu variation results shown here considered only the impacts of different neutron spectra found in the five possible RZs. Other uncertainties—for example, the variations in the initial isotopic mass in a fresh pebble and the variations in final burnups among the discharged pebbles, as well as variation in the measurement accuracy of the burnup—will also affect the Pu quantities in a container. It is recommended that such impacts be investigated when the necessary information becomes available to perform such assessments. Figure 8 shows the Pu isotopic compositions of five discharged pebbles irradiated in five different RZs with a final burnup of 160 GWd/MTU and the mean values among the five pebbles.

Table 6. The mean and standard deviation values of Pu total mass in two hypothesized discharged pebble containers.

Number of pebbles	Mean (g)	Std. dev. (g)	2 std. dev. (%)
2,000	470.73	0.36	0.15
10,000	2353.66	0.79	0.07

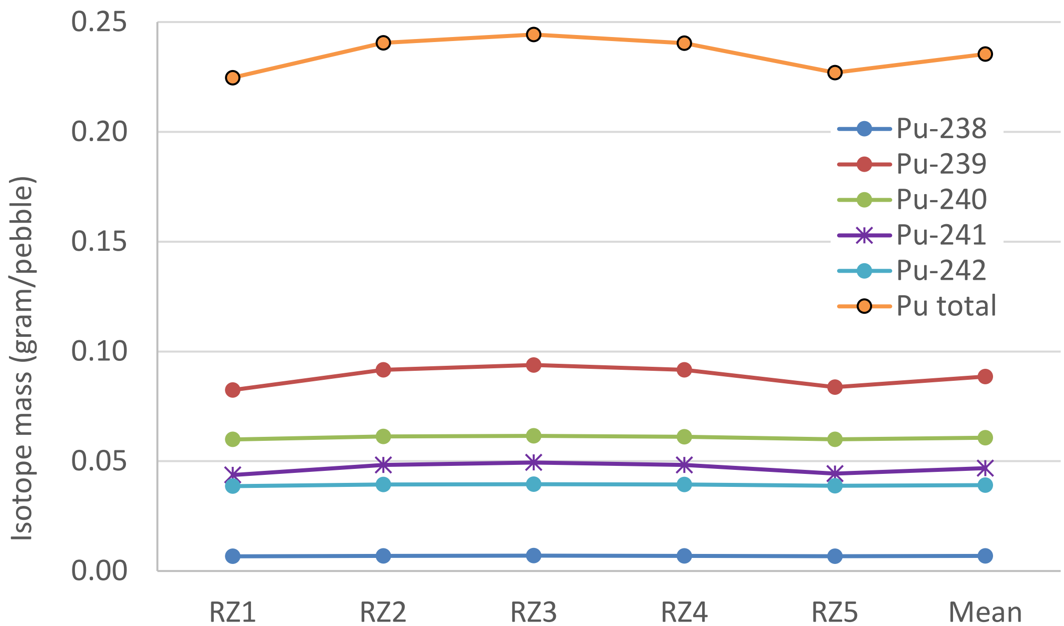

Figure 8. Pu isotopic compositions (grams per pebble) of five discharged pebbles irradiated in five different RZs with a final burnup of 160 GWd/MTU and the mean values among the five pebbles.

Appendix B includes two tables of nuclide masses at 13 different cooling times (from 0 to 30 days) in a discharged pebble. The neutron spectrum from RZ1 (110–127 cm) was used for this set of calculations because the spectrum from RZ1 is close to the core average. Table B-1 shows the results for a pebble with a final burnup of 80 GWd/MTU, and Table B-2 shows the results for 160 GWd/MTU. Both tables contain a full list of nuclides and were transmitted to SNL and other labs to assist detailed burnup measurement analysis.

3. FY22 WORK PLANS

Efforts in FY22 will continue to focus on work with industry, which is crucial for understanding and applying MC&A approaches to PBRs. Work will continue with X-energy under this project balanced with efforts on the ARDP scope, which includes ORNL and SNL. The partnership with Kairos Power is expanding with help from the 3 day technical exchange at the company's Alameda headquarters in August 2021. The project team will continue to work with other national laboratories.

Emerging from the FY20 and FY21 analysis was the overlap with physical protection based on the facility layout and implementation of remote handling, all of which would affect or complement the MC&A approaches for item control. In FY22, the project will further explore this interface with industry and a project being done at SNL for the security posture of a PBR, which will focus on the vulnerability for man-portable fuel and PBR vital areas regarding, theft, sabotage, diversion, and misuse.

The project will continue its investigation on the use of pebble stream average for declared U depletion and Pu production in spent pebbles. In FY21, the project determined likely distributions for a PBMR-400 and Xe-100 (proprietary). Using the stream average integrated with a measurement and statistical approach to monitor the average/variation will likely provide the simplest and most accurate approach for material accounting in spent fuel containers.

The project will develop generic functional requirements for a PBR MC&A system that outlines the approaches needed to report multiple material types/enrichments (e.g., normal U, enriched U, Pu) and rounding caused by hundreds of thousands small items to support system development and licensing under 10 CFR 74.

In FY22, work will continue on measurement systems in general. This includes following work on burnup measurements being conducted by other entities to understand its effect on declarations. It also will expand to possible confirmatory measurements for both the receipts of fresh fuel and spent fuel containers. Measurements for fresh fuel will address requirements for confirming shipper information, properly segregating nuclear material of differing material types or enrichments for material control and inventory, and segregating nonnuclear (moderator pebbles) from nuclear bearing pebbles.

4. REFERENCES

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[5] Nuclear Regulatory Commission (NRC), “Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors” ADAMS ML17325A611, April 2018.

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[7] Nuclear Science Committee, Nuclear Energy Agency (NEA), "PBMR Coupled Neutronics / Thermalhydraulics Transient Benchmark The PBMR-400 Core Design, vol. 1: The Benchmark Definition," NEA/NSC/DOC(2013)10, Paris, France, 2013.

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APPENDIX A. NMMSS RECONCILIATION PROCESS OVERVIEW

This appendix provides more information for the discussion on rounding covered in Section 2.4. It provides a brief overview of the NMMSS reconciliation process and a discussion of the types of groupings likely to occur within a PBR for inventory and reporting.

Periodically, licensee nuclear material records are compared and reconciled with NMMSS by SNM quantity and material type (e.g., enriched U, normal U, and Pu). This reconciliation is organized by material type and various subgroupings of interest within material type. Values must match gram for gram or kilogram for kilogram in transactions and inventory. Discrepancies between a licensee's records and NMMSS are corrected during the reconciliation process.

The reporting and reconciliation process is as follows.

- Transactions during a material balance period are reported to NMMSS per the instructions in NUREG/BR-0006, Rev. 9, on DOE/NRC Forms 741 and 740M. From these reports, NMMSS will generate an independent running balance for the facility (e.g., beginning inventory + receipts – removals = ending inventory).

- Inventory is reported to NMMSS at the end of the material balance period. The facility will submit Forms 742, *Material Balance Report*, and Forms 742C, *Physical Inventory Listing*, to NMMSS, which represent the facility's inventory.

- The facility's declared inventory as reported will be compared with the NMMSS running inventory balance.

- Discrepancies will be resolved through additional or correcting transactions used to update NMMSS or facility records.

Again, based on how groupings are used in the reporting and inventory process and how those groups are summed and rounded, there will be small differences between NMMSS and the facility for PBRs that must be resolved through this process.

Groupings in a PBR

Although the total U content in the core can be calculated based on the number pebbles and U loading per pebble, it arrives at the site and goes into/out of the core via a group captured in an MC&A transaction. Therefore, how transactions are grouped and summed will determine what type of rounding bias will occur and their magnitude.

Several types of groupings will occur in a PBR for MC&A from a physical perspective and a reporting perspective.

Example physical groupings and estimated numbers of pebbles in each group are as follows.

- Discreet pebbles: This is the smallest integral object within a PBR at one pebble.

- VP55 fresh fuel container: The VP55 is the current certified shipping container for pebbles. It will hold around 350 fresh fuel pebbles.

- Truck: There are projected to be 71 VP55s per truck. At 350 pebbles/VP55, that equals 24,850 pebbles per truck. Note that there could be multiple trucks in a single shipment; this example considers only one truck for illustration purposes.

- PBMR-400 reactor vessel: The reactor vessel holds around 452,000 pebbles, which is equal to 1,808 VP55s, or just over 25 trucks.

- Daily fuel usage: 490 pebbles per day, or 1.4 VP55s

- Spent fuel container: Current designs hold around 2,000 pebbles.

Example groupings for reporting to the NMMSS that will occur in a PBR are as follows.

- Material type: Two-digit code to identify the nuclide being reported. There will likely be three codes used in PBRs, which are:
    - 20 or E2 (U in enrichment of 5% or more but less than 20%)
    - 50: Pu (predominantly ^{239}Pu)
    - 81: Normal U
- COMP/FAC (composition/facility) code: Three-digit code describing the material and/or process location. There will likely be four codes used in PBRs, which are:
    - 860: In reactors and critical assemblies
    - 861: In cooling basins (spent pebbles)
    - 864: Materials not in process (fresh fuel)
    - 865: Unirradiated scrap awaiting recovery (applies to loose pellets in LWR but could apply to broken pebbles)
- Other groupings
    - Other potential groups might include owner codes and material with different reporting obligations, depending upon material origin.

In summary, Section 2.4 discusses a few examples that show how the small rounding discrepancies will likely occur in a PBR for inventory and reporting purposes. This appendix provides additional detail on the reporting process and the types of groupings—physical and reporting—that will be present in PBRs. Instructions for reporting to NMMSS can be found in NUREG/BR-0006, Rev. 9, and NUREG/BR-0007, Rev. 8. Licensee MC&A systems will be required to report SNM inventories to NMMSS per the requirements in 10 CFR Part 74 based on these instructions.

References:

US NRC, *Instructions for the Completing Nuclear Material Transaction Reports* (DOE/NRC Forms 741 and 740M), US Nuclear Regulatory Commission, NUREG/BR-0006, Rev. 9, 2020.

US NRC, *Instructions for the Preparation and Distribution of Material Status Reports* (DOE/NRC Forms 742 and 742C), US Nuclear Regulatory Commission, NUREG/BR-0007, Rev. 8, 2019.

APPENDIX B. PBMR 400 CALCULATIONS

Table B-1. Nuclide masses (grams per pebble) in a pebble with a discharged burnup of 80 GWd/MTU as a function of cooling time.

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5 h**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
he-4	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.10E-05	7.11E-05	7.12E-05	7.14E-05
be-9	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05
c-12	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02
c-13	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00
c-14	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06	4.55E-06
o-16	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00
o-17	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04
o-18	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03
si-28	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00
si-29	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.16E-01
si-30	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02
p-31	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05
u-234	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03	9.61E-03
u-235	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01	6.73E-01
u-236	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01
u-237	1.18E-04	1.18E-04	1.18E-04	1.18E-04	1.18E-04	1.18E-04	1.16E-04	1.13E-04	1.07E-04	8.68E-05	5.75E-05	2.53E-05	5.42E-06
u-238	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00	7.33E+00
u-239	1.17E-05	1.16E-05	1.14E-05	8.74E-06	4.84E-06	1.99E-06	1.65E-09	2.32E-13	3.84E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
np-237	4.37E-03	4.37E-03	4.37E-03	4.37E-03	4.37E-03	4.37E-03	4.37E-03	4.37E-03	4.38E-03	4.40E-03	4.43E-03	4.46E-03	4.48E-03
np-238	9.10E-06	9.10E-06	9.10E-06	9.08E-06	9.04E-06	8.98E-06	8.50E-06	7.94E-06	6.56E-06	3.41E-06	9.20E-07	6.70E-08	4.95E-10
np-239	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.68E-03	1.60E-03	1.51E-03	1.27E-03	7.05E-04	2.17E-04	2.07E-05	2.51E-07
pu-238	8.91E-04	8.91E-04	8.91E-04	8.91E-04	8.91E-04	8.91E-04	8.92E-04	8.92E-04	8.94E-04	8.99E-04	9.04E-04	9.11E-04	9.21E-04
pu-239	9.52E-02	9.52E-02	9.52E-02	9.53E-02	9.53E-02	9.53E-02	9.54E-02	9.54E-02	9.57E-02	9.62E-02	9.67E-02	9.69E-02	9.70E-02
pu-240	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02	4.99E-02
pu-241	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.75E-02	2.74E-02
pu-242	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03	6.99E-03
am-241	6.37E-04	6.37E-04	6.37E-04	6.37E-04	6.37E-04	6.37E-04	6.38E-04	6.38E-04	6.40E-04	6.48E-04	6.62E-04	6.91E-04	7.46E-04
am-242m	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05
am-243	4.19E-04	4.19E-04	4.19E-04	4.19E-04	4.19E-04	4.19E-04	4.19E-04	4.19E-04	4.20E-04	4.20E-04	4.20E-04	4.20E-04	4.20E-04
cm-242	1.84E-04	1.84E-04	1.84E-04	1.84E-04	1.84E-04	1.84E-04	1.84E-04	1.84E-04	1.84E-04	1.83E-04	1.80E-04	1.74E-04	1.63E-04
cm-244	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.03E-05	4.02E-05
as-75	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06	2.69E-06
ge-76	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06	7.43E-06
se-77	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.86E-05	1.87E-05	1.87E-05	1.87E-05

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5 h**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
se-78	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05	5.17E-05
se-79	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04	1.11E-04
se-80	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04	3.08E-04
br-81	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04	5.09E-04
se-82	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04	7.92E-04
kr-82	5.32E-06	5.32E-06	5.32E-06	5.32E-06	5.32E-06	5.32E-06	5.32E-06	5.33E-06	5.33E-06	5.34E-06	5.35E-06	5.35E-06	5.35E-06
kr-83	1.12E-03	1.12E-03	1.12E-03	1.12E-03	1.12E-03	1.12E-03	1.12E-03	1.13E-03	1.13E-03	1.13E-03	1.13E-03	1.13E-03	1.13E-03
kr-84	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03	2.51E-03
kr-85	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.25E-04	6.24E-04	6.22E-04
rb-85	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.47E-03	2.48E-03
kr-86	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03	4.62E-03
sr-86	2.86E-06	2.86E-06	2.86E-06	2.86E-06	2.86E-06	2.86E-06	2.86E-06	2.86E-06	2.86E-06	2.88E-06	2.90E-06	2.94E-06	2.99E-06
rb-87	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03	6.10E-03
sr-88	8.56E-03	8.56E-03	8.56E-03	8.56E-03	8.56E-03	8.56E-03	8.57E-03	8.57E-03	8.57E-03	8.57E-03	8.57E-03	8.57E-03	8.57E-03
sr-89	8.95E-04	8.95E-04	8.95E-04	8.95E-04	8.95E-04	8.95E-04	8.93E-04	8.90E-04	8.83E-04	8.59E-04	8.13E-04	7.29E-04	5.93E-04
y-89	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.06E-02	1.07E-02	1.07E-02	1.09E-02
sr-90	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02	1.37E-02
y-90	3.56E-06	3.56E-06	3.56E-06	3.56E-06	3.56E-06	3.55E-06	3.55E-06	3.55E-06	3.54E-06	3.52E-06	3.50E-06	3.48E-06	3.48E-06
zr-90	4.02E-04	4.02E-04	4.02E-04	4.02E-04	4.02E-04	4.02E-04	4.02E-04	4.02E-04	4.03E-04	4.05E-04	4.08E-04	4.16E-04	4.29E-04
sr-91	9.00E-06	9.00E-06	8.99E-06	8.91E-06	8.69E-06	8.39E-06	6.29E-06	4.39E-06	1.60E-06	5.06E-08	5.05E-11	5.03E-17	2.81E-28
y-91	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.31E-03	1.25E-03	1.13E-03	9.49E-04
zr-91	1.33E-02	1.33E-02	1.33E-02	1.33E-02	1.33E-02	1.33E-02	1.33E-02	1.33E-02	1.33E-02	1.34E-02	1.34E-02	1.35E-02	1.37E-02
sr-92	2.71E-06	2.71E-06	2.70E-06	2.60E-06	2.39E-06	2.10E-06	7.55E-07	2.10E-07	5.85E-09	2.73E-14	5.91E-25	2.78E-46	0.00E+00
y-92	3.58E-06	3.58E-06	3.58E-06	3.58E-06	3.56E-06	3.50E-06	2.47E-06	1.24E-06	1.13E-07	1.13E-11	7.84E-20	3.69E-36	0.00E+00
zr-92	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02
y-93	1.15E-05	1.15E-05	1.15E-05	1.15E-05	1.13E-05	1.09E-05	8.31E-06	5.91E-06	2.28E-06	8.67E-08	1.26E-10	2.64E-16	5.98E-27
zr-93	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02	1.70E-02
zr-94	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02	1.81E-02
zr-95	1.98E-03	1.98E-03	1.98E-03	1.98E-03	1.98E-03	1.98E-03	1.98E-03	1.97E-03	1.96E-03	1.92E-03	1.84E-03	1.68E-03	1.43E-03
nb-95	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.08E-03	1.06E-03	1.01E-03
mo-95	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.53E-02	1.54E-02	1.55E-02	1.59E-02
zr-96	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02	1.86E-02
mo-96	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04	3.49E-04
zr-97	2.15E-05	2.15E-05	2.15E-05	2.13E-05	2.11E-05	2.06E-05	1.75E-05	1.42E-05	7.96E-06	1.09E-06	2.06E-08	7.28E-12	2.46E-18
mo-97	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02	1.83E-02
mo-98	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02
mo-99	9.34E-05	9.34E-05	9.34E-05	9.33E-05	9.29E-05	9.25E-05	8.87E-05	8.41E-05	7.26E-05	4.39E-05	1.60E-05	2.13E-06	4.85E-08
tc-99	1.88E-02	1.88E-02	1.88E-02	1.88E-02	1.88E-02	1.88E-02	1.88E-02	1.88E-02	1.88E-02	1.89E-02	1.89E-02	1.89E-02	1.89E-02

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5 h**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
tc-99m	7.48E-06	7.48E-06	7.48E-06	7.48E-06	7.48E-06	7.47E-06	7.38E-06	7.17E-06	6.35E-06	3.86E-06	1.41E-06	1.87E-07	4.27E-09
mo-100	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02	2.07E-02
ru-100	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04	8.20E-04
ru-101	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02	1.74E-02
ru-102	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02	1.60E-02
ru-103	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.02E-03	1.01E-03	9.77E-04	9.11E-04	7.91E-04	6.07E-04
rh-103	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.03E-02	1.03E-02	1.03E-02	1.04E-02	1.05E-02	1.07E-02
ru-104	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
pd-104	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03	2.10E-03
ru-105	3.16E-06	3.16E-06	3.15E-06	3.13E-06	3.00E-06	2.78E-06	1.49E-06	6.83E-07	7.67E-08	4.27E-11	1.32E-17	1.27E-30	0.00E+00
rh-105	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.38E-05	2.23E-05	1.75E-05	6.85E-06	1.04E-06	2.42E-08	2.09E-11
pd-105	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.97E-03	6.98E-03	6.99E-03	6.99E-03	6.99E-03
ru-106	2.84E-03	2.84E-03	2.84E-03	2.84E-03	2.84E-03	2.84E-03	2.84E-03	2.83E-03	2.83E-03	2.82E-03	2.80E-03	2.76E-03	2.68E-03
pd-106	2.40E-03	2.40E-03	2.40E-03	2.40E-03	2.40E-03	2.40E-03	2.40E-03	2.40E-03	2.40E-03	2.41E-03	2.44E-03	2.48E-03	2.55E-03
pd-107	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03	3.35E-03
pd-108	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03	2.17E-03
pd-109	2.57E-06	2.57E-06	2.57E-06	2.55E-06	2.51E-06	2.44E-06	2.00E-06	1.55E-06	7.64E-07	6.73E-08	5.24E-10	3.17E-14	3.90E-22
ag-109	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03	1.32E-03
pd-110	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04	7.03E-04
ag-110m	4.89E-06	4.89E-06	4.89E-06	4.89E-06	4.89E-06	4.89E-06	4.89E-06	4.88E-06	4.87E-06	4.85E-06	4.79E-06	4.69E-06	4.50E-06
cd-110	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04	1.97E-04
ag-111	7.05E-06	7.05E-06	7.05E-06	7.05E-06	7.04E-06	7.03E-06	6.93E-06	6.80E-06	6.44E-06	5.34E-06	3.68E-06	1.75E-06	4.33E-07
cd-111	3.37E-04	3.37E-04	3.37E-04	3.37E-04	3.37E-04	3.37E-04	3.37E-04	3.37E-04	3.38E-04	3.39E-04	3.40E-04	3.42E-04	3.44E-04
cd-112	1.65E-04	1.65E-04	1.65E-04	1.65E-04	1.65E-04	1.65E-04	1.65E-04	1.65E-04	1.65E-04	1.66E-04	1.66E-04	1.66E-04	1.66E-04
cd-113	2.38E-06	2.38E-06	2.38E-06	2.38E-06	2.38E-06	2.39E-06	2.40E-06	2.41E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06
cd-114	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04	2.11E-04
in-115	5.59E-05	5.59E-05	5.59E-05	5.59E-05	5.59E-05	5.59E-05	5.59E-05	5.60E-05	5.60E-05	5.61E-05	5.63E-05	5.63E-05	5.64E-05
sn-115	3.46E-06	3.46E-06	3.46E-06	3.46E-06	3.46E-06	3.46E-06	3.46E-06	3.46E-06	3.46E-06	3.47E-06	3.47E-06	3.48E-06	3.48E-06
cd-116	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05	8.29E-05
sn-116	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05
sn-117	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05	7.63E-05
sn-118	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05	6.33E-05
sn-119	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05
sn-120	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05	6.65E-05
sn-121m	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06
sb-121	6.69E-05	6.69E-05	6.69E-05	6.69E-05	6.69E-05	6.69E-05	6.69E-05	6.69E-05	6.70E-05	6.70E-05	6.71E-05	6.71E-05	6.71E-05
sn-122	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05	8.86E-05
sn-123	3.57E-06	3.57E-06	3.57E-06	3.57E-06	3.57E-06	3.57E-06	3.57E-06	3.57E-06	3.56E-06	3.52E-06	3.44E-06	3.30E-06	3.04E-06

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5 h**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
sb-123	8.45E-05	8.45E-05	8.45E-05	8.45E-05	8.45E-05	8.45E-05	8.45E-05	8.45E-05	8.45E-05	8.46E-05	8.46E-05	8.48E-05	8.50E-05
sn-124	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04	1.55E-04
sb-125	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.62E-04	1.61E-04
te-125	4.41E-05	4.41E-05	4.41E-05	4.41E-05	4.41E-05	4.41E-05	4.41E-05	4.41E-05	4.42E-05	4.44E-05	4.49E-05	4.57E-05	4.74E-05
sn-126	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04	3.62E-04
te-126	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.09E-05	1.09E-05
sb-127	7.54E-06	7.54E-06	7.54E-06	7.54E-06	7.53E-06	7.52E-06	7.35E-06	7.09E-06	6.39E-06	4.46E-06	2.17E-06	5.14E-07	3.45E-08
te-127m	1.95E-05	1.95E-05	1.95E-05	1.95E-05	1.95E-05	1.95E-05	1.95E-05	1.96E-05	1.96E-05	1.97E-05	1.95E-05	1.88E-05	1.72E-05
i-127	8.74E-04	8.74E-04	8.74E-04	8.74E-04	8.74E-04	8.75E-04	8.75E-04	8.75E-04	8.76E-04	8.78E-04	8.80E-04	8.83E-04	8.85E-04
te-128	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03	1.87E-03
xe-128	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05	1.64E-05
te-129m	3.28E-05	3.28E-05	3.28E-05	3.28E-05	3.28E-05	3.28E-05	3.27E-05	3.26E-05	3.23E-05	3.10E-05	2.85E-05	2.42E-05	1.77E-05
i-129	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	2.99E-03	3.00E-03	3.00E-03
te-130	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03	8.14E-03
xe-130	6.38E-05	6.38E-05	6.38E-05	6.38E-05	6.38E-05	6.38E-05	6.38E-05	6.39E-05	6.39E-05	6.39E-05	6.39E-05	6.39E-05	6.39E-05
te-131m	6.20E-06	6.20E-06	6.20E-06	6.18E-06	6.15E-06	6.09E-06	5.60E-06	5.05E-06	3.77E-06	1.39E-06	1.87E-07	3.42E-09	1.88E-12
i-131	1.87E-04	1.87E-04	1.87E-04	1.87E-04	1.87E-04	1.87E-04	1.85E-04	1.83E-04	1.75E-04	1.49E-04	1.07E-04	5.35E-05	1.47E-05
xe-131	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.14E-02	1.15E-02	1.15E-02	1.16E-02
xe-131m	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.87E-06	2.69E-06	2.14E-06	1.14E-06
te-132	1.09E-04	1.09E-04	1.08E-04	1.08E-04	1.08E-04	1.08E-04	1.04E-04	9.92E-05	8.74E-05	5.67E-05	2.39E-05	4.23E-06	1.65E-07
i-132	3.31E-06	3.31E-06	3.31E-06	3.30E-06	3.30E-06	3.29E-06	3.19E-06	3.05E-06	2.69E-06	1.75E-06	7.34E-07	1.30E-07	5.07E-09
xe-132	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.13E-02	2.13E-02	2.13E-02
i-133	4.37E-05	4.37E-05	4.37E-05	4.37E-05	4.35E-05	4.30E-05	3.81E-05	3.22E-05	2.02E-05	4.08E-06	1.67E-07	2.77E-10	1.71E-15
xe-133	2.53E-04	2.53E-04	2.53E-04	2.53E-04	2.53E-04	2.53E-04	2.53E-04	2.52E-04	2.45E-04	2.03E-04	1.23E-04	4.31E-05	5.94E-06
xe-133m	3.16E-06	3.16E-06	3.16E-06	3.16E-06	3.16E-06	3.16E-06	3.15E-06	3.11E-06	2.90E-06	1.85E-06	5.68E-07	4.58E-08	3.97E-10
cs-133	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.74E-02	2.74E-02	2.75E-02	2.76E-02
i-134	2.10E-06	2.10E-06	2.09E-06	2.04E-06	1.85E-06	1.51E-06	1.21E-07	2.86E-09	4.82E-14	1.49E-30	0.00E+00	0.00E+00	0.00E+00
xe-134	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02
cs-134	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.29E-03	1.27E-03
ba-134	3.38E-04	3.38E-04	3.38E-04	3.38E-04	3.38E-04	3.38E-04	3.38E-04	3.39E-04	3.39E-04	3.42E-04	3.47E-04	3.56E-04	3.74E-04
i-135	1.33E-05	1.33E-05	1.32E-05	1.30E-05	1.26E-05	1.19E-05	7.83E-06	4.62E-06	1.05E-06	6.67E-09	2.66E-13	4.25E-22	1.36E-38
xe-135	7.18E-06	7.18E-06	7.19E-06	7.33E-06	7.60E-06	7.96E-06	9.40E-06	9.07E-06	5.08E-06	2.08E-07	1.59E-10	7.59E-17	1.06E-28
cs-135	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02	1.15E-02
xe-136	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02	4.69E-02
cs-136	9.68E-06	9.68E-06	9.68E-06	9.68E-06	9.67E-06	9.66E-06	9.58E-06	9.47E-06	9.19E-06	8.27E-06	6.70E-06	4.39E-06	1.99E-06
ba-136	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.53E-04	2.55E-04	2.57E-04	2.59E-04
cs-137	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02	2.72E-02
ba-137	7.17E-04	7.17E-04	7.17E-04	7.17E-04	7.17E-04	7.17E-04	7.18E-04	7.18E-04	7.19E-04	7.22E-04	7.29E-04	7.43E-04	7.69E-04

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5 h**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
ba-138	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02
ba-139	2.75E-06	2.75E-06	2.75E-06	2.69E-06	2.38E-06	1.88E-06	2.54E-07	2.08E-08	1.88E-11	6.84E-22	9.10E-43	0.00E+00	0.00E+00
la-139	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02	2.79E-02
ba-140	5.88E-04	5.88E-04	5.88E-04	5.88E-04	5.87E-04	5.87E-04	5.81E-04	5.75E-04	5.57E-04	5.00E-04	4.02E-04	2.60E-04	1.15E-04
la-140	8.23E-05	8.23E-05	8.23E-05	8.23E-05	8.22E-05	8.22E-05	8.18E-05	8.14E-05	7.99E-05	7.37E-05	6.05E-05	3.94E-05	1.75E-05
ce-140	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.75E-02	2.75E-02	2.76E-02	2.78E-02	2.80E-02
la-141	7.17E-06	7.17E-06	7.17E-06	7.14E-06	6.92E-06	6.45E-06	3.21E-06	1.33E-06	1.12E-07	2.30E-11	9.76E-19	1.76E-33	0.00E+00
ce-141	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.42E-03	1.41E-03	1.35E-03	1.24E-03	1.04E-03	7.58E-04
pr-141	2.43E-02	2.43E-02	2.43E-02	2.43E-02	2.43E-02	2.43E-02	2.43E-02	2.43E-02	2.44E-02	2.44E-02	2.45E-02	2.47E-02	2.50E-02
la-142	2.74E-06	2.74E-06	2.73E-06	2.68E-06	2.41E-06	1.95E-06	3.15E-07	3.21E-08	5.38E-11	1.64E-20	1.52E-39	0.00E+00	0.00E+00
ce-142	2.58E-02	2.58E-02	2.58E-02	2.58E-02	2.58E-02	2.58E-02	2.59E-02	2.59E-02	2.59E-02	2.59E-02	2.59E-02	2.59E-02	2.59E-02
nd-142	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04	1.90E-04
ce-143	5.89E-05	5.89E-05	5.89E-05	5.88E-05	5.86E-05	5.80E-05	5.34E-05	4.81E-05	3.58E-05	1.31E-05	1.75E-06	3.11E-08	1.63E-11
pr-143	5.62E-04	5.62E-04	5.62E-04	5.62E-04	5.62E-04	5.62E-04	5.62E-04	5.62E-04	5.57E-04	5.24E-04	4.37E-04	2.92E-04	1.36E-04
nd-143	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.14E-02	2.14E-02	2.15E-02	2.17E-02	2.18E-02
ce-144	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	9.98E-03	9.93E-03	9.84E-03	9.65E-03	9.30E-03
nd-144	1.76E-02	1.76E-02	1.76E-02	1.76E-02	1.76E-02	1.76E-02	1.76E-02	1.77E-02	1.77E-02	1.77E-02	1.78E-02	1.80E-02	1.83E-02
pr-145	7.21E-06	7.21E-06	7.21E-06	7.14E-06	6.87E-06	6.49E-06	4.08E-06	2.29E-06	4.52E-07	1.74E-09	2.58E-14	5.65E-24	4.39E-42
nd-145	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02	1.66E-02
nd-146	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02	1.44E-02
nd-147	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.92E-04	1.89E-04	1.82E-04	1.61E-04	1.25E-04	7.53E-05	2.92E-05
pm-147	5.93E-03	5.93E-03	5.93E-03	5.93E-03	5.93E-03	5.93E-03	5.93E-03	5.93E-03	5.94E-03	5.95E-03	5.97E-03	5.98E-03	5.96E-03
sm-147	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.94E-03	1.96E-03	1.99E-03	2.06E-03
nd-148	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03	8.10E-03
pm-148	1.95E-05	1.95E-05	1.95E-05	1.95E-05	1.95E-05	1.94E-05	1.90E-05	1.85E-05	1.72E-05	1.33E-05	8.00E-06	2.93E-06	5.13E-07
pm-148m	2.94E-05	2.94E-05	2.94E-05	2.94E-05	2.94E-05	2.94E-05	2.93E-05	2.92E-05	2.89E-05	2.79E-05	2.61E-05	2.28E-05	1.78E-05
sm-148	1.52E-03	1.52E-03	1.52E-03	1.52E-03	1.52E-03	1.52E-03	1.53E-03	1.53E-03	1.53E-03	1.53E-03	1.54E-03	1.55E-03	1.56E-03
pm-149	2.65E-05	2.65E-05	2.65E-05	2.65E-05	2.65E-05	2.64E-05	2.54E-05	2.39E-05	1.99E-05	1.06E-05	3.04E-06	2.48E-07	2.25E-09
sm-149	7.74E-05	7.74E-05	7.74E-05	7.74E-05	7.75E-05	7.77E-05	7.91E-05	8.07E-05	8.47E-05	9.39E-05	1.02E-04	1.04E-04	1.05E-04
nd-150	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03	3.58E-03
sm-150	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03	5.78E-03
pm-151	5.66E-06	5.66E-06	5.66E-06	5.65E-06	5.62E-06	5.56E-06	5.04E-06	4.46E-06	3.17E-06	9.83E-07	9.44E-08	8.70E-10	1.33E-13
sm-151	4.24E-04	4.24E-04	4.24E-04	4.24E-04	4.24E-04	4.24E-04	4.25E-04	4.25E-04	4.27E-04	4.29E-04	4.30E-04	4.30E-04	4.30E-04
sm-152	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03	2.98E-03
sm-153	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.39E-05	1.38E-05	1.30E-05	1.21E-05	9.82E-06	4.80E-06	1.15E-06	6.56E-08	3.06E-10
eu-153	1.91E-03	1.91E-03	1.91E-03	1.91E-03	1.91E-03	1.91E-03	1.91E-03	1.91E-03	1.91E-03	1.92E-03	1.92E-03	1.92E-03	1.92E-03
sm-154	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04	6.19E-04
eu-154	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.95E-04	2.94E-04	2.93E-04

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5 h**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
gd-154	1.60E-05	1.60E-05	1.60E-05	1.60E-05	1.60E-05	1.60E-05	1.60E-05	1.61E-05	1.61E-05	1.62E-05	1.65E-05	1.70E-05	1.80E-05
eu-155	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.25E-05	5.24E-05	5.22E-05	5.19E-05
eu-156	2.79E-05	2.79E-05	2.79E-05	2.79E-05	2.79E-05	2.79E-05	2.77E-05	2.75E-05	2.68E-05	2.45E-05	2.04E-05	1.42E-05	7.15E-06
gd-156	5.80E-04	5.80E-04	5.80E-04	5.80E-04	5.80E-04	5.80E-04	5.80E-04	5.80E-04	5.81E-04	5.84E-04	5.88E-04	5.94E-04	6.01E-04
gd-157	2.16E-06	2.16E-06	2.16E-06	2.16E-06	2.16E-06	2.17E-06	2.21E-06	2.25E-06	2.32E-06	2.39E-06	2.40E-06	2.40E-06	2.40E-06
gd-158	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04	2.17E-04
tb-159	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05	3.41E-05
gd-160	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05	1.52E-05
dy-161	5.51E-06	5.51E-06	5.51E-06	5.51E-06	5.51E-06	5.51E-06	5.51E-06	5.51E-06	5.52E-06	5.54E-06	5.58E-06	5.62E-06	5.65E-06
dy-162	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06	3.54E-06
Totals	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**

Table B-2. Nuclide masses (grams per pebble) in a pebble with a discharged burnup of 160 GWd/MTU as a function of cooling time.

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
h-3	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.25E-06	2.24E-06
he-4	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.90E-04	1.91E-04
be-9	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04	1.39E-04
be-10	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06	2.82E-06
c-12	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02	1.91E+02
c-13	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00	2.24E+00
c-14	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05	1.07E-05
o-16	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00	1.22E+00
o-17	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04
o-18	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03	2.81E-03
mg-25	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06	4.10E-06
si-28	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00
si-29	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01
si-30	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02	7.92E-02
p-31	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05	5.73E-05
u-234	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03	7.18E-03
u-235	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01	2.61E-01
u-236	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01	1.78E-01
u-237	2.45E-04	2.45E-04	2.45E-04	2.45E-04	2.45E-04	2.44E-04	2.40E-04	2.35E-04	2.21E-04	1.80E-04	1.19E-04	5.25E-05	1.13E-05
u-238	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00	6.86E+00
u-239	1.55E-05	1.54E-05	1.50E-05	1.15E-05	6.39E-06	2.62E-06	2.18E-09	3.07E-13	5.07E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
np-237	1.35E-02	1.35E-02	1.35E-02	1.35E-02	1.35E-02	1.35E-02	1.35E-02	1.35E-02	1.35E-02	1.36E-02	1.36E-02	1.37E-02	1.38E-02
np-238	4.00E-05	4.00E-05	4.00E-05	3.99E-05	3.97E-05	3.95E-05	3.74E-05	3.49E-05	2.88E-05	1.50E-05	4.04E-06	2.95E-07	2.17E-09
np-239	2.24E-03	2.24E-03	2.24E-03	2.24E-03	2.23E-03	2.22E-03	2.12E-03	1.99E-03	1.68E-03	9.32E-04	2.87E-04	2.73E-05	3.36E-07
pu-238	6.94E-03	6.94E-03	6.94E-03	6.94E-03	6.94E-03	6.94E-03	6.94E-03	6.95E-03	6.96E-03	6.98E-03	7.00E-03	7.03E-03	7.08E-03
pu-239	9.16E-02	9.16E-02	9.16E-02	9.16E-02	9.16E-02	9.16E-02	9.17E-02	9.18E-02	9.21E-02	9.29E-02	9.35E-02	9.38E-02	9.38E-02
pu-240	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02	6.13E-02
pu-241	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.83E-02	4.82E-02	4.82E-02	4.81E-02
pu-242	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02	3.94E-02
pu-243	5.60E-06	5.59E-06	5.58E-06	5.47E-06	5.22E-06	4.86E-06	2.78E-06	1.38E-06	1.95E-07	2.37E-10	3.51E-16	1.79E-18	1.79E-18
am-241	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.44E-03	1.46E-03	1.51E-03	1.61E-03
am-242m	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05	2.68E-05
am-242	5.47E-06	5.47E-06	5.47E-06	5.44E-06	5.36E-06	5.24E-06	4.41E-06	3.55E-06	1.94E-06	2.43E-07	4.16E-09	3.47E-10	3.46E-10
am-243	6.19E-03	6.19E-03	6.19E-03	6.19E-03	6.19E-03	6.19E-03	6.19E-03	6.20E-03	6.20E-03	6.20E-03	6.20E-03	6.20E-03	6.20E-03
cm-242	9.13E-04	9.13E-04	9.13E-04	9.13E-04	9.13E-04	9.13E-04	9.13E-04	9.13E-04	9.12E-04	9.05E-04	8.90E-04	8.60E-04	8.07E-04
cm-243	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05
cm-244	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.65E-03	1.64E-03

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
cm-245	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05	7.44E-05
cm-246	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06	6.99E-06
as-75	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06	5.14E-06
ge-76	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05	1.40E-05
se-77	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05
se-78	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05	9.96E-05
se-79	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04	2.07E-04
se-80	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04
br-81	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04	9.41E-04
se-82	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03	1.46E-03
kr-82	2.28E-05	2.28E-05	2.28E-05	2.28E-05	2.28E-05	2.28E-05	2.29E-05	2.29E-05	2.29E-05	2.29E-05	2.29E-05	2.29E-05	2.29E-05
kr-83	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03	1.69E-03
kr-84	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03	4.85E-03
kr-85	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.02E-03
rb-85	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03	4.46E-03
kr-86	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03	8.13E-03
sr-86	1.35E-05	1.35E-05	1.35E-05	1.35E-05	1.35E-05	1.35E-05	1.35E-05	1.35E-05	1.35E-05	1.36E-05	1.36E-05	1.37E-05	1.38E-05
rb-87	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02
sr-88	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02	1.50E-02
sr-89	6.60E-04	6.60E-04	6.60E-04	6.60E-04	6.60E-04	6.60E-04	6.59E-04	6.57E-04	6.52E-04	6.34E-04	6.00E-04	5.38E-04	4.38E-04
y-89	1.93E-02	1.93E-02	1.93E-02	1.93E-02	1.93E-02	1.93E-02	1.93E-02	1.94E-02	1.94E-02	1.94E-02	1.94E-02	1.95E-02	1.96E-02
sr-90	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.33E-02	2.32E-02
y-90	6.13E-06	6.13E-06	6.13E-06	6.13E-06	6.13E-06	6.12E-06	6.12E-06	6.10E-06	6.08E-06	6.01E-06	5.94E-06	5.91E-06	5.90E-06
zr-90	1.45E-03	1.45E-03	1.45E-03	1.45E-03	1.45E-03	1.45E-03	1.45E-03	1.45E-03	1.46E-03	1.46E-03	1.46E-03	1.48E-03	1.50E-03
sr-91	6.87E-06	6.87E-06	6.87E-06	6.80E-06	6.64E-06	6.40E-06	4.80E-06	3.35E-06	1.22E-06	3.86E-08	3.86E-11	3.84E-17	2.14E-28
y-91	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.03E-03	1.02E-03	1.00E-03	9.55E-04	8.68E-04	7.27E-04
zr-91	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.49E-02	2.50E-02	2.51E-02	2.52E-02
sr-92	2.15E-06	2.15E-06	2.14E-06	2.06E-06	1.89E-06	1.67E-06	5.99E-07	1.67E-07	4.64E-09	2.16E-14	4.69E-25	2.21E-46	0.00E+00
y-92	2.84E-06	2.84E-06	2.84E-06	2.84E-06	2.82E-06	2.78E-06	1.96E-06	9.85E-07	8.96E-08	8.97E-12	6.22E-20	2.93E-36	0.00E+00
zr-92	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02	2.82E-02
y-93	9.56E-06	9.56E-06	9.56E-06	9.52E-06	9.35E-06	9.04E-06	6.88E-06	4.90E-06	1.89E-06	7.19E-08	1.04E-10	2.19E-16	4.95E-27
zr-93	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02
zr-94	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02
zr-95	1.74E-03	1.74E-03	1.74E-03	1.74E-03	1.74E-03	1.74E-03	1.73E-03	1.73E-03	1.72E-03	1.68E-03	1.61E-03	1.48E-03	1.26E-03
nb-95	9.51E-04	9.51E-04	9.51E-04	9.51E-04	9.51E-04	9.51E-04	9.51E-04	9.51E-04	9.51E-04	9.50E-04	9.46E-04	9.31E-04	8.82E-04
mo-95	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.07E-02	3.08E-02	3.09E-02	3.12E-02
zr-96	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02	3.52E-02
mo-96	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03	1.75E-03

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
zr-97	2.00E-05	2.00E-05	2.00E-05	1.99E-05	1.96E-05	1.92E-05	1.63E-05	1.32E-05	7.42E-06	1.02E-06	1.91E-08	6.78E-12	2.30E-18
mo-97	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02	3.53E-02
mo-98	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02	3.62E-02
mo-99	9.06E-05	9.06E-05	9.06E-05	9.05E-05	9.01E-05	8.97E-05	8.60E-05	8.16E-05	7.04E-05	4.25E-05	1.55E-05	2.06E-06	4.70E-08
tc-99	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.51E-02	3.52E-02	3.52E-02
tc-99m	7.25E-06	7.25E-06	7.25E-06	7.25E-06	7.25E-06	7.24E-06	7.16E-06	6.95E-06	6.15E-06	3.74E-06	1.37E-06	1.82E-07	4.14E-09
mo-100	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02	4.11E-02
ru-100	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03	3.91E-03
ru-101	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02	3.44E-02
ru-102	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02	3.43E-02
ru-103	1.22E-03	1.22E-03	1.22E-03	1.22E-03	1.22E-03	1.22E-03	1.21E-03	1.21E-03	1.20E-03	1.15E-03	1.08E-03	9.34E-04	7.17E-04
rh-103	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.84E-02	1.85E-02	1.87E-02	1.89E-02
ru-104	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02	2.42E-02
pd-104	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02	1.05E-02
ru-105	4.38E-06	4.38E-06	4.38E-06	4.35E-06	4.17E-06	3.86E-06	2.07E-06	9.48E-07	1.07E-07	5.93E-11	1.84E-17	1.77E-30	0.00E+00
rh-105	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.35E-05	3.27E-05	3.07E-05	2.40E-05	9.42E-06	1.43E-06	3.33E-08	2.87E-11
pd-105	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02
ru-106	5.59E-03	5.59E-03	5.59E-03	5.59E-03	5.59E-03	5.59E-03	5.59E-03	5.59E-03	5.58E-03	5.56E-03	5.52E-03	5.44E-03	5.29E-03
pd-106	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.02E-02	1.04E-02
pd-107	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02
pd-108	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03	6.96E-03
pd-109	4.61E-06	4.61E-06	4.61E-06	4.58E-06	4.50E-06	4.39E-06	3.58E-06	2.78E-06	1.37E-06	1.21E-07	9.40E-10	5.68E-14	7.00E-22
ag-109	3.65E-03	3.65E-03	3.65E-03	3.65E-03	3.65E-03	3.65E-03	3.66E-03	3.66E-03	3.66E-03	3.66E-03	3.66E-03	3.66E-03	3.66E-03
pd-110	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03	2.29E-03
ag-110m	2.27E-05	2.27E-05	2.27E-05	2.27E-05	2.27E-05	2.27E-05	2.27E-05	2.27E-05	2.26E-05	2.25E-05	2.23E-05	2.18E-05	2.09E-05
cd-110	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03	1.43E-03
ag-111	1.20E-05	1.20E-05	1.20E-05	1.20E-05	1.20E-05	1.20E-05	1.18E-05	1.16E-05	1.10E-05	9.10E-06	6.27E-06	2.98E-06	7.38E-07
cd-111	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.09E-03	1.09E-03	1.09E-03	1.10E-03
cd-112	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04	5.11E-04
cd-113	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.62E-06	2.63E-06	2.65E-06	2.65E-06	2.65E-06	2.65E-06	2.65E-06
cd-114	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04	5.77E-04
in-115	9.82E-05	9.82E-05	9.82E-05	9.82E-05	9.82E-05	9.82E-05	9.83E-05	9.83E-05	9.84E-05	9.85E-05	9.87E-05	9.88E-05	9.89E-05
sn-115	8.00E-06	8.00E-06	8.00E-06	8.00E-06	8.00E-06	8.00E-06	8.00E-06	8.00E-06	8.01E-06	8.02E-06	8.02E-06	8.02E-06	8.03E-06
cd-116	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04	1.94E-04
sn-116	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05	7.46E-05
sn-117	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04	1.75E-04
sn-118	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04	1.45E-04
sn-119	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04	1.49E-04

Nuclide	0 s	15 s	1 min	10 min	30 min	1 h	5	10 h	1 day	3 day	7 day	15 day	30 day
sn-120	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04	1.50E-04
sn-121m	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05	1.29E-05
sb-121	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04	1.47E-04
sn-122	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04
te-122	8.69E-06	8.69E-06	8.69E-06	8.69E-06	8.69E-06	8.69E-06	8.69E-06	8.69E-06	8.70E-06	8.72E-06	8.73E-06	8.74E-06	8.74E-06
sn-123	4.82E-06	4.82E-06	4.82E-06	4.82E-06	4.82E-06	4.82E-06	4.82E-06	4.81E-06	4.80E-06	4.74E-06	4.64E-06	4.45E-06	4.10E-06
sb-123	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.89E-04
sn-124	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04	3.43E-04
te-124	6.93E-06	6.93E-06	6.93E-06	6.93E-06	6.93E-06	6.93E-06	6.93E-06	6.93E-06	6.94E-06	6.96E-06	7.00E-06	7.08E-06	7.21E-06
sn-125	2.39E-06	2.39E-06	2.39E-06	2.39E-06	2.39E-06	2.38E-06	2.35E-06	2.32E-06	2.22E-06	1.93E-06	1.44E-06	8.13E-07	2.76E-07
sb-125	2.97E-04	2.97E-04	2.97E-04	2.97E-04	2.97E-04	2.97E-04	2.97E-04	2.97E-04	2.97E-04	2.96E-04	2.96E-04	2.95E-04	2.93E-04
te-125	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.75E-04	1.77E-04	1.80E-04
te-125m	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.75E-06	3.76E-06	3.77E-06	3.79E-06
sn-126	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04	8.24E-04
te-126	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.30E-05	2.31E-05
sb-127	8.81E-06	8.81E-06	8.81E-06	8.81E-06	8.80E-06	8.78E-06	8.58E-06	8.28E-06	7.46E-06	5.21E-06	2.53E-06	6.00E-07	4.03E-08
te-127m	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.94E-05	1.95E-05	1.95E-05	1.95E-05	1.97E-05	1.96E-05	1.89E-05	1.73E-05
i-127	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.94E-03	1.94E-03	1.94E-03
te-128	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03	4.01E-03
xe-128	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05	9.08E-05
te-129m	3.70E-05	3.70E-05	3.70E-05	3.70E-05	3.70E-05	3.70E-05	3.70E-05	3.69E-05	3.65E-05	3.50E-05	3.22E-05	2.73E-05	2.01E-05
i-129	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.45E-03	6.46E-03	6.46E-03
te-130	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02
xe-130	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04
te-131m	6.73E-06	6.73E-06	6.73E-06	6.71E-06	6.67E-06	6.61E-06	6.08E-06	5.48E-06	4.09E-06	1.50E-06	2.03E-07	3.71E-09	2.04E-12
i-131	1.92E-04	1.92E-04	1.92E-04	1.92E-04	1.91E-04	1.91E-04	1.89E-04	1.87E-04	1.79E-04	1.53E-04	1.09E-04	5.48E-05	1.50E-05
xe-131	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.92E-02	1.93E-02	1.93E-02	1.94E-02
xe-131m	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.06E-06	3.06E-06	3.05E-06	3.05E-06	3.05E-06	3.01E-06	2.81E-06	2.22E-06	1.18E-06
te-132	1.09E-04	1.09E-04	1.09E-04	1.09E-04	1.08E-04	1.08E-04	1.04E-04	9.95E-05	8.77E-05	5.69E-05	2.39E-05	4.24E-06	1.65E-07
i-132	3.34E-06	3.34E-06	3.34E-06	3.34E-06	3.33E-06	3.32E-06	3.21E-06	3.06E-06	2.70E-06	1.75E-06	7.37E-07	1.31E-07	5.09E-09
xe-132	4.73E-02	4.73E-02	4.73E-02	4.73E-02	4.73E-02	4.73E-02	4.73E-02	4.73E-02	4.73E-02	4.74E-02	4.74E-02	4.74E-02	4.74E-02
i-133	4.25E-05	4.25E-05	4.25E-05	4.25E-05	4.23E-05	4.18E-05	3.70E-05	3.14E-05	1.97E-05	3.97E-06	1.62E-07	2.70E-10	1.66E-15
xe-133	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.52E-04	2.51E-04	2.50E-04	2.43E-04	2.01E-04	1.22E-04	4.27E-05	5.89E-06
xe-133m	3.34E-06	3.34E-06	3.34E-06	3.34E-06	3.34E-06	3.34E-06	3.31E-06	3.26E-06	3.01E-06	1.90E-06	5.82E-07	4.69E-08	4.06E-10
cs-133	4.98E-02	4.98E-02	4.98E-02	4.98E-02	4.98E-02	4.98E-02	4.98E-02	4.99E-02	4.99E-02	4.99E-02	5.00E-02	5.01E-02	5.01E-02
xe-134	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02	6.71E-02
cs-134	4.88E-03	4.88E-03	4.88E-03	4.88E-03	4.88E-03	4.88E-03	4.88E-03	4.88E-03	4.88E-03	4.87E-03	4.85E-03	4.82E-03	4.75E-03
ba-134	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.53E-03	2.54E-03	2.54E-03	2.55E-03	2.56E-03	2.60E-03	2.67E-03

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
i-135	1.31E-05	1.31E-05	1.31E-05	1.28E-05	1.24E-05	1.18E-05	7.72E-06	4.55E-06	1.04E-06	6.57E-09	2.62E-13	4.19E-22	1.34E-38
xe-135	5.68E-06	5.69E-06	5.70E-06	5.85E-06	6.16E-06	6.56E-06	8.32E-06	8.29E-06	4.78E-06	1.99E-07	1.53E-10	7.28E-17	1.01E-28
cs-135	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02
ba-135	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05	1.46E-05
xe-136	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02	9.62E-02
cs-136	2.22E-05	2.22E-05	2.22E-05	2.22E-05	2.21E-05	2.21E-05	2.19E-05	2.17E-05	2.10E-05	1.89E-05	1.53E-05	1.01E-05	4.56E-06
ba-136	9.87E-04	9.87E-04	9.87E-04	9.87E-04	9.87E-04	9.87E-04	9.88E-04	9.88E-04	9.89E-04	9.91E-04	9.94E-04	1.00E-03	1.01E-03
cs-137	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.29E-02	5.28E-02
ba-137	2.80E-03	2.80E-03	2.80E-03	2.80E-03	2.80E-03	2.80E-03	2.80E-03	2.81E-03	2.81E-03	2.81E-03	2.83E-03	2.85E-03	2.90E-03
ba-138	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02
ba-139	2.61E-06	2.61E-06	2.61E-06	2.55E-06	2.26E-06	1.78E-06	2.41E-07	1.97E-08	1.78E-11	6.49E-22	8.63E-43	0.00E+00	0.00E+00
la-139	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02	5.40E-02
ba-140	5.55E-04	5.55E-04	5.55E-04	5.55E-04	5.55E-04	5.54E-04	5.49E-04	5.43E-04	5.26E-04	4.72E-04	3.80E-04	2.46E-04	1.09E-04
la-140	7.72E-05	7.72E-05	7.72E-05	7.72E-05	7.71E-05	7.71E-05	7.68E-05	7.64E-05	7.51E-05	6.95E-05	5.72E-05	3.72E-05	1.65E-05
ce-140	5.41E-02	5.41E-02	5.41E-02	5.41E-02	5.41E-02	5.41E-02	5.41E-02	5.41E-02	5.41E-02	5.42E-02	5.43E-02	5.44E-02	5.46E-02
la-141	6.70E-06	6.70E-06	6.69E-06	6.66E-06	6.47E-06	6.03E-06	3.00E-06	1.24E-06	1.04E-07	2.15E-11	9.12E-19	1.64E-33	0.00E+00
ce-141	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.34E-03	1.33E-03	1.33E-03	1.31E-03	1.26E-03	1.16E-03	9.76E-04	7.08E-04
pr-141	4.80E-02	4.80E-02	4.80E-02	4.80E-02	4.80E-02	4.80E-02	4.80E-02	4.80E-02	4.80E-02	4.81E-02	4.82E-02	4.84E-02	4.87E-02
la-142	2.52E-06	2.52E-06	2.52E-06	2.47E-06	2.22E-06	1.79E-06	2.90E-07	2.96E-08	4.96E-11	1.51E-20	1.40E-39	0.00E+00	0.00E+00
ce-142	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02	4.97E-02
nd-142	9.66E-04	9.66E-04	9.66E-04	9.66E-04	9.66E-04	9.66E-04	9.66E-04	9.66E-04	9.67E-04	9.67E-04	9.67E-04	9.67E-04	9.67E-04
ce-143	5.31E-05	5.31E-05	5.31E-05	5.31E-05	5.29E-05	5.24E-05	4.82E-05	4.34E-05	3.23E-05	1.18E-05	1.58E-06	2.81E-08	1.47E-11
pr-143	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.10E-04	5.06E-04	4.76E-04	3.97E-04	2.65E-04	1.23E-04
nd-143	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.24E-02	3.25E-02	3.27E-02	3.28E-02
ce-144	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.01E-02	9.88E-03	9.52E-03
nd-144	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.13E-02	5.14E-02	5.16E-02	5.20E-02
pr-145	6.58E-06	6.58E-06	6.58E-06	6.51E-06	6.27E-06	5.92E-06	3.72E-06	2.09E-06	4.12E-07	1.59E-09	2.35E-14	5.16E-24	4.00E-42
nd-145	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02	2.98E-02
nd-146	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02
nd-147	1.87E-04	1.87E-04	1.87E-04	1.87E-04	1.87E-04	1.86E-04	1.84E-04	1.82E-04	1.76E-04	1.55E-04	1.20E-04	7.25E-05	2.81E-05
pm-147	6.75E-03	6.75E-03	6.75E-03	6.75E-03	6.75E-03	6.75E-03	6.75E-03	6.75E-03	6.75E-03	6.76E-03	6.78E-03	6.79E-03	6.76E-03
sm-147	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.83E-03	4.85E-03	4.89E-03	4.97E-03
nd-148	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02
pm-148	3.13E-05	3.13E-05	3.13E-05	3.13E-05	3.12E-05	3.11E-05	3.05E-05	2.97E-05	2.75E-05	2.13E-05	1.28E-05	4.65E-06	7.82E-07
pm-148m	3.59E-05	3.59E-05	3.59E-05	3.59E-05	3.59E-05	3.59E-05	3.58E-05	3.57E-05	3.53E-05	3.41E-05	3.19E-05	2.79E-05	2.17E-05
sm-148	5.90E-03	5.90E-03	5.90E-03	5.90E-03	5.90E-03	5.90E-03	5.90E-03	5.90E-03	5.91E-03	5.91E-03	5.93E-03	5.94E-03	5.95E-03
pm-149	3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.13E-05	3.12E-05	3.00E-05	2.82E-05	2.35E-05	1.26E-05	3.59E-06	2.92E-07	2.66E-09
sm-149	6.23E-05	6.23E-05	6.23E-05	6.23E-05	6.25E-05	6.27E-05	6.43E-05	6.62E-05	7.09E-05	8.18E-05	9.08E-05	9.41E-05	9.44E-05

Nuclide	**0 s**	**15 s**	**1 min**	**10 min**	**30 min**	**1 h**	**5**	**10 h**	**1 day**	**3 day**	**7 day**	**15 day**	**30 day**
nd-150	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03	7.60E-03
sm-150	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02	1.18E-02
pm-151	6.56E-06	6.56E-06	6.56E-06	6.56E-06	6.52E-06	6.45E-06	5.85E-06	5.18E-06	3.68E-06	1.14E-06	1.10E-07	1.01E-09	1.54E-13
sm-151	5.04E-04	5.04E-04	5.04E-04	5.04E-04	5.04E-04	5.04E-04	5.05E-04	5.05E-04	5.07E-04	5.09E-04	5.10E-04	5.10E-04	5.10E-04
sm-152	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03	5.21E-03
sm-153	2.95E-05	2.95E-05	2.94E-05	2.94E-05	2.92E-05	2.90E-05	2.73E-05	2.54E-05	2.06E-05	1.01E-05	2.41E-06	1.38E-07	6.43E-10
eu-153	5.58E-03	5.58E-03	5.58E-03	5.58E-03	5.58E-03	5.58E-03	5.58E-03	5.58E-03	5.59E-03	5.60E-03	5.60E-03	5.61E-03	5.61E-03
sm-154	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03	1.55E-03
eu-154	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.47E-03
gd-154	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.52E-04	1.53E-04	1.56E-04	1.61E-04
eu-155	1.58E-04	1.58E-04	1.58E-04	1.58E-04	1.58E-04	1.58E-04	1.58E-04	1.58E-04	1.58E-04	1.57E-04	1.57E-04	1.57E-04	1.56E-04
gd-155	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.43E-06	2.45E-06	2.48E-06	2.61E-06	2.86E-06	3.36E-06	4.30E-06
eu-156	9.66E-05	9.66E-05	9.66E-05	9.66E-05	9.65E-05	9.64E-05	9.58E-05	9.49E-05	9.26E-05	8.45E-05	7.04E-05	4.89E-05	2.47E-05
gd-156	2.91E-03	2.91E-03	2.91E-03	2.91E-03	2.91E-03	2.91E-03	2.91E-03	2.91E-03	2.92E-03	2.92E-03	2.94E-03	2.96E-03	2.98E-03
gd-157	3.71E-06	3.71E-06	3.71E-06	3.72E-06	3.72E-06	3.73E-06	3.81E-06	3.89E-06	4.03E-06	4.17E-06	4.19E-06	4.19E-06	4.19E-06
gd-158	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04	7.51E-04
tb-159	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04
gd-160	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05	5.01E-05
dy-160	7.37E-06	7.37E-06	7.37E-06	7.37E-06	7.37E-06	7.37E-06	7.38E-06	7.38E-06	7.39E-06	7.43E-06	7.50E-06	7.64E-06	7.87E-06
dy-161	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.46E-05	1.46E-05	1.47E-05	1.48E-05
dy-162	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05	1.17E-05
dy-163	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06	8.37E-06
ho-165	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06	2.91E-06
totals	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**	**2.06E+02**