ORNL/TM-2019/1222

Post Placement Nuclear Criticality Evaluations Involving 6- and 12-Inch Pipe Overpack TRU Waste Containers at the Waste Isolation Pilot Plant

Bret D. Brickner

October 2019

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

ORNL/TM-2019/1222

Reactor and Nuclear Systems Division

POST-PLACEMENT NUCLEAR CRITICALITY EVALUATIONS INVOLVING 6- AND 12-INCH PIPE OVERPACK TRU WASTE CONTAINERS AT THE WASTE ISOLATION PILOT PLANT

Bret D. Brickner

October 2019

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

CBFO	Carlsbad Field Office
CCO	criticality control overpack
CFR	Code of Federal Regulations
CH	contact-handled
DOE	US Department of Energy
EPA	US Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEP	feature, event and process
FGE	fissile gram equivalent
MCNP	Monte Carlo N-Particle code
MOX	mixed oxide
NEA	Nuclear Energy Agency
NWP	Nuclear Waste Partnership, LLC
ORNL	Oak Ridge National Laboratory
POC	pipe overpack container
RNSD	Reactor and Nuclear Systems Division
SBMS	Systems-Based Management System
SNL	Sandia National Laboratories
TRU	transuranic
TRUPACT	TRU Package Transporter
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

This report documents a nuclear criticality assessment of the Waste Isolation Pilot Plant (WIPP) repository with fissile masses up to 200 fissile gram equivalent (FGE) in a plutonium disposition waste form inside 6- and 12-inch pipe overpack containers (POCs) considering various geometry and material compositions resulting from salt-creep–induced room compaction scenarios. Although water is not expected to be in the 6- and 12-inch POCs, intrusion of brine is possible during the regulatory time frame of 10,000 years. Thus, both water (as brine) and polyethylene as possible H-bearing materials within the vicinity of the fissile mass is also accounted for in the evaluations. This criticality assessment is being performed to support the WIPP repository regulatory post-closure disposal time period for feature, event, and process (FEP) considerations of 10,000 years.

The main objective of this evaluation is to examine the reactivity of fissile material surrounded by various reflector material compositions in conjunction with spacing configurations related to room compaction. The studies described herein considered two separate ways of modeling the system, (1) uniform arrays of optimally moderated $^{239}PuO_2$ spheres with as-emplaced FGE masses—the actual, recorded mass value for each POC in the room—randomly distributed within a panel room configuration and (2) arrays of optimally moderated $^{239}PuO_2$ spheres with 200 FGE, in either a uniform array with spacing based on the results from Reedlunn [10], or at specific locations, based on the centroid[1] locations from the explicitly modeled compaction results from Reedlunn [10]. Using this combination of (1) optimally moderated bounding fissile mass geometry, (2) worst-case composition reflector material combinations, and (3) the full range of pitch spacing, allow material degradation scenarios in conjunction with different compaction configurations of the as-emplaced 6- and 12-inch POCs to be evaluated in a conservative (with respect to criticality) manner. The studies which use the as-emplaced FGE masses provide an evaluation for the reactivity for emplacement activities to date. The studies which use the centroid locations from the compactions results from Reedlunn [10] investigate the POC fissile mass design limit of 200 g.

During this post-closure period at WIPP, FEP screening is governed by US Environmental Protection Agency (EPA) risk-based standards contained in 40 CFR 191, as well as the EPA implementing regulations in 40 CFR 194. An FEP screening can be based on either a low-consequence rationale or a low-probability rationale. A low-probability rationale includes either (1) a qualitative rationale that the FEP is not credible, or (2) a quantitative demonstration that the probability is less than 10^{-4} in 10^4 years. A range of configurations was modeled to understand competing effects on system neutron multiplication due to varying reflector material compositions in conjunction with spacing configuration changes related to room compaction. The configurations modeled are inherently conservative because:

1) Each mass of emplaced fissile material is treated as an optimally moderated sphere of $^{239}PuO_2$ (optimum H/Pu ratio). Sources of H come from brine[2] and plastic bagging materials. Using this modeling approach allows the analysis comparisons to be performed without further geometric considerations of the fissile mass.

2) Different reflector materials were evaluated in a systematic fashion beginning with salt and adding other constituents such as Be, MgO, Fe (from the 6- and 12-inch pipe), brine [2] (water and salt) and cellulose. Because the human intrusion event scenario is considered likely, the

[1] Centroids are the center point of the 6- and 12-inch pipes.

[2] Water is only possible as brine. Including the salt along with the water in brine within the waste form would decrease reactivity. Therefore, with the exception of calculations which specifically evaluate the reactivity effect of brine within the waste form, the salt from the brine is not included with the water so that the H from the water can be considered without including the negative reactivity effect of neutron capture in salt.

introduction of brine and subsequent dry out (i.e., reduction in amount of H present) is considered. Retention of materials such as cellulose decreases after a brine intrusion event, therefore the evaluation considers various amounts of cellulose. Limiting the analysis to these compositions maximizes reactivity for the non-brine cases and does not attempt to credit any material compositions for reactivity control via neutron capture. When brine is present in the system the neutron absorption in Cl is significant and therefore the brine configuration is bounded by the dry configuration. Using these compositions in this manner is therefore conservative and allows the evaluation to be performed without further consideration of reflector material compositions.

Compaction studies were performed by Reedlunn [10] and show that the overall amount of lateral movement of fissile material masses is limited (See Figure ES-1), but compaction approaches 100% in the vertical, z-direction.

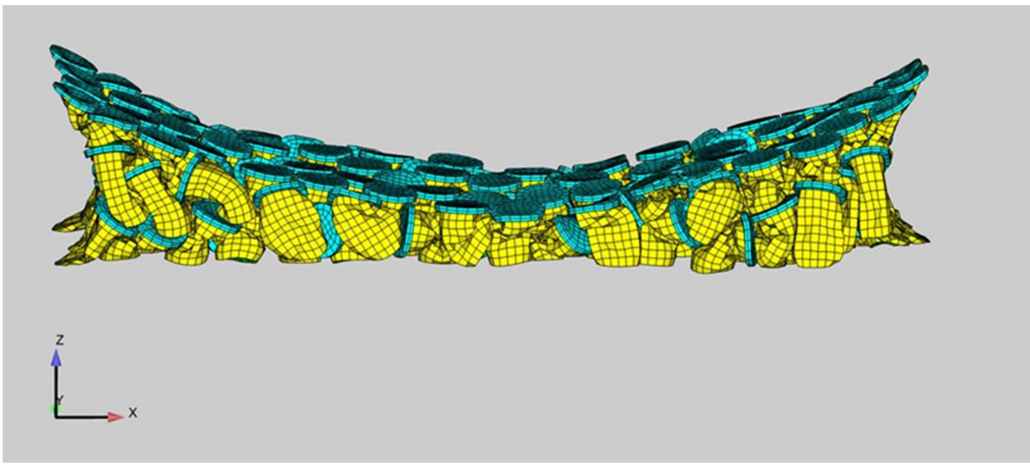


Figure ES-1. Example of room compaction study results Reedlunn [10].

Criticality calculations were performed using the 6- and 12-inch pipe centroid[3] locations from the explicitly modeled compaction results Reedlunn [10]. The full range of possible compaction configurations using incremental spacing of uniform arrays of centroid locations was also modeled to investigate effects of other possible arrangements of centroids. Note that an as-emplaced uncompacted room is subcritical with the POCs placed at a center to center pitch between the 6- and 12-inch pipes of 58 cm; therefore, the uniform array calculations begin with the room fully compacted and then space is added incrementally. The uniform array incremental spacing studies were performed considering variations focused on the width and length of the room than the vertical direction. These spacing studies were performed for various combinations of reflector compositions.

The results of the post compaction centroid locations with 200 FGE masses are shown in Figure ES-2 for the repository time period which includes brine intrusion. Figure ES-3 shows the results without the cellulose for post brine intrusion conditions, and Figure ES-4 shows results for the uniform arrays of the as-emplaced FGE masses for the bounding reflector material composition and for various incremental changes in fissile sphere spacing.

[3] Centroids are the center point of the 6- and 12-inch pipes.

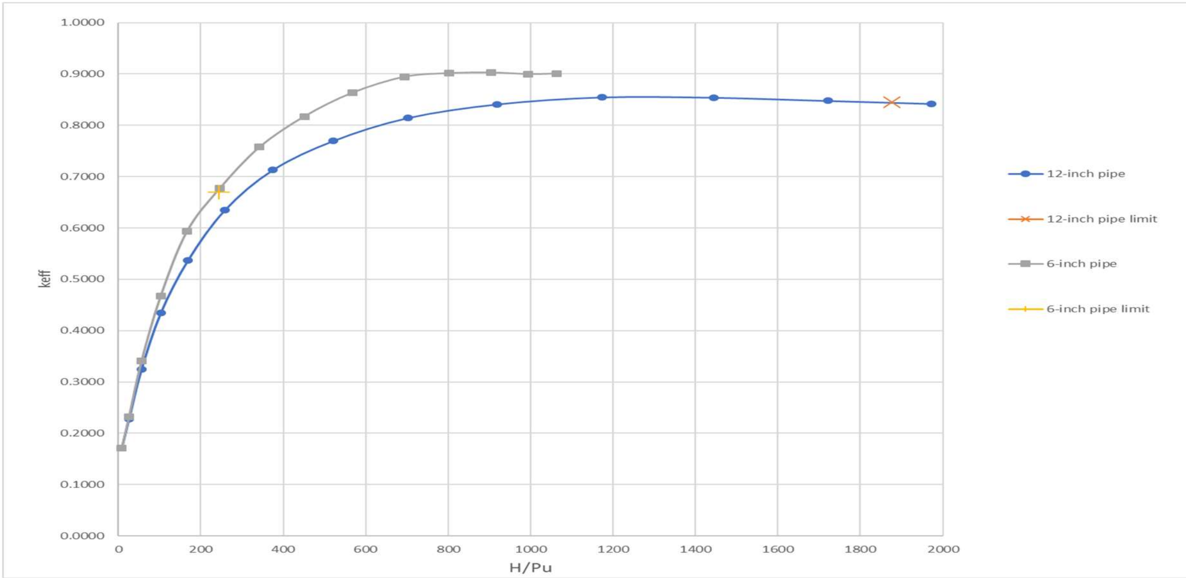


Figure ES-2. 6-inch and 12-inch pipe[4] H/Pu Curves for 153 compacted centroid locations for brine before 2000 years with tight-fitting reflector with 1% Be, Fe, 40% fiberboard, MgO, 20% brine and reflective boundary conditions.

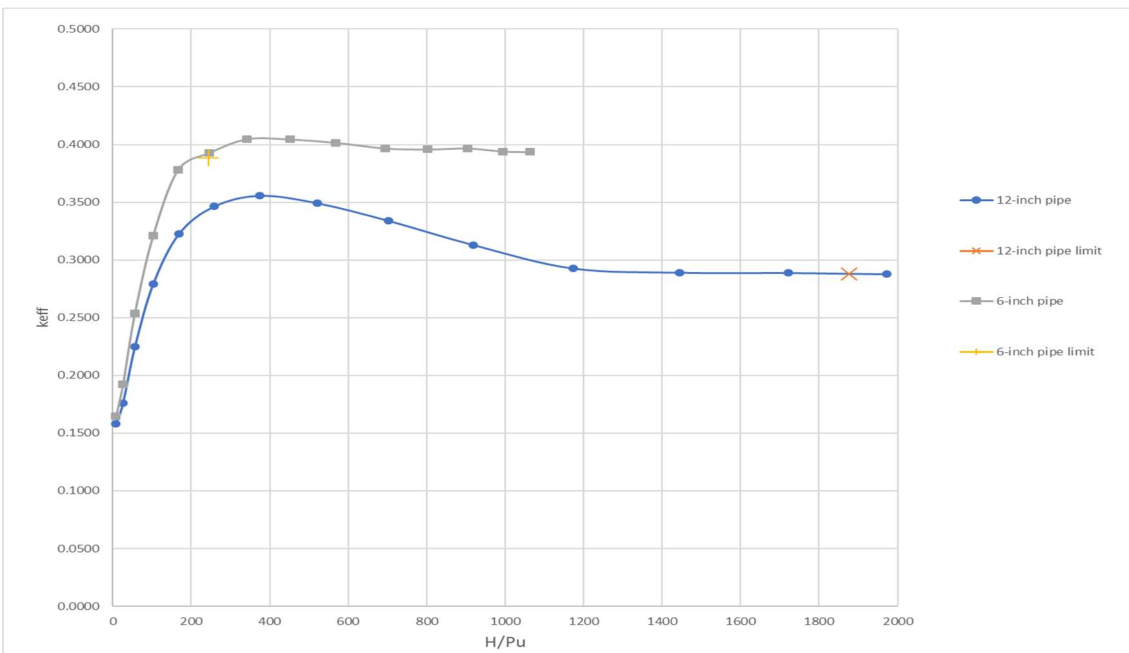


Figure ES-3. 6-inch and 12-inch pipe H/Pu curves for 153 compacted centroid locations for brine after 2000 years with tight-fitting reflector with 1% Be, Fe, MgO, 20% brine and reflective boundary conditions.

[4] Figure ES-2 and ES-3 include the 6- and 12-inch pipe size limit result as a reference point for the size of the sphere which equals the inner diameter of the pipe.

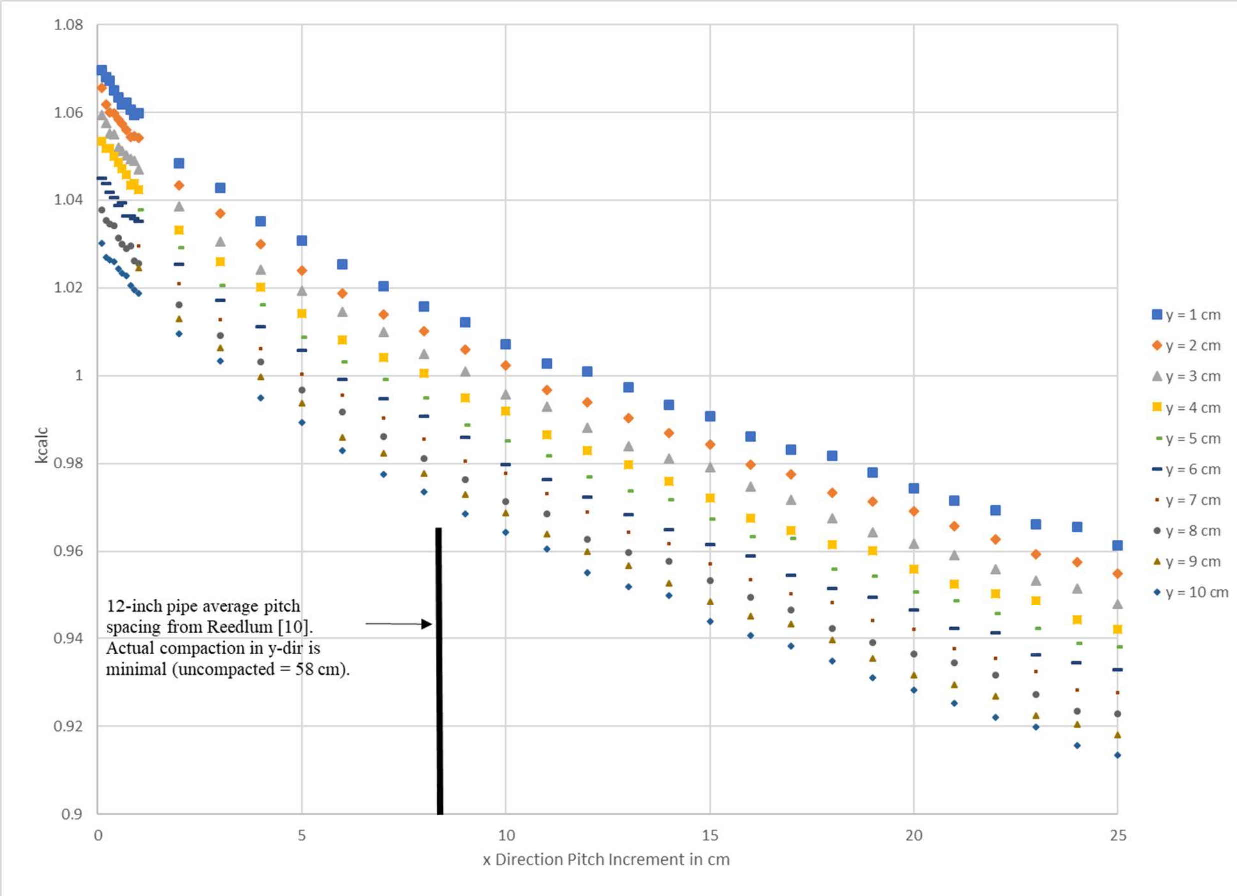


Figure ES-4. Results[5] of incremental edge-to-edge spacing studies for the bounding reflector material composition.

Overall, the configurations analyzed in this report are considered to subsume the range of possible configurations that could potentially occur during the post-closure disposal time period. Ranges of results are provided, but when combined with information considering mechanical deformation resulting from room collapse per Reedlunn [10], the expected amount of compaction in a room is limited, and the configurations within this phase space are all subcritical. Therefore, a low-probability rationale can be derived.

[5] All analysis results are reported as "kcalc" values, meaning the numbers are raw MCNP values with no statistical uncertainty included. The average MCNP uncertainty associated with the analysis calculations is about 0.0006. Any result reported as "k_{eff}" includes 2 * the uncertainty.

1. PURPOSE

This report documents a nuclear criticality assessment of the Waste Isolation Pilot Plant (WIPP) repository with a plutonium disposition waste form in 6- and 12-inch pipe overpacks inside transuranic (TRU) pipe overpack containers (POCs), and it also considers various room compaction scenarios based on the results of Sandia National Laboratories (SNL) compaction studies Reedlunn [10]. This criticality assessment is being performed to support the WIPP repository regulatory post-closure disposal time period for feature, event, and process (FEP) considerations of 10,000 years. To certify the compliance of a geologic repository for radioactive waste, the US Environmental Protection Agency (EPA) requires estimates of the range of future behavior through models that capture essential FEPs of the disposal system. At the WIPP, an operating repository in southeastern New Mexico owned by the US Department of Energy (DOE) for the geologic disposal of wastes containing TRU radioisotopes from atomic energy defense activities, one potential FEP is the possibility of sufficient fissile mass and concentration causing a self-sustained neutron chain reaction (criticality). In the past, concern about the criticality scenario in TRU waste has been low because of the low initial concentration and limit on mass of fissile material (mostly plutonium) in contact-handled containers on all drums in the transportation cask, the neutronic isolation of remote-handled containers, and the natural tendency of fissile solute to disperse once released from the disposal container, as discussed in Rechard et al. [19] and summarized in Rechard et al. [20]. However, waste destined for WIPP has expanded to include other TRU waste with high initial concentration (although still low fissile mass) [20] or larger mass limits for the set of drums in a transportation cask. Hence, a renewed evaluation of the likelihood of assembling a critical mass in or near a repository after closure has been undertaken.

The main objective of this evaluation is to examine the reactivity of fissile material surrounded by various reflector material compositions in conjunction with spacing configurations related to room compaction. The studies described herein considered two separate ways of modeling the system, (1) uniform arrays of optimally moderated $^{239}PuO_2$ spheres with as-emplaced FGE masses—the actual, recorded mass value for each POC in the room—randomly distributed within a panel room configuration and (2) arrays of optimally moderated $^{239}PuO_2$ spheres with 200 FGE, in either a uniform array with spacing based on the results from Reedlunn [10], or at specific locations, based on the centroid[6] locations from the explicitly modeled compaction results from Reedlunn [10]. Using this combination of (1) optimally moderated bounding fissile mass geometry, (2) worst-case composition reflector material combinations, and (3) the full range of pitch spacing, allow material degradation scenarios in conjunction with different compaction configurations of the as-emplaced 6- and 12-inch POCs to be evaluated in a conservative (with respect to criticality) manner. The studies which use the as-emplaced FGE masses provide an evaluation for the reactivity for emplacement activities to date. The studies which use the centroid locations from the compactions results from Reedlunn [10] investigate the POC fissile mass design limit of 200 g. The current WIPP waste acceptance criteria also limit beryllium to less than or equal to 1% of the waste contents by weight [22].

During this post-closure period at WIPP, screening of FEPs is governed by the risk-based standards of US Environmental Protection Agency (EPA) 40 CFR 191 and the implementing regulations in 40 CFR 194. An FEP screening can be based on either a low-consequence rationale or a low-probability rationale. A low-probability rationale includes either (1) a qualitative rationale that the FEP is not credible, or (2) a quantitative demonstration that the probability is less than 10^{-4} in 10^4 years. In this evaluation, a

[6] Centroids are the center point of the 6- and 12-inch pipes.

qualitative low-probability rationale of *not credible* is used by demonstrating that the most probable waste configurations Reedlunn [10] would not be critical while also considering a conservative geometry for the fissile masses (i.e., the optimally moderated spheres) and the reflector material. This approach is therefore inherently conservative. Subcriticality is demonstrated through quantitative calculations, but probability of criticality is never evaluated. The scope of this assessment is focused on long-term waste disposition in the currently emplaced POCs through the repository's performance period of up to 10,000 years.

Section 2 discuses quality assurance specifications and describes the process used to develop this report. The software used to perform these calculations is described in Section 3. Direct inputs that were used in the development of this technical product are documented in Section 4. Section 5 describes the assumptions used in the absence of direct confirming data or evidence to perform the modeling and analyses documented herein. A description of the different analyses performed—as well as the systems, processes, and phenomena considered to assess criticality potential over the WIPP post-closure period are provided in Section 6. Appendix A provides the results of the H/Pu studies; Appendix B provides the results of the reflector material studies; Appendix C provides the results of the incremental spacing studies; Appendix D provides the results of additional studies; Appendix E provides a description of the MCNP files, Appendix F provides the results of full room standard pipe overpack container model calculations, Appendix G provides the results of the 153 centroid studies, and Appendix H provides the results of the 200 FGE spheres in a 959 uniform array with specific spacing studies.

2. QUALITY ASSURANCE

This report was prepared in accordance with Oak Ridge National Laboratory (ORNL) procedures meeting DOE Order 414.1D, Admin Change 1, *Quality Assurance*. Procedures, policies, and guidelines can be found in the *Publications and Other Scientific Communications* subject area of the ORNL Standards-Based Management System (SBMS) under the Integrated Performance Management system.

3. SOFTWARE AND CALCULATIONS

The calculations for this investigation were performed using the Monte Carlo N-Particle Transport Code System (MCNP), Version 6.2 [12]. The code was used to calculate neutron multiplication factors. All calculations were performed with ENDF/B-VII.1 cross section data on the THEBEAST.ornl.gov computer. THEBEAST is a Windows 10 system maintained under the configuration control of ORNL's Reactor and Nuclear Systems Division (RNSD) staff with the following configuration:

- 64-bit Operating System: Windows 10 Enterprise (Product ID: 00329-0000-00003-AA284)
- x64-based processor: Intel® Xeon® Gold 6140 CPU @ 2.30 GHz
- Machine Serial Number: MXL91924MY

The MCNP code package was installed following the installation instructions [12], the test cases included with the software package were executed and the results examined to verify proper installation. All analysis calculations were run with a sufficient number of neutron histories (generations, neutrons per generation, and generations skipped) to yield converged results that passed the appropriate statistical checks. Fission source convergence was verified by the Shannon entropy. The results are reported as k_{calc} values—that is, the MCNP result without any uncertainty—due to the nature of the calculations: reactivity results are being used to establish reactivity trends. The average MCNP uncertainty is about 0.0006.

4. DATA USED TO DEVELOP MODELS

The WIPP underground disposal repository consists of multiple salt panels mined from the Salado formation, a series of salt beds that are 2,000 feet thick. A typical underground panel includes several rooms, each of which is approximately 33 feet wide by 13 feet high by 300 feet long [3]. The emplaced configuration of the waste form consists of 7-packs of POCs stacked three high in a closely packed hexagonal array stacked no more than three high. MgO supersacks are placed on top of the stacks of waste containers. A representative photograph showing how a room is loaded at WIPP is provided in Figure 1.

Figure 1. Photograph of WIPP room loaded with waste containers.

Transuranic (TRU) waste is currently authorized to be shipped to WIPP from DOE generator sites in a limited choice of approved shipping containers. The approved contact-handled (CH) Type B shipping packages include the TRU Package Transporter Model II (TRUPACT-II), the Half-Package Transporter (HalfPACT), and the TRUPACT-III. Waste containers shipped in TRUPACT-IIs and HalfPACTs include 55-gallon drums, 85-gallon drums, 100-gallon drums, shielded containers, standard waste boxes, ten-drum overpacks, criticality control overpacks (CCOs), and pipe configurations overpacked in 55-gallon drums. Transportation analyses include descriptions and nuclear criticality safety evaluations for these various containers [4,6,8]. The scope of this evaluation is limited to the already as-emplaced 6- and 12-inch POCs.

The material compositions vary for the different evaluation models and are either the waste form (fissile spheres) or the reflector (everything exterior to the fissile spheres). The challenge of determining which materials to use in the evaluation is based on the regulatory time frame of 10,000 years. The WIPP repository may be subject to various geologic, environmental, and material degradation, as well as biological transmutation processes, over that time frame. Because the final amount and configuration of any emplaced materials cannot be known, care is taken to avoid an approach which attempts to credit any specific amount of material either as a waste form or reflector. Instead known compositions and quantities are used to establish the most likely material compositions and configurations with which to evaluate system reactivity under various scenarios.

Detailed descriptions of the materials in the WIPP POCs are found in literature [1,2,3,4,6,8,9]. From these material descriptions, compositions were selected for use in this evaluation based on their relative quantity and their potential to impact reactivity.

In this evaluation, the term *reflector* is used for compositions external to the fissile spheres, and *waste form* is used for compositions internal to the fissile sphere. See Figure 2.

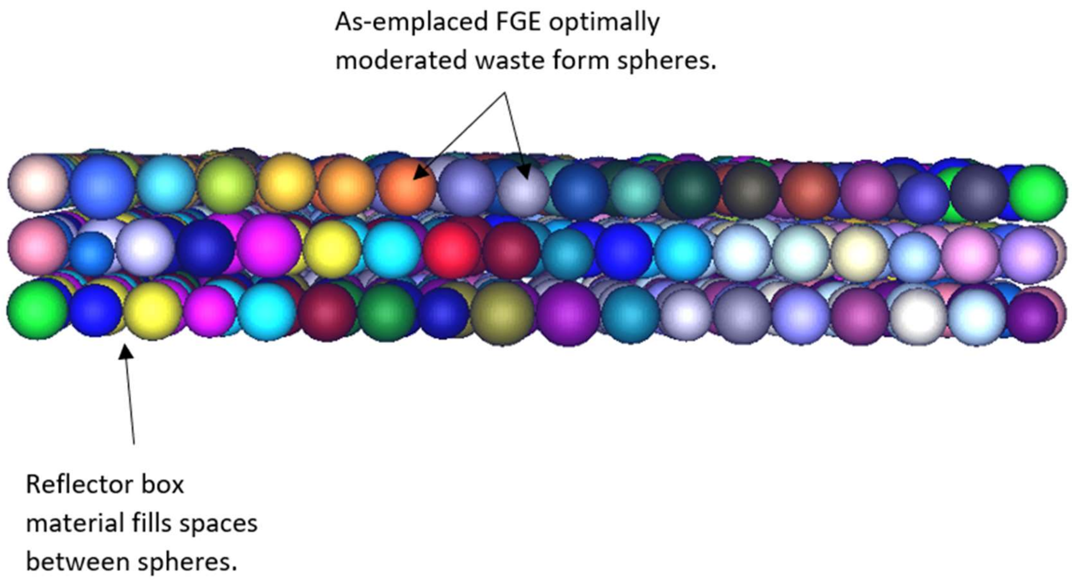


Figure 2. Three-dimensional representation of the as-emplaced FGE optimally moderated sphere uniform array calculation model.

4.1 REFLECTOR MATERIALS

The reflector materials are those materials in the model geometry outside of the fissile spheres, including in-between and surrounding every sphere. The materials in this evaluation consider only those materials with a credible likelihood to be present over the regulatory timeframe of 10,000 years and which have a potential to substantially impact criticality. The reflector materials are described in detail below. All reflector materials described herein are homogenously mixed together to form a uniform mixture which surrounds each sphere.

The following reflector materials are evaluated for the studies related to the as-emplaced FGE uniform array calculations; additional material descriptions are provided in the appendices as needed. The reflector material studies consider first salt, and then additional compositions are added to the mixture. The reflector materials are designated by *m* for *material* followed by a number. The sources of the input data for materials m1–m8 are provided in the following subsections.

m1: salt. The presence of only salt in the system is evaluated.

m2: salt and Fe. In a dry system, the remnant of the steel pipe may act as a reflector because the neutrons which escape the fissile sphere will tend to be high energy and thus will avoid the capture cross section of the fissile material on the outer surface; they will also avoid the capture cross section of the Fe, allowing the Fe to act as a reflector rather than as an absorber.

m3: salt, Fe and beryllium. The reactivity effect of homogenously mixed beryllium in the salt and Fe mixture is evaluated.

m4: salt and beryllium. This case is used to clarify the reactivity impact of the beryllium independently of the Fe.

m5: salt and MgO. This case varies the amount of MgO present from 10 to 50% by volume with the salt. Based on the results of those studies, the 50% ratio of MgO to salt was selected for use in additional studies.

m6: brine (salt and water). Previous evaluations [2] have shown that brine will have a negative effect on criticality. Two brine compositions from these evaluations [2] are evaluated to establish consistency between the results of this evaluation and the previous evaluation.

m7: salt, Fe, beryllium and MgO. This material combination includes all the materials which increase reactivity under dry conditions.

m8: salt, Fe, beryllium, MgO and brine. This material combination includes all the materials which increase reactivity under dry conditions, along with brine to show the reactivity offset associated with the wet condition created by the brine. The more reactive of the two brine materials, m6-1, is used in this material.

4.1.1 Steel and Cellulose from the Standard Pipe Overpack

The POC consists of a pipe component positioned by dunnage (fiberboard) within a 55-gallon drum. The pipe component is a stainless-steel cylindrical pipe with a welded or formed bottom cap and a bolted stainless-steel lid. The pipes analyzed in this evaluation are 6-inches and 12-inches in diameter. Table 1 lists the dimensions of the pipe's components. This information is used to determine the mass of steel associated with each pipe. Figure 3 and Figure 4 [4] show the pipe's components and their respective dunnage arrangements and dimensions. This information provides the basis for calculating the approximate amount of stainless steel and fiberboard (cellulose) associated with each POC in the room. The intent of the evaluation is to determine the reactivity effect of the various reflector materials. No credit is taken for the amount of steel present under wet conditions; nor is it suggested that a penalty be applied for some maximum possible amount of steel present for dry conditions. The relative reactivity effect of a reasonable amount of steel and/or cellulose is being established based on known input data. The effect is being determined relative to the other materials which may make up the reflector under dry and wet conditions.

Table 1. Pipe Component Dimensions

Dimension	6-inch		12-inch	
	Inches	Centimeters	Inches	Centimeters
Steel pipe outer diameter	6.7	17.018	12.8	32.512
Steel pipe outer radius	3.35	8.509	6.4	16.256
Steel pipe wall thickness	0.245	0.6223	0.219	0.55626
Steel pipe inner radius	3.105	7.8867	6.181	15.69974
Steel pipe outer length	26.0	66.04	25.7	65.278
Steel pipe floor thickness	0.25	0.635	0.25	0.635

Steel pipe inner length	25.75	65.405	25.45	64.643
Steel pipe lid thickness	0.9	2.286	0.9	2.286

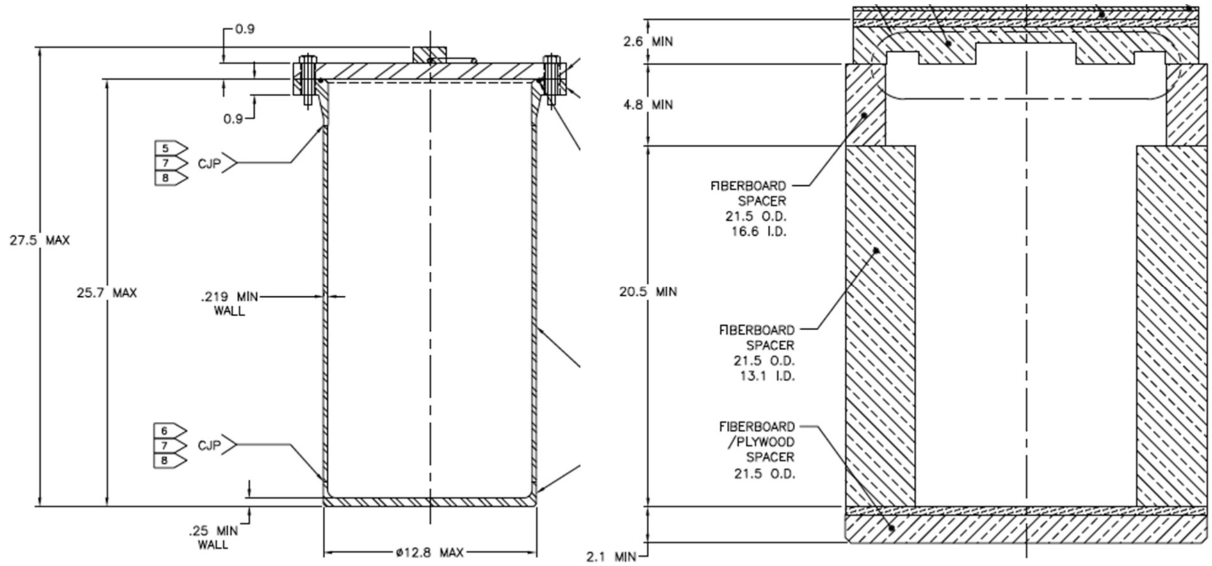


Figure 3. 12-inch standard pipe component and dunnage.

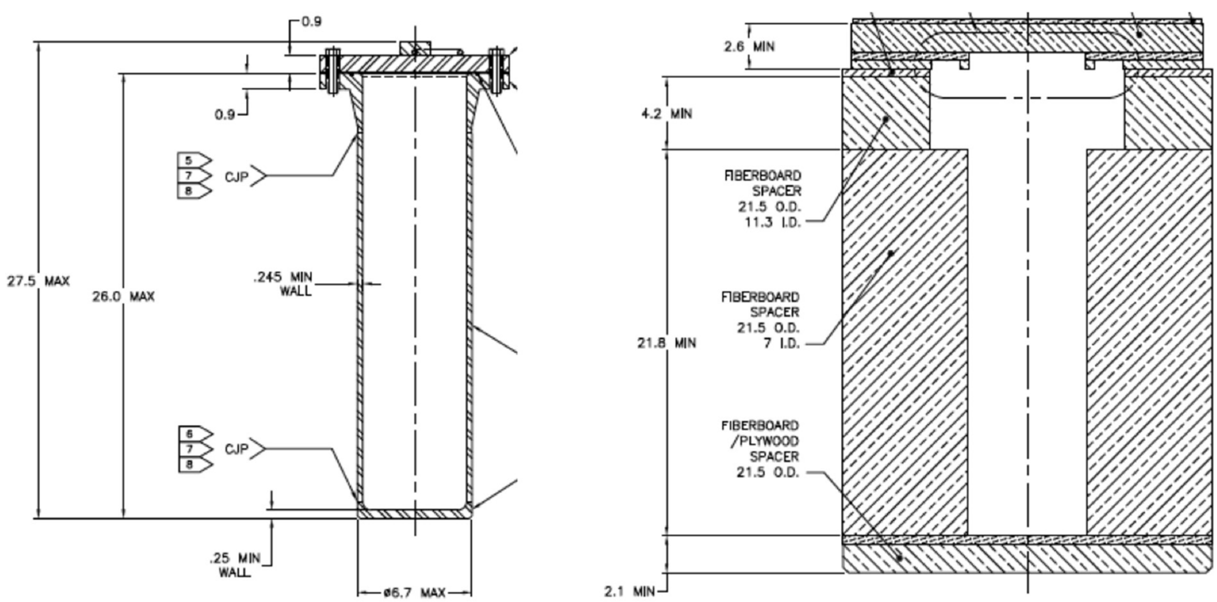


Figure 4. 6-inch standard pipe component and dunnage.

This evaluation does not rely on the geometry of the pipe or the 55-gallon drum for criticality control; however, the dimensions of the pipes are used to determine the mass of steel and/or cellulose associated with each pipe and fissile mass location. The steel and/or cellulose are included because it is known to be present and will have significant neutron interactions for the various scenarios.

Additionally, the radius of the 55-gallon drum is 28.70 cm (11.29 inches) [3]. This value gives one a sense of the distance associated with the noncompacted configuration for comparison to compacted configurations after salt creep and room closure.

The steel from the pipe is assumed to be present as a generic Fe, thus neglecting the other elements in steel. The iron is important to consider because it can act either as a reflector or an absorber, depending on the neutron spectrum. The relative amount of Fe to O is not important since the intent is to approximate the presence of Fe.

The mass of iron used in the evaluation is approximated using the initial mass of the 6- and 12-inch pipes to estimate the potential reactivity effect of the iron. The amount of iron is therefore derived as shown below for the 6- and 12-inch pipe:

- Volume of steel pipe lid: (PI) (r^2)(lid thickness) = 3077.57 cm^3
- Volume of steel pipe base: (PI) (r^2)(base thickness) = 527.17 cm^3
- Volume of steel pipe sides: (PI) (r^2 outer)(pipe length) - (PI)(r^2 inner)(pipe length) = 3609.92 cm^3
- Volume of steel pipe total = 7214.67 cm^3
- Total mass of steel in panel 1 room 1: (959)(7214.67)(7.94) = 5.49×10^7 g
- The relative amount of iron within the steel associated with the pipe (as compared to a drum) is 96.8143% Fe [4]. The steel amount is derived as an equivalent mass of Fe to approximate the amount of Fe. The total mass of Fe in panel 1, room 1 is = 5.32×10^7 g and 2.69×10^7 g for the 12-inch and 6-inch pipes, respectively.

Cellulose is present in the 55-gallon drum system as fiberboard. The cellulose is modeled as $C_6H_{10}O_5$, and its composition is derived using the mass of cellulose calculated for the POC with the 12-inch pipe as 25156.336 g per POC and 35,640.5 g per POC for the 6-inch pipe [2]. The density of the cellulose 0.224 g/ cm^3 [2] is also considered.

4.1.2 Salt

The salt in WIPP can act either as a reflector or an absorber, depending on the neutron spectrum. The salt is evaluated both as dry, modeled as NaCl, and as saturated or brine, modeled as NaCl and H_2O.

The dry salt is assumed to always be present in the reflector. For the brine cases, a procedure developed by SNL [14] lists two equilibrated (saturated) brine concentrations with compositions based on the geochemistry of the area. For this evaluation and to establish the reactivity trend associated with brine in the system as modeled in this evaluation, the two brine compositions [2] that bound the geochemistry of the area in terms of modality are considered: the 6.24 m (moles/kg of H_2O) groundwater depth (GWD), equilibrated (synthetic Salado) and the 5.98 m the Energy Research and Development Administration ERDA-6, equilibrated (synthetic Castile) [14]. For all cases which consider brine, the MCNP model includes the neutron thermal scattering data card provided with the code package.

4.1.3 MgO

The presence of MgO in the reflector material is due to the use of MgO supersacks, which are bags of MgO used at WIPP that are placed on top of about half of the stacks of three 7-packs (see Figure 1). The

MgO is used to absorb CO_2 produced by the decay of carbon-based materials such as wood, paper, plastic, rubber etc. However, as noted in the High Bridge Associates report [9], the MgO has a large neutron scattering cross section and can therefore make a good neutron reflector and/or moderator. Previous studies have evaluated the impact of the MgO as a reflector in its as-emplaced configuration, which is essentially a layer of MgO on top of the stacks of three 7-packs [2]. However, in this evaluation, the MgO is assumed to be mixed homogenously with the other reflector materials. The amount of MgO in the calculations is assumed to be varied by volume ratio with the amount of salt, depending on which case is being considered.

4.1.4 Beryllium

Beryllium is an important consideration within the allowable POC contents because one of its nuclear decay processes is n2n. Previous sensitivity studies were performed that included beryllium as part of the plutonium disposition waste form [2,4] and within the reflector material. Beryllium is limited to 1% by weight limit in the POCs [6]. Consideration of the 1% beryllium by mass would yield an average mass of beryllium that is less than 1.021 kilograms per container in this evaluation of 12-inch POCs and 0.2994 kilograms per container in this evaluation of 6-inch POCs. These values are low compared to values in other container designs, which may be intermixed within the rooms containing the POCs. Therefore, to consider the possibility of much larger masses of beryllium, the approach is to use the mass of beryllium allowed by other containers—4.54 kg—but to consider it homogenously mixed in the reflector rather than within the waste form (see below). For the evaluations in Appendix A, B and C the value for beryllium in the reflector material of 4.54 kg [3] per waste form mass is used to maximize its reactivity effect on the system. For the studies presented in Appendix D and Appendix G, the value for beryllium in the waste form of 1% of the waste mass is used.

4.2 WASTE FORM

The 6- and 12-inch pipe contains the materials holding various amounts of fissile material, along with the materials which are discarded because of their fissile material contamination. The fissile material present in the waste form was quantified in terms of ^{239}Pu FGE using the information from Kirkes [13] and was specified in the calculational models as ^{239}Pu in the form of $^{239}PuO_2$ [5]. The known mass of ^{239}Pu and its reported measurement uncertainty are considered by adding the uncertainty to the mass.

The actual as-emplaced configuration of fissile material is variable; however, it is contained within the geometry of the 6- and 12-inch pipe, along with other materials such as plastic, beryllium, etc. Therefore, the configuration has some heterogenous distribution, along with the other material. To account for the unknown changes possible over the regulatory timeframe of 10,000 years, the fissile material is treated in its bounding geometry and moderation configuration with respect to criticality: optimally moderated spheres [5]. This approach is also consistent with existing analyses presented in the TRUPACT-II Safety Analysis Report [4], which also considered optimally moderated spheres. The spherical geometry yields the greatest mass per unit of surface area [11]. While this configuration maximizes reactivity potential, it is not credible to form uniformly under natural conditions within the repository considering the number of competing forces as the room collapses. However, this configuration is used to evaluate impacts of room closure geometry and material redistribution effects.

The neutronic properties of the optimally moderated spheres also make them the correct evaluation configuration for this analysis. For neutronic coupling to occur between the spheres, the neutrons must be able to exit one sphere and either be reflected back into that sphere where it can be moderated and absorbed for a new fission, or they must be able to exit the sphere and enter another sphere in the room, or be lost (e.g., leakage). For that process to be promoted to maximize reactivity, the material on the outside of the sphere (reflector) should not absorb neutrons or moderate and then absorb neutrons. Parametric studies are used to determine the sphere size and material composition for this purpose, and this is included independently for each mass in the room.

4.2.1 Single Sphere Model H/Pu Waste Form

Existing analyses address a mixture of 74% water, 25% polyethylene and 1% beryllium by volume [6,7]. Although water is not expected to be in the 6- and 12-inch pipe, intrusion of brine is possible during the regulatory time frame of 10,000 years. Thus, both water and polyethylene would be possible H-bearing materials within the vicinity of the fissile mass[7]. Since the Cl in the brine composition is expected to decrease reactivity, the water used in the waste form conservatively neglects the salt and is treated as pure water. Treating the brine as water only is conservative both because it neglects the parasitic absorptions of neutrons in the Cl but for every molecule of NaCl that is replaced by a molecule of H_2O the amount of H per unit volume is increased. Increasing the amount of H per unit volume of the waste form spheres increases the H/Pu ratio for smaller sphere sizes relative to including the NaCl from the brine and therefore the spheres are more reactive at smaller radii. Previous studies [6,7] showed that 25% polyethylene is conservative relative to lesser volume fractions, so the waste form used 25% polyethylene and 75% water as the source of H for optimum moderation. Therefore, studies are performed to confirm the same relative amounts (25% and 75%) previously considered [6,7], and the bounding ratio is used for the waste form for various fissile masses. The material composition and radius of each fissile sphere is determined as follows:

$$\text{Mass}^{8} \text{ of } PuO_2 = \text{mass of } {}^{239}Pu/0.881945^{9} \quad (1)$$

$$\textit{Volume} \text{ of } PuO_2 = (\text{Mass of } PuO_2) / (\text{density of } PuO_2)^{10} \quad (2)$$

$$\text{Initial radius of } PuO_2 \text{ sphere} = [(\text{Volume of } PuO_2)\ (3) / (4PI)]^{1/3} \quad (3)$$

To determine the H/Pu ratio, volumes of moderator (mixture of polyethylene and water) are added to the initial radius of the PuO_2 sphere in radius-size increments for a range of increments to create the H/Pu plots and to determine the peak reactivity mixture and associated incremental radius size.

$$\text{Radius of sphere} = \text{Initial radius of } PuO_2 \text{ sphere} + \text{moderator incremental radius} \quad (4)$$

From the new total radius of the sphere, the volume and mass of each component (75% H_2O (water from brine, neglecting the NaCl) and 25% CH_2) is calculated to determine the weight fractions and number densities for MCNP and the H/Pu ratio, respectively.

For the H/Pu parametric studies, various reflector materials were considered: either pure water (an infinite reflector) or some combination of reflector materials, and then pure water (infinite reflector).

The H/Pu fissile masses of 50–200 g are grouped into 25 g increments to create fissile mass bins. In this way, any fissile mass from 50–200 g can be further evaluated.

[7] Therefore are typically used to bound all possible materials mixed with waste form.
[8] This mass varies depending on the mass of ^{239}Pu for each sphere.
[9] Mass ratio of Pu in PuO_2, calculated from the values in Table 2 and Table 3.
[10] See value used in Table 4.

4.2.2 Full Room Model Waste Form

The bounding results of the single sphere H/Pu waste form studies are used in the full-room model with the random fissile masses and bounding moderator corresponding to the fissile mass bin associated with the POC's fissile mass. The set of POC data used for the full-room evaluations is selected from the set of POC data provided by Kirkes [13]. In general, these data [13] show that the POCs have a well-defined mass that is on average less than the 200 g limit (average for the rooms). There is also an uncertainty associated with these defined, emplaced masses which is added to each mass for this evaluation. The fissile mass population per panel and room is therefore well known and defined by its as-loaded mass plus its associated uncertainty. The population of these masses is presented in Figure 5. The data from Kirkes [13] was also used to discern panel 1, room 1 masses, where there are 959 POCs emplaced [13]. Based on the information presented in Figure 3, the distribution of masses within the various rooms of the various panels shows that panels have similar mass distributions. Therefore, panel 1, room 1 is an adequate representation of the WIPP repository.

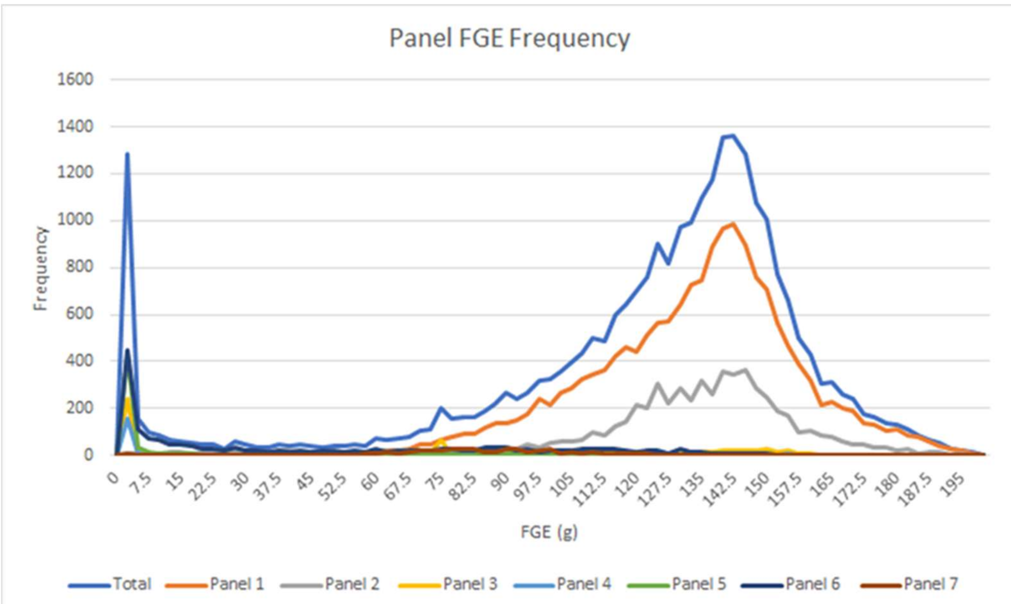


Figure 5. Distribution of fissile mass per panel and room.

While the as-emplaced configuration of these 959 masses is well known [13], these POCs and associated contents can move as the room undergoes salt intrusion and compaction during the regulatory time period of 10,000 years. To account for this, each mass is randomly distributed within the model configuration to generate a distribution of k_{eff} values so that a confidence interval can be determined on what the maximum reactivity increase could be. A distribution based on 300 realizations of these random distributions was used [17]. The results of the 300 realizations show that there is no significant variation in reactivity associated with any subset of possible configurations, regardless of the reflector material composition (external to the spheres in the room models). Therefore, the use of any particular realization of the random distributions is acceptable to use for additional studies.

4.3 INPUT DATA TABLES AND MATERIAL COMPOSITIONS

The material compositions used in this evaluation are based on elemental data and calculated values, depending on the case. The total waste form volume of the panel 1, room 1 optimally moderated spheres is 4,606,171.6 cm^3.

Table 2. Isotope and Elementary Data

Parameter	Value	Unit	Source
Neutron mass	1.008664967	amu	MCNP USER'S MANUAL Code Version 6.2 [12]
N_a	0.6022	entities	Avogadro's number [18]
H-1 mass	1.007825082	amu	atomic weight ratio times n mass [12]
H-1 abundance	0.999885	Isotope fraction	NEA database [7]
H-2 mass	2.014101883	amu	atomic weight ratio times n mass [12]
H-2 abundance	0.000115	Isotope fraction	NEA database [7]
A[11]-1	1.007940804	amu	calculated
^{9}Be	9.012182659	amu	atomic weight ratio times n mass [12]
C	12.01103748	amu	atomic weight ratio times n mass [12]
^{16}O mass	15.99491544	amu	atomic weight ratio times n mass [12]
^{16}O abundance	0.99757	Isotope fraction	NEA database [7]
^{17}O mass	16.99913256	amu	atomic weight ratio times n mass [12]
^{17}O abundance	0.00038	Isotope fraction	NEA database [7]
^{18}O[12] mass	17.84453957	amu	atomic weight ratio times n mass [12]
^{18}O abundance	0.00205	Isotope fraction	NEA database [7]
A-8	15.99908877	amu	calculated
^{23}Na mass	22.98977045	amu	atomic weight ratio times n mass [12]
A-11	22.98977045	amu	calculated
^{24}Mg mass	23.98504292	amu	atomic weight ratio times n mass [12]
^{24}Mg abundance	0.7899	Isotope fraction	NEA database [7]
^{25}Mg mass	24.98583819	amu	atomic weight ratio times n mass [12]
^{25}Mg abundance	0.1	Isotope fraction	NEA database [7]
^{26}Mg mass	25.98259425	amu	atomic weight ratio times n mass [12]
^{26}Mg abundance	0.1101	Isotope fraction	NEA database [7]
A-12	24.30505285	amu	calculated
^{35}Cl mass	34.96885446	amu	atomic weight ratio times n mass [12]
^{35}Cl abundance	0.7578	Isotope fraction	NEA database [7]
Table 2. Isotope and Elementary Data (cont.)			
^{37}Cl mass	36.96590447	amu	atomic weight ratio times n mass [12]
^{37}Cl abundance	0.2422	Isotope fraction	NEA database [7]
A-17	35.45253997	amu	Calculated

[11] A = atomic mass of an element, considering the isotopes listed for that element.
[12] ^{18}O has no cross sections available in MCNP, so the contribution from ^{18}O is added to ^{17}O.

^{54}Fe mass	53.47624336	amu	atomic weight ratio times n mass [12]
^{54}Fe abundance	0.05845	Isotope fraction	NEA database [7]
^{56}Fe mass	55.45442952	amu	atomic weight ratio times n mass [12]
^{56}Fe abundance	0.91754	Isotope fraction	NEA database [7]
A-26	54.00734369	amu	calculated
^{239}Pu	239.0521755	amu	atomic weight ratio times n mass [12]

Table 3. Molar Mass of Compounds

Parameter	Value	Source
PuO_2	271.0503531	Calculated from values in Table 2. For example: $M_{NaCl} = M_{Na} + M_{Cl}$ = (Na-23 mass) + (Cl-35 mass)*(^{35}Cl abundance) + (^{27}Cl mass)*(^{37}Cl abundance)
polyethylene (CH_2)	14.02691909	
H_2O	18.01497038	
MgO	40.30414162	
NaCl	58.44231042	
Cellulose ($C_6H_{10}O_5$)	162.142662	

Table 4. Material Densities (g/cm^3)

Parameter	Value (g/ cm^3)	Source
PuO_2	11.96[13]	Compendium of Material Composition Data for Radiation Transport Modeling [16]
polyethylene (CH_2)	0.93	Nuclear Criticality Safety Assessment of Potential Disposition at WIPP [2]
H_2O	1	Compendium of Material Composition Data for Radiation Transport Modeling [16]
Be	1.848	Nuclear Criticality Safety Assessment of Potential Disposition at WIPP [2]
MgO	1.45	Nuclear Criticality Safety Assessment of Potential Disposition at WIPP [2]
Salt (NaCl)	2.165	Nuclear Criticality Safety Assessment of Potential Disposition at WIPP [2]
cellulose ($C_6H_{10}O_5$)	0.224	Nuclear Criticality Safety Assessment of Potential Disposition at WIPP [2]

[13] This value is slightly higher than the actual theoretical density.

Table 5. Material Composition for the Optimally Moderated Sphere Studies (Case for 200 g PuO_2 sphere with radius 11.6545 cm, optimally moderated with 25% CH_2 and 75% H_2O, pure water reflector)

Parameter	Reflector	Sphere
MCNP ZAID[14].XS	Weight fraction	
1001.70c	0.111873	0.115371
1002.70c	2.57E-05	2.65E-05
8016.70c	0.885694	0.657259
8017.70c	0.002407	0.001786
94239.70c	n/a	0.0297635
6000.70c	n/a	0.195793
Material density g/cm^3	1.0	1.01391

[14] The MCNP ZAID is the numerical identifier unique to each isotope in the given cross section library [12].

Table 6. Reflector Material Composition for the Full Room Reflector Material Studies

Isotope	m1 (salt)	m2 (salt, Fe)	m3 (salt, Fe, Be)	m4 (salt, Be)	m5 (50% salt, 50% MgO)	m5 (60% salt, 40% MgO)	m5 (70% salt, 30% MgO)	m5 (80% salt, 20% MgO)	m5 (90% salt, 10% MgO)	m6-1 (brine 5.98 M)	m6-2 (brine2 6.32 M)	m7 (salt, Fe, MgO, Be)	m8 (salt, Fe, MgO, Be, Brine 5.98 M)
MCNP ZAID.XS	**Weight fraction (reflector box volume 1.3939e8 cm^3)**												
1001.70c										0.0817484	0.0858248		0.0271112
1002.70c										1.879E-05	1.973E-05		6.231E-06
8016.70c		0.026077	0.026137		0.158793	0.122201	0.088291	0.056779	0.02742	0.6472012	0.6794744	0.1572183	0.4162439
8017.70c		7.08626E-05	7.1E-05		0.000431	0.000332	0.00024	0.000154	7.45E-05	0.0017587	0.0018464	0.0004272	0.0011311
11023.70c	0.393375	0.330554	0.325259	0.387686	0.23559	0.23559	0.23559	0.23559	0.23559	0.1059254	0.0915914	0.188345	0.0351293
17035.70c	0.453428	0.381016	0.374913	0.446871	0.271555	0.313466	0.352305	0.388397	0.422023	0.122096	0.1055738	0.2170978	0.0404921
17037.70c	0.153196	0.128731	0.126669	0.150981	0.091748	0.105908	0.11903	0.131224	0.142586	0.0412516	0.0356694	0.0733491	0.0136807
26054.70c		0.007729	0.007747									0.0089714	0.0115043
26056.70c		0.125819	0.126102									0.1460419	0.1872733
4009.70c			0.013102	0.014463								0.0151742	0.0194583
12024.70c					0.188547	0.145098	0.104834	0.067418	0.032558			0.1507358	0.1932924
12025.70c					0.024866	0.019136	0.013826	0.008891	0.004294			0.0198791	0.0254915
12026.70c					0.028469	0.021909	0.015829	0.01018	0.004916			0.0227601	0.0291858
material density (g/cm^3)	2.165	2.3892	2.3838	2.1418	1.8075	1.879	1.9505	2.022	2.0935	1.1695	1.1432	2.0584	1.6052

Table 7. Reflector Material Composition for the Full Room Spacing Studies

MCNP ZAID.XS	m3 (salt, Fe, Be)	m6-1 (brine 5.98 M)	m7 (salt, Fe, MgO)	m8 (salt, Fe, MgO, Be, Brine 5.98 M)
	Weight fraction (reflector box volume 3.0554e9 cm^3)			
1001.70c		0.0817484		0.0211531
1002.70c		1.879E-05		4.862E-06
8016.70c	0.001307	0.6472012	0.241465	0.2970935
8017.70c	3.55E-06	0.0017587	0.000656	0.0008073
11023.70c	0.389969	0.1059254	0.232381	0.1884419
17035.70c	0.449502	0.122096	0.267856	0.2172095
17037.70c	0.15187	0.0412516	0.090498	0.0733868
26054.70c	0.000387	0.1059254	0.000464	0.0003759
26056.70c	0.006306		0.007546	0.0061191
4009.70c	0.000655		0.000784	0.0006358
12024.70c			0.273513	0.1520562
12025.70c			0.036071	0.0200533
12026.70c			0.041299	0.0229594
material density (g/cm^3)	2.175	1.1695	1.8175	1.3238

5. ASSUMPTIONS

5.1 REFLECTOR MATERIAL COMPOSITIONS

*Assumptio*n: The reflector material composition is assumed to be homogenized over the reflector region.

Basis: The intent of the analysis is to determine the reactivity effect of the fissile masses in various spatial orientations. Reactivity is also dependent upon the spatial orientation of the reflector materials relative to the waste forms. Since the final configuration of the materials in the repository system after 10,000 cannot be specifically determined, the spatial orientation of the materials is treated homogenously to remove any dependence of specific spatial orientations from the calculations.

5.2 MAGNESIUM OXIDE MODEL

*Assumptio*n: The magnesium oxide super sacks are assumed to be homogeneously mixed with the salt and other reflector materials.

Basis: Studies were performed which showed that increasing the ratio of MgO to salt in the reflector from 10% to 50% MgO increases reactivity significantly (See Appendix B, Case B5). The MgO super sacks are typically placed on every other stack of the 7-pack stacks [2], resulting in an approximately 50% coverage rate. In the fully compacted scenario, 50% of the stacks with MgO supersacks approximates 50% of the remaining volume of the compacted POCs. The post closure behavior of the repository is expected to include roof fall scenarios at first, and then compaction from above as well as from the sides of the rooms. It is likely that the roof fall and compaction from above will puncture the supersacks, resulting in the MgO falling in and around the containers. Then, as compaction continues, salt will also mix in with the MgO in some ratio. In lieu of better information, the studies presented in Appendix B for the ratio of MgO to salt to consider is therefore limited to a 50/50 ratio. As is discussed in Section 5.1, the reflector materials are homogenized. For cases in the analysis which consider MgO, the MgO is treated as having 50% of the volume that the salt would occupy in the model, and it is assumed to be homogenized with any other reflector materials.

6. ANALYSIS DISCUSSION

This report documents the investigation of scenarios associated with disposal of plutonium waste in 6- and 12-inch POCs at WIPP over a 10,000-year performance period. The analysis considers both uniform arrays at various pitches (for as-emplaced FGE masses and 200 FGE masses) and centroid specific orientations (for 200 FGE masses) based on compactions studies Reedlunn [10] using conservative reflector and waste form compositions and geometries to establish reactivity trends associated with various parameters such as material composition and fissile mass spacing. Neutron multiplication in the repository system depends on the amount and location of fissile material (i.e., the waste form) and the composition of the material which surrounds the fissile material (i.e., the reflector material).

The uniform array analysis evaluates the waste form and potential reflector materials beginning with salt and then adding materials one at a time in order to determine the reactivity effect of each material independently and in conjunction with the other materials. Since each POC contains a unique fissile mass, and these masses are known [13], the analysis calculates the reactivity of one of the repository panel rooms as it is currently emplaced.

Randomly distributing the masses within the room model makes the results independent of spatial locations of the as-emplaced POCs and makes the results of the analysis applicable to any other room. To justify the selection of the randomly distributed fissile masses, extensive studies are referenced for 300 sets of distributed masses to show that the reactivity of the room system is essentially unchanged with respect to the distribution of fissile mass. See Appendix B and Appendix C.

A conservative approach is considered for the fissile mass waste form: optimally moderated spheres are modeled. To obtain the optimum H/Pu ratio for an individual randomly distributed mass within the room model, the H/Pu parametric studies are used to determine the optimum H/Pu ratio for the range of fissile masses (50–200 g ^{239}Pu) so that the resulting mass bins can be used for each random mass. Various infinite moderating reflector materials are considered to verify that the peak H/Pu ratio does not change significantly for different reflector materials. The results of the H/Pu single sphere studies are then used in the room model calculations for parametric studies of reflector materials and for incremental spacing studies. See Appendix A. The calculations for the 200 FGE masses evaluate the H/Pu ratio for each scenario evaluated, using the uniform array model or the centroid specific model, depending on the case.

Figure 6 illustrates the location of the optimally moderated fissile spheres and reflector materials. This figure is a partial representation of the entire model.

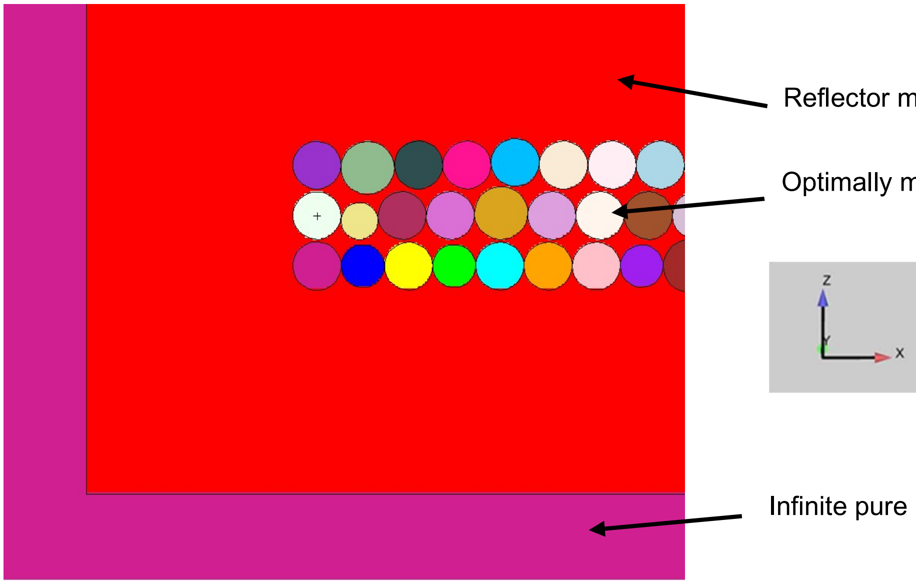


Figure 6. A partial representation of a full room model to illustrate the optimally moderated spheres and reflector materials.

The results of the analysis are discussed below and are presented in the appendixes to the report. As with any computer code/calculation used for safety analyses and assessments, the ability of the calculation to prove a configuration to be subcritical is obtained through a validation process. Although the application model in this evaluation is not the same as that used in Appendix D of the Nuclear Criticality Safety Assessment of Potential Disposition at WIPP [2], an estimate of the bias and bias uncertainty associated with the calculated results in this report are expected to be consistent with the value reported in [2] of a bias of 0 with a bias uncertainty in the range of 0.0165 to 0.0029.

6.1 H/^{239}PU (H/PU) CURVE PARAMETRIC STUDIES

The reactivity of each individual fissile mass in each POC depends on the moderation available to the fissile mass. The most reactive configuration of a fissile mass is a critical sphere, a geometry which balances size (radius) with internal moderation (H content) such that reactivity is maximized. For masses which cannot reach a critical configuration because there is insufficient mass, the most reactive balance between size and internal moderation remains applicable. The determination of the optimum moderator sphere radius, or H/Pu ratio, is required to maximize reactivity in the room models so that each POC fissile mass in the model is conservatively at its most reactive configuration.

The following sequence was used for this purpose:

1. Water-reflected (infinite) single cell models are used with fissile spheres of various radii as determined by the range of H/Pu considered to establish the optimum. See Figure 7 for an illustration of the single-cell models.

2. Sequential calculations are performed for incremental increases in the radius of the sphere. The radius of each fissile sphere is determined in the following manner:

   a. For each fissile mass considered in the range of 50–200 g ^{239}Pu, the initial mass of the fissile material is used to calculate the bare sphere radius for $^{239}PuO_2$.

b. The total fissile mass is increased by the addition of O_2 using the ratio of O to Pu in PuO_2 (0.881945, calculated from values in Table 2).

c. From the total mass of $^{239}PuO_2$, the volume of $^{239}PuO_2$ is determined using the density of $^{239}PuO_2$ (see Table 4).

d. From the volume of $^{239}PuO_2$, the radius of an equivalent volume sphere is determined using the equation for the volume of a sphere ($4/3\pi R^3$) and solving for R.

3. For each bare sphere which has an equivalent mass to each fissile mass considered, incremental radius increases are used to increase the volume. For each incremental volume increase, the difference in volume to the bare sphere volume is the moderating material volume (polyethylene and water). Polyethylene and water are both considered because the polyethylene is known to be present in the packaging [4], and water is well known as a moderating material which may ingress over the regulatory time period of 10,000 years. Although the water would be present as brine, the salt is not included (except for specific cases in Appendix D and Appendix G) for conservatism.

   a. The material composition of the H-bearing polyethylene and water combinations within the fissile spheres is determined per case, depending on the parametric study. Although these two materials may be present alone or together, and in the full range of possible ratios (0–100%), an effort is made to remain consistent with previous analyses [2, 3, 4] with respect to their ratios in the waste form. Specific studies are performed to justify the approach.

4. The radii of the bare sphere increments range from very small (0.001–0.009 cm), to moderate (0.01–0.09 cm), to large (1–20 cm). These increments are selected to evaluate potential peaks for small increments and to establish the overall trend in reactivity with respect to sphere size (H/Pu ratio).

   a. For each radius increment, the reactivity effects of various materials external to the fissile sphere, including salt, water and polyethylene combinations, steel, and beryllium, are considered.

   b. The models are fully reflected by either water or salt, conservatively neglecting the absorption of water moderated neutrons in Cl.

   c. Results of these parametric studies are then used in the full-room models to provide the derived radius and material compositions for each independent fissile sphere.

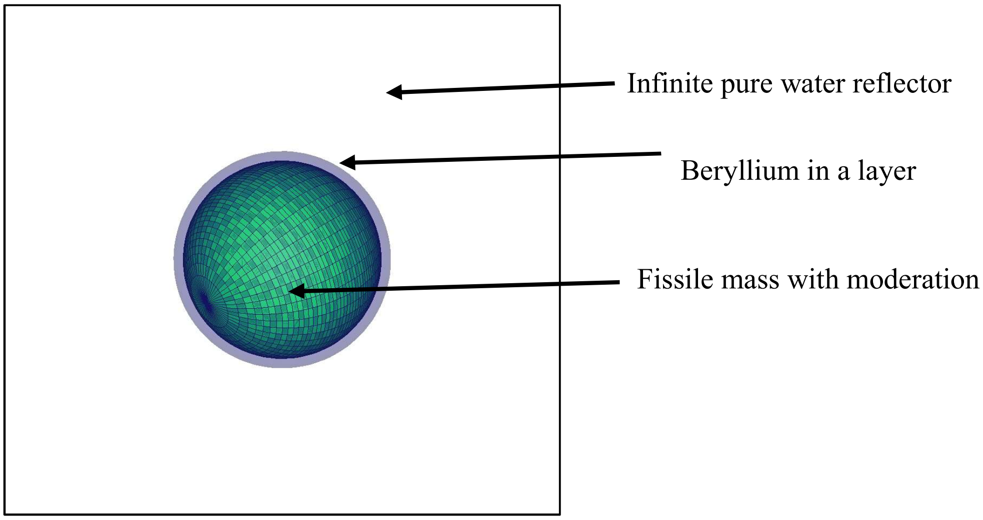


Figure 7. A partial representation of a single sphere model to illustrate the calculations to determine the optimum moderation of the fissile masses under various internal and external conditions.

Results for the H/P studies are presented in Appendix A. The results show that reactivity is maximized when the waste form spheres have an H/Pu ratio between 900-1100, regardless of the source of H, the total fissile mass, or the reflecting media. The reactivity effect of the Be is not used to reflect the sphere.

6.2 REFLECTOR MATERIAL STUDIES USING RANDOM DISTRIBUTION OF FISSILE MASSES

The reactivity effect of the various reflector materials is evaluated using the room model with a random distribution of fissile masses based on the as-emplaced mass of each POC in panel 1, room 1. The results of the H/Pu studies described in Section 6.1 are used to develop the waste form for each fissile mass in room 1 by binning each mass according to the bins outlined in Section 6.1 and for the selection of the optimum moderator radius. The various reflector material compositions used in these studies are discussed in detail in Section 4. A full-room MCNP model is created for 300 sets of random distributions of the actual as-emplaced fissile masses. The room model is constructed in the following manner:

- Each fissile mass has its own unique composition based on the amount of polyethene and water required for optimum moderation, determined as described in Section 6.1. The waste form does not consider beryllium. (For studies which consider beryllium in the waste form see Appendix D and Appendix G). The overall range of fissile mass covers 50–200 g, and this range is divided into bins of 25 g each. Within each bin, the radius increment that yields the optimum H/Pu is selected for each randomly selected POC mass. For each as-emplaced mass in room 1, the mass bin and subsequent bounding H/Pu radius increment is selected for the fissile mass.

- The room model is the *base case*, a fully compacted model in which all space between the spheres is reduced, and full room closure is assumed in every direction. This approach maximizes the reactivity and the parametric reactivity effect of each reflector material evaluated.

- The model is constructed by filling the coordinate system starting at (0,0,0) and working in the positive sense for each direction, starting with x with 18 centroids, then z with 3 centroids, then y with 17–18 centroids. The same sense is used for each direction, as presented in Figure 1. Each sphere selected for the next location is based on a random selection of the masses available from panel 1, room 1. Thus, no two spheres adjacent to each other are likely to have the same radius, but all spheres have a radius yielding the optimum H/Pu.

- Filling the room model requires 18 spheres across the face of the room in the x direction, 3 in the z direction, and about 17–18 in the y direction. This uses up all 959 room 1 fissile masses. This configuration mimics the as-emplaced geometry while eliminating the gaps created between adjacent rows of 7-packs by the triangular pitch [2].

- The total volume of the waste form spheres is calculated and used to determine the relative composition of the reflector material based on the dimensions of reflector box constructed around the area filled by the spheres (see Table 6).

  Volume of reflector box material = (volume of reflector box) – (total volume of spheres)

  The reflector material composition is a homogenization of the various compositions in the material. Therefore, care has been taken to make the reflector box conservative in size, so the reflector box is not spread too large or too distant from the outer edge of the exterior spheres where the material would not be able to interact with important neutrons. The final size is therefore based on engineering judgement. The impact of stipulating that the reflector box only contains the array of spheres results in maximizing the reflector box material density. This is an important parameter of this system, because many of the compositions considered are based on their relative mass present. Therefore, reactivity is maximized, and the relative impact of the reflector materials is maximized. This reactivity effect is seen in the results discussed in Section 6.3. Salt is modeled outside the reflector box with a thickness of 1,000 cm.

The results of these uniform array, as-emplaced FGE masses in a fully compacted configuration are presented in Appendix B. The results show that there is a significant reactivity effect from some reflector material and little to no effect from other reflector materials. Adding Fe to salt increases reactivity by about 0.5 delta-k, adding beryllium to salt and/or salt and Fe has minimal impact, adding MgO increases reactivity by about 0.04 delta-k at the 50% ratio limit used while adding brine reduces reactivity by about 0.19 delta-k. Combining the materials which increase reactivity, the salt, Fe, beryllium and MgO yields a bounding reflector material which is about 0.04 delta-k more reactive than just salt, which is dominated by the MgO.

Upper tolerance limits were calculated for each of the data sets composed of 300 calculations apiece. The tolerance limits were calculated such that there was 95% confidence that 95% of the population of true k_{eff}'s were below the calculated tolerance limits. First, each of the samples were tested for normality using several omnibus normality tests (including the Shapiro-Wilks and Anderson-Darling test). For cases which passed all the normality tests at the 95% confidence level the upper tolerance limit was calculated by adding 1.79964 [17] times the pooled standard deviation of the k_{eff}'s (combined spread in data and Monte Carlo uncertainty) to the average k_{eff}. For cases which did not pass the normality tests upper, tolerance limit was taken as the 9^{th} highest k_{eff} among the 300 calculated values [23], which corresponds to the 95/95 one sided tolerance limit based on Wilks equation for 300 samples.

6.3 INCREMENTAL SPACING STUDIES TO EVALUATE VARIOUS COMPACTION SCENARIOS

As discussed in Section 6.2, a single case from among the 300 sets of random mass distributions was selected for use in additional parametric studies to determine the reactivity trends associated with spacing between POCs. The approach considered in this criticality evaluation is to consider the results of the compaction studies in Reedlunn [10] to determine the reactivity of the system under various POC-to-POC pitch changes due to the ingress of the salt. In all cases, the pitch[15] changes are in increments that begin from the base case configuration, with all spheres at their closest approach. To capture the potential reactivity effect caused specifically by the various reflector materials in conjunction with the various spacing increments, the following studies are considered:

- Based on the results of the reflector material studies, the following subset of reflector materials was selected for incremental spacing studies:

  m3: salt, Fe and beryllium

  m6: brine

  m7: salt, Fe, beryllium and MgO

  m8: salt, Fe, beryllium, MgO and brine

- The same room model used in Section 6.2 is also used for the incremental spacing studies, except it is modified to expand the size of the reflector box to accommodate the changing location of the spheres and to maintain the reflector material around the spheres. For consistency between cases, the reflector box is set to a larger fixed size for all cases, regardless of the spacing increment. Therefore, the reactivity effect seen for each study is due solely to the change in spacing and not the change in the spacing in conjunction with the change in the density of the reflector material. Variations in this approach which consider tight fitting reflector boxes are evaluated in Appendix H.

- The increments used consider both small (0.1– 0.9 cm) and large (1–25 cm) increments. The small increments are provided to determine if there is any optimum spacing (i.e., a reactivity peak) at small increments.

- Within the reflector box, the pitch between spheres is increased for variations in x, y and z directions (where x, y and z have the same sense as shown in Figure 6)— one direction at a time, and in conjunction with the other directions. For each increment, the directional increase means that the pitch between all spheres in that direction is increased by the increment.

- The material outside of reflector box is salt with a thickness of 1,000 cm thick.

The results of these calculations are presented in Appendix C. The results for the bounding reflector material are presented in Figure C-5. Although the model considers a random distribution of as-emplaced FGE masses, resulting in a variety of sphere sizes, the model is constructed such that at 0 spacing the spheres approximate their closest approach. In order to compare the results of this calculation to the results of the compaction study in Reedlunn [10], the maximum sphere radius is used to determine at which x-dir increment is the spacing equivalent to the average 12-inch pipe center to center spacing determined from Reedlunn [10]. The reactivity trend with respect to spacing in the y-dir is clearly established with only 10 1 cm increments. Since the compaction in the y-dir is expected to be insignificant, the trend may be used to determine that the reactivity of the system under compaction is subcritical.

---

[15] Note that the cases in Appendix C use the randomly distributed masses and therefore each sphere has a radius related to the mass. Therefore, the center to center pitch varies across the model. Thus, for these studies, "pitch" refers to the increase in distance between spheres, but this increase in distance is uniform across the model and therefore is better understood as a change in edge to edge spacing.

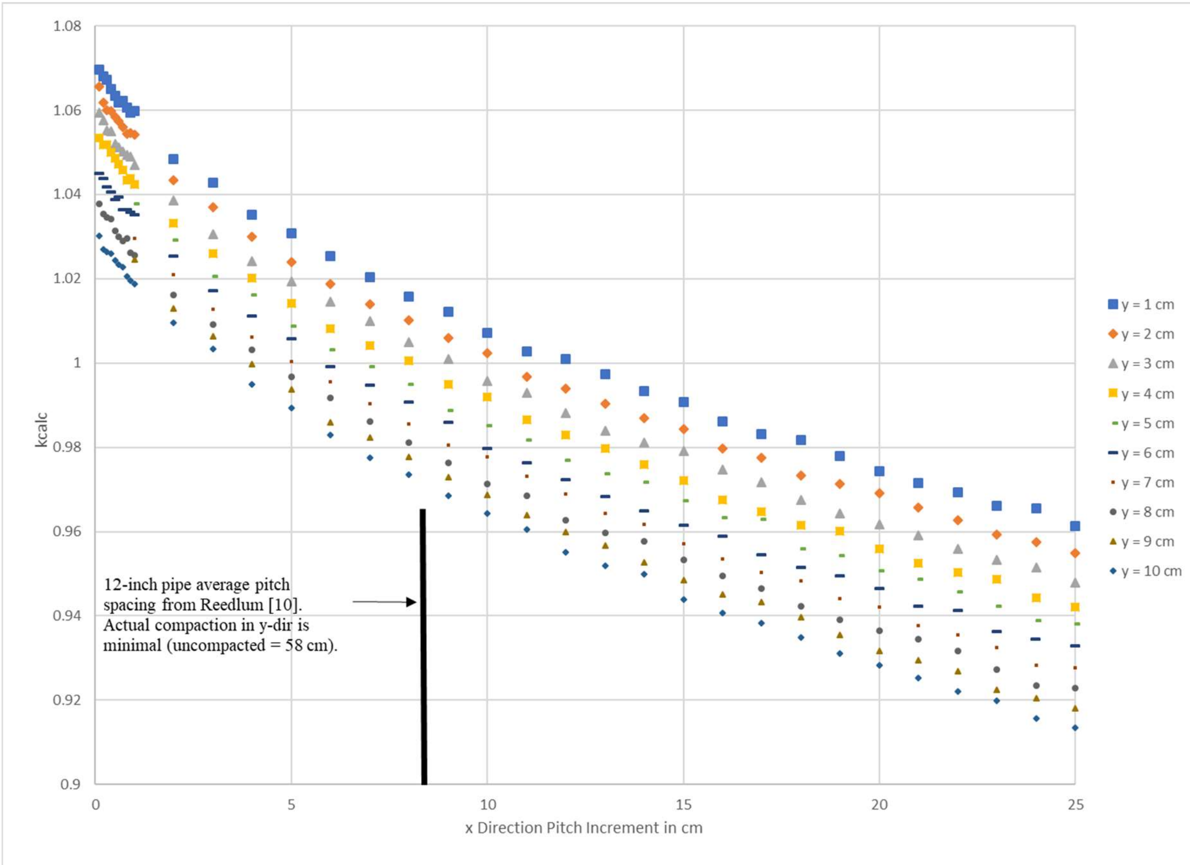


Figure 8. Results of incremental edge-to-edge spacing studies for the bounding reflector material composition, see Appendix C.

6.4 SPECIFIC SPACING STUDIES TO EVALUATE CALCULATED COMPACTION SCENARIOS

In addition to the previously described studies which evaluated the reactivity of the as-emplaced fissile masses under various reflector and incremental spacing configurations, additional evaluations which consider specific spacing configurations and material configurations relevant to the calculated compaction configurations from Reedlunn [10] and repository material configurations expected during the regulatory time frame are considered. These additional evaluations are described in the following appendices:

- Appendix D: evaluates the reactivity of 200 FGE masses under a "two-high" compacted scenarios with 648 spheres with uniform center to center spacing based on Reedlunn [10]. Various material compositions are considered for both the reflector material and the waste form. The results from Appendix D show the reactivity trends for the 6- and 12-inch pipe configurations for both the minimum and average centroid to centroid pitch values from the compaction analysis Reedlunn [10].

- Appendix F: provides full room POC calculations based on the evaluations from Saylor [2]. The results of the calculations in Appendix F are presented to provide a comparison of the modeling approach from considering the configuration of masses and reflector materials in a discreet configuration versus the homogenous configuration.

- Appendix G: evaluates the reactivity of 200 FGE masses under a specific centroid location based on Reedlunn [10]. The model considers 153 centroids locations and nearest neighbor data under various reflector material conditions. The results of the calculations presented in Appendix G provide the reactivity of the system for various material (waste form and reflector materials) expected for the repository time frame of 10,000 years. The timeframe is segregated into up to 2,000 years and after 2,000 years. The results are summarized in the Figure 9[16] and Figure 10 below.

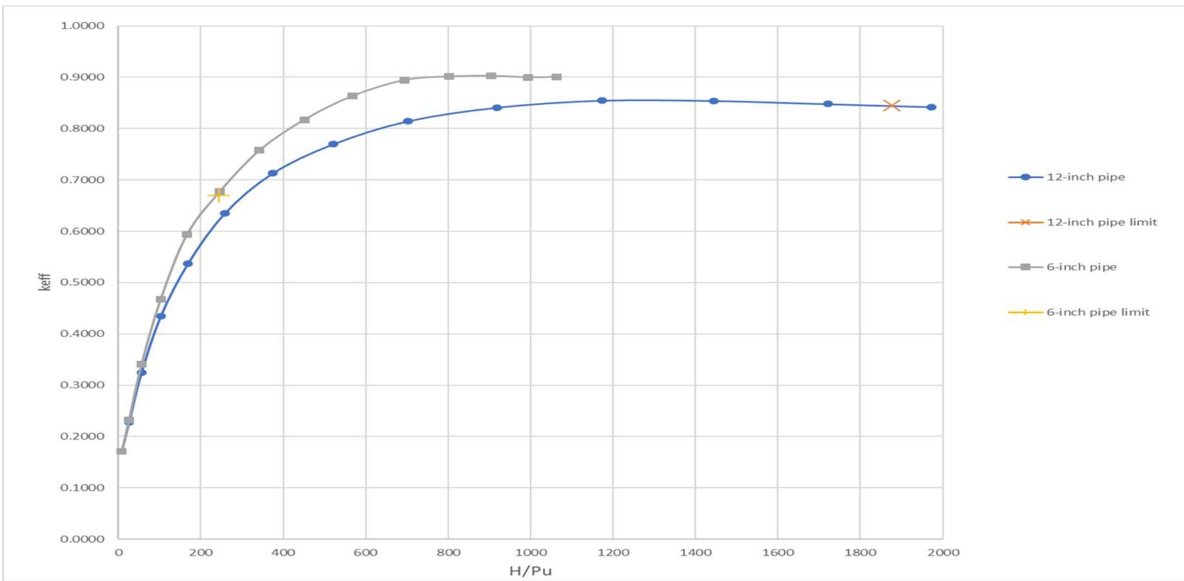


Figure 9. 6-inch and 12-inch pipe H/Pu Curves for 153 compacted centroid locations for brine before 2000 years with tight-fitting reflector with 1% Be, Fe, 40% fiberboard, MgO, 20% brine and reflective boundary conditions.

[16] Figure 9 and 10 include the 6- and 12-inch pipe size limit result as a reference point for the size of the sphere which equals the inner diameter of the pipe.

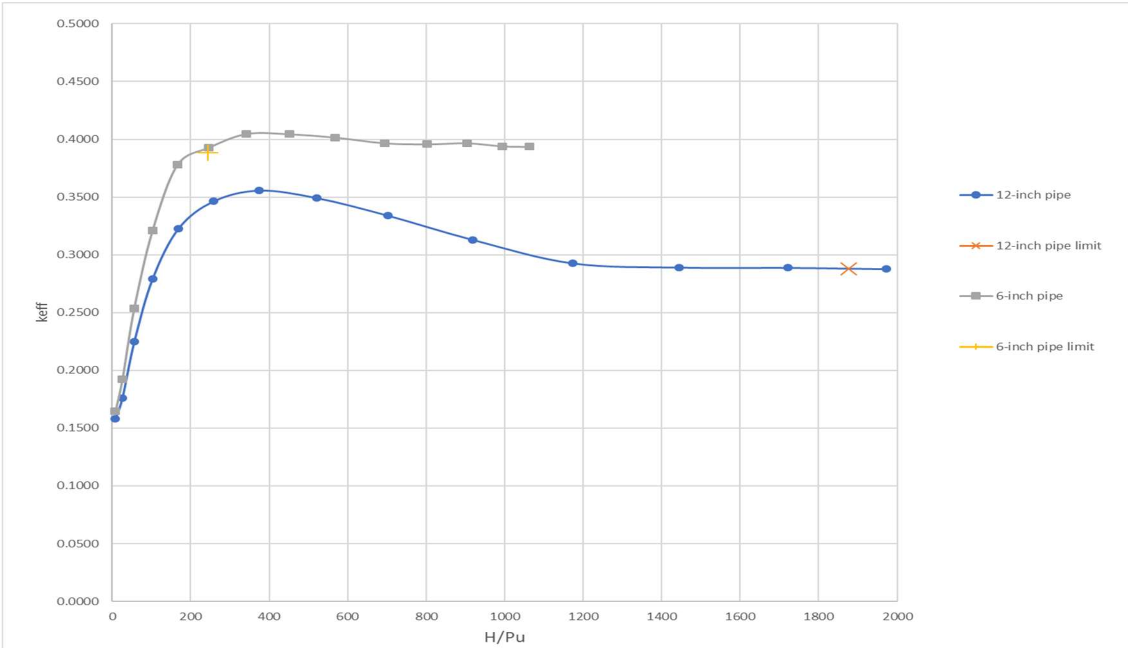


Figure 10. 6-inch and 12-inch pipe H/Pu curves for 153 compacted centroid locations for brine after 2000 years with tight-fitting reflector with 1% Be, Fe, MgO, 20% brine and reflective boundary conditions.

Appendix H: evaluates the reactivity of 200 FGE masses under the same 959 sphere model considered in Appendix B and Appendix C, albeit with specific center to center spacing based on Reedlunn [10]. The results presented in Appendix H show how reactivity changes as a function of H/Pu for a uniform array of 200 FGE masses with center to center pitches for the 6- and 12-inch pipes under compaction for minimum and average values. Additional results are presented which demonstrates that considering all spheres in the model at the same maximum H/Pu ratio (same size) is conservative relative to the spheres having a random distribution of H/Pu. The conservatism ranges from about 0.05 to 0.13 delta-k.

6.5 POST BRINE INTRUSION EVALUATION

Initially dry, the repository may experience brine intrusion because the human intrusion event scenario is considered likely. Therefore, the introduction of brine and subsequently dry out (i.e., reduction in amount of H present) is considered. Due to dry out, the moisture content of the repository during post brine intrusion will be very low, leaving only the H from degraded plastics etc. behind. Also, the intrusion of the brine is expected to create conditions under which the cellulose and Fe undergo composition changes and are no longer relevant to reactivity. Subsequent to the brine intrusion, as the moisture leaves the system and the material composition and arrangement of the reflector materials undergoes changes, the main source of H in the waste form is also removed. As discussed in Section 6.1, one of the significant conservatisms in the analysis is the inclusion in the waste form of water from brine but without the salt. As the various results from Appendix G and H show, the reactivity of the system is very low for low H/Pu ratios. Furthermore, the waste form itself is expected to dissolve and dissipate the Pu among the reflector material, furthering the decrease in reactivity. As the waste form dry out and only the H from plastics remain, the H/Pu ratio decreases significantly. Therefore, the reactivity of the repository is expected to be very low for post brine intrusion conditions.

7. REFERENCES

[1] SNL, Consideration of Nuclear Criticality When Disposing of Transuranic Waste at the Waste Isolation Pilot Plant, SAND99-2898, Sandia National Laboratories, 2000.

[2] Saylor, Ellen M., Scaglione, John M. *Nuclear Criticality Safety Assessment of Potential Disposition at the Waste Isolation Plant*, ORNL/TM-2017/751/R1, 2017.

[3] NWP, *Nuclear Criticality Safety Evaluation for Contact-Handled Transuranic Waste Containers at the Waste Isolation Pilot Plant,* WIPP-016, Revision 5, Nuclear Waste Partnership LLC, 2015.

[4] DOE-CBFO. 2013a. *TRUPACT-II Safety Analysis Report*, Revision 23, Carlsbad, NM: US Department of Energy, Carlsbad Field Office.

[5] William N. Miner, US Atomic Energy Commission Division of Technical Information, *Plutonium*, 65-60923, 1964.

[6] DOE-CBFO. 2013b. *Contact-Handled Transuranic Waste Authorized Methods for Payload Control (CH-TRAMPAC)*, Revision 4, Carlsbad, NM: US Department of Energy, Carlsbad Field Office.

[7] NEA database (Janis 3.3).

[8] DOE-CBFO. 2013c. *CH-TRU Payload Appendices*, Revision 3, Carlsbad, NM: US Department of Energy, Carlsbad Field Office.

[9] High Bridge Associates, Inc. "Comparison of Plutonium Disposition Alternatives: WIPP Diluted Plutonium Storage and MOX Fuel Irradiation," 2016.

[10] Reedlunn, B., J. Bean. Simulations of Pipe Overpack Container Compaction at the Waste Isolation Pilot Plant; Memorandum to Distribution, July 18, 2019. Sandia National Laboratories, 2019.

[11] *American Journal of Physics* 82, 977, 2014.

[12] LA-UR-17-29981, *MCNP USER'S MANUAL Code Version 6.2,* Los Alamos National Laboratory report.

[13] Kirkes, G. R. 2019. "POC data as of June_1_2019.xlsx." Machine readable data. Excel spreadsheet showing all emplaced pipe overpack containers, emplacement locations, and waste information as of June 1, 2019. July 8, 2019. Sandia National Laboratories, Carlsbad Programs Group. ERMS 571584.

[14] SNL. 2008. *Preparing Synthetic Brines for Geochemical Experiments*, Rev. 2, Activity/Project Specific Procedures, SP 20-4, Carlsbad, NM: Sandia National Laboratories.

[15] Title 40 CFR Part 191 Subpart B (Environmental Standards for Disposal).

[16] PNNL-15870, *Compendium of Material Composition Data for Radiation Transport Modeling*, March 4, 2011.

[17] NUREG-1475, Revision 1, *Applying Statistics*, March 2011.

[18] Lockheed Martin, *Nuclides and Isotopes, Chart of the Nuclides*, 16th Edition 2002.

[19] R. P. RECHARD, L. C. SANCHEZ, H. R. TRELLUE and C. T. STOCKMAN, "Unfavorable Conditions for Nuclear Criticality Following Disposal of Transuranic Waste at the Waste Isolation Pilot Plant," *Nuclear Technology*, **136**(*1*), 99-129 (2001).

[20] R. P. RECHARD, "Probability and Consequences of Nuclear Criticality at a Geologic Repository--I: Conceptual Overview for Screening," *Nuclear Technology*, **190**(*2*), 97-126 (2015).

[21] DOE (US DEPARTMENT OF ENERGY), "Surplus Plutonium Disposition, Record of Decision," *Federal Register*, **81**(*65*), 19588-19594 (2016).

[22] DOE/WIPP-02-3122, *Transuranic Waste Acceptance Criteria For The Waste Isolation Pilot Plant*, Revision 8, July 5, 2016.

[23] *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook/

APPENDIX A. FISSILE MASS OPTIMUM MODERATOR RATIO STUDY RESULTS (H/PU)

APPENDIX A. INTRODUCTION

The results presented in this appendix are the results from the H/Pu studies discussed in Section 6.1. The H/Pu studies included the following cases:

Case A1: waste form mixture ranges from 50–200 g $^{239}PuO_2$ and 75–95% water and 5–25% CH_2. Reflector material is water with and without beryllium (4.54 kg, see Section 4.2) present as a layer around the waste form sphere. These studies justify the use of the waste form with the water/CH_2 ratio [2,4]. Additionally, the beryllium is modeled outside the waste form as a reflective layer directly adjacent to the waste form, as a layered sphere.

> **Case A1.a:** Fissile mass calculations for 50–200 g $^{239}PuO_2$. Reflector includes a layer of beryllium around the waste form. The results are presented in Figure A-1 and show that reactivity trend associated with fissile mass is consistent as the fissile mass increases from 50–200 g.
>
> **Case A1.b:** Same as Case A1.a, but there is no beryllium included. The results are presented in Figure A-2 and show that the inclusion of the beryllium in a layer around the waste form is more reactive.
>
> **Case A1.c:** Calculations to show the reactivity trend associated with changing the ratio of H_2O to CH_2. Reflector includes a layer of beryllium around the waste form. The results are presented in Figures A-3 and show that the use of 75% H_2O mixed with 25% CH_2 is appropriate [2,4] since this maximizes reactivity, and 25% CH_2 is consistent with [2].
>
> **Case A1.d:** Same as Case A1.c, but there is no beryllium included. The results are presented in Figure A-4 and show the same trend as Case A1.c ,and they also show that the inclusion of the beryllium in a layer around the waste form is more reactive.

Case A2: Waste form mixture for 100 and 200 g $^{239}PuO_2$, with constant 75% water and 25% CH_2. Homogenized reflector materials are various combinations of salt, water, CH_2 and beryllium. External reflection is full salt.

> **Case A2.a:** Homogenized reflector material varies from 10% H_2O, 90% CH_2 homogenized with beryllium. The results are presented in Figure A-5 and Figure A-6 and show that there is little to no impact related to the ratio of H_2O with CH_2 in the reflector.
>
> **Case A2.b:** Same as Case A2.a, but the beryllium is considered as a layer adjacent to the waste form sphere. The results are presented in Figure A-7 and Figure A-8 and show that there is little to no impact related to the ratio of H_2O with CH_2 in the reflector and that the reactivity increases over Case A2.a.
>
> **Case A2.c:** Same as Case A2.a, but with no beryllium. The results are presented in Figure A-9 and Figure A-10 and show that there is little to no impact related to the ratio of H_2O with CH_2 in the reflector.

Case A3: Waste form mixture for 100 and 200 g $^{239}PuO_2$, with constant 75% H_2O and 25% CH_2. Reflector material is pure CH_2 with and without homogenized beryllium. External reflection is full salt. The results are presented in Figure A-11 and show that there is little impact due to pure polyethylene and/or the beryllium.

Case A4: Waste form mixture for 100 and 200 g $^{239}PuO_2$, with constant 75% H_2O and 25% CH_2. Reflector material varies from 10% H_2O, 90% CH_2 homogenized with Fe and with and without beryllium. External reflection is full salt.

Case A4.a: Homogenized reflector material varies from 10% H_2O, 90% CH_2 homogenized with beryllium, and Fe. The results are presented in Figure A-12 and Figure A-13 and show that there is little to no impact related to the ratio of H_2O with CH_2 in the reflector and that the reactivity decreases due to the presence of the Fe.

Case A4.b: Same as Case A4.a, but with no beryllium. The results are presented in Figure A-14 and Figure A-15 and show that there is little to no impact related to the ratio of H_2O with CH_2 in the reflector and that the inclusion of Beryllium in reflector may increase reactivity slightly.

Case A5: Comparison of equivalent volume spheres and cylinders with a height to diameter ratio of 1. See Figure A-16.

The results presented in this Appendix A for the cases discussed above establish various H/Pu trends associated with the waste form and reflector materials. The results of the H/Pu studies show good agreement with previous H/Pu studies [4], having peak reactivity H/Pu ratios ranging from 900–1,100, depending on the fissile mass. Furthermore, the results show that there is not a strong trend with respect to mass and the optimum H/Pu: the peaks for each mass tend to be about the same H/Pu ratio. The results also show that the reactivity of the fissile mass varies significantly for variations of H/Pu. Therefore, using the optimum H/Pu for the various analysis studies is very conservative. Furthermore, in general, the resulting maximum reactivity H/Pu ratios are consistent with those found in previous evaluations [4] and show little trending with respect to the reflector materials.

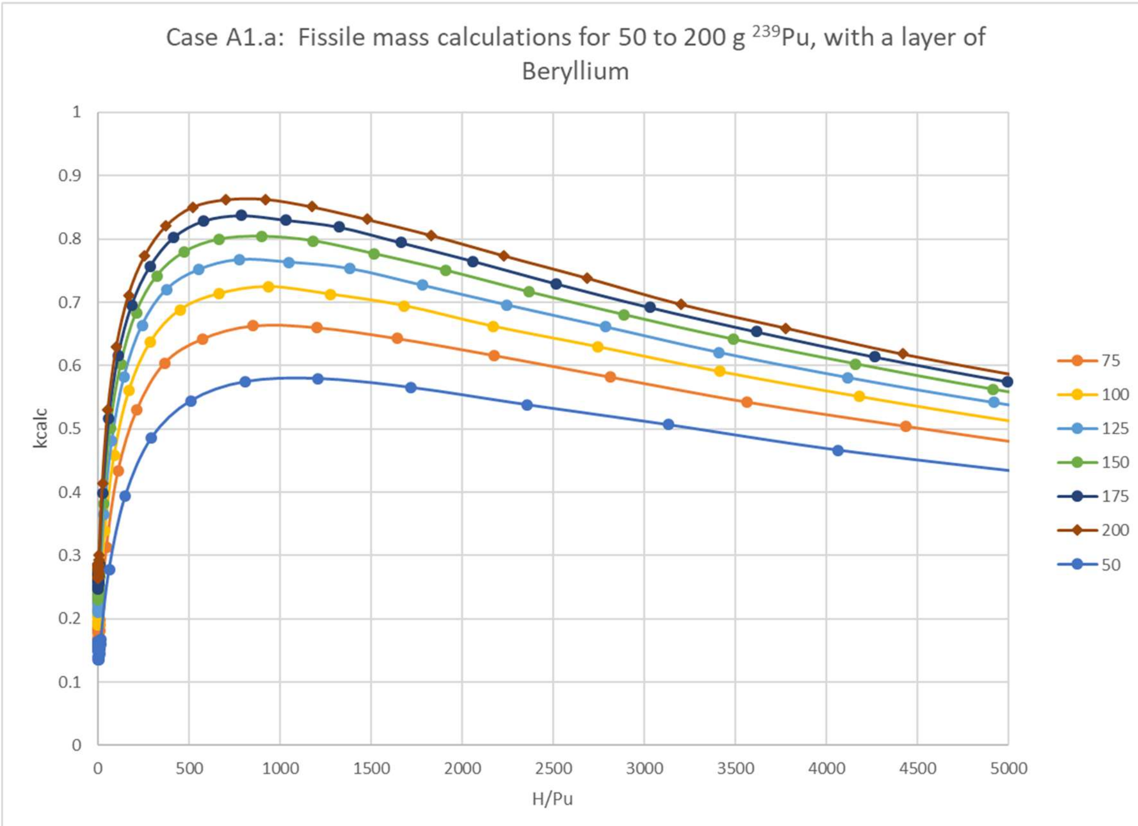


Figure A-1. H/Pu study, waste form is 50–200 g $^{239}PuO_2$, 75% H_2O, 25% CH_2; reflector is a beryllium layer around waste form sphere and infinite H_2O.

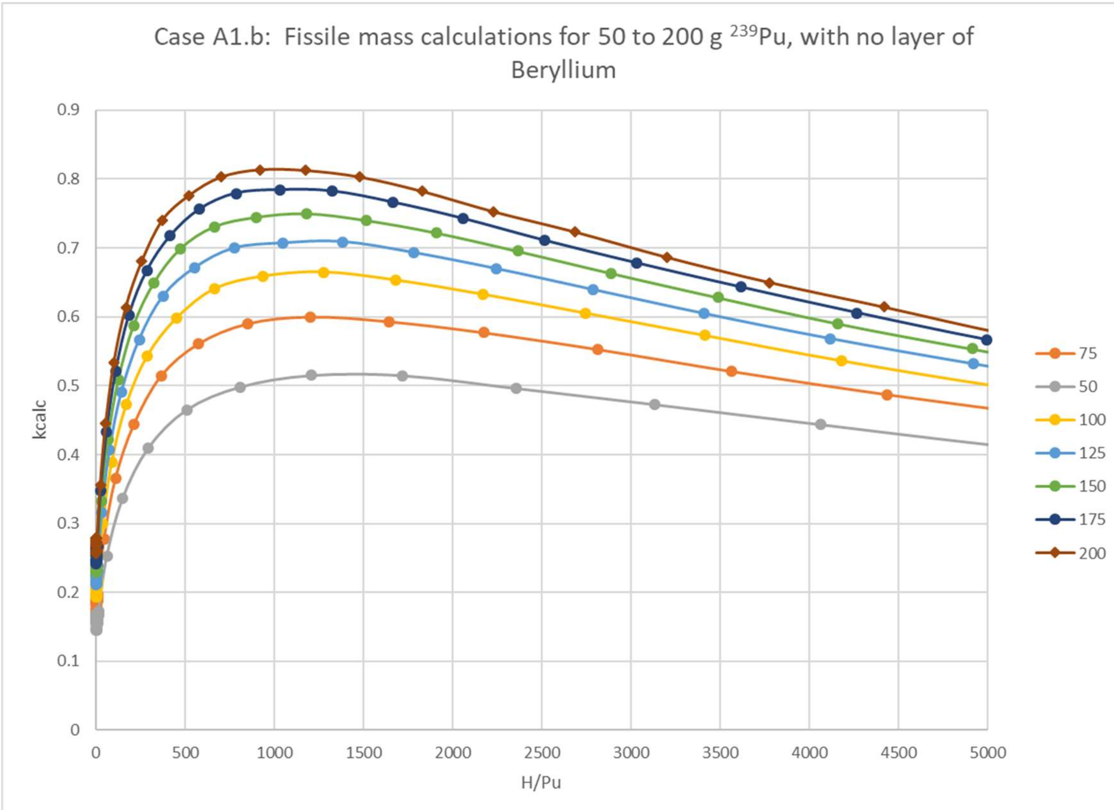


Figure A-2. H/Pu study, waste form is 50–200 g $^{239}PuO_2$, 75% H_2O, 25% CH_2; reflector is infinite H_2O.

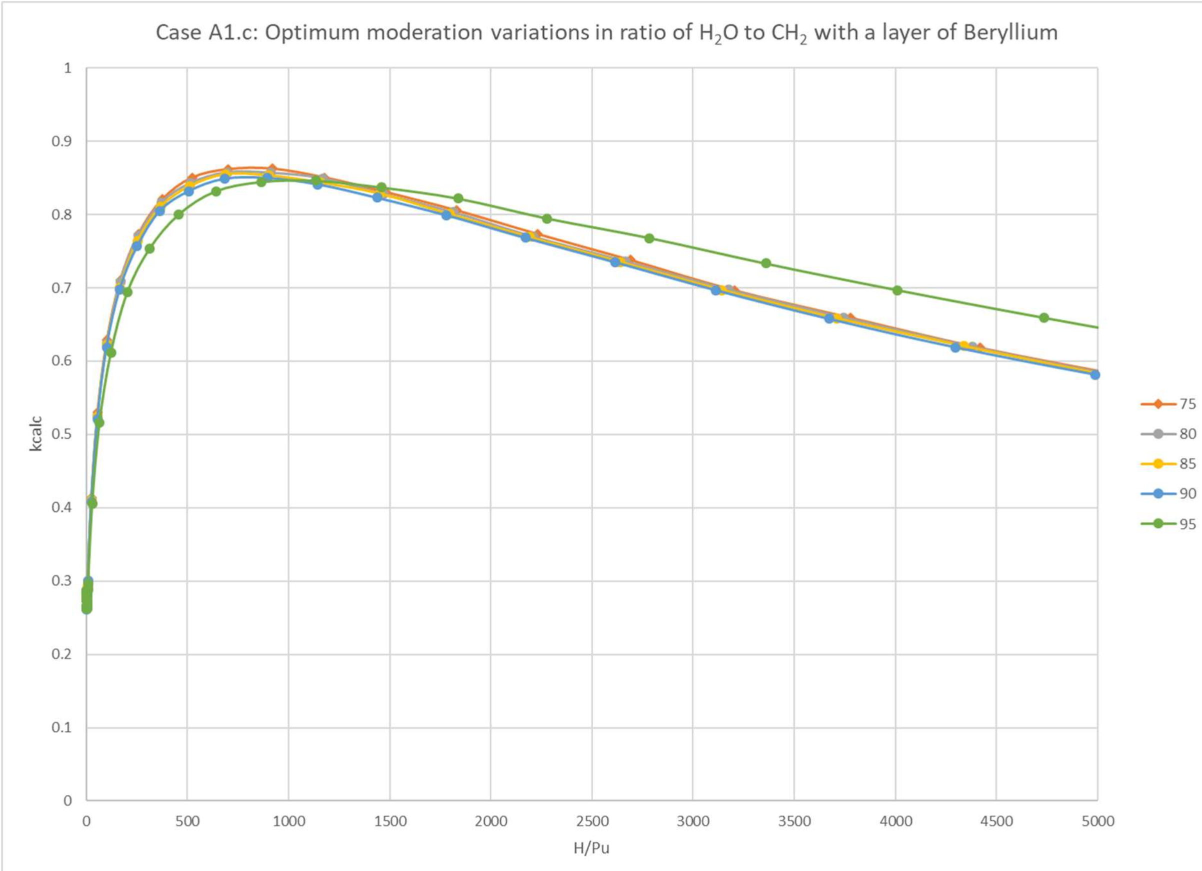


Figure A-3. H/Pu study, waste form is 200 g $^{239}PuO_2$, 75–95% H_2O with 25%-5% CH_2; reflector is a beryllium layer around waste form sphere and infinite H_2O.

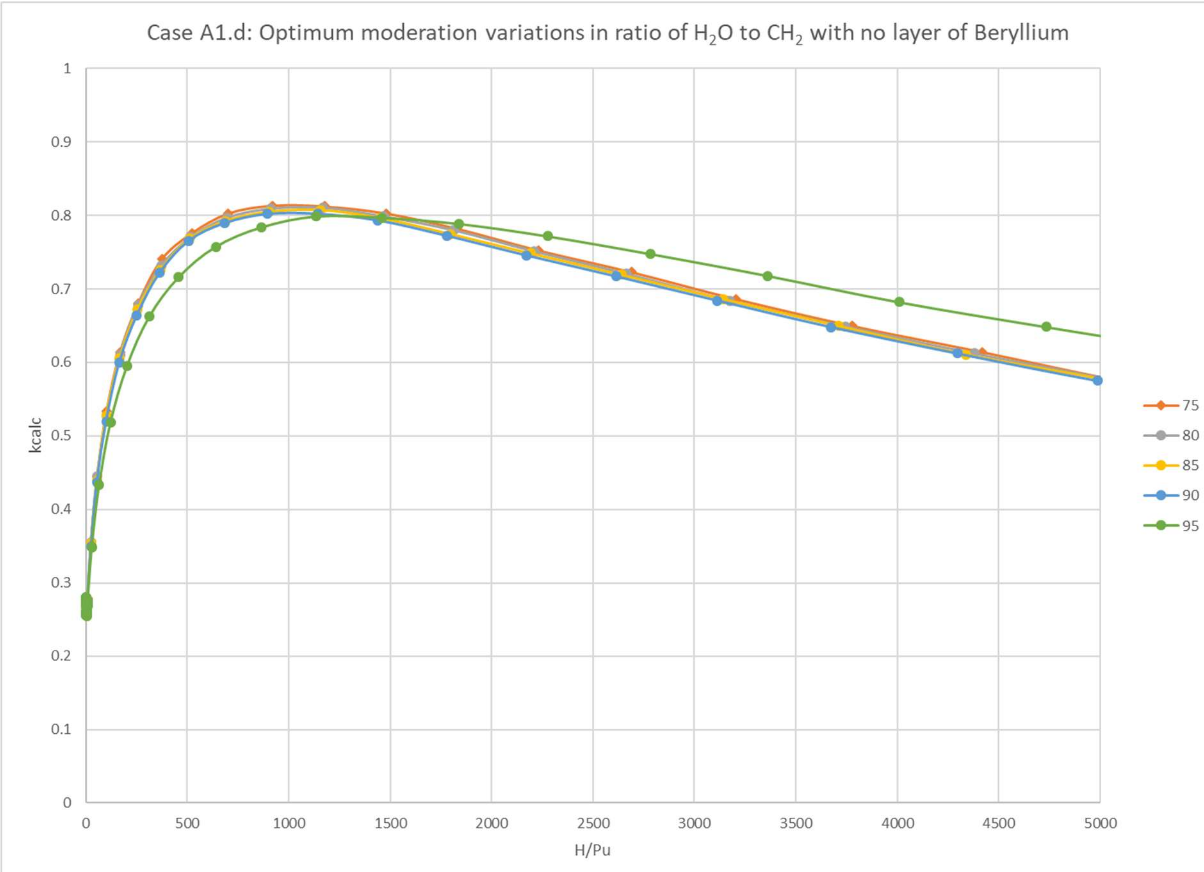


Figure A-4. H/Pu study, waste form is 200 g $^{239}PuO_2$, H_2O varies from 75–95% (with respect to CH_2); reflector has no beryllium layer around waste form sphere and infinite H_2O.

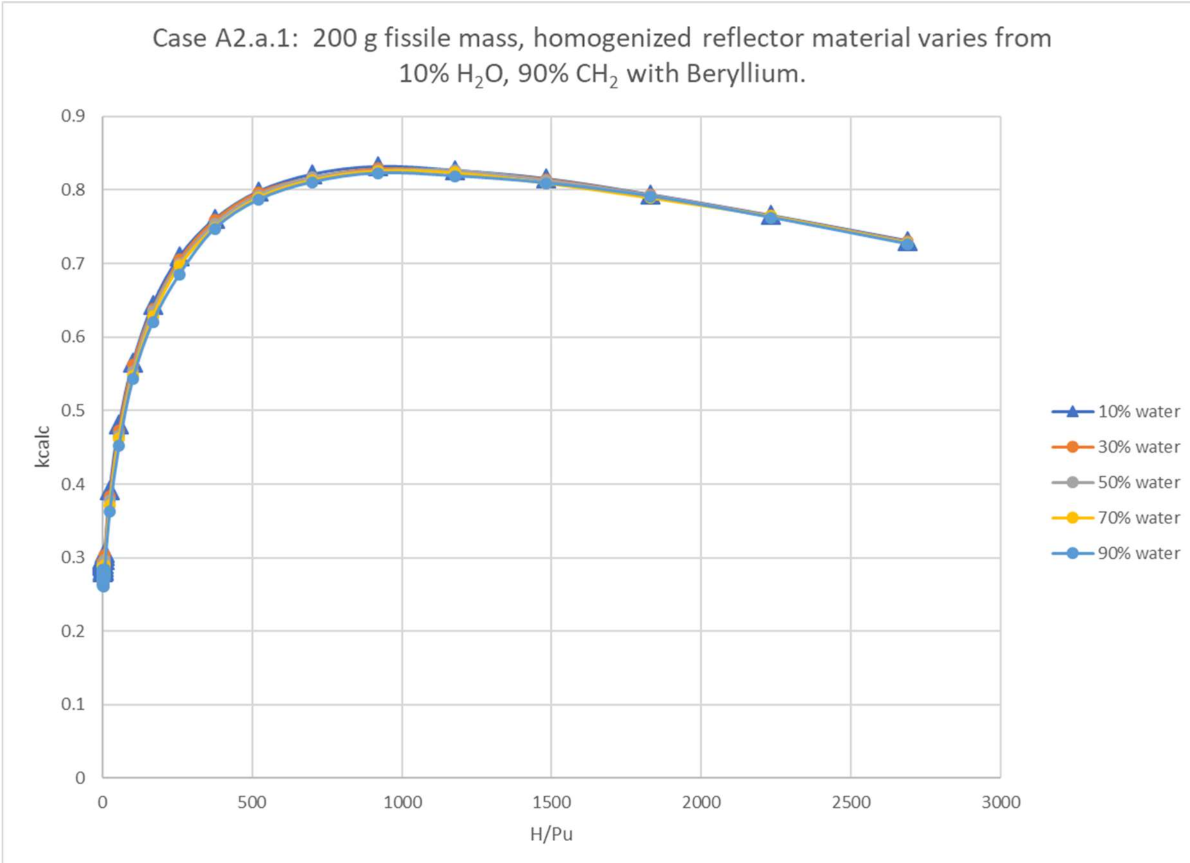


Figure A-5. H/Pu study, waste form is 200 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized beryllium with 10–90% H_2O and 90–10% CH_2; infinite salt reflection.

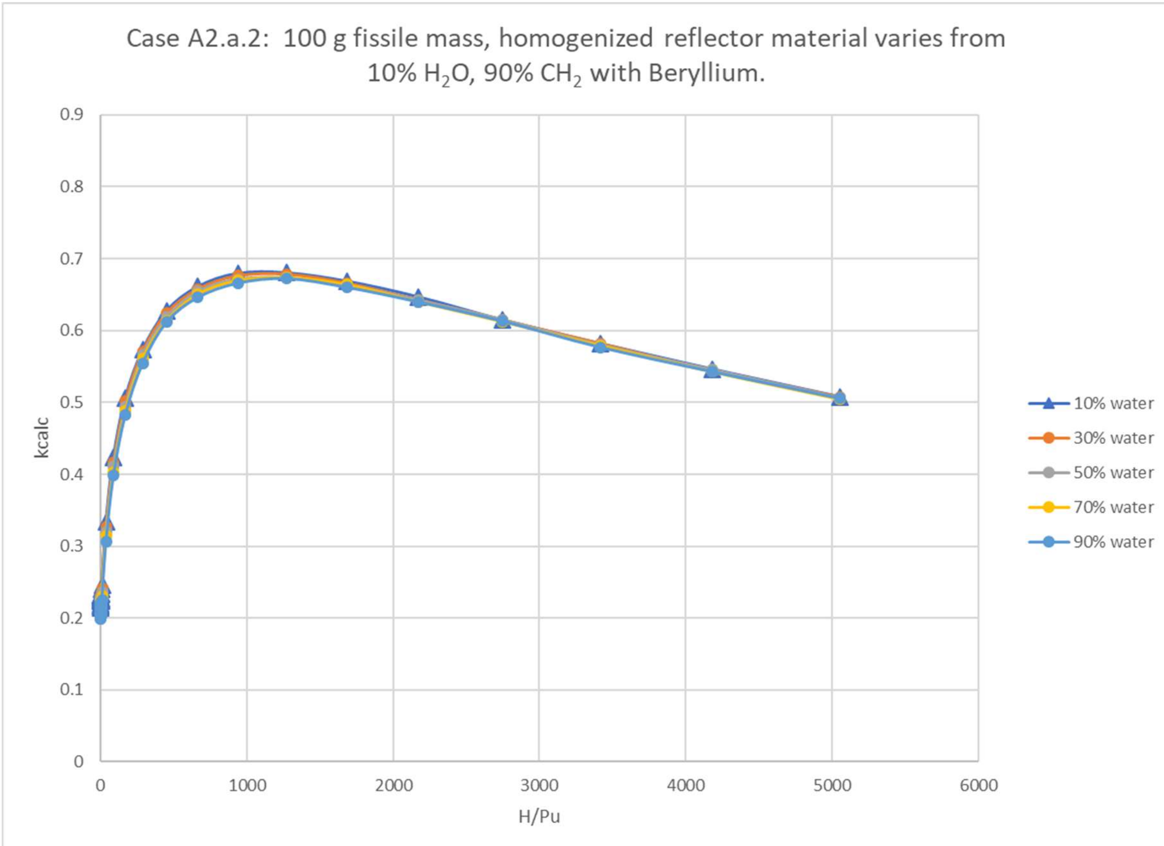


Figure A-6. H/Pu study, waste form is 100 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized beryllium with 10–90% H_2O and 90–10% CH_2; infinite salt reflection.

Figure A-7. H/Pu study, waste form is 200 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2, while beryllium is a layer around waste form sphere; infinite salt reflection.

Figure A-8. H/Pu study, waste form is 100 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2, while beryllium is a layer around waste form sphere; infinite salt reflection.

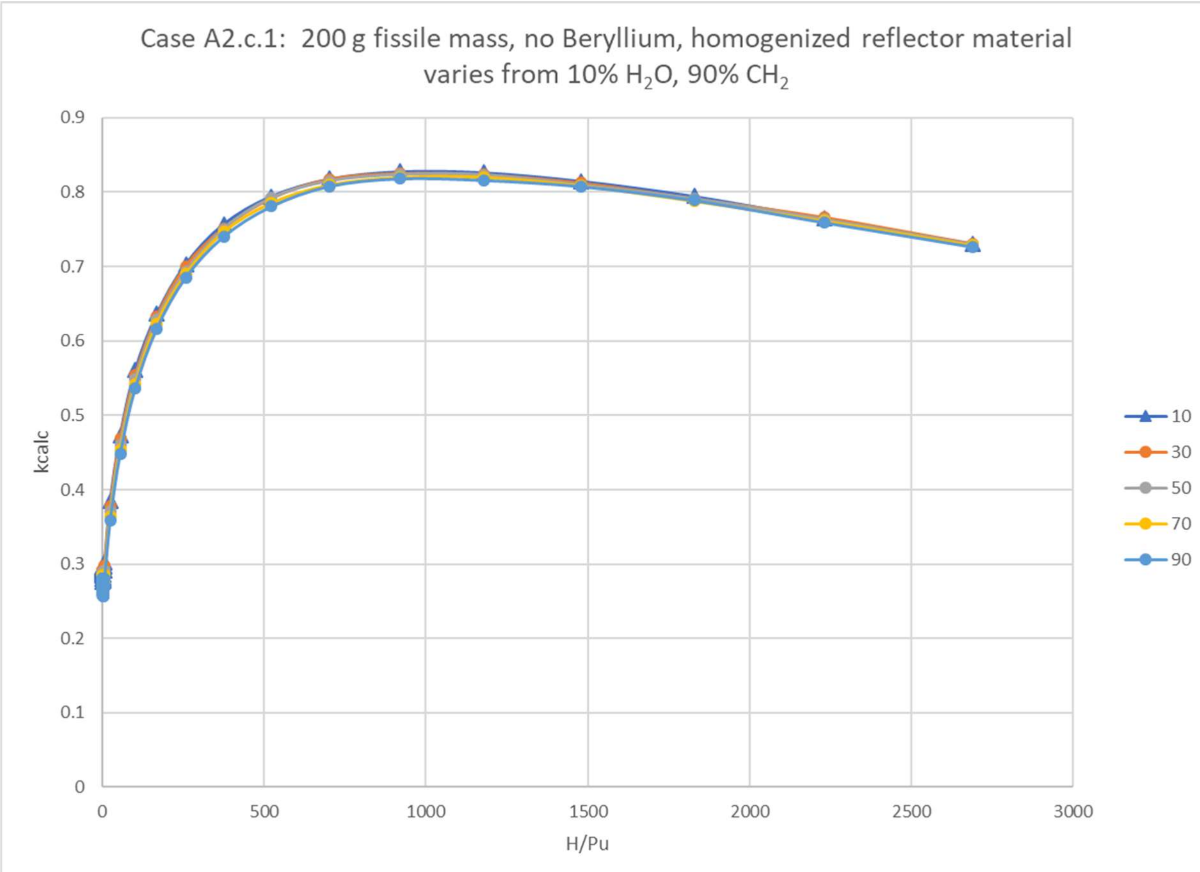


Figure A-9. H/Pu study, waste form is 200 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2 with 0% beryllium; infinite salt reflection.

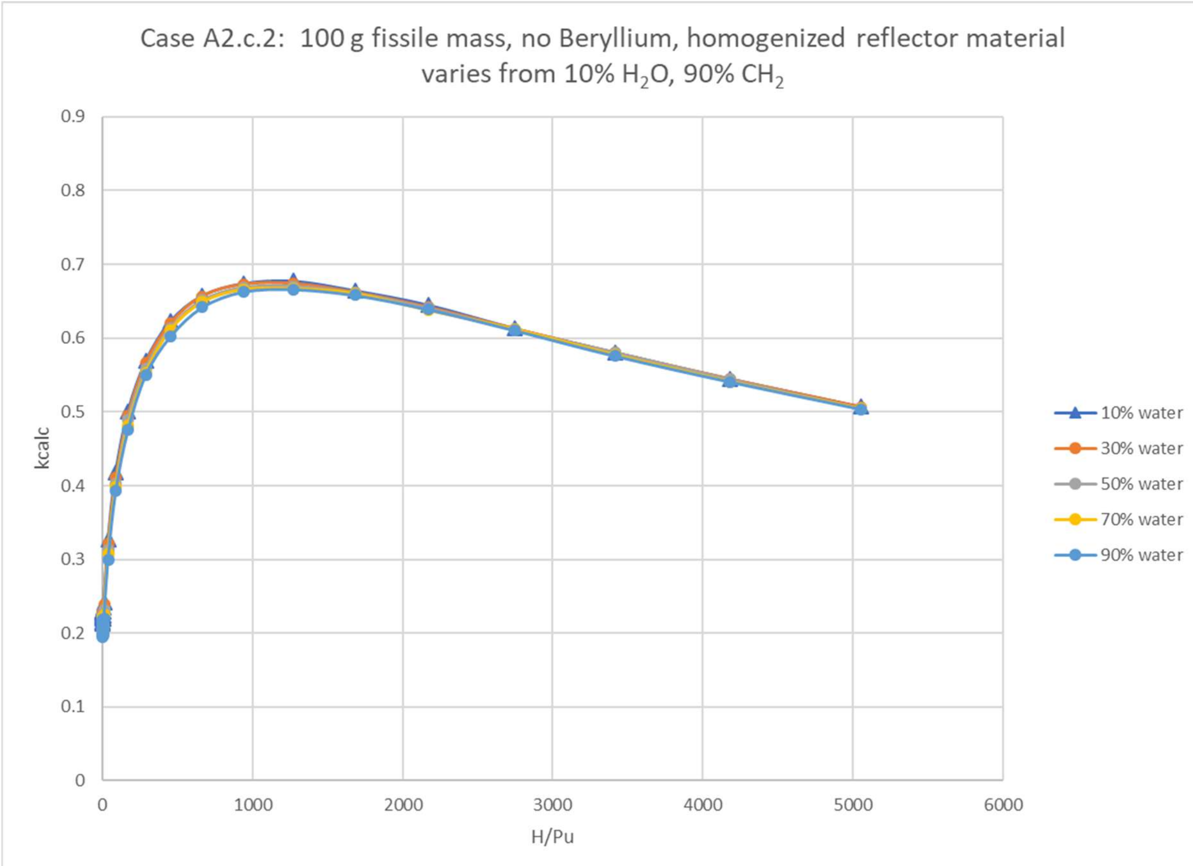


Figure A-10, H/Pu study, waste form is 100 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2 with 0% beryllium; infinite salt reflection.

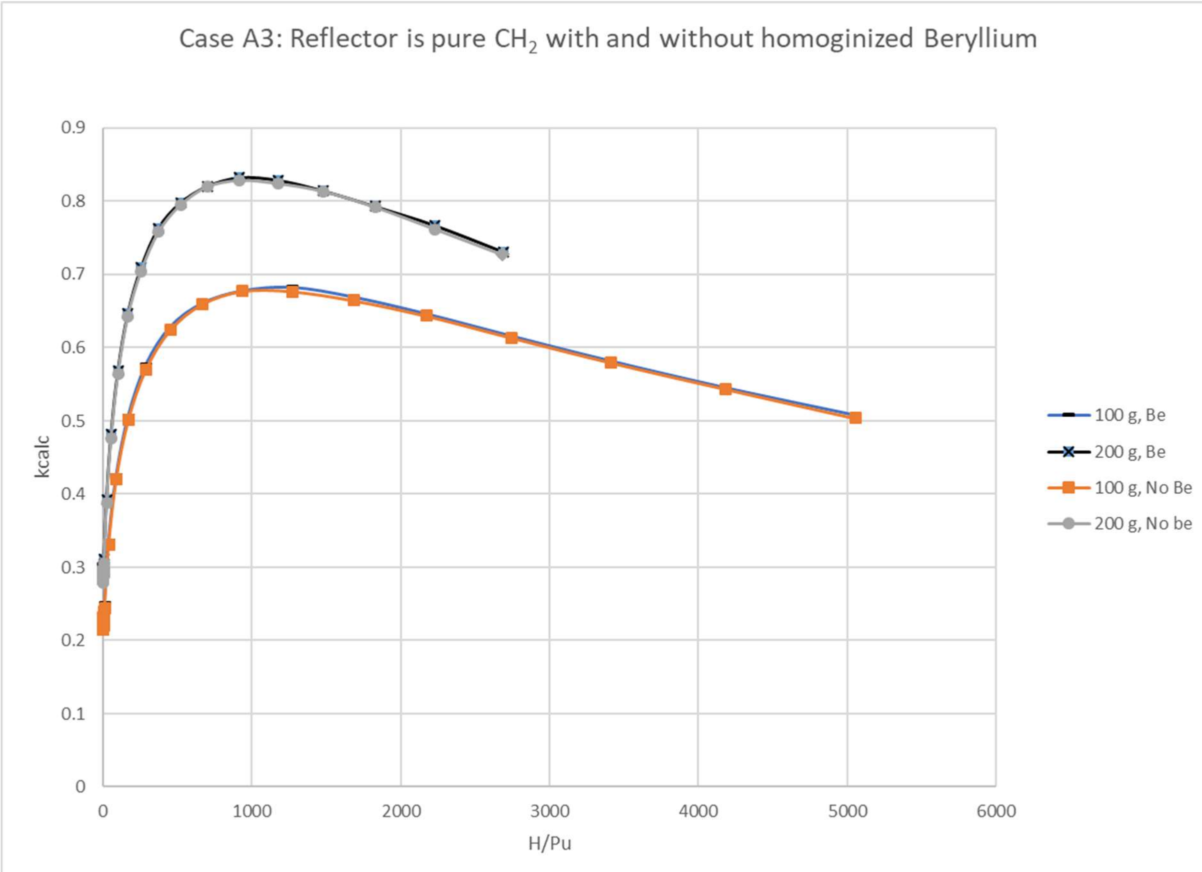


Figure A-11. H/Pu study, waste form is 100 g $^{239}PuO_2$ and 200 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is 100% CH_2 homogenized with and without beryllium; infinite salt reflection.

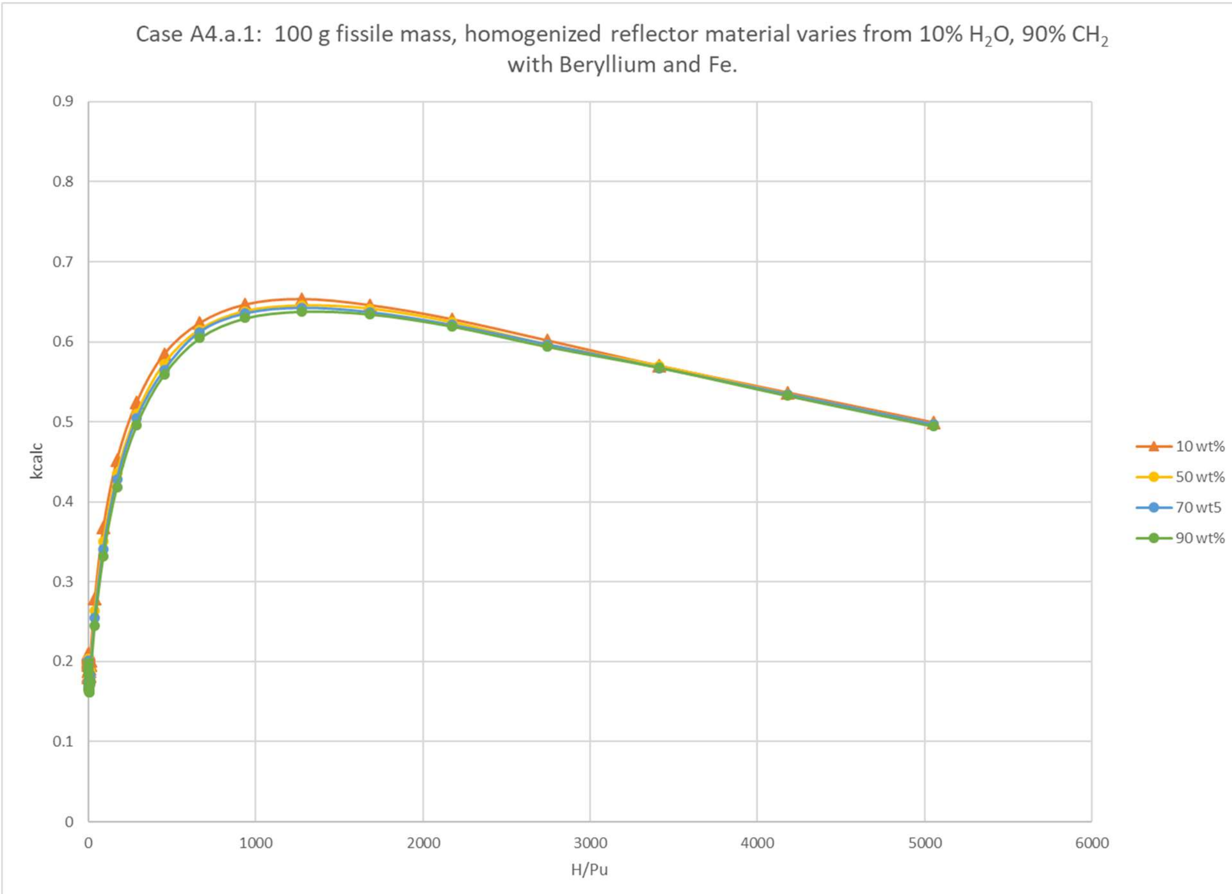


Figure A-12. H/Pu study, waste form is 100 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2 with beryllium and Fe; infinite salt reflection.

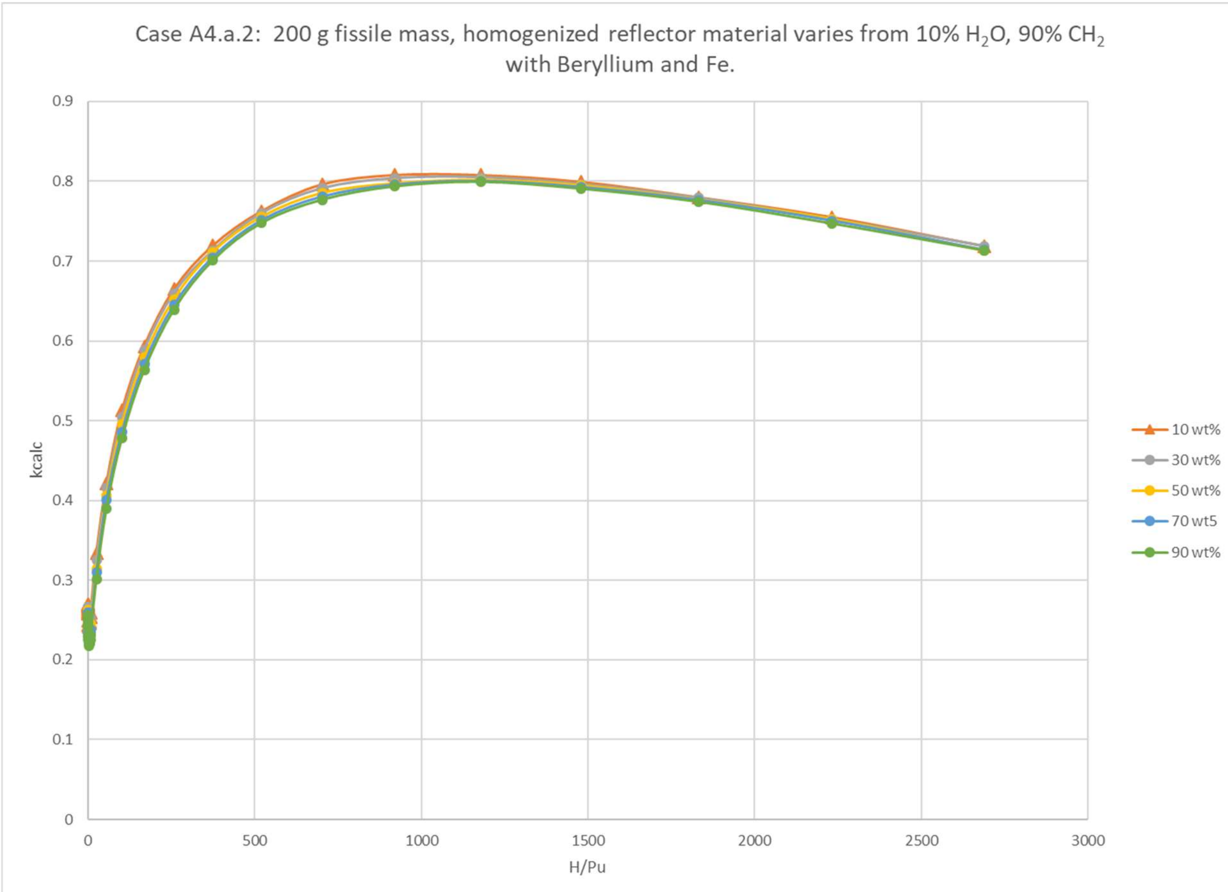


Figure A-13. H/Pu study, waste form is 200 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2 with beryllium and Fe; infinite salt reflection.

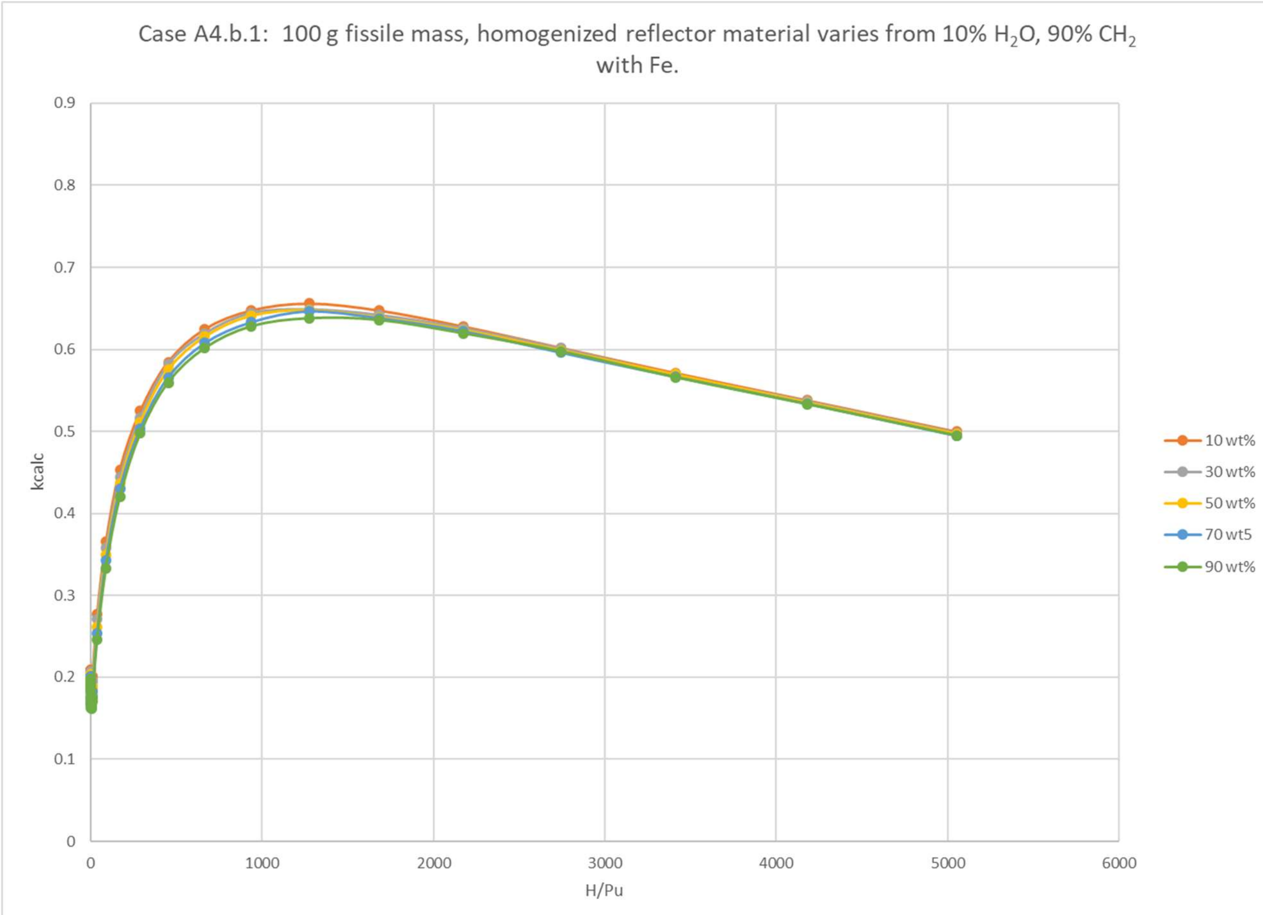


Figure A-14. H/Pu study, waste form is 100 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2 with 0% beryllium and Fe; infinite salt reflection.

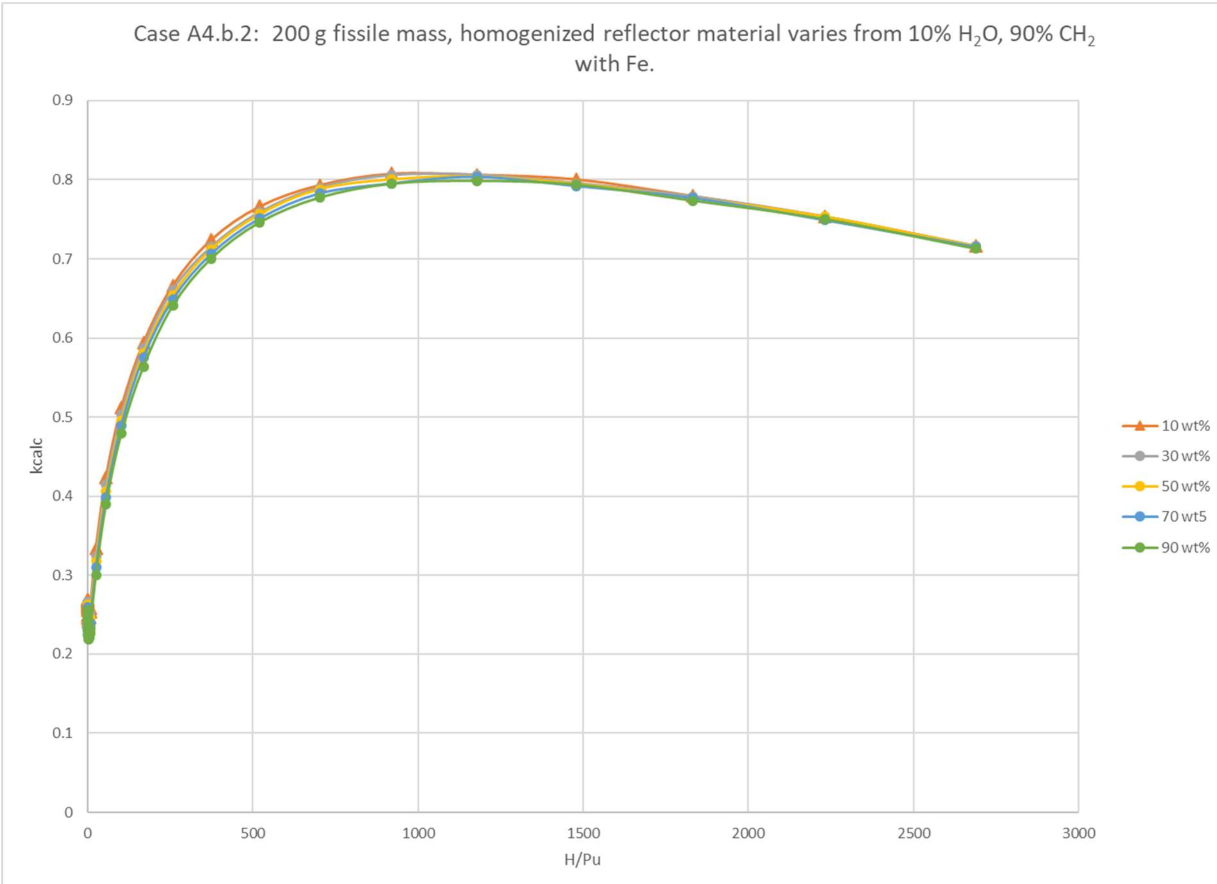


Figure A-15. H/Pu study, waste form is 200 g $^{239}PuO_2$, 75% H_2O with 25% CH_2; reflector is homogenized 10–90% H_2O and 90–10% CH_2 with 0% beryllium and Fe; infinite salt reflection.

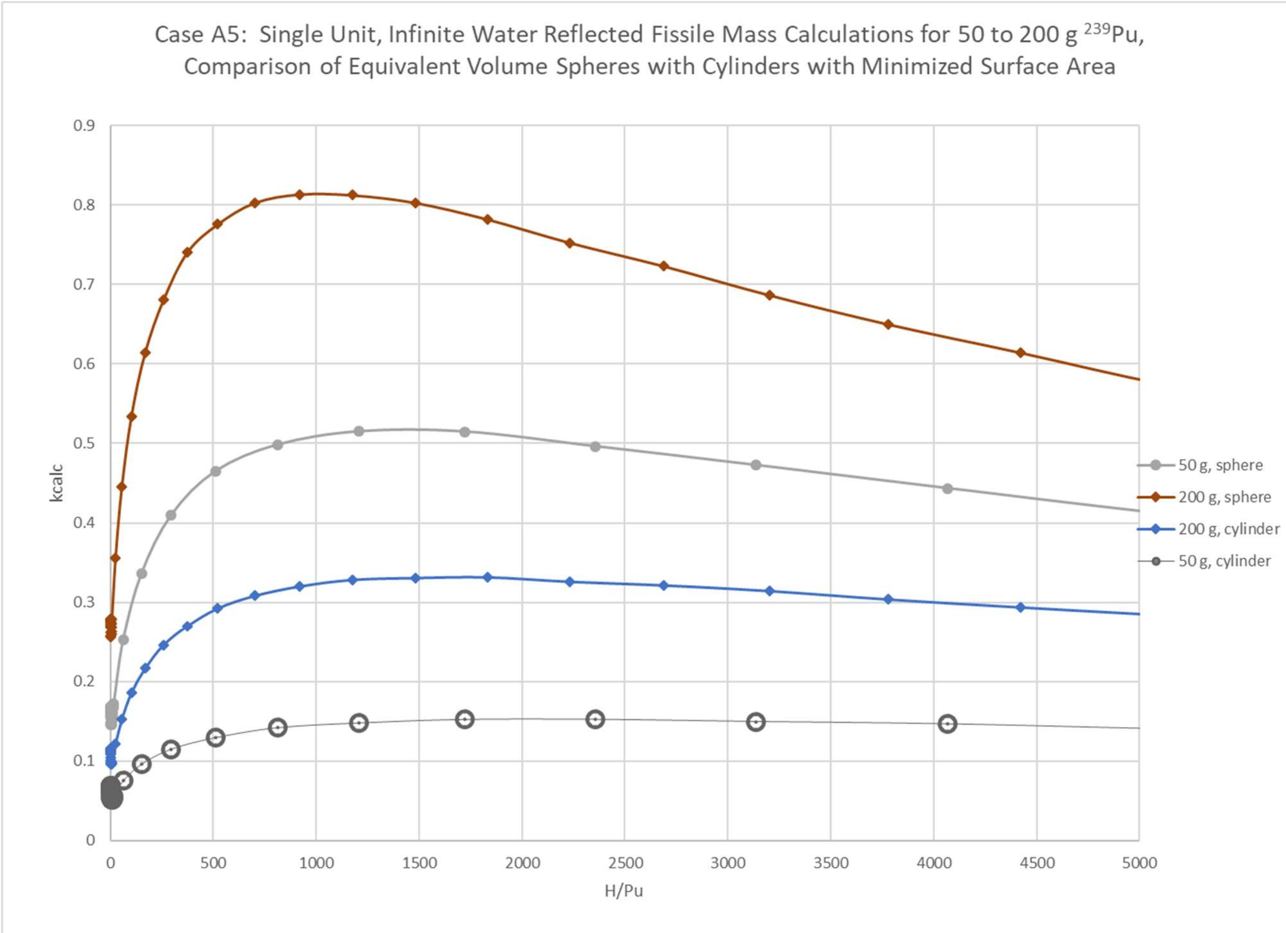


Figure A-16. H/Pu study, waste form is 50–200 g $^{239}PuO_2$, 75% H_2O, 25% CH_2; comparison of equivalent volume spheres and cylinders.

APPENDIX B. SUMMARY OF THE REFLECTOR MATERIAL STUDIES

APPENDIX B. INTRODUCTION

The results presented in this Appendix B are the results from the reflector material studies discussed in Section 6.2. The following sets of 300 calculations were performed (representing 300 variations of random distributions of fissile mass per case) for the following cases:

- **Case B1:** evaluation of salt as a reflector material. The model is the base case, fully compacted. The results of the calculations are presented in Figure B-1.

- **Case B2:** evaluation of salt and Fe homogeneously mixed as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-2 show that the addition of the Fe increases reactivity in the dry system.

- **Case B3:** evaluation of salt, Fe and beryllium homogeneously mixed as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-3 show that the addition of the beryllium to the salt and Fe may result in a small, insignificant increase in reactivity.

- **Case B4:** evaluation of salt and beryllium homogeneously mixed as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-4, when compared to Figure B-1 (salt only), show that the addition of the beryllium may insignificantly increase reactivity.

- **Case B5:** evaluation of salt and MgO variations homogeneously mixed as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-5.a for the variations of the ratio of MgO to salt (see Section 4.1.3) show that the reactivity of the system increases with increasing amounts of MgO. The results for the 300 sets of randomly distributed fissile masses using the 50/50 ratio of salt with MgO are presented in Figure B-5.b.

- **Case B6:** evaluation of brine variations as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-6.a for brine variation m6-1 (see Section 4.1.5) and Figure B-6.b for brine variation m6-2 (see Section 4.1.5) show that brine variation m6-1 is slightly more reactive than m6-2, while both variations are significantly subcritical when compared with the other cases in this section.

- **Case B7:** evaluation of salt, Fe, beryllium, and MgO homogeneously mixed as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-7 show that this combination of materials is the most reactive combination under dry conditions.

- **Case B8:** evaluation of salt, Fe, beryllium, MgO, and brine homogeneously mixed as a reflector material. The model is the base case, fully compacted. The results of the calculations presented in Figure B-8 show that the combination of materials is essentially subcritical.

The results presented in Figures B-1 through B-10 show that the set of 300 randomly distributed masses have no trends with respect to the arrangement of masses considered or the material composition of the reflector material. Furthermore, as previously discussed in Section 1, the currently as-emplaced panels and rooms in the WIPP repository have a very similar distribution of mass, so the results for panel 1, room 1 are applicable to all panels and rooms. The results also show that there is a significant reactivity difference between the reflector materials evaluated. Therefore, the most reactive reflector materials are selected for the incremental spacing studies (discussed in Section 6.3), and a single case is selected from the set of 300 randomly distributed cases to use for this purpose. The results from these additional parametric studies (discussed in Section 6.3) are therefore applicable to any possible distribution of fissile masses within a room.

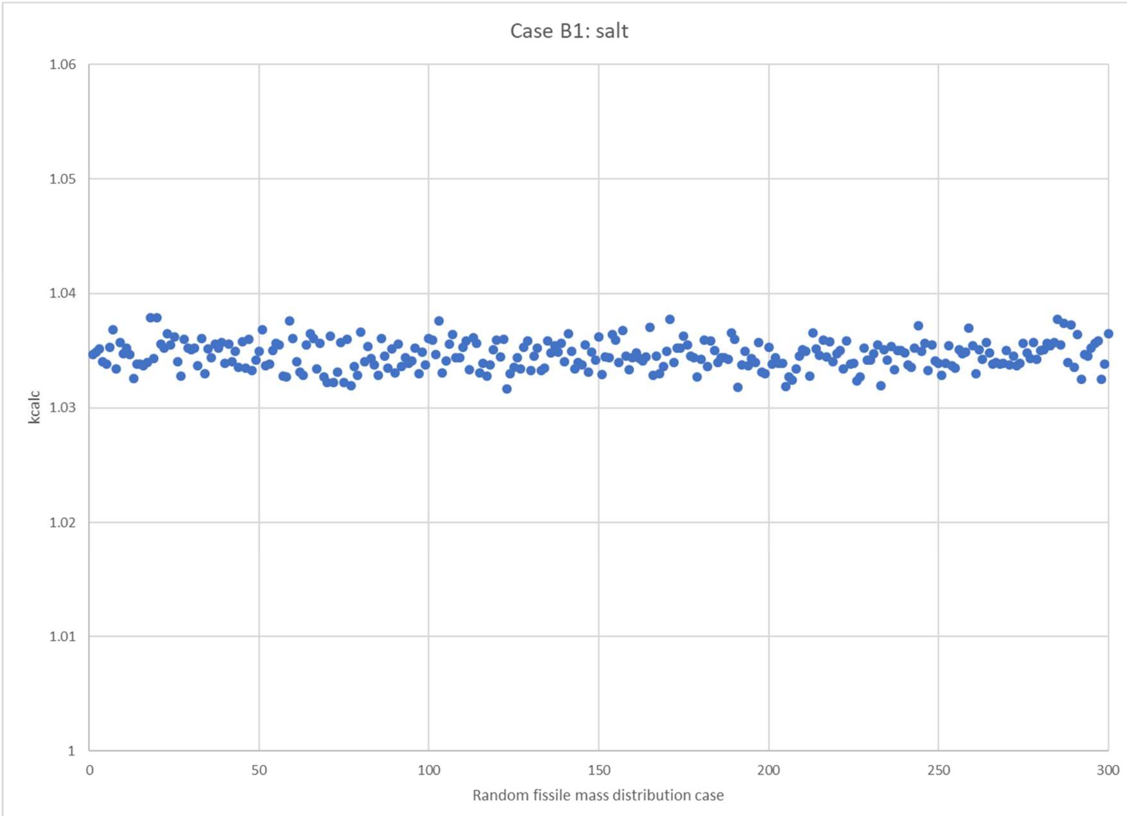


Figure B-1. Reflector material study: reflector material "m1" is salt only. Fully compacted configuration. Upper tolerance limit: 1.037

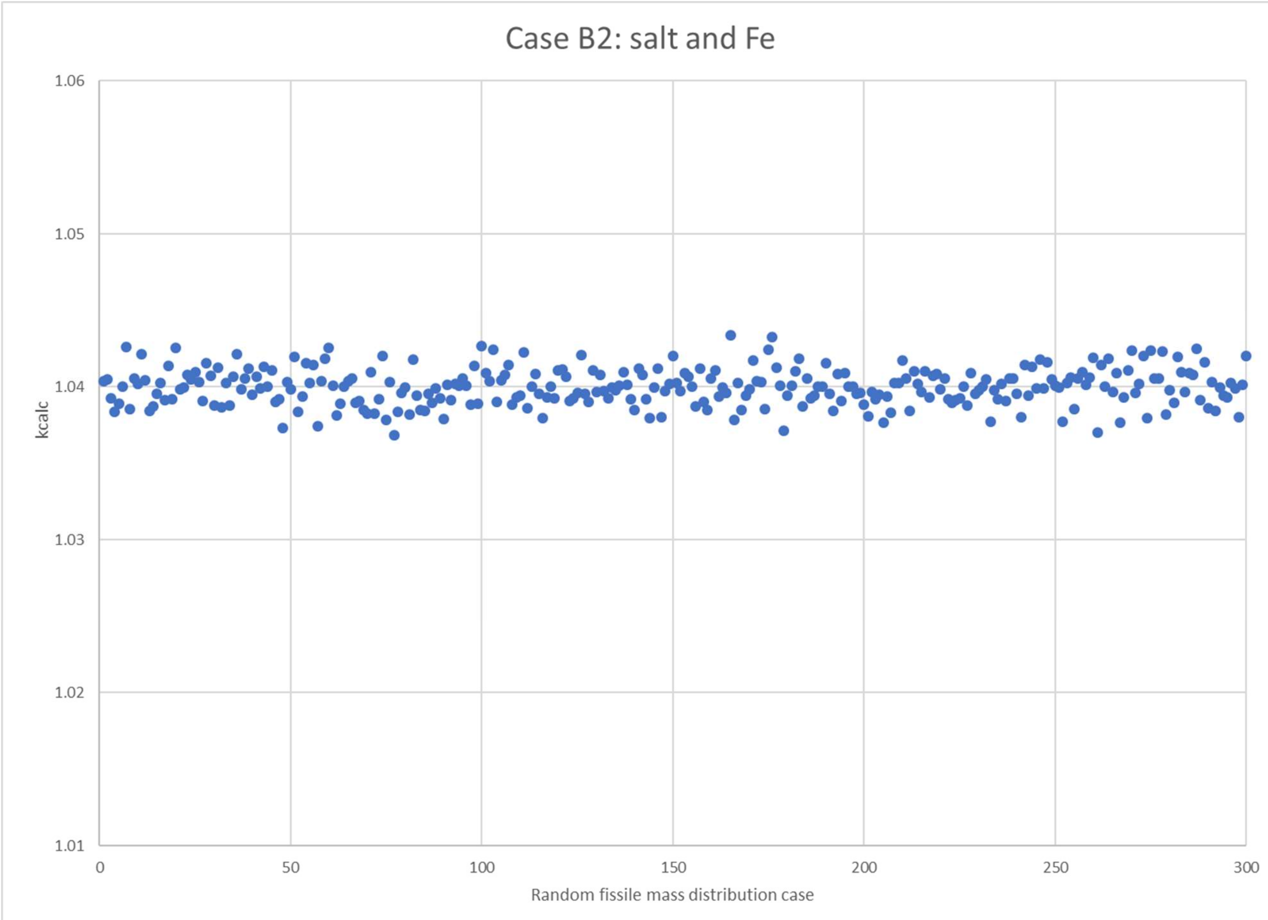


Figure B-2. Reflector material study: reflector material "m2" is salt and Fe homogeneously mixed. Fully compacted configuration. Upper tolerance limit: 1.042

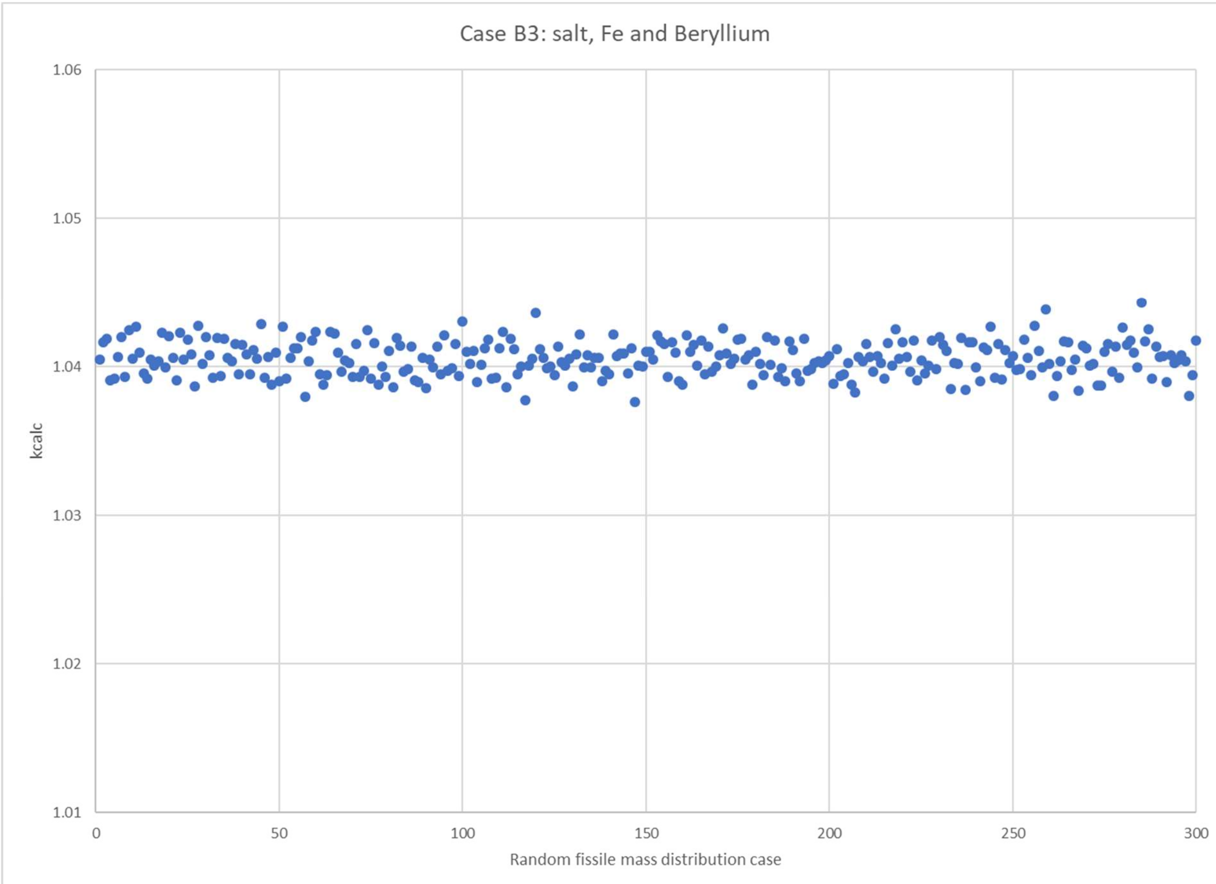


Figure B-3. Reflector material study: reflector material "m3" is salt, Fe, and beryllium homogeneously mixed. Fully compacted configuration. Upper tolerance limit: 1.043

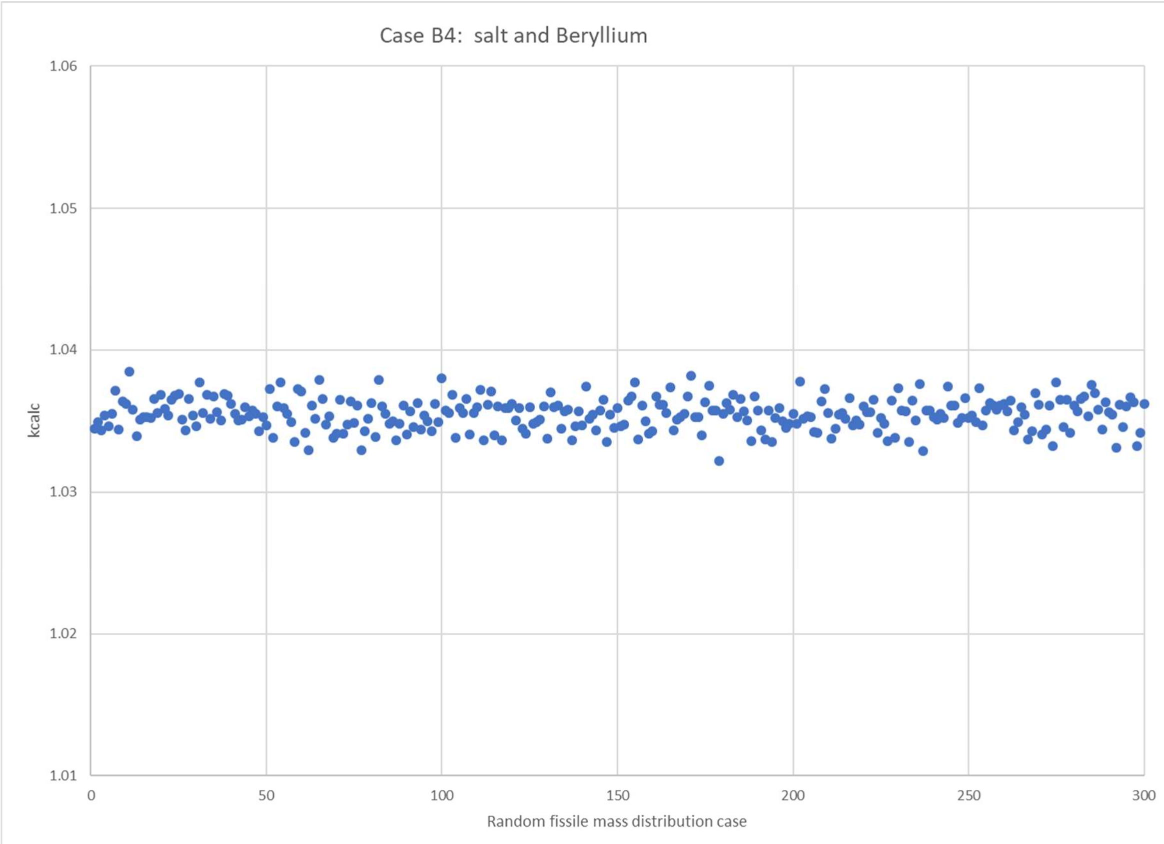


Figure B-4. Reflector material study: reflector material "m4" is salt and beryllium homogeneously mixed. Fully compacted configuration. Upper tolerance limit: 1.038

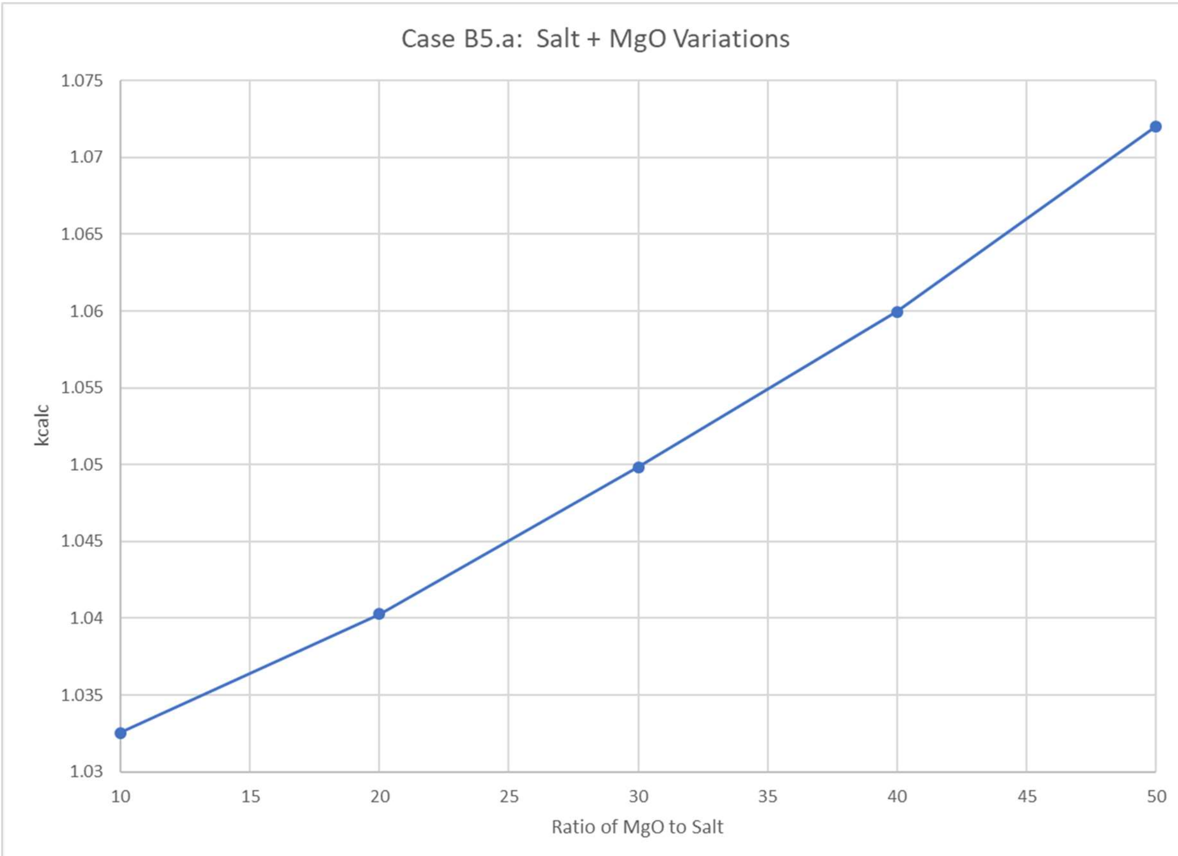


Figure B-5. Reflector material study: reflector material "m5" is salt and MgO variations homogeneously mixed. Fully compacted configuration.

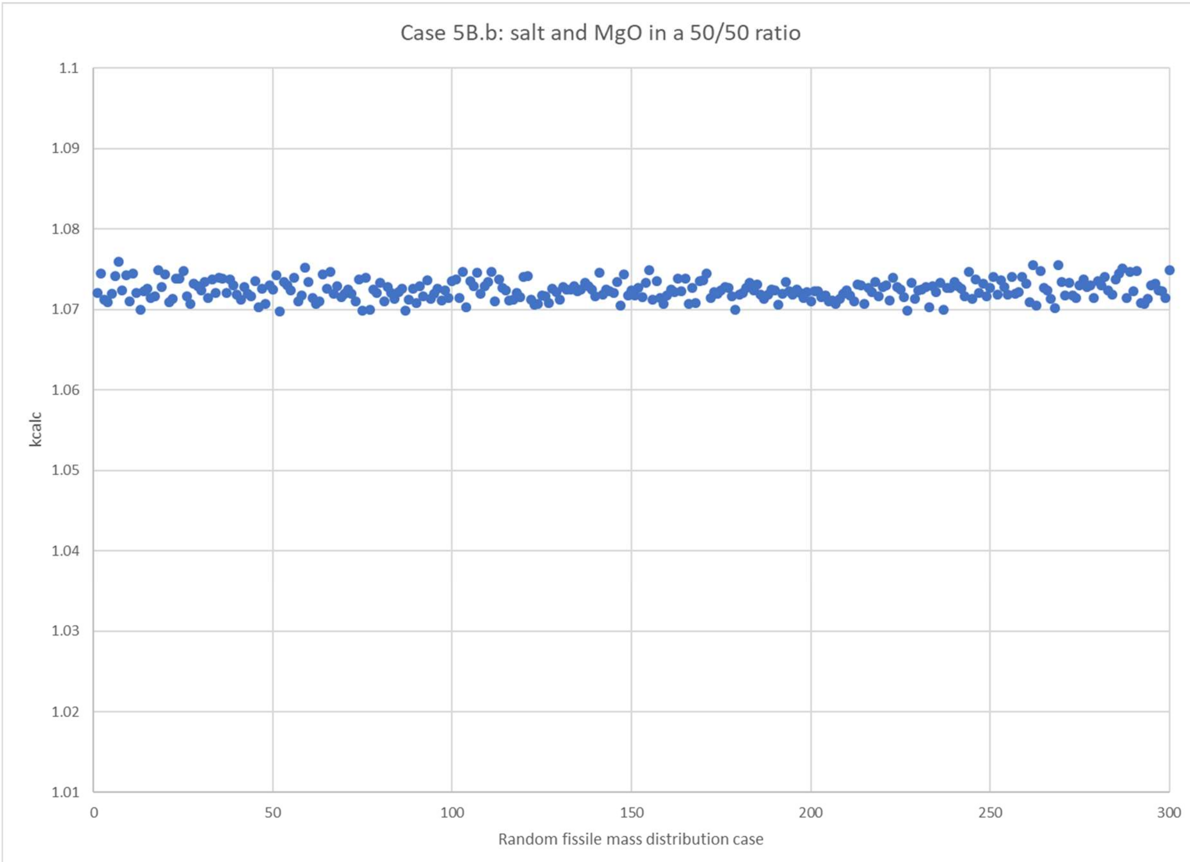


Figure B-6. Reflector material study: reflector material "m5" is salt and MgO in a 50/50 ratio homogeneously mixed. Fully compacted configuration. Upper tolerance limit: 1.075

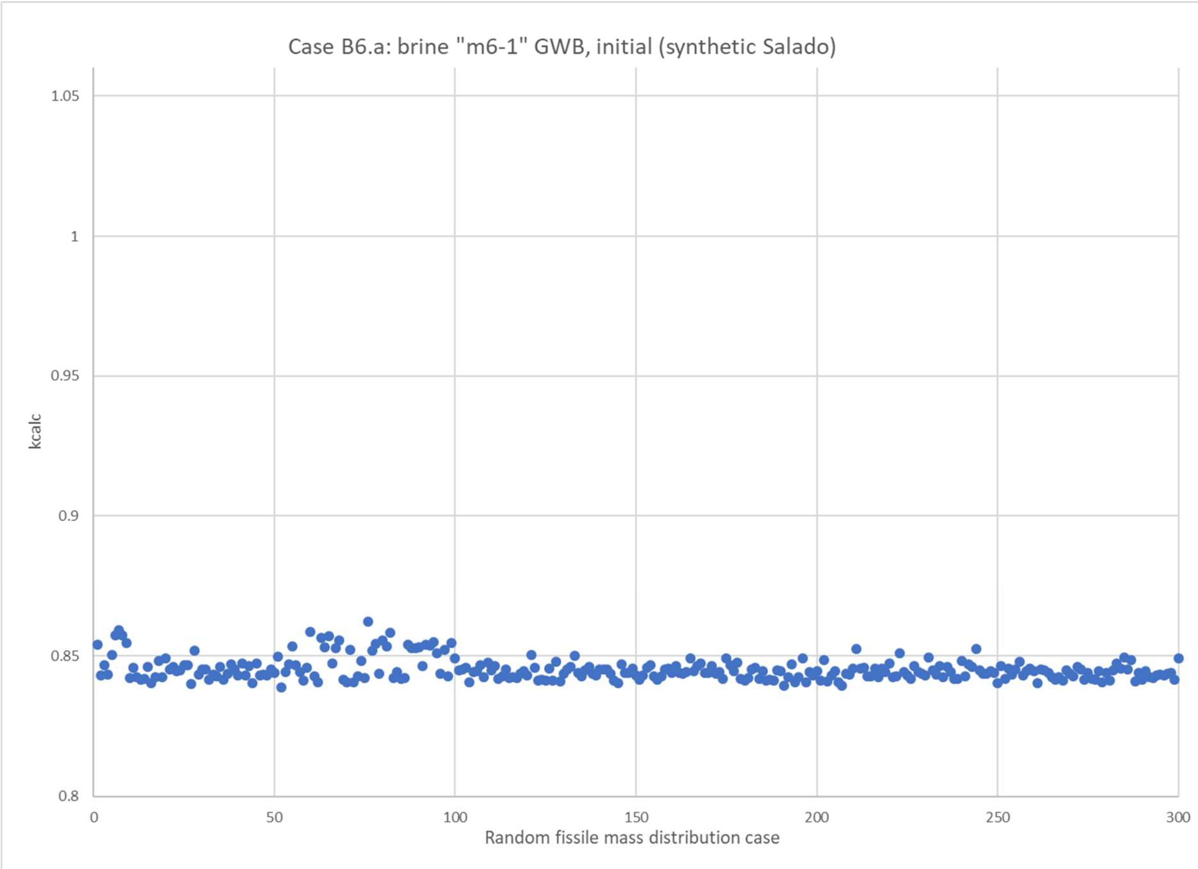


Figure B-7. Reflector material study: reflector material "m6-1" is the brine variation 6.32 m GWD, initial (synthetic Salado). Fully compacted configuration. Upper tolerance limit: 0.8568[17]

[17] Includes 2σ for nonparametric results.

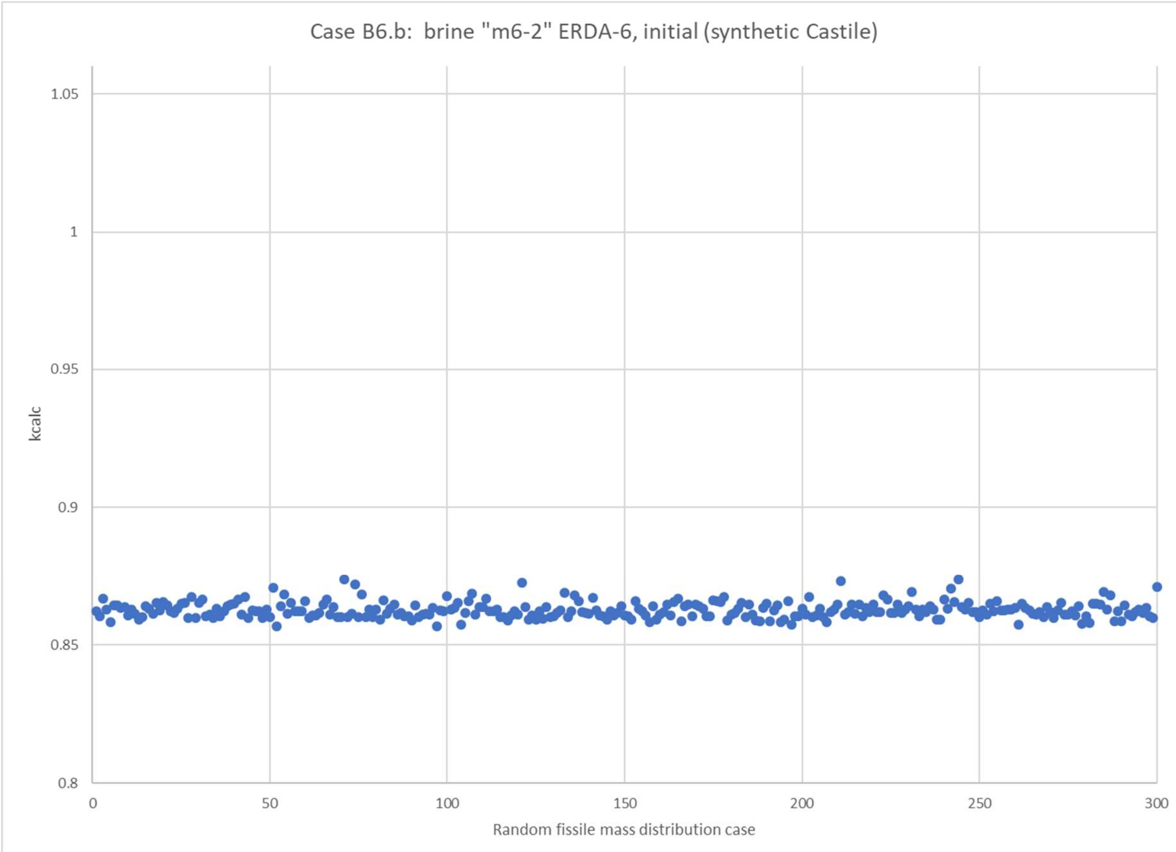


Figure B-8. Reflector material study: reflector material "m6-2" is the brine variation 5.20 m ERDA-6, initial (synthetic Castile). Fully compacted configuration. Upper tolerance limit: 0.8703[18]

[18] Includes 2σ for nonparametric results.

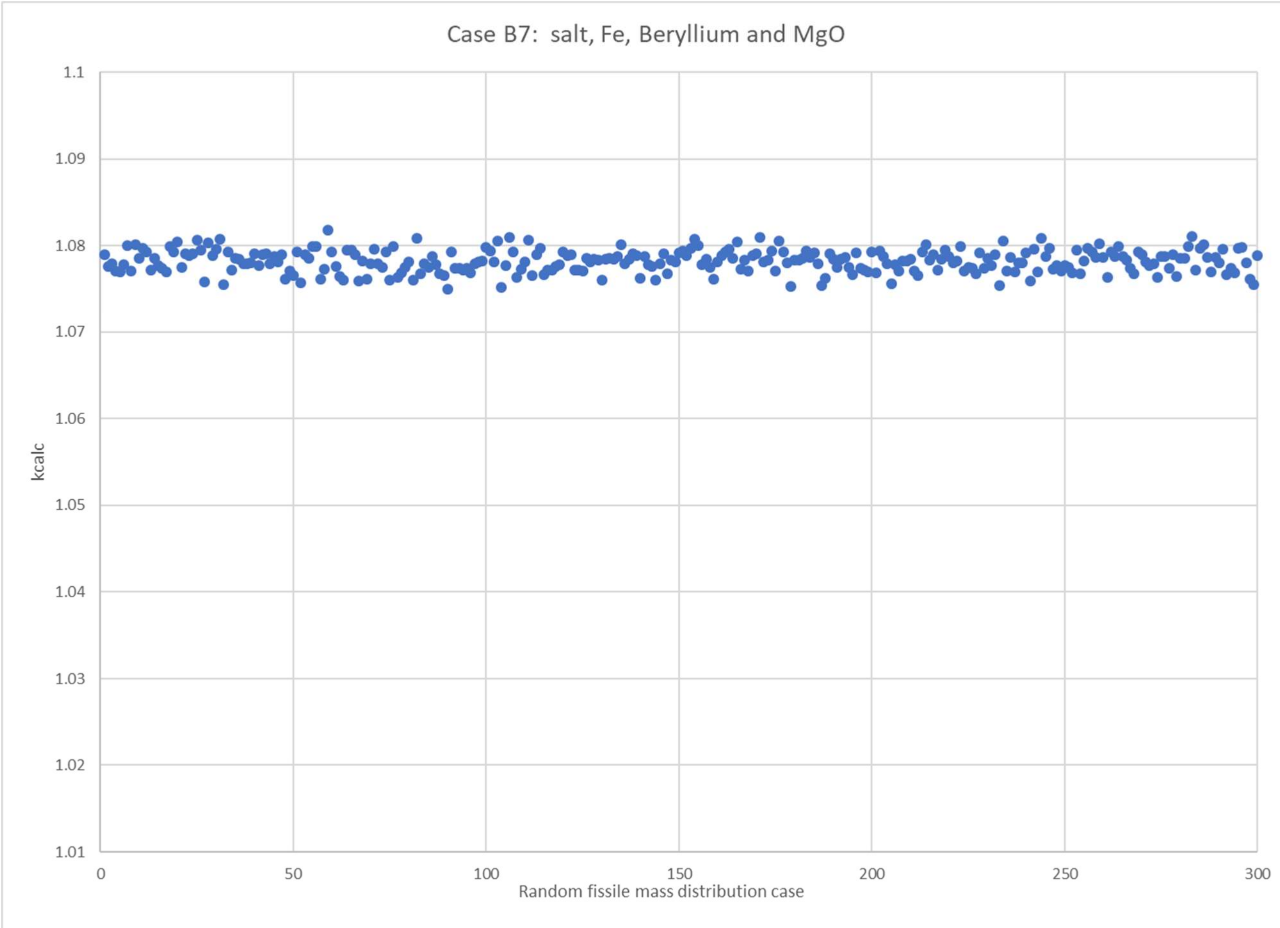


Figure B-9. Reflector material study: reflector material "m7" is salt, Fe, Beryllium and MgO. Fully compacted configuration. Upper tolerance limit: 1.081

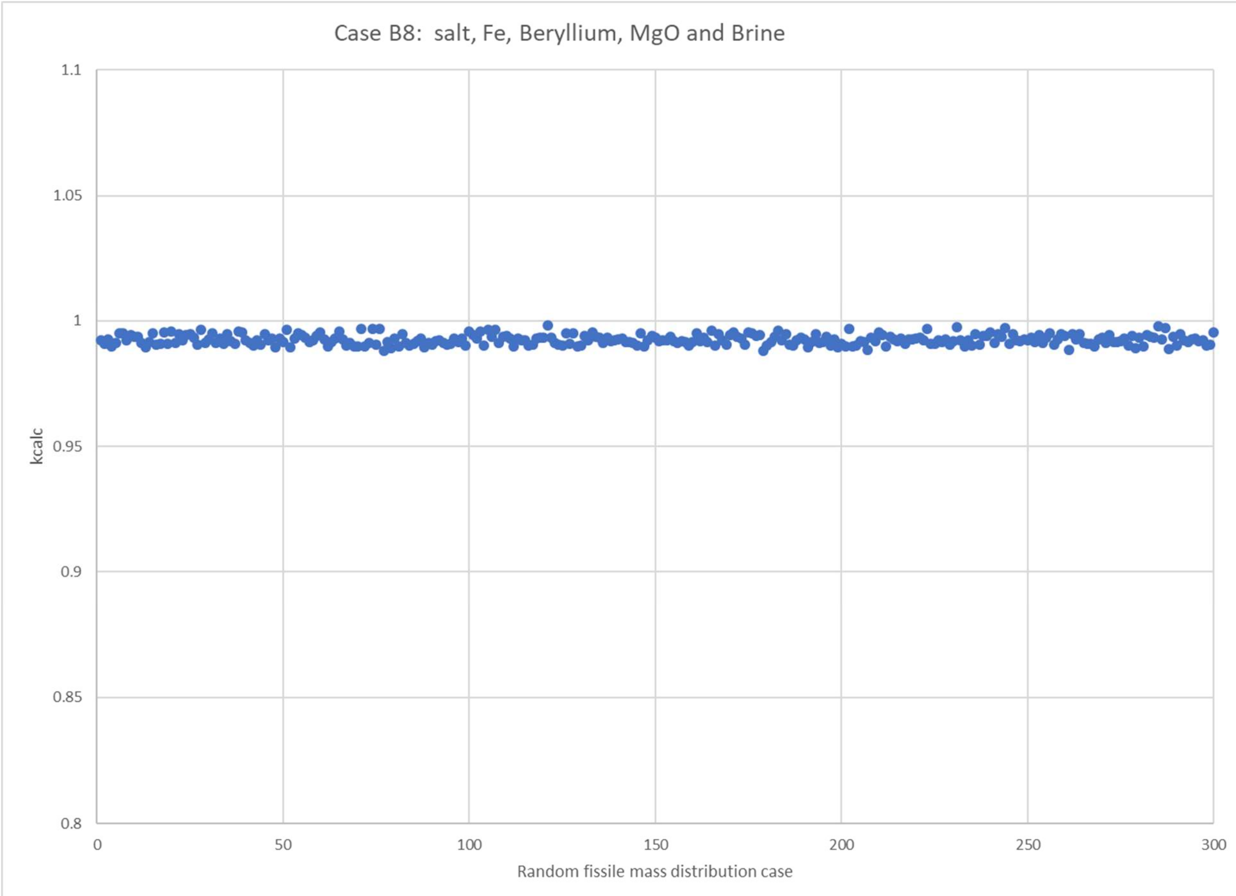


Figure B-10. Reflector material study: reflector material "m8" is salt, Fe, beryllium, MgO, and brine. Fully compacted configuration. Upper tolerance limit: 0.9969

APPENDIX C. RESULTS OF THE INCREMENTAL SPACING STUDIES

APPENDIX C. INTRODUCTION

Results from the cases presented in this appendix are from the studies discussed in Section 6.3. Based on scoping studies for compaction, the expectation from Reedlunn [10] is that the room will fully collapse in the z direction, while compaction in the x and y directions will not be very significant. Therefore, subsets of the incremental spacing studies keep z fixed at 0 spacing (closest approach), only increasing x and y. Some cases also increase z, as indicated. The following cases are considered:

- **Case C1:** the variation in pitch[19] is performed for each direction, x, y, or z, in one direction at a time while keeping the other two directions fixed at zero spacing. Additionally, results are presented for increasing all three directions at the same time. These evaluations are performed using the following materials:

  m3: salt, Fe, and beryllium

  m6: brine

  m7: salt, Fe, beryllium, and MgO

  m8: salt, Fe, beryllium, MgO, and brine

- **Case C2:** the variation in pitch is performed for both x and y directions together, while z remains at closest approach. For this case, the most reactive combination of reflector materials is considered:

  m7: salt, Fe, beryllium, and MgO

For all the cases presented in this appendix, the sphere radius is varied according to the mass used. Therefore, the pitch between sphere, while minimized, varies across the array.

The results of the spacing studies presented in Figures C-1 through C-5 show that the reactivity effect of increasing the spacing between POCs reduces reactivity. In particular, the reactivity effect of increasing the spacing in the z direction is small compared to increasing the spacing in the x and/or y direction.

---

[19] Note that the cases in Appendix C use the randomly distributed masses and therefore each sphere has a radius related to the mass. Therefore, the center to center pitch varies across the model. Thus, for these studies, "pitch" refers to the increase in distance between spheres, but this increase in distance is uniform across the model and therefore is better understood as a change in edge to edge spacing.

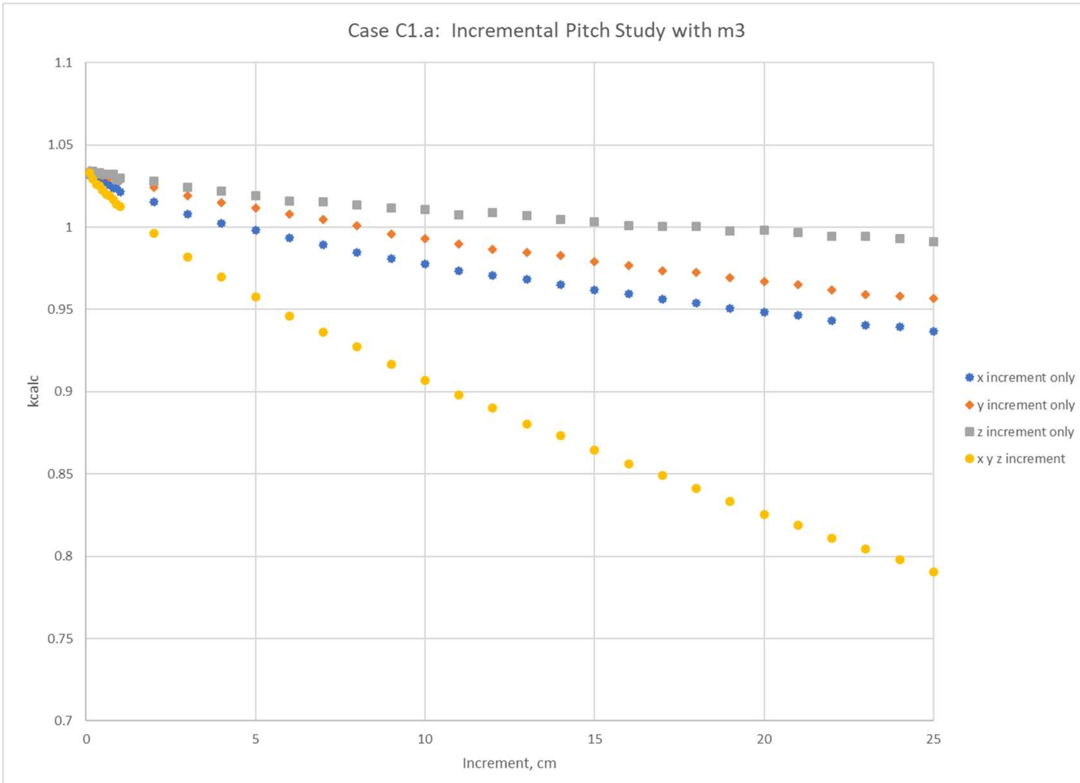


Figure C-1. Incremental pitch study Case C1.a: reflector material “m3” is salt, Fe, and beryllium.

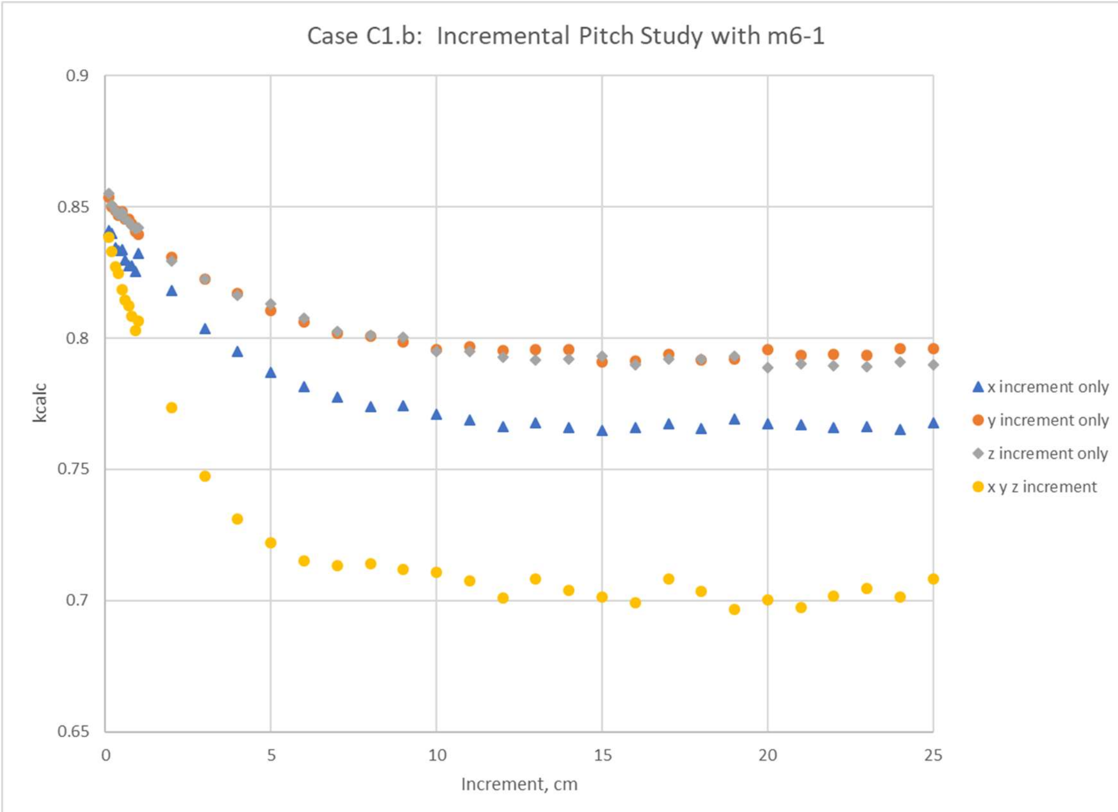


Figure C-2. Incremental pitch study Case C1.b: reflector material "m6-1" is brine.

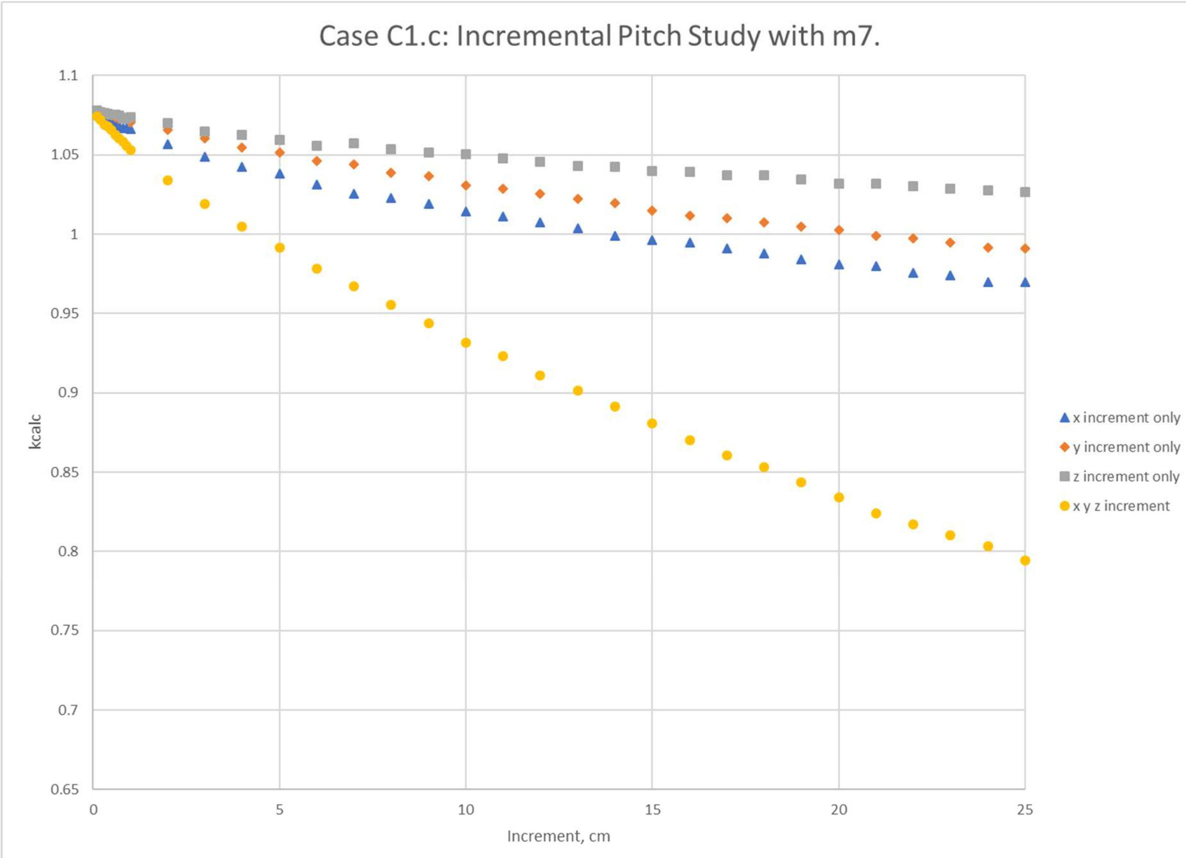


Figure C-3. Incremental pitch study Case C1.c: reflector material "m7" is salt, Fe, beryllium, and MgO.

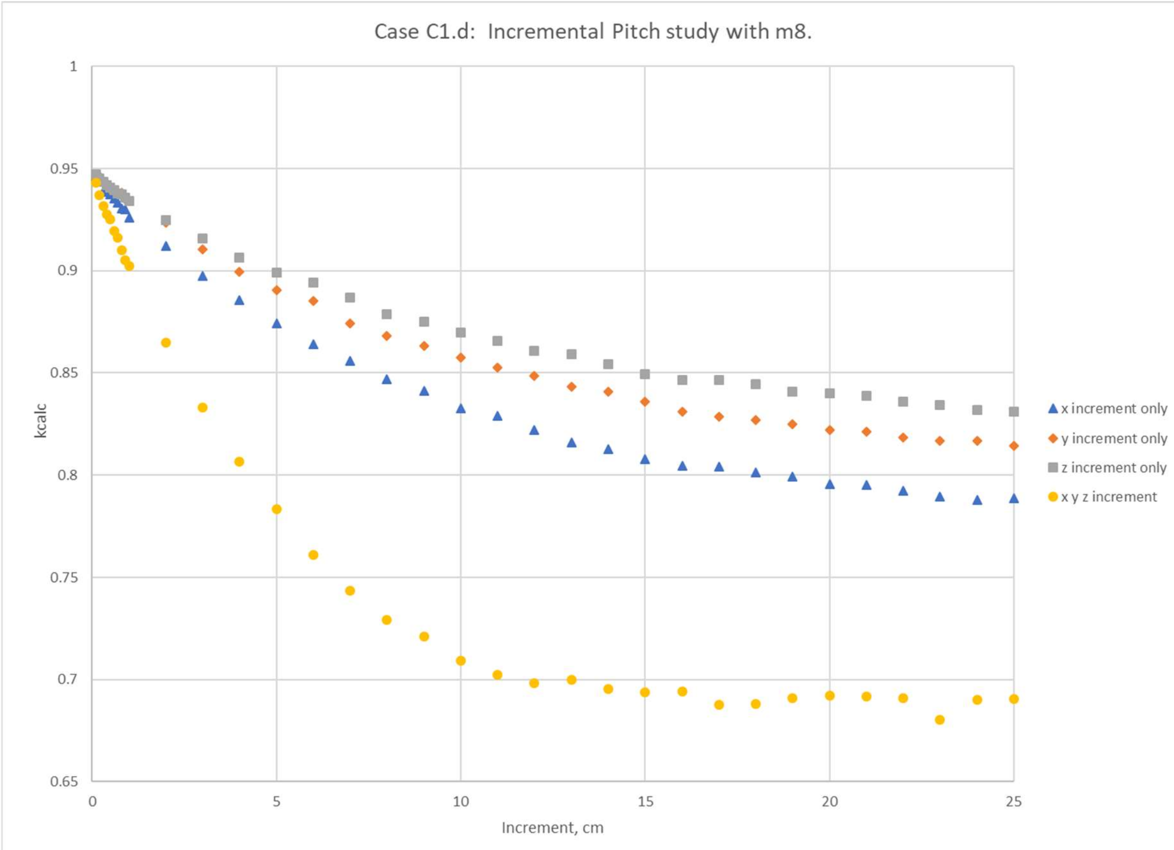


Figure C-4. Incremental pitch study Case C1.d: reflector material "m8" is salt, Fe, beryllium, MgO, and brine.

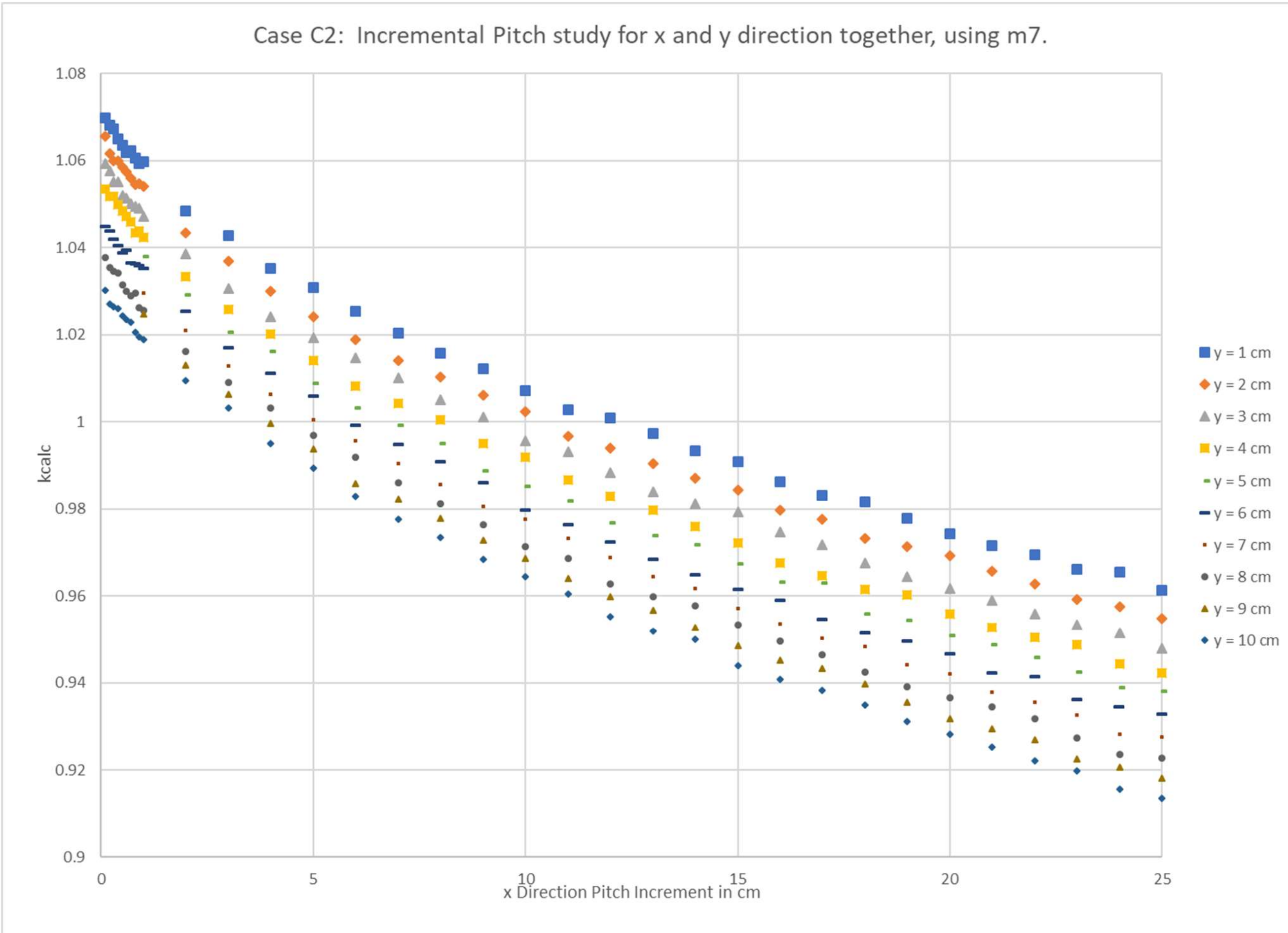


Figure C-5. Incremental pitch study Case C2: reflector material "m7" is salt, Fe, beryllium, and MgO.

APPENDIX D. ADDITIONAL STUDIES

APPENDIX D. INTRODUCTION

Additional studies are included in this appendix to present additional results for other scenarios which consider uniform arrays of 200 FGE masses with spacing based on Reedlunn [10]. For the additional studies, the calculations are the same as that described in Section 6.3, with exceptions as discussed below.

In general, the MCNP models for the additional studies consider the following:

- 648 equally spaced (based on values from Reedlunn [10]) waste form spheres with 200 g fissile mass, in an array similar to those in the cases presented in Section 6.2, except with only two rows of spheres in the z direction.

- Two sets of cases:

  - (1) 31.8 cm nearest neighbor spacing (average) and 23.3 cm nearest neighbor spacing (minimum) for the 12-inch pipe, and
  - (2) 23.7 cm nearest neighbor spacing (average) and 10.9 cm nearest neighbor spacing (minimum) for the 6-inch pipe.

- The reflector material follows the same approach as discussed in Section 4.2, however, the size of the reflector box is constricted to just contain the size of the spheres in the array.

A complete description of the material compositions is provided below and in Table D-1. In Table D-1, each material description is specified using the material number and the waste form designation. For example, "m10-701" represents material 10 and a sphere radius 2.65 cm. The waste form designations considered are as follows:

- 12-inch average spacing (pitch of 31.8 cm):

  - 701-714 for no Be in the waste form and for sphere radius is increments from 2.65 cm to 15.65 cm (covers the range of spheres which may fit in the pitch size).

  - 718-731 with Be in the waste form and for sphere radius is increments from 5.32 cm to 15.83 cm (covers the range of spheres which may fit in the pitch size).

  - 735-748 for no Be, but with brine in the waste form and for sphere radius is increments from 2.65 cm to 15.65 cm (covers the range of spheres which may fit in the pitch size).

- 12-inch minimum spacing (pitch of 23.3 cm):

  - 701-709 for no Be in the waste form and for sphere radius is increments from 2.65 cm to 10.65 cm (covers the range of spheres which may fit in the pitch size).

  - 718-726 with Be in the waste form and for sphere radius is increments from 5.32 cm to 11.03 cm (covers the range of spheres which may fit in the pitch size).

  - 735-743 for no Be, but with brine in the waste form and for sphere radius is increments from 2.65 cm to 10.65 cm (covers the range of spheres which may fit in the pitch size).

- 6-inch average spacing (pitch of 23.7 cm):
    - 701-710 for no Be in the waste form and for sphere radius is increments from 2.65 cm to 15.65 cm (covers the range of spheres which may fit in the pitch size).
    - 718-726 with Be in the waste form and for sphere radius is increments from 5.32 cm to 11.03 cm (covers the range of spheres which may fit in the pitch size).
    - 735-744 for no Be, but with brine in the waste form and for sphere radius is increments from 2.65 cm to 11.65 cm (covers the range of spheres which may fit in the pitch size).
- 6-inch min spacing (pitch of 10.9 cm):
    - 701-703 for no Be in the waste form and for sphere radius is increments from 2.65 cm to 4.65 cm (covers the range of spheres which may fit in the pitch size).
    - 718 with Be in the waste form and for sphere radius is 5.32 cm (covers the range of spheres which may fit in the pitch size).
    - 735-737 for no Be, but with brine in the waste form and for sphere radius is increments from 2.65 cm to 4.65 cm (covers the range of spheres which may fit in the pitch size).

The following reflector materials are used for the additional studies, as designated by "m" for "material" and a number for sequential material number:

- **m10:** reflector box is homogenized cellulose (60% of as-emplaced amount) and beryllium (1%).
- **m11:** reflector box is cellulose (60% of as-emplaced amount).
- **m12:** reflector box is homogenized cellulose (60% of as-emplaced amount), beryllium (1%), and Fe.
- **m13:** reflector box is homogenized cellulose (60% of as-emplaced amount) and Fe (total mass based on 648 pipes).
- **m14:** reflector box is homogenized brine (20% of the amount considered in material m6-1 Section 4.1) and beryllium (1%).
- **m15:** reflector box is homogenized brine (20% of the amount considered in material m6-1 Section 4.1), beryllium (1%), and Fe (total mass based on 648 pipes).
- **m16:** reflector box is homogenized brine (20% of the amount considered in material m6-1 Section 4.1), cellulose (40% of as-emplaced amount), and beryllium (1%).
- **m17:** reflector box is homogenized brine (20% of the amount considered in material m6-1 Section 4.1), cellulose (40% of as-emplaced amount), beryllium (1%), and Fe (total mass based on 648 pipes).
- **m18:** reflector box is homogenized Fe (total mass based on 648 pipes) and beryllium (1%).
- **m19:** reflector box is homogenized Fe (total mass based on 648 pipes), beryllium (1%), and salt and MgO (the ratio of salt to MgO is 50% by volume).

- **m20:** reflector box is homogenized Fe (total mass based on 648 pipes), beryllium (1%), and brine (20% of the amount considered in material m6-1 Section 4.1).

- **m21:** reflector box is homogenized Fe (total mass based on 648 pipes), beryllium (1%), salt and MgO (the ratio of salt to MgO is 50% by volume) and brine (20% of the amount considered in material m6-1 Section 4.1).

The cases considered for the additional studies in Appendix D are described below. The following cases are used to determine the optimum moderation H/Pu ratio and maximum reactivity for each scenario:

- **Case D1.a:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 701–717[20]. Reflector box material is m10.

- **Case D1.b:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$, beryllium (1%), with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 718–734[21]. Reflector box material is m11.

- **Case D1.c:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 701–717. Reflector box material is m12.

- **Case D1.d:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$, beryllium (1%) and H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 718–734. Reflector box material is m13.

- **Case D2.a:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 701–717. Reflector box material is m14.

- **Case D2.b:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 701–717. Reflector box material is m15.

- **Case D3.a:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 701–717. Reflector box material is m16.

- **Case D3.b:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% H_2O and 25% CH_2; optimum moderation determined using sphere radius increment cases 701–717. Reflector box material is m17.

- **Case D4.a:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% brine (material m6-1 Section 4.1) and 25% CH_2; optimum moderation determined using sphere radius increment cases 735–751[22]. Reflector box material is m18.

---

[20] These numbers represent a sphere radius increase from 1 to 17 cm as possible to fit in the pitch size, respectively, without including beryllium.
[21] These numbers represent a sphere radius increase from 1 to 17 cm as possible to fit in the pitch size, respectively, including beryllium.
[22] These numbers represent a sphere radius increase from 1 to 17 cm as possible to fit in the pitch size, respectively, including brine.

- **Case D4.b:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% brine (material m6-1 Section 4.1) and 25% CH_2; optimum moderation determined using sphere radius increment cases 735–751. Reflector box material is m19.

- **Case D4.c:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% brine (material m6-1 Section 4.1) and 25% CH_2; optimum moderation determined using sphere radius increment cases 735–751. Reflector box material is m20.

- **Case D4.d:** waste form is 200 g ^{239}Pu as $^{239}PuO_2$ with H as 75% brine (material m6-1 Section 4.1) and 25% CH_2; optimum moderation determined using sphere radius increment cases 735–751. Reflector box material is m21.

The results of the additional studies discussed in Appendix D are presented in Figure D-1 through Figure D-4.

Table D-1. Summary of material compositions for the additional studies with 200 g fissile mass (1 of 23)

12-inch Pipe (pitch = 31.8 cm)														
material	m10-701	m10-702	m10-703	m10-704	m10-705	m10-706	m10-707	m10-708	m10-709	m10-710	m10-711	m10-712	m10-713	m10-714
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662	4296462	5500063	6909751	8541811	10412530
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
1001.70c	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212
1002.70c	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013
8016.70c	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863
8017.70c	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252
4009.70c	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358
6000.70c	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302
material densty (g/cm3)	0.948539	0.899522	0.858869	0.826067	0.800736	0.782686	0.771960	0.768906	0.774272	0.789386	0.816453	0.859116	0.923544	1.020775

12-inch Pipe (pitch = 31.8 cm)														
material	m11-718	m11-719	m11-720	m11-721	m11-722	m11-723	m11-724	m11-725	m11-726	m11-727	m11-728	m11-729	m11-730	m11-731
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662	4296462	5500063	6909751	8541811	10412530
total reflector box volume (cm3)	12897005	13131054	13482477	13935301	14466789	15056922	15690433	16357013	17049661	17763557	18495728	19243749	20006257	20782133
MCNP ZAID.XS	Weight fraction													
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
4009.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	0.761373	0.752449	0.740473	0.727485	0.715647	0.706718	0.702082	0.702913	0.710451	0.726273	0.752619	0.792994	0.853141	0.943217

Table D-1. continued (2 of 23)

12-inch Pipe (pitch = 31.8 cm)														
material	m12-701	m12-702	m12-703	m12-704	m12-705	m12-706	m12-707	m12-708	m12-709	m12-710	m12-711	m12-712	m12-713	m12-714
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662	4296462	5500063	6909751	8541811	10412530
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
1001.70c	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293
8017.70c	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626
4009.70c	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265
6000.70c	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729
26045.70c	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502
26056.70c	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476
material densty (g/cm3)	4.212965	3.995253	3.814694	3.668999	3.556491	3.476322	3.428685	3.415118	3.438952	3.506080	3.626301	3.815788	4.101949	4.533801

12-inch Pipe (pitch = 31.8 cm)														
material	m13-718	m13-719	m13-720	m13-721	m13-722	m13-723	m13-724	m13-725	m13-726	m13-727	m13-728	m13-729	m13-730	m13-731
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662	4296462	5500063	6909751	8541811	10412530
total reflector box volume (cm3)	12897005	13131054	13482477	13935301	14466789	15056922	15690433	16357013	17049661	17763557	18495728	19243749	20006257	20782133
MCNP ZAID.XS	Weight fraction													
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
4009.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
26045.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
material densty (g/cm3)	3.558905	3.517191	3.461215	3.400505	3.345170	3.303433	3.281761	3.285647	3.320882	3.394837	3.517987	3.706712	3.987858	4.408904

Table D-1. continued (2 of 23)

12-inch Pipe (pitch = 31.8 cm)														
material	m14-701	m14-702	m14-703	m14-704	m14-705	m14-706	m14-707	m14-708	m14-709	m14-710	m14-711	m14-712	m14-713	m14-714
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
1001.70c	0.064588	0.517100	0.521948	0.525905	0.528982	0.531173	0.532453	0.532762	0.532000	0.530001	0.526504	0.521097	0.513115	0.501430
1002.70c	0.000015	0.001405	0.001418	0.001429	0.001437	0.001443	0.001447	0.001448	0.001446	0.001440	0.001431	0.001416	0.001394	0.001363
8016.70c	0.511343	0.201021	0.193531	0.187417	0.182663	0.179277	0.177300	0.176821	0.177999	0.181088	0.186491	0.194845	0.207178	0.225233
8017.70c	0.001389	0.084632	0.085426	0.086073	0.086577	0.086935	0.087145	0.087195	0.087071	0.086744	0.086171	0.085286	0.083980	0.082067
4009.70c	0.209916	0.097552	0.098467	0.099213	0.099794	0.100207	0.100448	0.100507	0.100363	0.099986	0.099326	0.098306	0.096800	0.094596
11023.70c	0.083690	0.084632	0.085426	0.086073	0.086577	0.086935	0.087145	0.087195	0.087071	0.086744	0.086171	0.085286	0.083980	0.082067
17035.70c	0.096466	0.097552	0.098467	0.099213	0.099794	0.100207	0.100448	0.100507	0.100363	0.099986	0.099326	0.098306	0.096800	0.094596
17037.70c	0.032592	0.032959	0.033268	0.033520	0.033716	0.033856	0.033938	0.033957	0.033909	0.033781	0.033559	0.033214	0.032705	0.031960
material densty (g/cm3)	0.286401	0.283702	0.281469	0.279671	0.278290	0.277314	0.276747	0.276610	0.276947	0.277835	0.279401	0.281858	0.285565	0.291171

12-inch Pipe (pitch = 31.8 cm)														
material	m15-701	m15-702	m15-703	m15-704	m15-705	m15-706	m15-707	m15-708	m15-709	m15-710	m15-711	m15-712	m15-713	m15-714
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
1001.70c	0.005208	0.005480	0.005727	0.005941	0.006118	0.006248	0.006326	0.006346	0.006299	0.006178	0.005975	0.005682	0.005289	0.004786
1002.70c	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
8016.70c	0.191359	0.192979	0.194450	0.195729	0.196777	0.197555	0.198021	0.198136	0.197855	0.197136	0.195929	0.194184	0.191844	0.188846
8017.70c	0.000520	0.000524	0.000528	0.000532	0.000535	0.000537	0.000538	0.000538	0.000538	0.000536	0.000532	0.000528	0.000521	0.000513
4009.70c	0.016925	0.016865	0.016811	0.016763	0.016724	0.016695	0.016678	0.016674	0.016684	0.016711	0.016756	0.016821	0.016907	0.017019
11023.70c	0.006748	0.007100	0.007420	0.007699	0.007927	0.008096	0.008197	0.008222	0.008161	0.008005	0.007742	0.007363	0.006853	0.006201
17035.70c	0.007778	0.008184	0.008553	0.008874	0.009137	0.009332	0.009449	0.009478	0.009407	0.009227	0.008924	0.008487	0.007900	0.007148
17037.70c	0.002628	0.002765	0.002890	0.002998	0.003087	0.003153	0.003192	0.003202	0.003178	0.003117	0.003015	0.002867	0.002669	0.002415
26045.70c	0.044496	0.044338	0.044195	0.044070	0.043967	0.043892	0.043846	0.043835	0.043862	0.043932	0.044050	0.044221	0.044449	0.044742
26056.70c	0.724337	0.721762	0.719425	0.717392	0.715726	0.714491	0.713750	0.713568	0.714014	0.715157	0.717074	0.719847	0.723566	0.728330
material densty (g/cm3)	3.552061	3.381522	3.240370	3.126795	3.039493	2.977830	2.942025	2.933382	2.954670	3.010759	3.109735	3.264972	3.499228	3.853477

Table D-1. continued (3 of 23)

12-inch Pipe (pitch = 31.8 cm)														
material	m16-701	m16-702	m16-703	m16-704	m16-705	m16-706	m16-707	m16-708	m16-709	m16-710	m16-711	m16-712	m16-713	m16-714
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
1001.70c	0.062944	0.063211	0.063449	0.063652	0.063816	0.063936	0.064008	0.064025	0.063982	0.063872	0.063684	0.063406	0.063025	0.062518
1002.70c	0.000014	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000014	0.000014
8016.70c	0.498328	0.500444	0.502325	0.503933	0.505231	0.506182	0.506748	0.506886	0.506547	0.505670	0.504182	0.501988	0.498967	0.494955
8017.70c	0.001354	0.001360	0.001365	0.001369	0.001373	0.001375	0.001377	0.001377	0.001376	0.001374	0.001370	0.001364	0.001356	0.001345
4009.70c	0.068402	0.067430	0.066566	0.065827	0.065231	0.064794	0.064534	0.064470	0.064626	0.065029	0.065713	0.066721	0.068109	0.069953
11023.70c	0.027271	0.028389	0.029383	0.030232	0.030918	0.031420	0.031719	0.031792	0.031613	0.031150	0.030364	0.029205	0.027608	0.025488
17035.70c	0.031434	0.032723	0.033868	0.034847	0.035637	0.036217	0.036561	0.036646	0.036439	0.035905	0.034999	0.033663	0.031823	0.029379
17037.70c	0.010620	0.011056	0.011443	0.011774	0.012041	0.012236	0.012353	0.012381	0.012311	0.012131	0.011825	0.011373	0.010752	0.009926
6000.70c	0.299631	0.295373	0.291587	0.288351	0.285739	0.283825	0.282686	0.282408	0.283091	0.284855	0.287850	0.292265	0.298347	0.306422
material densty (g/cm3)	0.878920	0.845768	0.818329	0.796251	0.779280	0.767293	0.760333	0.758653	0.762791	0.773694	0.792934	0.823111	0.868649	0.937513

12-inch Pipe (pitch = 31.8 cm)														
material	m17-701	m17-702	m17-703	m17-704	m17-705	m17-706	m17-707	m17-708	m17-709	m17-710	m17-711	m17-712	m17-713	m17-714
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
1001.70c	0.013348	0.013557	0.013746	0.013911	0.014046	0.014147	0.014207	0.014222	0.014185	0.014092	0.013937	0.013712	0.013411	0.013025
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.234345	0.235603	0.236746	0.237741	0.238558	0.239163	0.239527	0.239616	0.239398	0.238837	0.237897	0.236540	0.234721	0.232395
8017.70c	0.000637	0.000640	0.000643	0.000646	0.000648	0.000650	0.000651	0.000651	0.000651	0.000649	0.000646	0.000643	0.000638	0.000631
4009.70c	0.014506	0.014462	0.014421	0.014386	0.014358	0.014336	0.014324	0.014321	0.014328	0.014348	0.014381	0.014429	0.014493	0.014574
11023.70c	0.005783	0.006088	0.006366	0.006607	0.006805	0.006952	0.007040	0.007062	0.007009	0.006873	0.006645	0.006316	0.005875	0.005310
17035.70c	0.006666	0.007018	0.007337	0.007616	0.007844	0.008013	0.008115	0.008140	0.008079	0.007922	0.007659	0.007280	0.006771	0.006121
17037.70c	0.002252	0.002371	0.002479	0.002573	0.002650	0.002707	0.002742	0.002750	0.002730	0.002677	0.002588	0.002460	0.002288	0.002068
6000.70c	0.063541	0.063348	0.063172	0.063018	0.062893	0.062800	0.062744	0.062730	0.062764	0.062850	0.062994	0.063203	0.063483	0.063841
26054.70c	0.038135	0.038019	0.037913	0.037821	0.037746	0.037690	0.037656	0.037648	0.037668	0.037720	0.037807	0.037932	0.038100	0.038315
26056.70c	0.620784	0.618891	0.617173	0.615676	0.614449	0.613538	0.612991	0.612857	0.613186	0.614029	0.615442	0.617483	0.620217	0.623715
material densty (g/cm3)	4.144579	3.943587	3.777231	3.643375	3.540483	3.467810	3.425611	3.415424	3.440513	3.506618	3.623268	3.806226	4.082313	4.499819

Table D-1. continued (4 of 23)

12-inch Pipe (pitch = 31.8 cm)														
material	m18-735	m18-736	m18-737	m18-738	m18-739	m18-740	m18-741	m18-742	m18-743	m18-744	m18-745	m18-746	m18-747	m18-748
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
26054.70c	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524
26056.70c	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619
4009.70c	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077
8016.70c	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344
8017.70c	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436
material densty (g/cm3)	3.325780	3.154850	3.013374	2.899539	2.812036	2.750233	2.714345	2.705682	2.727019	2.783236	2.882439	3.038033	3.272826	3.627887

12-inch Pipe (pitch = 31.8 cm)														
material	m19-735	m19-736	m19-737	m19-738	m19-739	m19-740	m19-741	m19-742	m19-743	m19-744	m19-745	m19-746	m19-747	m19-748
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
26054.70c	0.040012	0.039044	0.038200	0.037490	0.036925	0.036515	0.036273	0.036214	0.036359	0.036735	0.037381	0.038350	0.039718	0.041597
26056.70c	0.651338	0.635581	0.621839	0.610287	0.601089	0.594418	0.590475	0.589516	0.591873	0.597999	0.608512	0.624282	0.646551	0.677140
4009.70c	0.015220	0.014851	0.014530	0.014260	0.014046	0.013890	0.013798	0.013775	0.013830	0.013973	0.014219	0.014587	0.015108	0.015823
8016.70c	0.160099	0.160067	0.160040	0.160017	0.159998	0.159985	0.159977	0.159975	0.159980	0.159992	0.160013	0.160045	0.160089	0.160151
8017.70c	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435	0.000435
11023.70c	0.037238	0.042037	0.046222	0.049740	0.052541	0.054572	0.055773	0.056065	0.055347	0.053482	0.050280	0.045478	0.038696	0.029381
17035.70c	0.042923	0.048454	0.053278	0.057333	0.060561	0.062903	0.064287	0.064624	0.063796	0.061646	0.057956	0.052420	0.044603	0.033866
17037.70c	0.014502	0.016371	0.018001	0.019371	0.020461	0.021253	0.021720	0.021834	0.021554	0.020828	0.019581	0.017711	0.015070	0.011442
12024.70c	0.029802	0.033643	0.036992	0.039807	0.042049	0.043675	0.044636	0.044870	0.044295	0.042802	0.040240	0.036397	0.030969	0.023514
12025.70c	0.003930	0.004437	0.004879	0.005250	0.005545	0.005760	0.005887	0.005917	0.005842	0.005645	0.005307	0.004800	0.004084	0.003101
12026.70c	0.004500	0.005080	0.005586	0.006011	0.006349	0.006595	0.006740	0.006775	0.006688	0.006463	0.006076	0.005496	0.004676	0.003550
material densty (g/cm3)	3.950157	3.840034	3.748888	3.675549	3.619174	3.579357	3.556236	3.550655	3.564401	3.600620	3.664532	3.764774	3.916041	4.144792

Table D-1. continued (5 of 23)

12-inch Pipe (pitch = 31.8 cm)														
material	m20-735	m20-736	m20-737	m20-738	m20-739	m20-740	m20-741	m20-742	m20-743	m20-744	m20-745	m20-746	m20-747	m20-748
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
26054.70c	0.044496	0.044338	0.044195	0.044070	0.043967	0.043892	0.043846	0.043835	0.043862	0.043932	0.044050	0.044221	0.044449	0.044742
26056.70c	0.724337	0.721762	0.719425	0.717392	0.715726	0.714491	0.713750	0.713568	0.714014	0.715157	0.717074	0.719847	0.723566	0.728330
4009.70c	0.016925	0.016865	0.016811	0.016763	0.016724	0.016695	0.016678	0.016674	0.016684	0.016711	0.016756	0.016821	0.016907	0.017019
8016.70c	0.191359	0.192979	0.194450	0.195729	0.196777	0.197555	0.198021	0.198136	0.197855	0.197136	0.195929	0.194184	0.191844	0.188846
8017.70c	0.000520	0.000524	0.000528	0.000532	0.000535	0.000537	0.000538	0.000538	0.000538	0.000536	0.000532	0.000528	0.000521	0.000513
11023.70c	0.006748	0.007100	0.007420	0.007699	0.007927	0.008096	0.008197	0.008222	0.008161	0.008005	0.007742	0.007363	0.006853	0.006201
17035.70c	0.007778	0.008184	0.008553	0.008874	0.009137	0.009332	0.009449	0.009478	0.009407	0.009227	0.008924	0.008487	0.007900	0.007148
17037.70c	0.002628	0.002765	0.002890	0.002998	0.003087	0.003153	0.003192	0.003202	0.003178	0.003117	0.003015	0.002867	0.002669	0.002415
1001.70c	0.005208	0.005480	0.005727	0.005941	0.006118	0.006248	0.006326	0.006346	0.006299	0.006178	0.005975	0.005682	0.005289	0.004786
1002.70c	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
material densty (g/cm3)	3.552061	3.381522	3.240370	3.126795	3.039493	2.977830	2.942025	2.933382	2.954670	3.010759	3.109735	3.264972	3.499228	3.853477

12-inch Pipe (pitch = 31.8 cm)														
material	m21-735	m21-736	m21-737	m21-738	m21-739	m21-740	m21-741	m21-742	m21-743	m21-744	m21-745	m21-746	m21-747	m21-748
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019	5592635	7017488	8665863	10554047
total reflector box volume (cm3)	11059672	11741272	12431952	13131759	13840741	14558947	15286425	16023221	16769386	17524966	18290009	19064564	19848678	20642400
MCNP ZAID.XS	Weight fraction													
26054.70c	0.040363	0.039432	0.038617	0.037931	0.037384	0.036987	0.036752	0.036695	0.036836	0.037200	0.037826	0.038762	0.040081	0.041885
26056.70c	0.657058	0.641889	0.628632	0.617467	0.608564	0.602100	0.598276	0.597346	0.599632	0.605570	0.615750	0.630991	0.652454	0.681823
4009.70c	0.015353	0.014999	0.014689	0.014428	0.014220	0.014069	0.013980	0.013958	0.014011	0.014150	0.014388	0.014744	0.015246	0.015932
8016.70c	0.168182	0.169202	0.170093	0.170844	0.171443	0.171877	0.172135	0.172197	0.172043	0.171644	0.170960	0.169935	0.168492	0.166517
8017.70c	0.000457	0.000460	0.000462	0.000464	0.000466	0.000467	0.000468	0.000468	0.000467	0.000466	0.000465	0.000462	0.000458	0.000452
11023.70c	0.031145	0.035198	0.038741	0.041724	0.044103	0.045830	0.046852	0.047100	0.046489	0.044903	0.042183	0.038110	0.032375	0.024528
17035.70c	0.035900	0.040572	0.044655	0.048093	0.050835	0.052826	0.054004	0.054291	0.053586	0.051757	0.048622	0.043928	0.037318	0.028272
17037.70c	0.012129	0.013708	0.015087	0.016249	0.017175	0.017848	0.018246	0.018343	0.018105	0.017487	0.016428	0.014842	0.012608	0.009552
1001.70c	0.000843	0.000953	0.001049	0.001130	0.001194	0.001241	0.001269	0.001275	0.001259	0.001216	0.001142	0.001032	0.000877	0.000664
1002.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12024.70c	0.030064	0.033977	0.037396	0.040276	0.042572	0.044240	0.045226	0.045466	0.044876	0.043344	0.040719	0.036788	0.031252	0.023677
12025.70c	0.003965	0.004481	0.004932	0.005312	0.005614	0.005834	0.005964	0.005996	0.005918	0.005716	0.005370	0.004852	0.004122	0.003122
12026.70c	0.004539	0.005130	0.005647	0.006081	0.006428	0.006680	0.006829	0.006865	0.006776	0.006545	0.006148	0.005555	0.004719	0.003575
material densty (g/cm3)	3.915767	3.802295	3.708377	3.632807	3.574718	3.533690	3.509866	3.504115	3.518279	3.555599	3.621455	3.724746	3.880614	4.116322

Table D-1. continued (6 of 23)

12-inch Pipe (pitch = 23.3 cm)									
material	m10-701	m10-702	m10-703	m10-704	m10-705	m10-706	m10-707	m10-708	m10-709
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
1001.70c	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212	0.058212
1002.70c	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013	0.000013
8016.70c	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863	0.460863
8017.70c	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252	0.001252
4009.70c	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358	0.063358
6000.70c	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302	0.416302
material densty (g/cm3)	2.290347	2.153449	2.053093	1.987454	1.956660	1.963591	2.015359	2.126414	2.325724

12-inch Pipe (pitch = 23.3 cm)									
material	m11-718	m11-719	m11-720	m11-721	m11-722	m11-723	m11-724	m11-725	m11-726
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662
total reflector box volume (cm3)	5615473	5744422	5938398	6188972	6483963	6812606	7166669	7540595	7930610
MCNP ZAID.XS	Weight fraction								
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
4009.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	1.757642	1.742841	1.726606	1.716434	1.720691	1.748003	1.808794	1.918471	2.104323

Table D-1. continued (7 of 23)

12-inch Pipe (pitch = 23.3 cm)									
material	m12-701	m12-702	m12-703	m12-704	m12-705	m12-706	m12-707	m12-708	m12-709
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
1001.70c	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106	0.013106
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293	0.230293
8017.70c	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626	0.000626
4009.70c	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265	0.014265
6000.70c	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729	0.093729
26045.70c	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502	0.037502
26056.70c	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476	0.610476
material densty (g/cm3)	10.172647	9.564609	9.118873	8.827337	8.690565	8.721349	8.951278	9.444530	10.329772

12-inch Pipe (pitch = 23.3 cm)									
material	m13-718	m13-719	m13-720	m13-721	m13-722	m13-723	m13-724	m13-725	m13-726
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662
total reflector box volume (cm3)	5615473	5744422	5938398	6188972	6483963	6812606	7166669	7540595	7930610
MCNP ZAID.XS	Weight fraction								
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
4009.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
26045.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
material densty (g/cm3)	8.215793	8.146611	8.070722	8.023175	8.043072	8.170740	8.454896	8.967560	9.836295

Table D-1. continued (8 of 23)

12-inch Pipe (pitch = 23.3 cm)									
material	m14-701	m14-702	m14-703	m14-704	m14-705	m14-706	m14-707	m14-708	m14-709
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
1001.70c	0.048835	0.396826	0.404533	0.409635	0.411942	0.411119	0.406589	0.397356	0.381682
1002.70c	0.000011	0.001078	0.001099	0.001113	0.001119	0.001117	0.001105	0.001080	0.001037
8016.70c	0.386628	0.386858	0.374950	0.367068	0.363503	0.364773	0.371774	0.386039	0.410258
8017.70c	0.001051	0.064947	0.066209	0.067044	0.067421	0.067287	0.066545	0.065034	0.062469
4009.70c	0.402615	0.074862	0.076316	0.077278	0.077714	0.077559	0.076704	0.074962	0.072005
11023.70c	0.063278	0.064947	0.066209	0.067044	0.067421	0.067287	0.066545	0.065034	0.062469
17035.70c	0.072938	0.074862	0.076316	0.077278	0.077714	0.077559	0.076704	0.074962	0.072005
17037.70c	0.024643	0.025293	0.025784	0.026109	0.026257	0.026204	0.025915	0.025327	0.024328
material densty (g/cm3)	0.360752	0.353253	0.347789	0.344265	0.342694	0.343252	0.346360	0.352872	0.364504

12-inch Pipe (pitch = 23.3 cm)									
material	m15-701	m15-702	m15-703	m15-704	m15-705	m15-706	m15-707	m15-708	m15-709
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
1001.70c	0.002135	0.002277	0.002391	0.002471	0.002508	0.002495	0.002423	0.002285	0.002070
1002.70c	0.000000	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000000
8016.70c	0.173062	0.173904	0.174586	0.175061	0.175282	0.175203	0.174775	0.173950	0.172675
8017.70c	0.000470	0.000473	0.000474	0.000476	0.000476	0.000476	0.000475	0.000473	0.000469
4009.70c	0.017605	0.017574	0.017548	0.017531	0.017522	0.017525	0.017541	0.017572	0.017619
11023.70c	0.002767	0.002950	0.003099	0.003202	0.003250	0.003233	0.003140	0.002960	0.002683
17035.70c	0.003189	0.003401	0.003572	0.003691	0.003746	0.003726	0.003619	0.003412	0.003092
17037.70c	0.001078	0.001149	0.001207	0.001247	0.001266	0.001259	0.001223	0.001153	0.001045
26045.70c	0.046282	0.046200	0.046134	0.046087	0.046066	0.046073	0.046115	0.046196	0.046320
26056.70c	0.753411	0.752072	0.750988	0.750234	0.749883	0.750009	0.750688	0.751999	0.754026
material densty (g/cm3)	8.250247	7.776393	7.431177	7.208460	7.109218	7.144484	7.340878	7.752316	8.487396

Table D-1. continued (9 of 23)

12-inch Pipe (pitch = 23.3 cm)									
material	m16-701	m16-702	m16-703	m16-704	m16-705	m16-706	m16-707	m16-708	m16-709
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
1001.70c	0.059470	0.059651	0.059796	0.059896	0.059942	0.059925	0.059835	0.059660	0.059386
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.470820	0.472254	0.473401	0.474192	0.474559	0.474428	0.473717	0.472331	0.470156
8017.70c	0.001279	0.001283	0.001286	0.001289	0.001290	0.001289	0.001287	0.001283	0.001278
4009.70c	0.081042	0.080383	0.079856	0.079492	0.079324	0.079384	0.079711	0.080347	0.081347
11023.70c	0.012737	0.013495	0.014101	0.014519	0.014713	0.014643	0.014268	0.013536	0.012386
17035.70c	0.014682	0.015555	0.016254	0.016735	0.016959	0.016879	0.016446	0.015602	0.014277
17037.70c	0.004960	0.005255	0.005491	0.005654	0.005730	0.005703	0.005556	0.005271	0.004824
6000.70c	0.354997	0.352110	0.349802	0.348209	0.347471	0.347736	0.349166	0.351955	0.356333
material densty (g/cm3)	1.792214	1.700100	1.632993	1.589698	1.570406	1.577262	1.615439	1.695420	1.838315

12-inch Pipe (pitch = 23.3 cm)									
material	m17-701	m17-702	m17-703	m17-704	m17-705	m17-706	m17-707	m17-708	m17-709
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
1001.70c	0.011009	0.011116	0.011203	0.011263	0.011291	0.011281	0.011227	0.011122	0.010959
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.220223	0.220870	0.221393	0.221758	0.221928	0.221867	0.221539	0.220905	0.219926
8017.70c	0.000598	0.000600	0.000602	0.000603	0.000603	0.000603	0.000602	0.000600	0.000598
4009.70c	0.015002	0.014979	0.014961	0.014948	0.014942	0.014944	0.014956	0.014978	0.015012
11023.70c	0.002358	0.002515	0.002642	0.002730	0.002771	0.002757	0.002677	0.002523	0.002286
17035.70c	0.002718	0.002899	0.003045	0.003147	0.003194	0.003177	0.003086	0.002908	0.002635
17037.70c	0.000918	0.000979	0.001029	0.001063	0.001079	0.001074	0.001043	0.000983	0.000890
6000.70c	0.065715	0.065615	0.065535	0.065478	0.065452	0.065462	0.065512	0.065610	0.065760
26054.70c	0.039439	0.039380	0.039331	0.039298	0.039282	0.039288	0.039318	0.039376	0.039467
26056.70c	0.642018	0.641045	0.640258	0.639709	0.639454	0.639546	0.640039	0.640992	0.642464
material densty (g/cm3)	9.681710	9.123240	8.716381	8.453894	8.336929	8.378493	8.609957	9.094865	9.961206

Table D-1. continued (10 of 23)

12-inch Pipe (pitch = 23.3 cm)									
material	m18-735	m18-736	m18-737	m18-738	m18-739	m18-740	m18-741	m18-742	m18-743
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
26054.70c	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524	0.047524
26056.70c	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619	0.773619
4009.70c	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077	0.018077
8016.70c	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344	0.160344
8017.70c	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436	0.000436
material densty (g/cm3)	8.034740	7.559799	7.213791	6.990564	6.891094	6.926441	7.123286	7.535667	8.272432

12-inch Pipe (pitch = 23.3 cm)									
material	m19-735	m19-736	m19-737	m19-738	m19-739	m19-740	m19-741	m19-742	m19-743
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
26054.70c	0.043418	0.042325	0.041477	0.040906	0.040645	0.040738	0.041248	0.042267	0.043937
26056.70c	0.706776	0.688984	0.675192	0.665892	0.661641	0.663159	0.671461	0.688046	0.715224
4009.70c	0.033030	0.032199	0.031554	0.031120	0.030921	0.030992	0.031380	0.032155	0.033425
8016.70c	0.157588	0.157618	0.157642	0.157657	0.157665	0.157662	0.157648	0.157620	0.157573
8017.70c	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428
11023.70c	0.016465	0.021981	0.026257	0.029140	0.030458	0.029988	0.027414	0.022272	0.013846
17035.70c	0.018978	0.025337	0.030266	0.033589	0.035108	0.034566	0.031599	0.025672	0.015960
17037.70c	0.006412	0.008560	0.010226	0.011348	0.011862	0.011678	0.010676	0.008674	0.005392
12024.70c	0.013177	0.017592	0.021014	0.023322	0.024376	0.024000	0.021940	0.017825	0.011081
12025.70c	0.001738	0.002320	0.002771	0.003076	0.003215	0.003165	0.002893	0.002351	0.001461
12026.70c	0.001990	0.002656	0.003173	0.003521	0.003681	0.003624	0.003313	0.002691	0.001673
material densty (g/cm3)	4.397311	4.244224	4.132697	4.060745	4.028683	4.040076	4.103525	4.236446	4.473925

Table D-1. continued (11 of 23)

12-inch Pipe (pitch = 23.3 cm)									
material	m20-735	m20-736	m20-737	m20-738	m20-739	m20-740	m20-741	m20-742	m20-743
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
26054.70c	0.044343	0.044193	0.044071	0.043987	0.043947	0.043961	0.044037	0.044185	0.044413
26056.70c	0.721848	0.719393	0.717413	0.716038	0.715398	0.715627	0.716865	0.719260	0.722976
4009.70c	0.033735	0.033620	0.033527	0.033463	0.033433	0.033444	0.033502	0.033614	0.033787
8016.70c	0.182009	0.183591	0.184867	0.185753	0.186165	0.186017	0.185220	0.183676	0.181281
8017.70c	0.000495	0.000499	0.000502	0.000505	0.000506	0.000505	0.000503	0.000499	0.000493
11023.70c	0.005302	0.005644	0.005920	0.006112	0.006201	0.006169	0.005997	0.005663	0.005145
17035.70c	0.006111	0.006506	0.006824	0.007045	0.007148	0.007111	0.006912	0.006527	0.005930
17037.70c	0.002065	0.002198	0.002306	0.002380	0.002415	0.002402	0.002335	0.002205	0.002004
1001.70c	0.004092	0.004356	0.004569	0.004717	0.004786	0.004761	0.004628	0.004370	0.003970
1002.70c	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
material densty (g/cm3)	4.305499	4.064823	3.889483	3.776363	3.725956	3.743868	3.843619	4.052594	4.425950

12-inch Pipe (pitch = 23.3 cm)									
material	m21-735	m21-736	m21-737	m21-738	m21-739	m21-740	m21-741	m21-742	m21-743
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353
total reflector box volume (cm3)	4610058	4981593	5359828	5744811	6136589	6535210	6940723	7353175	7772615
MCNP ZAID.XS	Weight fraction								
26054.70c	0.043585	0.042543	0.041734	0.041187	0.040936	0.041026	0.041514	0.042488	0.044079
26056.70c	0.709507	0.692543	0.679362	0.670460	0.666386	0.667841	0.675792	0.691647	0.717546
4009.70c	0.033158	0.032365	0.031749	0.031333	0.031143	0.031211	0.031582	0.032323	0.033534
8016.70c	0.161134	0.162359	0.163311	0.163954	0.164248	0.164143	0.163569	0.162424	0.160554
8017.70c	0.000438	0.000441	0.000444	0.000446	0.000446	0.000446	0.000444	0.000441	0.000436
11023.70c	0.013704	0.018318	0.021904	0.024326	0.025434	0.025038	0.022875	0.018562	0.011517
17035.70c	0.015796	0.021115	0.025248	0.028039	0.029317	0.028860	0.026367	0.021396	0.013275
17037.70c	0.005337	0.007134	0.008530	0.009473	0.009905	0.009751	0.008909	0.007229	0.004485
1001.70c	0.000371	0.000496	0.000593	0.000659	0.000689	0.000678	0.000619	0.000503	0.000312
1002.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12024.70c	0.013228	0.017683	0.021144	0.023482	0.024551	0.024169	0.022081	0.017918	0.011117
12025.70c	0.001745	0.002332	0.002788	0.003097	0.003238	0.003187	0.002912	0.002363	0.001466
12026.70c	0.001997	0.002670	0.003193	0.003546	0.003707	0.003649	0.003334	0.002705	0.001679
material densty (g/cm3)	4.380384	4.222413	4.107328	4.033080	3.999995	4.011752	4.077225	4.214387	4.459443

Table D-1. continued (12 of 23)

6-inch Pipe (pitch = 23.7 cm)										
material	m10-701	m10-702	m10-703	m10-704	m10-705	m10-706	m10-707	m10-708	m10-709	m10-710
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662	4296462
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
1001.70c	0.062149	0.062149	0.062149	0.062149	0.062149	0.062149	0.062149	0.062149	0.062149	0.062149
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492030	0.492030	0.492030	0.492030	0.492030	0.492030	0.492030	0.492030	0.492030	0.492030
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
4009.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
6000.70c	0.444456	0.444456	0.444456	0.444456	0.444456	0.444456	0.444456	0.444456	0.444456	0.444456
material densty (g/cm3)	2.896896	2.724681	2.597197	2.512117	2.469354	2.471949	2.527656	2.652197	2.876587	3.265661

6-inch Pipe (pitch = 23.7 cm)									
material	m11-718	m11-719	m11-720	m11-721	m11-722	m11-723	m11-724	m11-725	m11-726
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662
total reflector box volume (cm3)	5873210	6006409	6206752	6465513	6770085	7109330	7474735	7860551	8262875
MCNP ZAID.XS	Weight fraction								
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
4009.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	2.379928	2.359060	2.335546	2.319223	2.320978	2.351787	2.424500	2.557508	2.782417

Table D-1. continued (13 of 23)

6-inch Pipe (pitch = 23.7 cm)										
material	m12-701	m12-702	m12-703	m12-704	m12-705	m12-706	m12-707	m12-708	m12-709	m12-710
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662	4296462
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
1001.70c	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155
1002.70c	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005
8016.70c	0.275195	0.275195	0.275195	0.275195	0.275195	0.275195	0.275195	0.275195	0.275195	0.275195
8017.70c	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748
4009.70c	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005
6000.70c	0.151290	0.151290	0.151290	0.151290	0.151290	0.151290	0.151290	0.151290	0.151290	0.151290
26045.70c	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924
26056.70c	0.519678	0.519678	0.519678	0.519678	0.519678	0.519678	0.519678	0.519678	0.519678	0.519678
material densty (g/cm3)	8.510411	8.004485	7.629965	7.380019	7.254394	7.262017	7.425669	7.791544	8.450750	9.593759

6-inch Pipe (pitch = 23.7 cm)									
material	m13-718	m13-719	m13-720	m13-721	m13-722	m13-723	m13-724	m13-725	m13-726
total sphere volume (cm3)	50753	132447	273652	490656	799744	1217203	1759318	2442376	3282662
total reflector box volume (cm3)	5873210	6006409	6206752	6465513	6770085	7109330	7474735	7860551	8262875
MCNP ZAID.XS	Weight fraction								
1001.70c	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155	0.021155
1002.70c	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005
8016.70c	0.275197	0.275197	0.275197	0.275197	0.275197	0.275197	0.275197	0.275197	0.275197
8017.70c	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748	0.000748
4009.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.151291	0.151291	0.151291	0.151291	0.151291	0.151291	0.151291	0.151291	0.151291
26045.70c	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924	0.031924
26056.70c	0.519680	0.519680	0.519680	0.519680	0.519680	0.519680	0.519680	0.519680	0.519680
material densty (g/cm3)	6.991743	6.930437	6.861358	6.813406	6.818560	6.909071	7.122687	7.513438	8.174173

Table D-1. continued (14 of 23)

6-inch Pipe (pitch = 23.7 cm)										
material	m14-701	m14-702	m14-703	m14-704	m14-705	m14-706	m14-707	m14-708	m14-709	m14-710
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
1001.70c	0.081734	0.647096	0.647100	0.647104	0.647105	0.647105	0.647103	0.647097	0.647088	0.647072
1002.70c	0.000019	0.001758	0.001758	0.001758	0.001758	0.001758	0.001758	0.001758	0.001758	0.001758
8016.70c	0.647089	0.000163	0.000156	0.000151	0.000148	0.000149	0.000152	0.000160	0.000175	0.000199
8017.70c	0.001758	0.105908	0.105909	0.105909	0.105910	0.105910	0.105909	0.105908	0.105907	0.105904
4009.70c	0.000174	0.122076	0.122077	0.122078	0.122078	0.122078	0.122077	0.122076	0.122075	0.122072
11023.70c	0.105907	0.105908	0.105909	0.105909	0.105910	0.105910	0.105909	0.105908	0.105907	0.105904
17035.70c	0.122075	0.122076	0.122077	0.122078	0.122078	0.122078	0.122077	0.122076	0.122075	0.122072
17037.70c	0.041244	0.041245	0.041245	0.041245	0.041245	0.041245	0.041245	0.041245	0.041244	0.041243
material densty (g/cm3)	0.233926	0.233923	0.233922	0.233921	0.233920	0.233920	0.233921	0.233923	0.233926	0.233931

6-inch Pipe (pitch = 23.7 cm)										
material	m15-701	m15-702	m15-703	m15-704	m15-705	m15-706	m15-707	m15-708	m15-709	m15-710
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
1001.70c	0.003267	0.003463	0.003622	0.003736	0.003793	0.003784	0.003697	0.003523	0.003249	0.002862
1002.70c	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
8016.70c	0.182634	0.183791	0.184736	0.185407	0.185747	0.185692	0.185182	0.184150	0.182526	0.180234
8017.70c	0.000496	0.000499	0.000502	0.000504	0.000505	0.000505	0.000503	0.000500	0.000496	0.000490
4009.70c	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007
11023.70c	0.004233	0.004487	0.004693	0.004840	0.004915	0.004903	0.004791	0.004565	0.004210	0.003708
17035.70c	0.004879	0.005172	0.005410	0.005579	0.005665	0.005651	0.005522	0.005262	0.004852	0.004274
17037.70c	0.001649	0.001747	0.001828	0.001885	0.001914	0.001909	0.001866	0.001778	0.001639	0.001444
26045.70c	0.046464	0.046348	0.046254	0.046187	0.046153	0.046158	0.046209	0.046313	0.046475	0.046704
26056.70c	0.756370	0.754485	0.752948	0.751854	0.751302	0.751390	0.752221	0.753901	0.756545	0.760277
material densty (g/cm3)	5.852325	5.521865	5.278644	5.118302	5.040998	5.053212	5.171028	5.426916	5.885152	6.681391

Table D-1. continued (15 of 23)

6-inch Pipe (pitch = 23.7 cm)										
material	m16-701	m16-702	m16-703	m16-704	m16-705	m16-706	m16-707	m16-708	m16-709	m16-710
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
1001.70c	0.064264	0.064381	0.064476	0.064543	0.064577	0.064571	0.064520	0.064417	0.064253	0.064018
1002.70c	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015	0.000015
8016.70c	0.508776	0.509704	0.510455	0.510986	0.511253	0.511210	0.510808	0.509989	0.508689	0.506828
8017.70c	0.001383	0.001385	0.001387	0.001389	0.001389	0.001389	0.001388	0.001386	0.001382	0.001377
4009.70c	0.000019	0.000019	0.000019	0.000018	0.000018	0.000018	0.000018	0.000019	0.000019	0.000019
11023.70c	0.011433	0.012067	0.012579	0.012942	0.013124	0.013095	0.012820	0.012262	0.011374	0.010103
17035.70c	0.013179	0.013909	0.014500	0.014917	0.015128	0.015094	0.014777	0.014133	0.013110	0.011646
17037.70c	0.004453	0.004699	0.004899	0.005040	0.005111	0.005100	0.004993	0.004775	0.004430	0.003935
6000.70c	0.396479	0.393823	0.391671	0.390150	0.389385	0.389508	0.390660	0.393004	0.396728	0.402060
material densty (g/cm3)	2.166843	2.053152	1.969475	1.914311	1.887715	1.891918	1.932451	2.020486	2.178136	2.452072

6-inch Pipe (pitch = 23.7 cm)										
material	m17-701	m17-702	m17-703	m17-704	m17-705	m17-706	m17-707	m17-708	m17-709	m17-710
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
1001.70c	0.017886	0.018006	0.018104	0.018173	0.018209	0.018203	0.018150	0.018043	0.017875	0.017639
1002.70c	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004
8016.70c	0.259452	0.260179	0.260773	0.261195	0.261409	0.261374	0.261053	0.260404	0.259385	0.257949
8017.70c	0.000705	0.000707	0.000709	0.000710	0.000710	0.000710	0.000709	0.000708	0.000705	0.000701
4009.70c	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005
11023.70c	0.003182	0.003375	0.003532	0.003644	0.003701	0.003691	0.003606	0.003434	0.003164	0.002784
17035.70c	0.003668	0.003890	0.004071	0.004200	0.004265	0.004255	0.004157	0.003959	0.003647	0.003209
17037.70c	0.001239	0.001314	0.001376	0.001419	0.001441	0.001438	0.001404	0.001338	0.001232	0.001084
6000.70c	0.110351	0.110144	0.109975	0.109855	0.109794	0.109804	0.109895	0.110080	0.110370	0.110779
26054.70c	0.034928	0.034863	0.034809	0.034771	0.034752	0.034755	0.034784	0.034842	0.034934	0.035064
26056.70c	0.568578	0.567513	0.566643	0.566023	0.565710	0.565760	0.566231	0.567183	0.568678	0.570783
material densty (g/cm3)	7.785243	7.341093	7.014197	6.798692	6.694793	6.711209	6.869557	7.213479	7.829363	8.899533

Table D-1. continued (16 of 23)

6-inch Pipe (pitch = 23.7 cm)										
material	m18-735	m18-736	m18-737	m18-738	m18-739	m18-740	m18-741	m18-742	m18-743	m18-744
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
26054.70c	0.048398	0.048398	0.048398	0.048398	0.048398	0.048398	0.048398	0.048398	0.048398	0.048398
26056.70c	0.787856	0.787856	0.787856	0.787856	0.787856	0.787856	0.787856	0.787856	0.787856	0.787856
4009.70c	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007
8016.70c	0.163295	0.163295	0.163295	0.163295	0.163295	0.163295	0.163295	0.163295	0.163295	0.163295
8017.70c	0.000444	0.000444	0.000444	0.000444	0.000444	0.000444	0.000444	0.000444	0.000444	0.000444
material densty (g/cm3)	5.618441	5.287979	5.044759	4.884416	4.807112	4.819326	4.937142	5.193031	5.651267	6.447507

6-inch Pipe (pitch = 23.7 cm)										
material	m19-735	m19-736	m19-737	m19-738	m19-739	m19-740	m19-741	m19-742	m19-743	m19-744
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
26054.70c	0.042762	0.041666	0.040809	0.040219	0.039927	0.039973	0.040416	0.041337	0.042866	0.045207
26056.70c	0.696097	0.678267	0.664319	0.654709	0.649952	0.650710	0.657907	0.672909	0.697802	0.735903
4009.70c	0.000009	0.000009	0.000009	0.000009	0.000009	0.000009	0.000009	0.000009	0.000009	0.000010
8016.70c	0.162770	0.162668	0.162589	0.162534	0.162506	0.162511	0.162552	0.162638	0.162780	0.162998
8017.70c	0.000442	0.000442	0.000442	0.000442	0.000442	0.000442	0.000442	0.000442	0.000442	0.000443
11023.70c	0.027438	0.032769	0.036940	0.039814	0.041236	0.041010	0.038858	0.034372	0.026928	0.015534
17035.70c	0.031626	0.037772	0.042580	0.045892	0.047531	0.047270	0.044790	0.039619	0.031038	0.017906
17037.70c	0.010685	0.012762	0.014386	0.015505	0.016059	0.015971	0.015133	0.013386	0.010487	0.006050
12024.70c	0.021959	0.026226	0.029564	0.031864	0.033002	0.032821	0.031098	0.027508	0.021551	0.012432
12025.70c	0.002896	0.003459	0.003899	0.004202	0.004352	0.004328	0.004101	0.003628	0.002842	0.001640
12026.70c	0.003316	0.003960	0.004464	0.004811	0.004983	0.004956	0.004696	0.004154	0.003254	0.001877
material densty (g/cm3)	4.296838	4.150422	4.042659	3.971617	3.937366	3.942778	3.994978	4.108354	4.311382	4.664169

Table D-1. continued (17 of 23)

6-inch Pipe (pitch = 23.7 cm)										
material	m20-735	m20-736	m20-737	m20-738	m20-739	m20-740	m20-741	m20-742	m20-743	m20-744
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
26054.70c	0.045590	0.045425	0.045291	0.045195	0.045147	0.045155	0.045227	0.045374	0.045605	0.045932
26056.70c	0.742133	0.739451	0.737267	0.735716	0.734934	0.735059	0.736237	0.738621	0.742383	0.747712
4009.70c	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010
8016.70c	0.191376	0.193023	0.194365	0.195317	0.195798	0.195721	0.194998	0.193533	0.191223	0.187949
8017.70c	0.000520	0.000525	0.000528	0.000531	0.000532	0.000532	0.000530	0.000526	0.000520	0.000511
11023.70c	0.006147	0.006508	0.006801	0.007010	0.007115	0.007098	0.006940	0.006619	0.006113	0.005397
17035.70c	0.007085	0.007501	0.007839	0.008080	0.008201	0.008182	0.007999	0.007630	0.007047	0.006221
17037.70c	0.002394	0.002534	0.002649	0.002730	0.002771	0.002764	0.002703	0.002578	0.002381	0.002102
1001.70c	0.004744	0.005022	0.005249	0.005410	0.005491	0.005478	0.005356	0.005108	0.004718	0.004165
1002.70c	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
material densty (g/cm3)	4.030300	3.807006	3.642660	3.534316	3.482081	3.490334	3.569943	3.742849	4.052481	4.590505

6-inch Pipe (pitch = 23.7 cm)										
material	m21-735	m21-736	m21-737	m21-738	m21-739	m21-740	m21-741	m21-742	m21-743	m21-744
total sphere volume (cm3)	54912	140272	286295	509266	825471	1251196	1802727	2496351	3348353	4375019
total reflector box volume (cm3)	4834226	5218260	5609105	6006810	6411422	6822990	7241561	7667183	8099905	8539775
MCNP ZAID.XS	Weight fraction									
26054.70c	0.043038	0.041988	0.041165	0.040597	0.040316	0.040360	0.040786	0.041672	0.043138	0.045372
26056.70c	0.700591	0.683503	0.670106	0.660861	0.656279	0.657009	0.663938	0.678360	0.702223	0.738586
4009.70c	0.000010	0.000009	0.000009	0.000009	0.000009	0.000009	0.000009	0.000009	0.000010	0.000010
8016.70c	0.168729	0.169793	0.170628	0.171204	0.171489	0.171444	0.171012	0.170114	0.168628	0.166363
8017.70c	0.000458	0.000461	0.000464	0.000465	0.000466	0.000466	0.000465	0.000462	0.000458	0.000452
11023.70c	0.022895	0.027378	0.030894	0.033319	0.034521	0.034330	0.032512	0.028728	0.022467	0.012926
17035.70c	0.026390	0.031558	0.035610	0.038406	0.039791	0.039571	0.037475	0.033114	0.025897	0.014900
17037.70c	0.008916	0.010662	0.012031	0.012976	0.013444	0.013369	0.012661	0.011188	0.008750	0.005034
1001.70c	0.000620	0.000741	0.000837	0.000902	0.000935	0.000930	0.000880	0.000778	0.000608	0.000350
1002.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12024.70c	0.022101	0.026428	0.029821	0.032163	0.033323	0.033139	0.031383	0.027731	0.021687	0.012478
12025.70c	0.002915	0.003485	0.003933	0.004242	0.004395	0.004370	0.004139	0.003657	0.002860	0.001646
12026.70c	0.003337	0.003990	0.004503	0.004856	0.005032	0.005004	0.004739	0.004187	0.003275	0.001884
material densty (g/cm3)	4.269275	4.118625	4.007746	3.934649	3.899407	3.904976	3.958685	4.075340	4.284240	4.647229

Table D-1. continued (18 of 23)

6-inch Pipe (pitch = 10.9 cm)			
material	m10-701	m10-702	m10-703
total sphere volume (cm3)	50753	132447	273652
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
1001.70c	0.062149	0.062149	0.062149
1002.70c	0.000014	0.000014	0.000014
8016.70c	0.492030	0.492030	0.492030
8017.70c	0.001337	0.001337	0.001337
4009.70c	0.000014	0.000014	0.000014
6000.70c	0.444456	0.444456	0.444456
material densty (g/cm3)	25.746277	25.512580	28.176665

6-inch Pipe (pitch = 10.9 cm)	
material	m11-718
total sphere volume (cm3)	50753
total reflector box volume (cm3)	827105
MCNP ZAID.XS	Weight fraction
1001.70c	0.062150
1002.70c	0.000014
8016.70c	0.492037
8017.70c	0.001337
4009.70c	0.000000
6000.70c	0.444462
material densty (g/cm3)	17.848912

Table D-1. continued (19 of 23)

6-inch Pipe (pitch = 10.9 cm)			
material	m12-701	m12-702	m12-703
total sphere volume (cm3)	50753	132447	273652
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
1001.70c	0.021155	0.021155	0.021155
1002.70c	0.000005	0.000005	0.000005
8016.70c	0.275195	0.275195	0.275195
8017.70c	0.000748	0.000748	0.000748
4009.70c	0.000005	0.000005	0.000005
6000.70c	0.151290	0.151290	0.151290
26045.70c	0.031924	0.031924	0.031924
26056.70c	0.519678	0.519678	0.519678
material densty (g/cm3)	75.636623	74.950074	82.776543

6-inch Pipe (pitch = 10.9 cm)	
material	m13-718
total sphere volume (cm3)	50753
total reflector box volume (cm3)	827105
MCNP ZAID.XS	Weight fraction
1001.70c	0.021155
1002.70c	0.000005
8016.70c	0.275197
8017.70c	0.000748
4009.70c	0.000000
6000.70c	0.151291
26045.70c	0.031924
26056.70c	0.519680
material densty (g/cm3)	52.436470

Table D-1. continued (20 of 23)

6-inch Pipe (pitch = 10.9 cm)			
material	m14-701	m14-702	m14-703
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
1001.70c	0.081622	0.646200	0.646083
1002.70c	0.000019	0.001756	0.001756
8016.70c	0.646197	0.001547	0.001728
8017.70c	0.001756	0.105761	0.105742
4009.70c	0.001551	0.121907	0.121885
11023.70c	0.105761	0.105761	0.105742
17035.70c	0.121907	0.121907	0.121885
17037.70c	0.041188	0.041188	0.041180
material densty (g/cm3)	0.234207	0.234207	0.234244

6-inch Pipe (pitch = 10.9 cm)			
material	m15-701	m15-702	m15-703
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
1001.70c	0.000378	0.000379	0.000340
1002.70c	0.000000	0.000000	0.000000
8016.70c	0.165535	0.165540	0.165306
8017.70c	0.000450	0.000450	0.000449
4009.70c	0.000007	0.000007	0.000007
11023.70c	0.000490	0.000492	0.000440
17035.70c	0.000565	0.000567	0.000507
17037.70c	0.000191	0.000191	0.000171
26045.70c	0.048174	0.048174	0.048197
26056.70c	0.784208	0.784200	0.784582
material densty (g/cm3)	50.513045	50.394430	56.274799

Table D-1. continued (21 of 23)

6-inch Pipe (pitch = 10.9 cm)			
material	m16-701	m16-702	m16-703
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
1001.70c	0.062410	0.062410	0.062383
1002.70c	0.000014	0.000014	0.000014
8016.70c	0.494097	0.494102	0.493886
8017.70c	0.001343	0.001343	0.001342
4009.70c	0.000021	0.000021	0.000021
11023.70c	0.001413	0.001416	0.001269
17035.70c	0.001629	0.001632	0.001463
17037.70c	0.000550	0.000552	0.000494
6000.70c	0.438524	0.438510	0.439127
material densty (g/cm3)	17.531806	17.490998	19.514065

6-inch Pipe (pitch = 10.9 cm)			
material	m17-701	m17-702	m17-703
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
1001.70c	0.016135	0.016136	0.016112
1002.70c	0.000004	0.000004	0.000004
8016.70c	0.248821	0.248825	0.248680
8017.70c	0.000676	0.000676	0.000676
4009.70c	0.000005	0.000005	0.000005
11023.70c	0.000365	0.000366	0.000328
17035.70c	0.000421	0.000422	0.000378
17037.70c	0.000142	0.000143	0.000128
6000.70c	0.113376	0.113375	0.113417
26054.70c	0.035886	0.035885	0.035898
26056.70c	0.584167	0.584163	0.584375
material densty (g/cm3)	67.810643	67.651221	75.554620

Table D-1. continued (22 of 23)

6-inch Pipe (pitch = 10.9 cm)			
material	m18-735	m18-736	m18-737
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
26054.70c	0.048398	0.048398	0.048398
26056.70c	0.787856	0.787856	0.787856
4009.70c	0.000007	0.000007	0.000007
8016.70c	0.163295	0.163295	0.163295
8017.70c	0.000444	0.000444	0.000444
material densty (g/cm3)	50.279200	50.160586	56.040960

6-inch Pipe (pitch = 10.9 cm)			
material	m19-735	m19-736	m19-737
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
26054.70c	0.040748	0.040705	0.042716
26056.70c	0.663324	0.662622	0.695347
4009.70c	0.000090	0.000090	0.000094
8016.70c	0.162570	0.162566	0.162752
8017.70c	0.000442	0.000442	0.000442
11023.70c	0.037219	0.037428	0.027642
17035.70c	0.042900	0.043142	0.031862
17037.70c	0.014494	0.014576	0.010765
12024.70c	0.029787	0.029955	0.022122
12025.70c	0.003928	0.003950	0.002917
12026.70c	0.004498	0.004523	0.003340
material densty (g/cm3)	4.035206	4.029950	4.290490

Table D-1. continued (23 of 23)

6-inch Pipe (pitch = 10.9 cm)			
material	m20-735	m20-736	m20-737
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
26054.70c	0.048067	0.048067	0.048101
26056.70c	0.782467	0.782455	0.783018
4009.70c	0.000011	0.000011	0.000011
8016.70c	0.166602	0.166610	0.166264
8017.70c	0.000453	0.000453	0.000452
11023.70c	0.000724	0.000726	0.000650
17035.70c	0.000835	0.000837	0.000749
17037.70c	0.000282	0.000283	0.000253
1001.70c	0.000559	0.000560	0.000502
1002.70c	0.000000	0.000000	0.000000
material densty (g/cm3)	34.207812	34.127663	38.101063

6-inch Pipe (pitch = 10.9 cm)			
material	m21-735	m21-736	m21-737
total sphere volume (cm3)	54912	140272	286295
total reflector box volume (cm3)	588976	675599	765450
MCNP ZAID.XS	Weight fraction		
26054.70c	0.041106	0.041065	0.042993
26056.70c	0.669147	0.668472	0.699870
4009.70c	0.000091	0.000091	0.000095
8016.70c	0.170670	0.170712	0.168756
8017.70c	0.000464	0.000464	0.000459
11023.70c	0.031128	0.031305	0.023067
17035.70c	0.035880	0.036085	0.026588
17037.70c	0.012123	0.012192	0.008983
1001.70c	0.000843	0.000848	0.000625
1002.70c	0.000000	0.000000	0.000000
12024.70c	0.030048	0.030219	0.022266
12025.70c	0.003963	0.003985	0.002936
12026.70c	0.004537	0.004563	0.003362
material densty (g/cm3)	4.000094	3.994687	4.262763

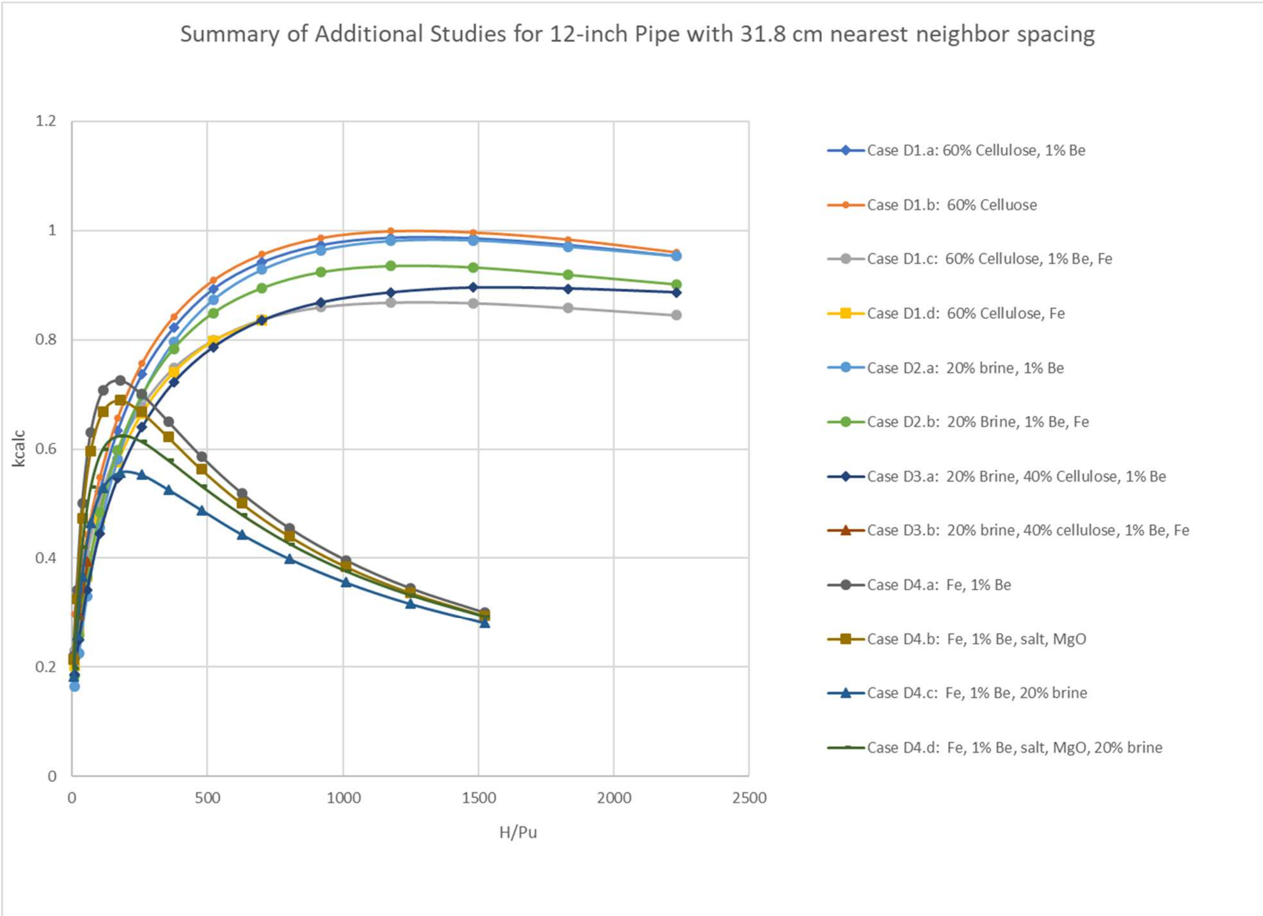


Figure D-1. Summary of results for the additional studies with 200 g fissile mass and the 12-inch pipe with a 31.8 cm nearest neighbor spacing.

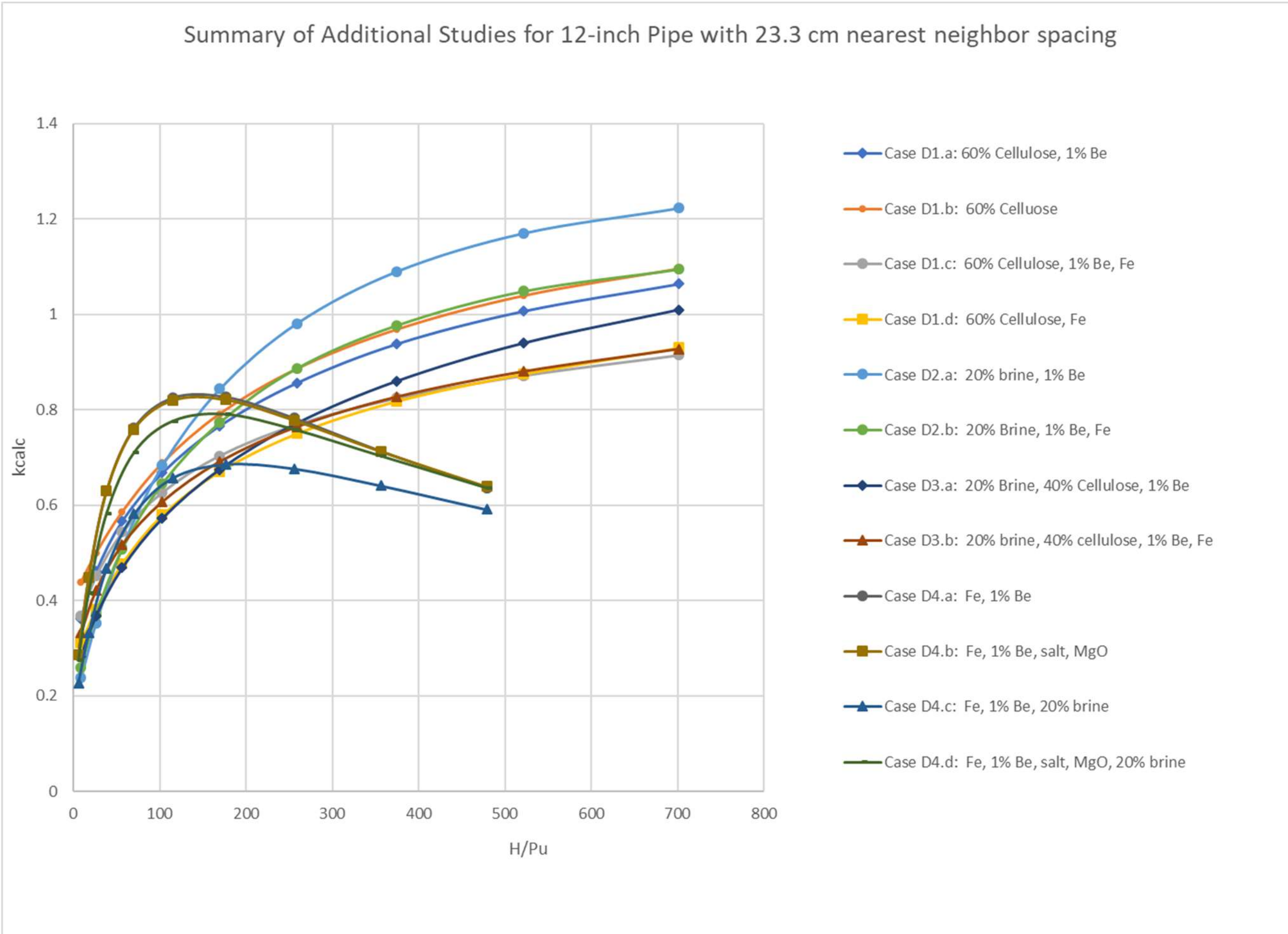


Figure D-2. Summary of results for the additional studies with 200 g fissile mass and the 12-inch pipe with a 23.3 cm nearest neighbor spacing.

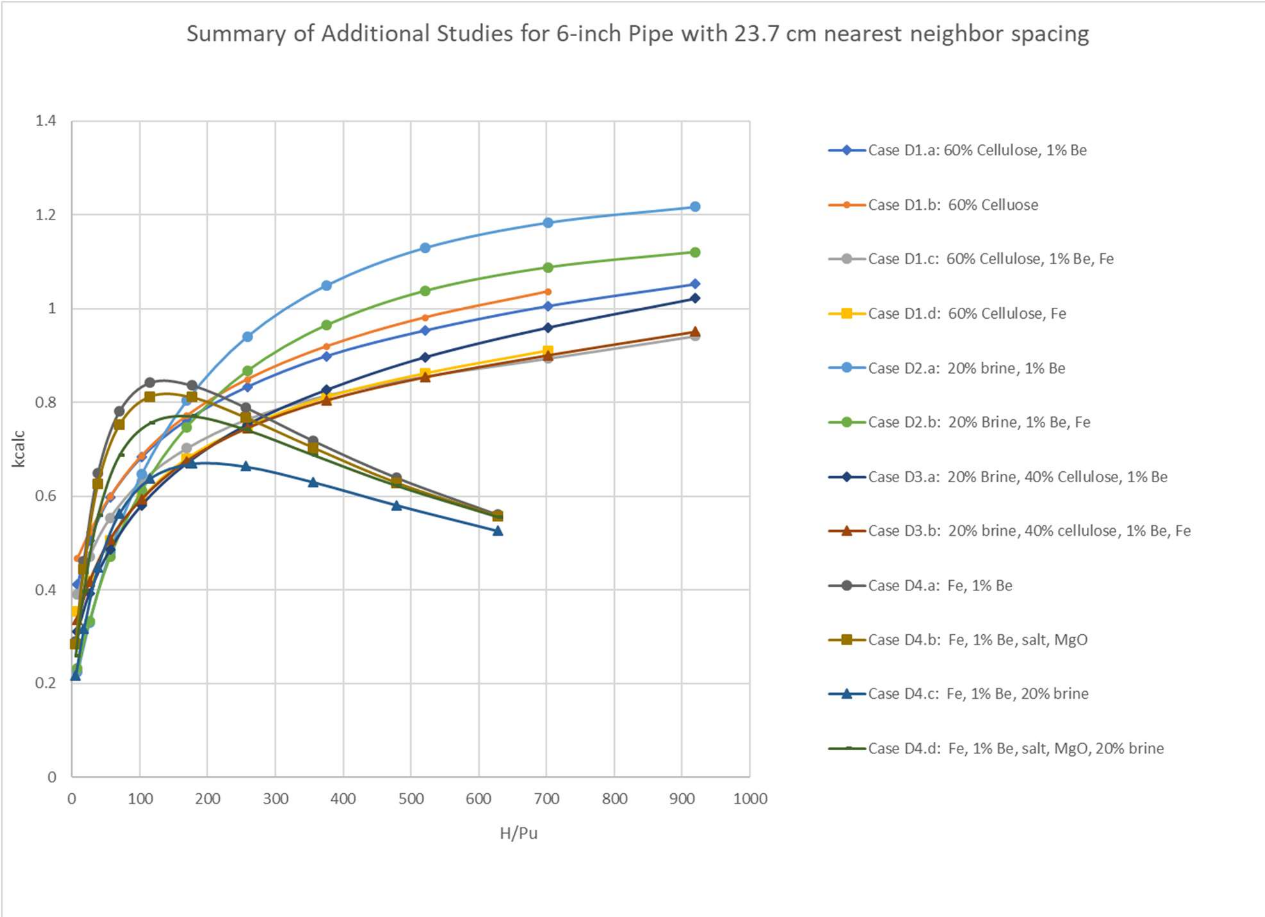


Figure D-3. Summary of results for the additional studies with 200 g fissile mass and the 6-inch pipe with a 23.7 cm nearest neighbor spacing.

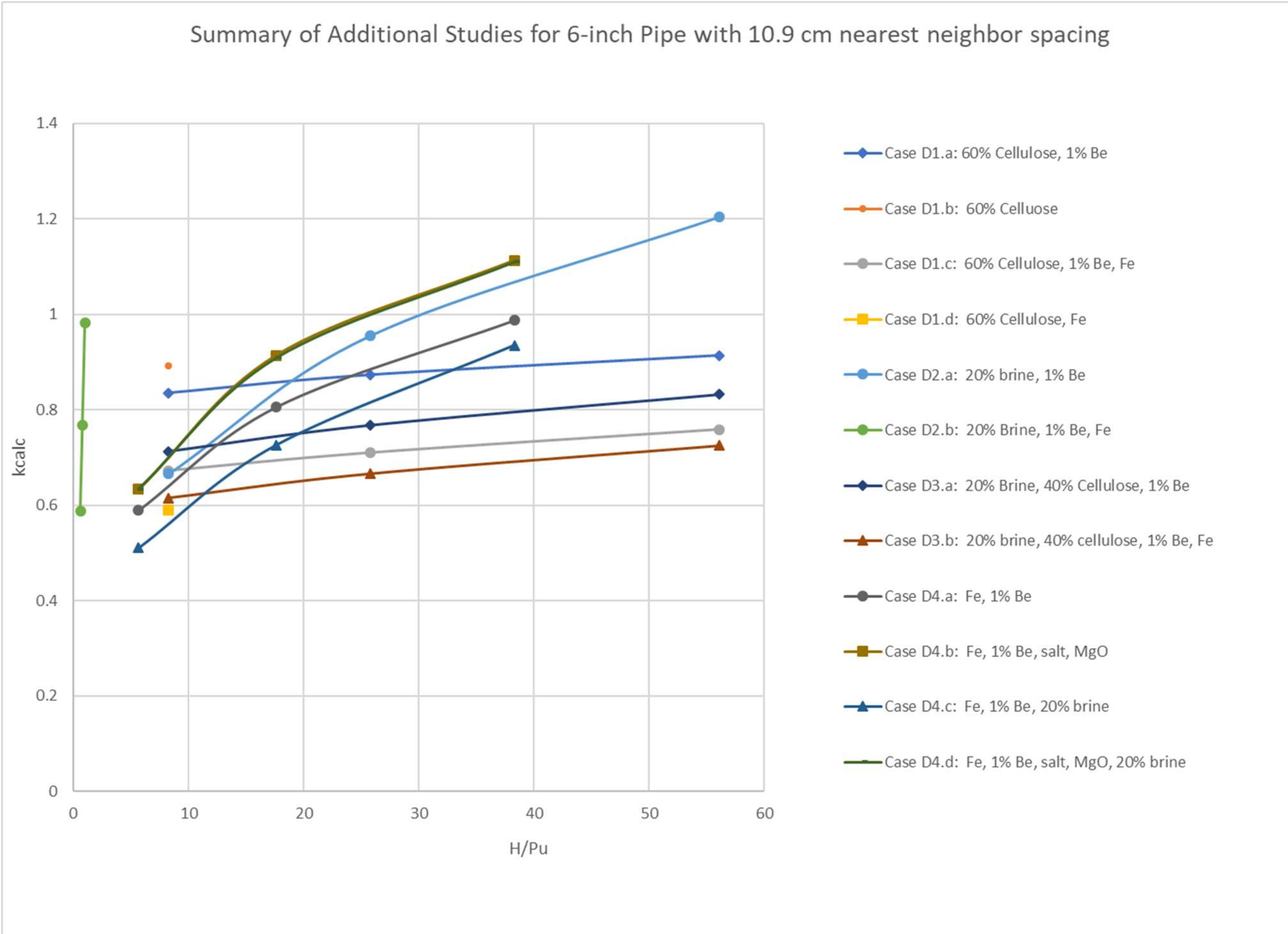


Figure D-4. Summary of results for the additional studies with 200 g fissile mass and the 6-inch pipe with a 10.9 cm nearest neighbor spacing.

APPENDIX E. MCNP RUNS

APPENDIX E. MCNP RUNS

This appendix contains a listing and description of the analysis files contained in the using the Windows 10 compression capabilities. The file attributes are as follows:

Directory Path	Filename	File size (bytes)	File Date	File Time
ORNL_TM-2019_1222-r0\MCNP\Appendix-A\	Appendix-A.tar	821,450,752	2019-10-18 14:39	14:39
ORNL_TM-2019_1222-r0\MCNP\ Appendix-B\	Appendix-B.tar	1,044,441,600	2019-10-18	14:39
ORNL_TM-2019_1222-r0\MCNP\ Appendix-C\	Appendix-C.zip	417,970,275	2019-07-22	12:51
ORNL_TM-2019_1222-r0\MCNP\ Appendix-D-updated\	Appendix-D-updated.tar	1,515,274,752	2019-10-18	14:39
ORNL_TM-2019_1222-r0\MCNP\ Appendix-G\	Appendix-G.tar	17,414,106,624	2019-10-18	14:42
ORNL_TM-2019_1222-r0\MCNP\ Appendix-H\	Appendix-H.tar	54,814,311,424	2019-10-18	14:45

Appendix A MCNP input file name nomenclature key:

```
{case}-{mass}-{r-inc}-{mod}-{sub-case1}-{sub-case2}
  |      |      |      |      |              |------ 1 - beryllium in a layer outside sphere
  |      |      |      |      |              |------ be - beryllium included
  |      |      |      |      |              |------ 0be - no beryllium included
  |      |      |      |      |
  |      |      |      |      |------ be - beryllium included
  |      |      |      |      |------ 0be - no beryllium included
  |      |      |      |      |------ # - ratio of reflector H2O and CH2
  |      |      |      |
  |      |      |      |-------- ratio of fissile sphere moderator H2O and CH2
  |      |      |
  |      |      |--------- #s1 - small radius increments, indicates 0.#
  |      |      |--------- #s2 - large radius increments, indicates #.0
```

```
    |           |
    |           |-------- 239Pu mass (g)
    |
    |---------- whx - H/U study Case A1
    |---------- whxm - H/U study Case A2.a
    |---------- whxm1 - H/U study Case A2.b
    |---------- whxm2 - H/U study Case A2.c
    |---------- whxm3 - H/U study Case A3
    |---------- whxm4 - H/U study Case A4
    |---------- chx - H/U study Case A5
```

Appendix B, Appendix C and Appendix D MCNP input file name nomenclature key:

```
{case}-{material}-x-{x-dir}-y-{y-dir}-z-{z-dir}
    |          |              |              |             |
    |          |              |              |             |
    |          |              |              |             |-------- incremental spacing added in y direction
    |          |              |              |
    |          |              |              |--------- incremental spacing added in y direction
    |          |              |
    |          |              |-------- incremental spacing added in x direction
    |          |
    |          |------- m# - material number for the reflector
    |
    |---------- w-p1r1-c{#} – panel 1 room 1, 959 sphere studies, case number (# < 699 for
Appendix B and Appendix C, # > 699 for Appendix D)
```

Appendix G MCNP input file name nomenclature key:

```
w-{pipe}_{boundary condition}-c{case}-m{reflector material}-x-0-y-0-z-0
        |                  |                  |                  |
        |                  |                  |                  |----m1, m30 to m36
        |                  |                  |-----1000-1044
        |                  |-----bc0 – no boundary condition
        |                  |-----bc1 – with boundary condition
        |-------poc – 12 inch pipe
        |-------cco – 6 inch pipe
```

Appendix H MCNP input file name nomenclature key:

w-poc_bc0-c{case}-m31}-x-0-y-0-z-0_RN_case_{random number variation}

```
|                                                   |
|                                                   |----1-300
|-----Case H-1:  9300-9340
|-----Case H-2:  930-934
```

APPENDIX F. FULL ROOM STANDARD PIPE OERPACK CONTAINER MODELS

APPENDIX F INTRODUCTION

The WIPP underground disposal repository consists of multiple salt panels mined from the Salado formation, a 2,000-foot-thick series of salt beds. A typical underground panel includes several rooms, each of which is approximately 33 feet wide by 13 feet high by 300 feet long. Magnesium oxide (MgO) is used as backfill, with sacks of MgO placed on top and possibly around the container stacks. ORNL/TM-2017/751/R1, *Nuclear Criticality Safety Assessment of Potential Disposition at the Waste Isolation Plant* [F-1], developed a bounding room model that focused on one waste container approved to be shipped to the WIPP; the Criticality Control Overpack (CCO). This appendix uses the same model, but with standard 12-inch Pipe Overpack Containers (POCs) in place of CCOs, both of which have standard 55-gallon drums as the overpack container.

F.1 POC MODEL AND ROOM MODEL DESCRIPTIONS

The standard POC consists of a pipe component positioned by dunnage within a 55-gallon drum. The pipe component is a stainless steel, cylindrical pipe with a welded or formed bottom cap and a bolted stainless-steel lid. The pipe component is available with either a 6-inch or 12-inch diameter. Table F-1 lists the dimensions of both pipe components. The pipe component is centered in a standard 55-gallon drum with dunnage consisting of fiberboard packing and plywood. Because the unshielded 12-inch pipe overpack assembly design allows for less dunnage and, therefore, greater interaction between drums, and the larger pipe diameter allows for more favorable fissile material geometry over that of the smaller 6-inch pipe overpack, choosing the 12-inch POC as a bounding container was considered conservative. Figure F-1 (image taken from the *TRUPACT-II Safety Analysis Report* [F-2]) shows the 12-inch pipe component and dunnage arrangements and dimensions. The pipe is modeled as 304 stainless steel and the fiberboard packing is represented by cellulose ($C_6H_{10}O_5$). The same reference lists the fiberboard packing as having a minimum density of 14 lb/ft^3 (0.224 g/cm^3). The plywood is conservatively modeled as the same cellulose material (plywood has the same basic composition as cellulose but with a higher density).

Table F-1. Pipe component dimensions

Dimension	6-inch		12-inch	
	Inches	Centimeters	Inches	Centimeters
Steel pipe outer diameter	6.7	17.018	12.8	32.512
Steel pipe outer radius	3.35	8.509	6.4	16.256
Steel pipe wall thickness	0.245	0.6223	0.219	0.55626
Steel pipe inner radius	3.105	7.8867	6.181	15.69974
Steel pipe outer length	26.0	66.04	25.7	65.278
Steel pipe floor thickness	0.25	0.635	0.25	0.635
Steel pipe inner length	25.75	65.405	25.45	64.643
Steel pipe lid thickness	0.9	2.286	0.9	2.286

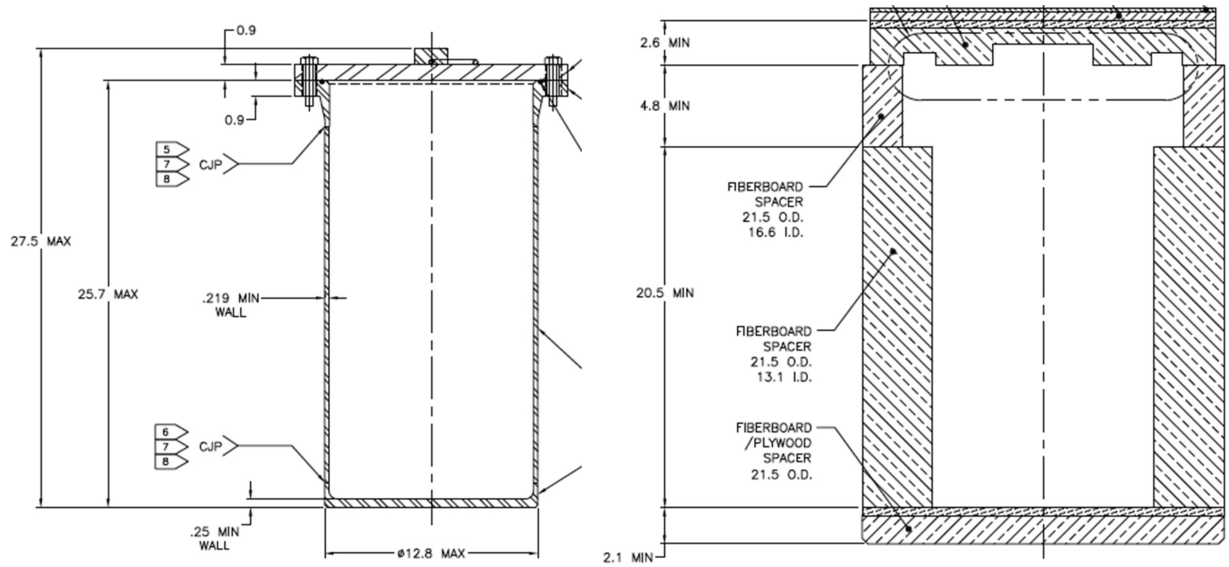


Figure F-1. 12-inch standard pipe component and dunnage.

The waste material in the POCs is a generic waste form model consistent with existing analyses [F-2], [F-3]. The generic waste model includes the fissile material homogenously mixed with a moderator. The fissile material is 200 FGE ^{239}Pu and the moderator is a mixture of 74% water, 25% polyethylene, and 1% beryllium by volume, with the amount of moderator being varied to maximize k-effective of the system (varying the H/Pu ratio, see the end of this appendix (section F.3.1) for more specific details).

The bounding full room model from [F-1] places the drums in a finite (approximate room size) three-high, close-packed triangular-pitched array. The model includes a salt (halite) floor, ceiling, and walls, all with a nominal thickness of 10 feet (at a density of 135.2 lb/ft^3 [2.165 g/cm^3]), and a continuous layer of MgO approximately 25 inches thick above the top layer of drums, between the top layer of drums and the salt ceiling (at a density of 90.5 lb/ft^3 [1.45 g/cm^3]), consistent with the analysis for initial emplacement [F-3]. The drum material is not modeled, but the initial radial spacing created by the drum structure is. The modeled drum height is 28.9425 inches (73.514 cm), which is less than the typical 55-gallon drum height of ~34.25 in. The pipe is placed in the center of the drum model and the waste material is modeled as a cylinder with an H/D (height to diameter ratio) of one in the center of the pipe (no inner waste container considered).

Figure F-2 shows a partial top view of the room model and Figure F-3 shows a partial side view.

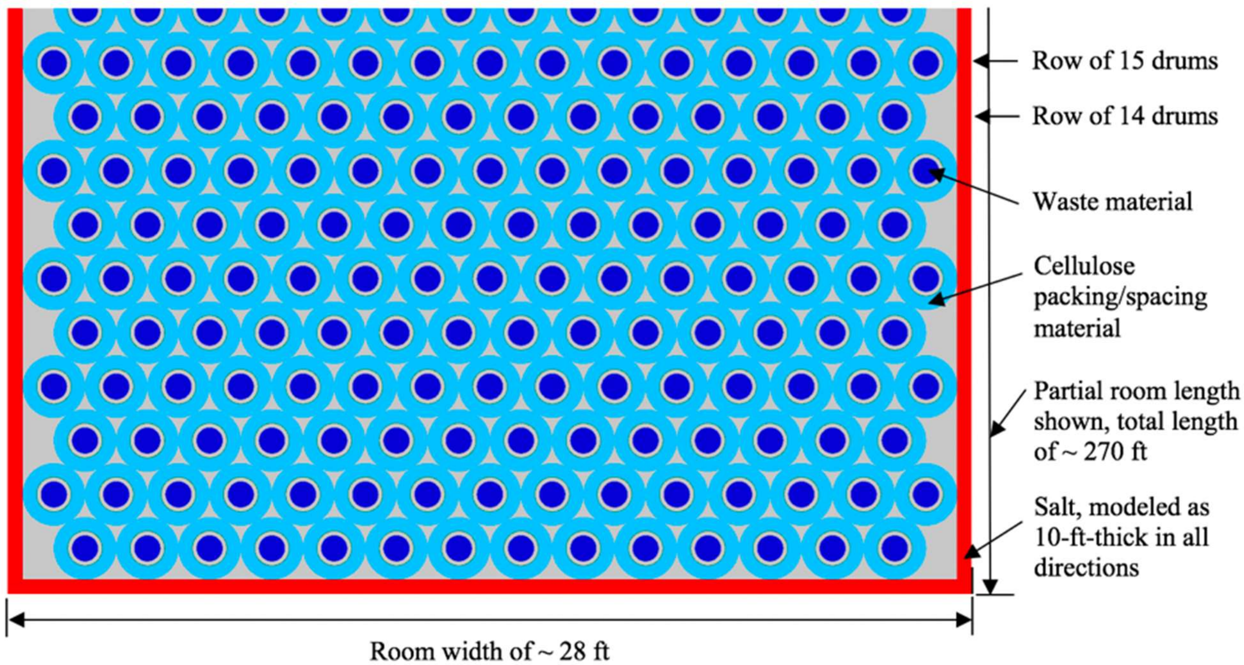


Figure F-2. Partial top view of triangular-pitched array in room.

The drums are arranged in alternating rows of 14 and 15 drums across. The modeled room width is ~ 28 feet. For the room model, there are 83 rows of drums 14 across and 82 rows of drums 15 across which totals 7176 drums and gives a modeled room length of ~ 270 feet. The modeled room height is ~ 9.3 feet (three times the drum height plus the MgO thickness).

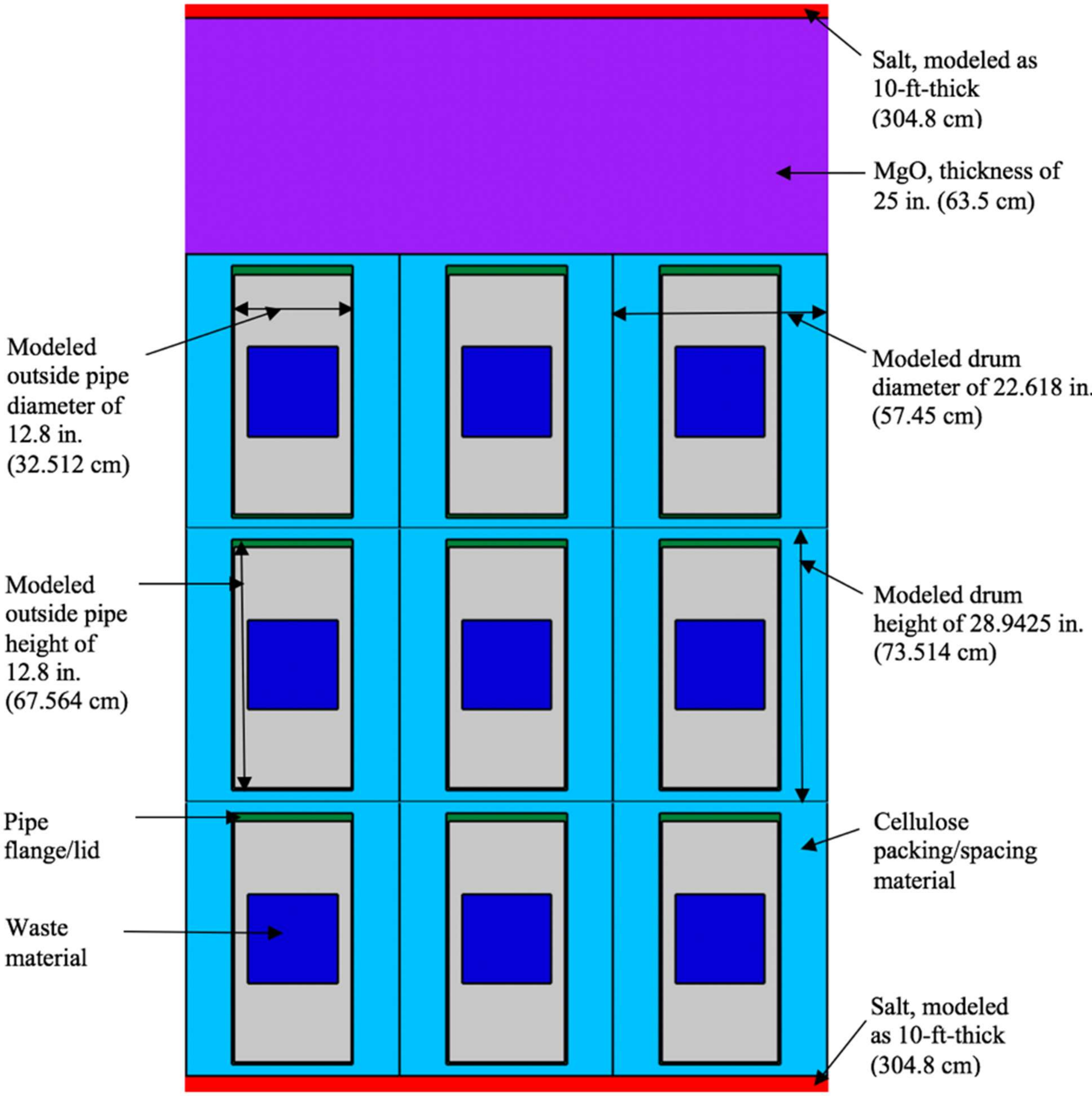


Figure F-3. Partial side view of triangular-pitched array in room.

F.2 POC FULL ROOM MODEL CALCULATIONS

For this appendix, the conditions analyzed include a reduced spacing scenario (to address salt creep/closing of the room) and varied amounts of the fiberboard packing material. For spacing, the array was modeled with the drums having their original radial spacing (full radius/diameter) and a reduced spacing consisting of the drum radius being reduced by 12 cm. The pipe size remained unchanged and no decrease in vertical spacing was considered here. The fiberboard packing material (including the plywood spacers) was modeled as cellulose ($C_6H_{10}O_5$). Per [F-2], the minimum density of the fiberboard packing was 14 lb/ft^3 (0.224 g/cm^3). Plywood has the same composition as the fiberboard packing material (cellulose) with a density that varies depending on the wood used but is larger than the specified minimum fiberboard density. Therefore, modeling it at the same density as the fiberboard was conservative. The fiberboard/plywood was included in the models as surrounding the pipes and filling the space between the pipe and the drum exterior. The modeled cellulose density was adjusted to conserve the total mass of the fiberboard present. The fiberboard pieces as shown in Figure F-1 don't completely physically fill the drum space, so in the full radius calculational model the density was slightly reduced to conserve mass (mass determined from drawing dimensions in [F-2]). Similarly, in the reduced spacing scenario, the density was increased to conserve mass. There is no place (empty space) for the fiberboard/plywood to go in the reduced spacing scenario caused by salt creep, the only thing for it to do is compress and increase in density. Cases were also analyzed with reduced cellulose densities to the show the effect of fiberboard degradation/loss over time. Figure F-4 shows a partial side view of the full and reduced spacing configurations for comparison.

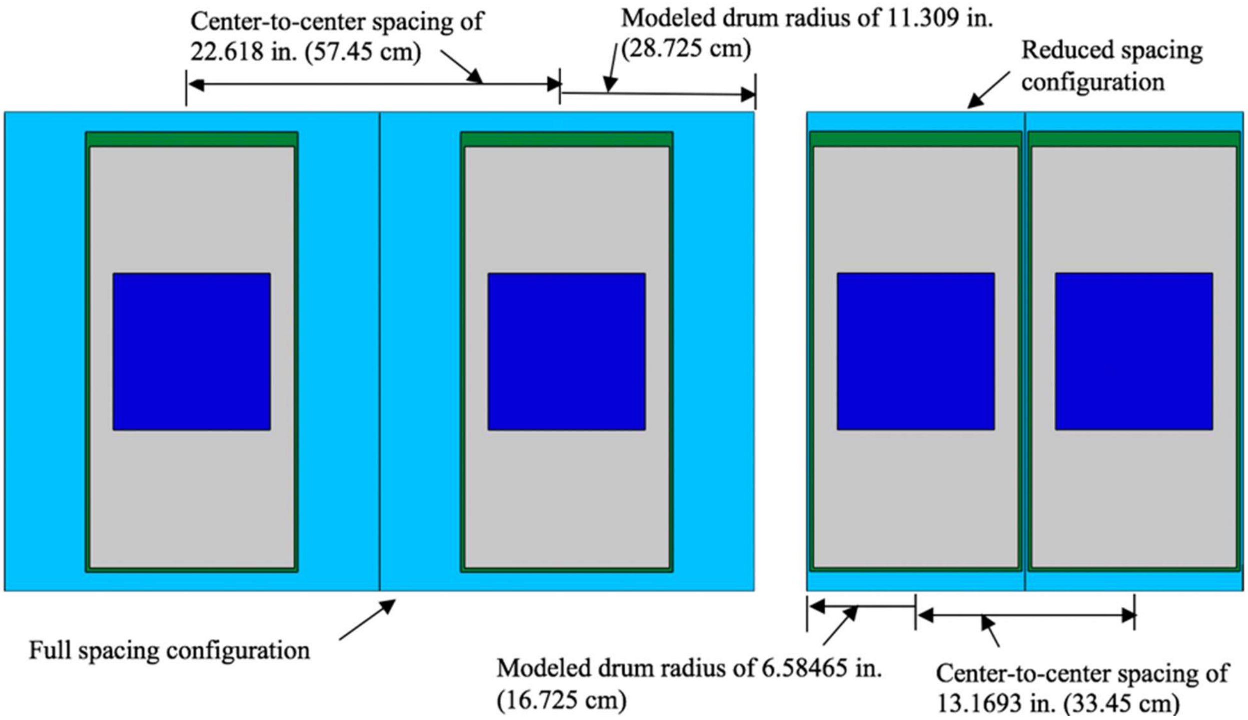


Figure F-4. Partial side view of full (left side) and reduced (right side) spacing configurations.

The waste material in the standard POCs (generic waste form of 200 FGE ^{239}Pu in a mixture of 74% water, 25% polyethylene, and 1% beryllium by volume) was centered vertically in the model, as mentioned above, with the amount of moderator varied to maximize the k-effective of the system (varying the H/Pu ratio). The waste material mixture was modeled as a cylinder with a height to diameter ratio of one, consistent with the existing analyses for handling and initial storage at the WIPP [F-3]. No credit was taken for any container around the waste material (other than the pipe component).

For each of the two spacing scenarios, a series of cases varying the H/Pu ratios from 500 to 1800 were run with the total cellulose mass conserved, with no cellulose present, and at two intermediate cellulose densities. See the end of this appendix (section F.3.2) for details on determining the cellulose mass and density. Tables F-2 and F-3 list the results for the full spacing configuration and for the reduced spacing configuration, respectively, with the highest $k_{eff} + 2\sigma$ for each H/Pu series in bold. The results are also shown in Figures F-5 and F-6.

Table F-2. Results for standard 12-inch POCs in triangular-pitched full room configuration

Case	H/Pu ratio	$k_{eff} + 2\sigma$	Case	H/Pu ratio	$k_{eff} + 2\sigma$
Full drum radius			**Full drum radius**		
No cellulose			**Cellulose conserved, density of 0.187 g/cm^3**		
g200fctpsp12hx0500rdfrvdcc	500	0.90821	g200fctpsp12hx0500rdfrvdcccpcm	500	0.64551
g200fctpsp12hx0600rdfrvdcc	600	0.93701	g200fctpsp12hx0600rdfrvdcccpcm	600	0.68045
g200fctpsp12hx0700rdfrvdcc	700	0.95698	g200fctpsp12hx0700rdfrvdcccpcm	700	0.70875
g200fctpsp12hx0800rdfrvdcc	800	0.96531	g200fctpsp12hx0800rdfrvdcccpcm	800	0.72608
g200fctpsp12hx0900rdfrvdcc	900	0.97008	g200fctpsp12hx0900rdfrvdcccpcm	900	0.74073
g200fctpsp12hx1000rdfrvdcc	**1000**	**0.97139**	g200fctpsp12hx1000rdfrvdcccpcm	1000	0.75130
g200fctpsp12hx1100rdfrvdcc	1100	0.96959	g200fctpsp12hx1100rdfrvdcccpcm	1100	0.75939
g200fctpsp12hx1200rdfrvdcc	1200	0.96587	g200fctpsp12hx1200rdfrvdcccpcm	1200	0.76386
g200fctpsp12hx1300rdfrvdcc	1300	0.96054	g200fctpsp12hx1300rdfrvdcccpcm	1300	0.76783
g200fctpsp12hx1400rdfrvdcc	1400	0.95347	g200fctpsp12hx1400rdfrvdcccpcm	1400	0.76908
g200fctpsp12hx1500rdfrvdcc	1500	0.94607	g200fctpsp12hx1500rdfrvdcccpcm	**1500**	**0.76937**
g200fctpsp12hx1600rdfrvdcc	1600	0.93791	g200fctpsp12hx1600rdfrvdcccpcm	1600	0.76851
g200fctpsp12hx1700rdfrvdcc	1700	0.92895	g200fctpsp12hx1700rdfrvdcccpcm	1700	0.76680
g200fctpsp12hx1800rdfrvdcc	1800	0.92001	g200fctpsp12hx1800rdfrvdcccpcm	1800	0.76418
Full drum radius			**Full drum radius**		
Cellulose reduced, density of 0.01 g/cm^3			**Cellulose reduced, density of 0.09 g/cm^3**		
g200fctpsp12hx0500rdfrvdcccprd01	500	0.86994	g200fctpsp12hx0500rdfrvdcccprd09	500	0.70996
g200fctpsp12hx0600rdfrvdcccprd01	600	0.90077	g200fctpsp12hx0600rdfrvdcccprd09	600	0.74527
g200fctpsp12hx0700rdfrvdcccprd01	700	0.92324	g200fctpsp12hx0700rdfrvdcccprd09	700	0.77310
g200fctpsp12hx0800rdfrvdcccprd01	800	0.93380	g200fctpsp12hx0800rdfrvdcccprd09	800	0.79001
g200fctpsp12hx0900rdfrvdcccprd01	900	0.94025	g200fctpsp12hx0900rdfrvdcccprd09	900	0.80356
g200fctpsp12hx1000rdfrvdcccprd01	1000	0.94366	g200fctpsp12hx1000rdfrvdcccprd09	1000	0.81271
g200fctpsp12hx1100rdfrvdcccprd01	**1100**	**0.94372**	g200fctpsp12hx1100rdfrvdcccprd09	1100	0.81908
g200fctpsp12hx1200rdfrvdcccprd01	1200	0.94153	g200fctpsp12hx1200rdfrvdcccprd09	1200	0.82255
g200fctpsp12hx1300rdfrvdcccprd01	1300	0.93746	g200fctpsp12hx1300rdfrvdcccprd09	1300	0.82418
g200fctpsp12hx1400rdfrvdcccprd01	1400	0.93231	g200fctpsp12hx1400rdfrvdcccprd09	**1400**	**0.82420**
g200fctpsp12hx1500rdfrvdcccprd01	1500	0.92591	g200fctpsp12hx1500rdfrvdcccprd09	1500	0.82314
g200fctpsp12hx1600rdfrvdcccprd01	1600	0.91893	g200fctpsp12hx1600rdfrvdcccprd09	1600	0.82082
g200fctpsp12hx1700rdfrvdcccprd01	1700	0.91108	g200fctpsp12hx1700rdfrvdcccprd09	1700	0.81726
g200fctpsp12hx1800rdfrvdcccprd01	1800	0.90269	g200fctpsp12hx1800rdfrvdcccprd09	1800	0.81359

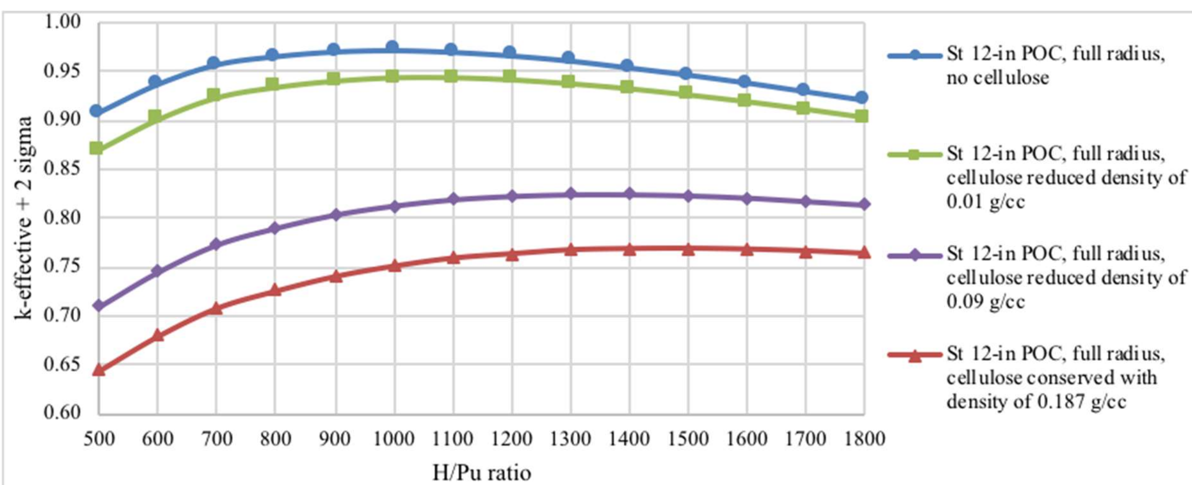


Figure F-5. Results for the full spacing configuration with varying amounts of cellulose.

Table F-3. Results for standard 12-inch POCs in triangular-pitched reduced spacing configuration

Case	H/Pu ratio	$k_{eff} + 2\sigma$	Case	H/Pu ratio	$k_{eff} + 2\sigma$
12-cm decrease in radius			**12-cm decrease in radius**		
No cellulose			**Cellulose conserved, density of 2.955 g/cm^3**		
g200fctpsp12hx0500rd12vdcc	500	1.10387	g200fctpsp12hx0500rd12vdcccpcm	500	0.72141
g200fctpsp12hx0600rd12vdcc	600	1.11766	g200fctpsp12hx0600rd12vdcccpcm	600	0.75792
g200fctpsp12hx0700rd12vdcc	**700**	**1.12410**	g200fctpsp12hx0700rd12vdcccpcm	700	0.78702
g200fctpsp12hx0800rd12vdcc	800	1.12077	g200fctpsp12hx0800rd12vdcccpcm	800	0.80423
g200fctpsp12hx0900rd12vdcc	900	1.11526	g200fctpsp12hx0900rd12vdcccpcm	900	0.81815
g200fctpsp12hx1000rd12vdcc	1000	1.10690	g200fctpsp12hx1000rd12vdcccpcm	1000	0.82877
g200fctpsp12hx1100rd12vdcc	1100	1.09685	g200fctpsp12hx1100rd12vdcccpcm	1100	0.83551
g200fctpsp12hx1200rd12vdcc	1200	1.08565	g200fctpsp12hx1200rd12vdcccpcm	1200	0.83990
g200fctpsp12hx1300rd12vdcc	1300	1.07332	g200fctpsp12hx1300rd12vdcccpcm	1300	0.84190
g200fctpsp12hx1400rd12vdcc	1400	1.06095	g200fctpsp12hx1400rd12vdcccpcm	**1400**	**0.84260**
g200fctpsp12hx1500rd12vdcc	1500	1.04828	g200fctpsp12hx1500rd12vdcccpcm	1500	0.84188
g200fctpsp12hx1600rd12vdcc	1600	1.03483	g200fctpsp12hx1600rd12vdcccpcm	1600	0.84016
g200fctpsp12hx1700rd12vdcc	1700	1.02173	g200fctpsp12hx1700rd12vdcccpcm	1700	0.83740
g200fctpsp12hx1800rd12vdcc	1800	1.00848	g200fctpsp12hx1800rd12vdcccpcm	1800	0.83397
12-cm decrease in radius			**12-cm decrease in radius**		
Cellulose reduced, density of 1.0 g/cm^3			**Cellulose reduced, density of 2.0 g/cm^3**		
g200fctpsp12hx0500rd12vdcccprd1	500	0.82207	g200fctpsp12hx0500rd12vdcccprd2	500	0.75233
g200fctpsp12hx0600rd12vdcccprd1	600	0.85696	g200fctpsp12hx0600rd12vdcccprd2	600	0.78880
g200fctpsp12hx0700rd12vdcccprd1	700	0.88360	g200fctpsp12hx0700rd12vdcccprd2	700	0.81725
g200fctpsp12hx0800rd12vdcccprd1	800	0.89801	g200fctpsp12hx0800rd12vdcccprd2	800	0.83380
g200fctpsp12hx0900rd12vdcccprd1	900	0.90892	g200fctpsp12hx0900rd12vdcccprd2	900	0.84740
g200fctpsp12hx1000rd12vdcccprd1	1000	0.91549	g200fctpsp12hx1000rd12vdcccprd2	1000	0.85653
g200fctpsp12hx1100rd12vdcccprd1	1100	0.91915	g200fctpsp12hx1100rd12vdcccprd2	1100	0.86265
g200fctpsp12hx1200rd12vdcccprd1	**1200**	**0.92005**	g200fctpsp12hx1200rd12vdcccprd2	1200	0.86594
g200fctpsp12hx1300rd12vdcccprd1	1300	0.91936	g200fctpsp12hx1300rd12vdcccprd2	**1300**	**0.86774**
g200fctpsp12hx1400rd12vdcccprd1	1400	0.91666	g200fctpsp12hx1400rd12vdcccprd2	1400	0.86739
g200fctpsp12hx1500rd12vdcccprd1	1500	0.91278	g200fctpsp12hx1500rd12vdcccprd2	1500	0.86561
g200fctpsp12hx1600rd12vdcccprd1	1600	0.90791	g200fctpsp12hx1600rd12vdcccprd2	1600	0.86337
g200fctpsp12hx1700rd12vdcccprd1	1700	0.90277	g200fctpsp12hx1700rd12vdcccprd2	1700	0.85987
g200fctpsp12hx1800rd12vdcccprd1	1800	0.89669	g200fctpsp12hx1800rd12vdcccprd2	1800	0.85515

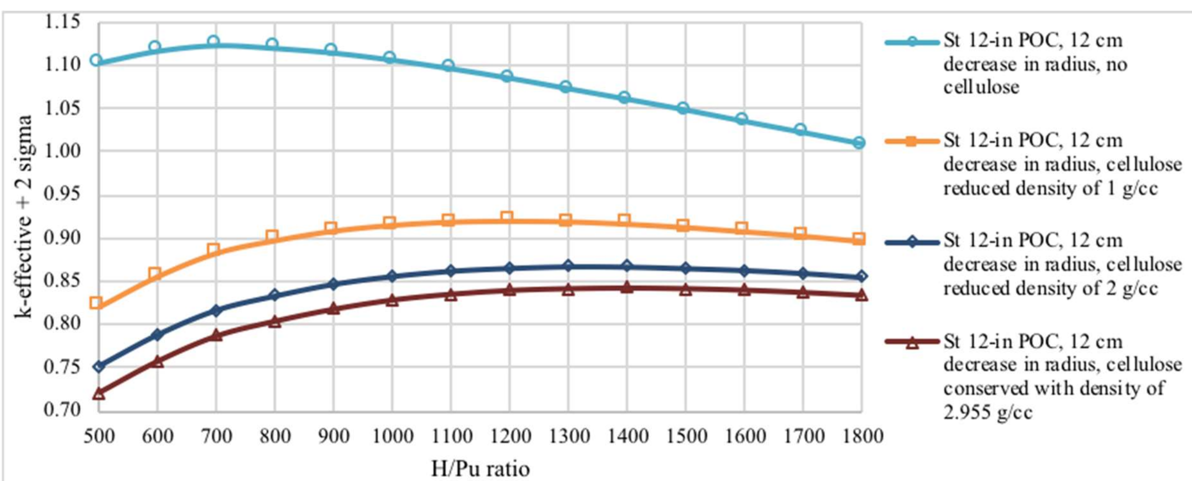


Figure F-6. Results for the reduced spacing configuration with varying amounts of cellulose.

The results indicate that any amount of packing modeled as being in the drums around the pipes reduces the calculated k-effective of the system, for all H/Pu ratios, with the largest reduction seen in the undermoderated systems (lower H/Pu ratios). While these calculations do include beryllium, the beryllium is not modeled at a bounding level (bounding level would be the maximum allowed ~ 1.02 kg/per POC, based on maximum allowed waste weight per POC).

F.3 ADDITIONAL CALCULATIONAL DETAILS

The calculations for this investigation were done with the SCALE code system [F-4], version 6.2.1. The Criticality Safety Analysis Sequences (CSAS) with KENO V.a (CSAS5) was used to calculate neutron multiplications factors (k-effective [k_{eff}] values). All cases were performed with ENDF/B-VII.1 cross-section data in the 252-group library on the romulus computer cluster. Romulus is maintained under the administrative control of ORNL Reactor and Nuclear Systems Division (RNSD) staff.

All calculations were run with sufficient numbers of neutrons (generations, neutrons per generation, and generations skipped) to yield converged results that pass the appropriate statistical checks. The results are reported as k-effective plus 2 times the standard deviation (k-effective + 2 sigma or $k_{eff} + 2\sigma$).

F.3.1 GENERIC WASTE MODEL

The generic waste model includes the fissile material homogenously mixed with a moderator. The amount of fissile material is 200 FGE ^{239}Pu. The moderator is a mixture of 74% water, 25% polyethylene, and 1% beryllium by volume, with the amount of moderator being varied to maximize reactivity (varying the H/Pu ratio). Figure F-7 is a screenshot from the spreadsheet used to determine number densities and Table F-4 lists the number densities for various H/Pu ratios.

						Number Densities for Non-fissile mixture (moderating material)									
						Determine for a 100 cm3 volume, given % is constant,									
						can then apply to H/Pu ratios to determine mixture number densities									
		Density	grams per	% of nonfissile			Volume	Mass	wt%						
Material	Grams	g/cm3	mole	Mixture			cm3	g						% of total H	
H2O		0.9982	18.0152	0.74		Total	100								
CH2		0.92	14.0267	0.25		H2O	74	73.8668	0.748270	**N(H2O)**	0.024692	**N(H) H2O**	0.0493834	0.7143	
Be		1.85	9.0122	0.01								**N(O) H2O**	0.0246917		
Pu	200	19.84	239.052			CH2	25	23	0.232990	**N(CH2)**	0.009874	**N(C) CH2**	0.0098745		
												N(H) CH2	0.0197489	0.2857	
						Be	1	1.85	0.018740	**N(Be)**	0.001236				
						Total		98.7168				Total N(H)	0.0691323		
		H/Pu													
Pu grams	200	**300**													
Pu cm3	10.0806														
Pu moles	0.8366														
H moles	250.9912													wt%	
H from H2O	179.2910	H2O moles	89.6455	H2O grams	1614.9814	nonfissile cm3	2186.3427	N(H2O)	2.4578E-02			**N(Pu)**	**2.2938E-04**	Pu	8.48%
				H2O cm3	1617.8936					N(H) H2O	4.9157E-02	**N(H) H2O**	**4.9157E-02**	Be	1.72%
				nonfissile	2186.3427	Total cm3	2196.4233			N(O) H2O	2.4578E-02	**N(O) H2O**	**2.4578E-02**	H2O	68.48%
H from CH2	71.7002	CH2 moles	35.8501	CH2 grams	502.8588			N(CH2)	9.8291E-03			**N(C)**	**9.8291E-03**	CH2	21.32%
				CH2 cm3	546.5857	Total grams	2358.2875			N(C) CH2	9.8291E-03	**N(H) poly**	**1.9658E-02**		
				nonfissile cm3	2186.3427	Total g/cm3	1.0737			N(H) CH2	1.9658E-02	**N(Be)**	**1.2305E-03**		
				Be cm3	21.8634			N(Be)	1.2305E-03						
				Be grams	40.4473			N(Pu)	2.2938E-04						

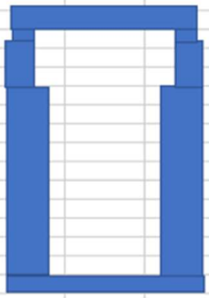
Figure F-7. Screenshot of generic waste composition spreadsheet.

Table F-4. Number densities for generic waste model

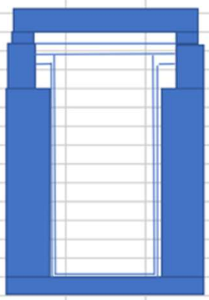
H/Pu	Number Densities (atom/b-cm)					
	Plutonium-239	Hydrogen (from H_2O)	Oxygen	Carbon	Hydrogen (from CH_2)	Beryllium
500	1.3788E-04	4.9247E-02	2.4624E-02	9.8472E-03	1.9694E-02	1.2328E-03
600	1.1496E-04	4.9270E-02	2.4635E-02	9.8517E-03	1.9703E-02	1.2333E-03
700	9.8566E-05	4.9286E-02	2.4643E-02	9.8550E-03	1.9710E-02	1.2337E-03
800	8.6266E-05	4.9298E-02	2.4649E-02	9.8574E-03	1.9715E-02	1.2340E-03
900	7.6696E-05	4.9308E-02	2.4654E-02	9.8593E-03	1.9719E-02	1.2343E-03
1000	6.9037E-05	4.9315E-02	2.4658E-02	9.8608E-03	1.9722E-02	1.2345E-03
1100	6.2769E-05	4.9321E-02	2.4661E-02	9.8621E-03	1.9724E-02	1.2346E-03
1200	5.7544E-05	4.9327E-02	2.4663E-02	9.8631E-03	1.9726E-02	1.2348E-03
1300	5.3122E-05	4.9331E-02	2.4665E-02	9.8640E-03	1.9728E-02	1.2349E-03
1400	4.9331E-05	4.9335E-02	2.4667E-02	9.8647E-03	1.9729E-02	1.2350E-03
1500	4.6046E-05	4.9338E-02	2.4669E-02	9.8654E-03	1.9731E-02	1.2350E-03
1600	4.3170E-05	4.9341E-02	2.4670E-02	9.8659E-03	1.9732E-02	1.2351E-03
1700	4.0633E-05	4.9343E-02	2.4672E-02	9.8664E-03	1.9733E-02	1.2352E-03
1800	3.8377E-05	4.9345E-02	2.4673E-02	9.8669E-03	1.9734E-02	1.2352E-03

F.3.2 FIBERBOARD PACKING IN STANDARD PIPE OVERPACKS

The standard 12-inch pipe overpack container (POCs) has the pipe surrounded and centered by fiberboard packing. Since the fiberboard surrounds the pipe and practically fills the drum, there really is no place for it to go in the decreasing-array-scenario, the only thing for it to do is compress and increase in density. Cases are run without the fiberboard present and also with the fiberboard present, modeled at densities to conserve the amount of fiberboard initially placed in the pipe overpack. To determine the respective densities, the total amount of fiberboard initially loaded into a drum is determined using the specified minimum density and then based on the volume available in the calculational model for the fiberboard, the density is adjusted to maintain the same amount of fiberboard at each spacing. Cases were also analyzed with reduced cellulose densities to the show the effect of fiberboard degradation/loss over time. Since the initially loaded fiberboard doesn't completely fill the drum, the density of the fiberboard in the full drum radius spacing configuration is less than the specified minimum density. Figure F-8 is a screenshot of the spreadsheets used to determine the cellulose densities.



		Volume																
1			outer			inner						outer	inner	total				
2			diameter		radius	diameter		radius	height			volume	volume	volume				
3			in	cm	cm	in	cm	cm	in	cm								
		1	20.5	52.07	26.035			0	1.7	4.318		9194.914	0	9194.914				
4																		
		2	20.5	52.07	26.035	16.3	41.402	20.701	0.9	2.286		4867.896	3077.576	1790.320				
		3	21.5	54.61	27.305	16.3	41.402	20.701	4.8	12.192		28556.777	16413.737	12143.040				
		4	21.5	54.61	27.305	13.1	33.274	16.637	20.5	52.07		121961.235	45278.026	76683.209				
		5	21.5	54.61	27.305			0	2.1	5.334		12493.590	0	12493.590				
												177074.411	64769.339				at	
													total				0.224	g/cm3
5									30	76.2			volume	112305.07	cm3	grams	25156.336	



1		Split 3 up into with flange and without flange																
2																		
3	3a	1	20.5	52.07	26.035				1.7	4.318		9194.914	0	9194.914				
	3b																	
4		2	20.5	52.07	26.035	16.3	41.402	20.701	0.9	2.286		4867.896	3077.576	1790.320				
		3a	21.5	54.61	27.305	16.3	41.402	20.701	1.8	4.572		10708.791	6155.151	4553.640				
		3b	21.5	54.61	27.305	16.3	41.402	20.701	3	7.62		17847.986	10258.586	7589.400	12143.04			
		4	21.5	54.61	27.305	13.1	33.274	16.637	20.5	52.07		121961.235	45278.026	76683.209				
		5	21.5	54.61	27.305				2.1	5.334		12493.590	0	12493.590				
												177074.411	64769.339				at	
													total				0.224	g/cm3
									30	76.2			volume	112305.07	cm3	grams	25156.336	
5																		

Modeled geometry							
	Amount of cellulose packing material is conserved by varying density in modeled volume to give same number of grams						
	Flange modeled with same diameter as pipe						
	Volume of void outside pipe (volume available for cellulose) is different because of modeling simplifications						
		(such as modeling flange with same diameter as pipe and modeling drum height same as CCC height)					
	Grams of cellulose material determined from dimenions on drawing						
	Grams of cellulose material is			25156.336	g		
	Starting density of cellulose material is			0.224	g/cm3		
	Radius of cellulose packing material is less than full drum radius						
	For full radius model, cellulose density determined as if cellulose had same radius as drum						
						Volume	Adjusted
			radius	height	Volume	available for	density of
			cm	cm	cm3	cellulose	cellulose
	modeled 'pipe'		16.256	67.564	56090.9257		
	modeled 'drum'						
	full radius		28.725	73.514	190563.623	134472.697	0.187
	4 cm decrease		24.725	73.514	141186.29	85095.3646	0.296
	8 cm decrease		20.725	73.514	99199.3908	43108.4651	0.584
	12 cm decrease		16.725	73.514	64602.9247	8511.999	2.955
			16.256	73.514	61030.5534	4939.62773	5.093

Figure F-8. Screenshots of spreadsheet determining cellulose in standard 12-inch pipe overpack container.

F.4 REFERENCES

[F-1] Saylor, Ellen M., Scaglione, John M. *Nuclear Criticality Safety Assessment of Potential Disposition at the Waste Isolation Plant*, ORNL/TM-2017/751/R1, 2018.

[F-2] *TRUPACT-II Safety Analysis Report*, Revision 23, Carlsbad, NM: US Department of Energy, Carlsbad Field Office, 2013.

[3] *Nuclear Criticality Safety Evaluation for Contact-Handled Transuranic Waste Containers at the Waste Isolation Pilot Plant,* WIPP-016, Revision 5, Nuclear Waste Partnership LLC, 2015.

[4] *SCALE Code System*, ORNL/TM-2005/39, Version 6.2.1, Oak Ridge National Laboratory. Available from Radiation Safety Information Computational Center as CCC-834.

APPENDIX G. 153 CENTROID STUDIES

APPENDIX G INTRODUCTION

Results of the cases presented in this appendix are from the studies discussed in Section 6.4. The studies presented in this appendix are based directly on POC spacing data from the compaction studies Reedlunn [10] which considered 153 POCs in the disposal environment. The results of the compaction studies yielded post closure data for centroid location and nearest neighbor data for both the 12-inch pipe and the 6-inch pipe designs. This data is used directly in the studies in this appendix.

The cases in this appendix consider the compaction study data in the following manner:

- The centroid location data is used explicitly to model the center location of each sphere.
- The nearest neighbor data is used to limit the potential size of the sphere for some cases.
- The inner diameter of the pipe is used as an upper limit of the size of the sphere for some cases where the nearest neighbor data is larger than the pipe inner diameter.

The cases in this appendix consider the following variations:

- Tight fitting or larger reflector box sizes to evaluation the impact of the reflector material density.
- Waste form with and without 1% Be; some cases include 20% brine.
- The reflector material may consider pure salt, cellulose (60 or 100%), brine (20%), Fe and 1% Be.
- Boundary conditions are included in some cases along the planes which define the edge of the length of the room.

The MCNP models are constructed as in the other array cases in this report such that the array of spheres is set in a reflector box which itself is set in a pure salt reflector. The only reflector material which varies is the reflector box which surrounds the spheres.

In Table D-1, each material description is specified using the material number and the waste form designation. For example, “m30-1001” represents material 30 and a sphere radius of 2.65 cm. The waste form designations considered are as follows:

- 12-inch centroid spacing:
    - 1000: for no Be in the waste form and the nearest neighbor data is limited to the inside diameter of the 12-inch pipe.
    - 1001-1014: no Be in the waste form and for sphere radius sizes where the nearest neighbor data is limited by increments from 2.65 cm to 14 cm.
    - 1015: with Be in the waste form and the nearest neighbor data is limited to the inside diameter of the 12-inch pipe.
    - 1016-1029: with Be in the waste form and for sphere radius sizes where the nearest neighbor data is limited by increments from 4 cm to 17.
    - 1030: for no Be in the waste form but with brine in the waste form, and the nearest neighbor data is limited to the inside diameter of the 12-inch pipe.

  - 1031-1044: for no Be in the waste form but with brine in the waste form and for sphere radius sizes where the nearest neighbor data is limited by increments from 2.65 cm to 15.65 cm

- 6-inch centroid spacing:
  - 1000: for no Be in the waste form and the nearest neighbor data is limited to the inside diameter of the 6-inch pipe.
  - 1001-1014: no Be in the waste form and for sphere radius sizes where the nearest neighbor data is limited by increments from 2.65 cm to 14 cm.
  - 1015: with Be in the waste form and the nearest neighbor data is limited to the inside diameter of the 6-inch pipe.
  - 1016-1029: with Be in the waste form and for sphere radius sizes where the nearest neighbor data is limited by increments from 4 cm to 17.
  - 1030: for no Be in the waste form but with brine in the waste form, and the nearest neighbor data is limited to the inside diameter of the 6-inch pipe.
  - 1031-1044: for no Be in the waste form but with brine in the waste form and for sphere radius sizes where the nearest neighbor data is limited by increments from 2.65 cm to 15.65 cm

The following materials are considered (see also full specification in Table G-1):

- m1: pure salt
- m30: 60% fiberboard with Fe (varies for the 6- and 12-inch pipes) for a tight-fitting reflector.
- m31: 60% fiberboard with Fe (varies for the 6- and 12-inch pipes) for a large reflector.
- m32: 100% fiberboard (varies for the 6- and 12-inch pipes) for a large reflector (see full specification in Table G-3).
- m33: 100% fiberboard and Fe (varies for the 6- and 12-inch pipes) for a tight-fitting reflector.
- m34: 100% fiberboard and Fe (varies for the 6- and 12-inch pipes) for a large reflector.
- m35: 40% fiberboard, 20% brine, MgO, Fe, 1% Be for a tight-fitting reflector.
- m36: 20% brine, MgO, Fe, 1% Be for a tight-fitting reflector.

The cases presented in this appendix are summarized as follows:

- Case G-1: Comparison of 6- and 12-inch pipe centroid data for larger (m31) and tight-fitting (m30) reflector box materials of pure salt and 60% fiberboard with Fe reflectors, with and without

1% Be in the waste form, with and without boundary conditions. Results are plotted up to the pipe size limit[23] and are presented in Figure G-1 and G-2.

- Case G-2: Comparison of 6- and 12-inch pipe centroid data for large (m32) reflector box materials of pure salt (m1) and 100% fiberboard (m32). Results are plotted up to the pipe size limit and are presented in Figure G-3 and G-4.

- Case G-3: Comparison of 6- and 12-inch pipe centroid data for larger (m34) and tight-fitting (m33) reflector box materials of pure salt (m1) and 100% fiberboard with Fe (m32). Results are plotted up to the pipe size limit and are presented in Figure G-5 and G-6.

- Case G-4: Comparison of 6- and 12-inch pipe uniform array (average pitch based on nearest neighbor data) for 153 centroids and 959 centroids. Results are plotted in Figure G-7.

- Case G-5: Comparison of 6- and 12-inch pipe centroid data for tight-fitting (m35) reflector box materials of 40% fiberboard, Fe, 1% Be, MgO and 20% brine. Results are presented in Figure G-8.

- Case G-5: Comparison of 6- and 12-inch pipe centroid data (with brine in the waste form) for tight-fitting (m36) reflector box materials of Fe, 1% Be, MgO and 20% brine. Results are presented in Figure G-9.

- Case G-6: Comparison of two spheres with two cylinders in salt. For both geometries, the two units are placed in a salt reflector and the H/Pu ratio is varied for the sphere by increasing the radius and for the cylinder by increasing the height. See Figure G-9.

---

[23] The pipe size limit is only with respect to the largest size sphere which may physically fit inside the pipe. Additional cases are added to address the larger H/Pu results which a cylindrical shape could possess should its height increase beyond the restricted sphere diameter. See Case G-6.

Table G-1. Specification of Reflector Material (1 of 13)

12-inch Pipe															
material	30-1000	30-1001	30-1002	30-1003	30-1004	30-1005	30-1006	30-1007	30-1008	30-1009	30-1010	30-1011	30-1012	30-1013	30-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	18923798	13029900	13453863	13885280	14324199	14770668	15224735	15686449	16155856	16633006	17117945	17610723	18111387	18619985	19136565
MCNP ZAID.XS	Weight fraction														
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
26054.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
material densty (g/cm3)	0.640367	0.829216	0.804215	0.781051	0.759738	0.740277	0.722656	0.706861	0.692877	0.680694	0.670308	0.661500	0.653421	0.645465	0.636268
material	30-1015	30-1016	30-1017	30-1018	30-1019	30-1020	30-1021	30-1022	30-1023	30-1024	30-1025	30-1026	30-1027	30-1028	30-1029
total sphere volume (cm3)	2066793	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974	2383139	2534096	2622243
total reflector box volume (cm3)	18923798	14324199	14770668	15224735	15686449	16155856	16633006	17117945	17610723	18111387	18619985	19136565	19661175	20193863	20734677
MCNP ZAID.XS	Weight fraction														
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
26054.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
material densty (g/cm3)	0.640367	0.759738	0.740277	0.722656	0.706861	0.692877	0.680694	0.670308	0.661500	0.653421	0.645465	0.636268	0.624762	0.611258	0.595981

Table G-1 continued (2 of 13)

	12-inch Pipe														
material	31-1000	31-1001	31-1002	31-1003	31-1004	31-1005	31-1006	31-1007	31-1008	31-1009	31-1010	31-1011	31-1012	31-1013	31-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746
MCNP ZAID.XS	Weight fraction														
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
26054.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
material densty (g/cm3)	0.411540	0.381642	0.381903	0.382353	0.383048	0.384042	0.385393	0.387161	0.389413	0.392219	0.395658	0.399736	0.404210	0.408879	0.413181

material	31-1015	31-1016	31-1017	31-1018	31-1019	31-1020	31-1021	31-1022	31-1023	31-1024	31-1025	31-1026	31-1027	31-1028	31-1029
total sphere volume (cm3)	2066793	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974	2383139	2534096	2622243
total reflector box volume (cm3)	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746
MCNP ZAID.XS	Weight fraction														
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
26054.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
material densty (g/cm3)	0.411540	0.383048	0.384042	0.385393	0.387161	0.389413	0.392219	0.395658	0.399736	0.404210	0.408879	0.413181	0.416564	0.419004	0.420443

Table G-1 continued (3 of 13)

12-inch Pipe															
material	32-1000	32-1001	32-1002	32-1003	32-1004	32-1005	32-1006	32-1007	32-1008	32-1009	32-1010	32-1011	32-1012	32-1013	32-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746
MCNP ZAID.XS	Weight fraction														
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
26054.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
26056.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	0.088043	0.081646	0.081702	0.081799	0.081947	0.082160	0.082449	0.082827	0.083309	0.083909	0.084645	0.085517	0.086474	0.087473	0.088394

material	32-1015	32-1016	32-1017	32-1018	32-1019	32-1020	32-1021	32-1022	32-1023	32-1024	32-1025	32-1026	32-1027	32-1028	32-1029
total sphere volume (cm3)	2066793	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974	2383139	2534096	2622243
total reflector box volume (cm3)	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746
MCNP ZAID.XS	Weight fraction														
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
26054.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
26056.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	0.088043	0.081947	0.082160	0.082449	0.082827	0.083309	0.083909	0.084645	0.085517	0.086474	0.087473	0.088394	0.089117	0.089640	0.089947

Table G-1 continued (4 of 13)

12-inch Pipe															
material	33-1000	33-1001	33-1002	33-1003	33-1004	33-1005	33-1006	33-1007	33-1008	33-1009	33-1010	33-1011	33-1012	33-1013	33-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	18923798	13029900	13453863	13885280	14324199	14770668	15224735	15686449	16155856	16633006	17117945	17610723	18111387	18619985	19136565
MCNP ZAID.XS	Weight fraction														
1001.70c	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394
1002.70c	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004
8016.70c	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880
8017.70c	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722
26054.70c	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296
26056.70c	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008
6000.70c	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695
material densty (g/cm3)	0.731698	0.947481	0.918915	0.892446	0.868094	0.845857	0.825724	0.807676	0.791698	0.777777	0.765909	0.755845	0.746614	0.737524	0.727015
material	33-1015	33-1016	33-1017	33-1018	33-1019	33-1020	33-1021	33-1022	33-1023	33-1024	33-1025	33-1026	33-1027	33-1028	33-1029
total sphere volume (cm3)	2066793	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974	2383139	2534096	2622243
total reflector box volume (cm3)	18923798	14324199	14770668	15224735	15686449	16155856	16633006	17117945	17610723	18111387	18619985	19136565	19661175	20193863	20734677
MCNP ZAID.XS	Weight fraction														
1001.70c	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394
1002.70c	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004
8016.70c	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880
8017.70c	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722
26054.70c	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296
26056.70c	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008
6000.70c	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695
material densty (g/cm3)	0.731698	0.868094	0.845857	0.825724	0.807676	0.791698	0.777777	0.765909	0.755845	0.746614	0.737524	0.727015	0.713868	0.698437	0.680982

Table G-1 continued (5 of 13)

12-inch Pipe															
material	34-1000	34-1001	34-1002	34-1003	34-1004	34-1005	34-1006	34-1007	34-1008	34-1009	34-1010	34-1011	34-1012	34-1013	34-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746
MCNP ZAID.XS	Weight fraction														
1001.70c	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394
1002.70c	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004
8016.70c	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880
8017.70c	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722
26054.70c	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296
26056.70c	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008
6000.70c	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695
material densty (g/cm3)	0.470235	0.436073	0.436371	0.436886	0.437680	0.438816	0.440359	0.442380	0.444952	0.448158	0.452088	0.456747	0.461860	0.467195	0.472110
material	34-1015	34-1016	34-1017	34-1018	34-1019	34-1020	34-1021	34-1022	34-1023	34-1024	34-1025	34-1026	34-1027	34-1028	34-1029
total sphere volume (cm3)	2066793	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974	2383139	2534096	2622243
total reflector box volume (cm3)	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746	28296746
MCNP ZAID.XS	Weight fraction														
1001.70c	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394	0.019394
1002.70c	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004	0.000004
8016.70c	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880	0.265880
8017.70c	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722	0.000722
26054.70c	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296	0.033296
26056.70c	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008	0.542008
6000.70c	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695	0.138695
material densty (g/cm3)	0.470235	0.437680	0.438816	0.440359	0.442380	0.444952	0.448158	0.452088	0.456747	0.461860	0.467195	0.472110	0.475975	0.478764	0.480408

Table G-1 continued (6 of 13)

12-inch Pipe															
material	m35-1000	m35-1001	m35-1002	m35-1003	m35-1004	m35-1005	m35-1006	m35-1007	m35-1008	m35-1009	m35-1010	m35-1011	m35-1012	m35-1013	m35-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	16857005	13017923	13422607	13820700	14208408	14581935	14937485	15271264	15579475	15858325	16104044	16318471	16520227	16723849	16965591
MCNP ZAID.XS	Weight fraction														
1001.70c	0.007188	0.007775	0.007693	0.007619	0.007551	0.007490	0.007436	0.007387	0.007345	0.007308	0.007277	0.007250	0.007226	0.007203	0.007176
1002.70c	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002	0.000002
8016.70c	0.211585	0.211297	0.211337	0.211374	0.211407	0.211437	0.211463	0.211487	0.211508	0.211526	0.211541	0.211554	0.211566	0.211577	0.211591
8017.70c	0.000575	0.000574	0.000574	0.000574	0.000574	0.000575	0.000575	0.000575	0.000575	0.000575	0.000575	0.000575	0.000575	0.000575	0.000575
26054.70c	0.016881	0.023109	0.022244	0.021454	0.020737	0.020089	0.019510	0.018995	0.018544	0.018153	0.017823	0.017544	0.017289	0.017040	0.016753
26056.70c	0.274794	0.376182	0.362099	0.349238	0.337560	0.327026	0.317592	0.309217	0.301867	0.295512	0.290130	0.285591	0.281448	0.277387	0.272715
6000.70c	0.028127	0.038505	0.037063	0.035747	0.034552	0.033473	0.032508	0.031650	0.030898	0.030248	0.029697	0.029232	0.028808	0.028392	0.027914
12024.70c	0.116033	0.085223	0.089503	0.093411	0.096960	0.100161	0.103028	0.105572	0.107806	0.109737	0.111373	0.112752	0.114011	0.115245	0.116665
12025.70c	0.015303	0.011239	0.011804	0.012319	0.012787	0.013209	0.013587	0.013923	0.014218	0.014472	0.014688	0.014870	0.015036	0.015199	0.015386
12026.70c	0.017520	0.012868	0.013514	0.014104	0.014640	0.015124	0.015556	0.015941	0.016278	0.016570	0.016817	0.017025	0.017215	0.017401	0.017616
4009.70c	0.006421	0.008790	0.008461	0.008161	0.007888	0.007642	0.007421	0.007225	0.007054	0.006905	0.006779	0.006673	0.006577	0.006482	0.006372
11023.70c	0.120205	0.088287	0.092721	0.096770	0.100445	0.103762	0.106732	0.109368	0.111682	0.113682	0.115377	0.116806	0.118110	0.119388	0.120859
17035.70c	0.138555	0.101765	0.106875	0.111542	0.115780	0.119602	0.123025	0.126064	0.128731	0.131037	0.132990	0.134637	0.136141	0.137614	0.139310
17037.70c	0.046813	0.034383	0.036109	0.037686	0.039118	0.040409	0.041566	0.042592	0.043493	0.044272	0.044932	0.045489	0.045997	0.046495	0.047067
material densty (g/cm3)	1.443214	1.365143	1.375478	1.385055	1.393865	1.401911	1.409195	1.415725	1.421506	1.426543	1.430836	1.434477	1.437817	1.441106	1.444908

Table G-1 continued (7 of 13)

6-inch Pipe															
material	30-1000	30-1001	30-1002	30-1003	30-1004	30-1005	30-1006	30-1007	30-1008	30-1009	30-1010	30-1011	30-1012	30-1013	30-1014
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	13814124	11725246	12130940	12543943	12964304	13392070	13827289	14270010	14720279	15178146	15643659	16116864	16597811	17086547	17583120
MCNP ZAID.XS	Weight fraction														
1001.70c	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912
1002.70c	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006
8016.70c	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647
8017.70c	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831
26054.70c	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441
26056.70c	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704
6000.70c	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460
material densty (g/cm3)	0.557895	0.645064	0.624464	0.605465	0.588062	0.572132	0.557488	0.543953	0.531310	0.519313	0.507852	0.496061	0.484322	0.472540	0.460406
material	30-1015	30-1016	30-1017	30-1018	30-1019	30-1020	30-1021	30-1022	30-1023	30-1024	30-1025	30-1026	30-1027	30-1028	30-1029
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	13814124	11725246	12130940	12543943	12964304	13392070	13827289	14270010	14720279	15178146	15643659	16116864	16597811	17086547	17583120
MCNP ZAID.XS	Weight fraction														
1001.70c	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912
1002.70c	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006
8016.70c	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647
8017.70c	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831
26054.70c	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441
26056.70c	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704
6000.70c	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460
material densty (g/cm3)	0.557895	0.645064	0.624464	0.605465	0.588062	0.572132	0.557488	0.543953	0.531310	0.519313	0.507852	0.496061	0.484322	0.472540	0.460406

Table G-1 continued (8 of 13)

	6-inch Pipe														
material	31-1000	31-1001	31-1002	31-1003	31-1004	31-1005	31-1006	31-1007	31-1008	31-1009	31-1010	31-1011	31-1012	31-1013	31-1014
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968
MCNP ZAID.XS	Weight fraction														
1001.70c	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912
1002.70c	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006
8016.70c	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647
8017.70c	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831
26054.70c	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441
26056.70c	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704
6000.70c	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460
material densty (g/cm3)	0.285845	0.283074	0.283279	0.283633	0.284178	0.284928	0.285880	0.287026	0.288337	0.289767	0.291300	0.292648	0.293921	0.295066	0.295935
material	31-1015	31-1016	31-1017	31-1018	31-1019	31-1020	31-1021	31-1022	31-1023	31-1024	31-1025	31-1026	31-1027	31-1028	31-1029
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968
MCNP ZAID.XS	Weight fraction														
1001.70c	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912
1002.70c	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006
8016.70c	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647
8017.70c	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831
26054.70c	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441
26056.70c	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704
6000.70c	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460
material densty (g/cm3)	0.285845	0.283074	0.283279	0.283633	0.284178	0.284928	0.285880	0.287026	0.288337	0.289767	0.291300	0.292648	0.293921	0.295066	0.295935

Table G-1 continued (9 of 13)

6-inch Pipe															
material	32-1000	32-1001	32-1002	32-1003	32-1004	32-1005	32-1006	32-1007	32-1008	32-1009	32-1010	32-1011	32-1012	32-1013	32-1014
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968
MCNP ZAID.XS	Weight fraction														
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
26054.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
26056.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	0.123776	0.122576	0.122665	0.122818	0.123054	0.123379	0.123791	0.124287	0.124855	0.125474	0.126138	0.126722	0.127273	0.127769	0.128145
material	32-1015	32-1016	32-1017	32-1018	32-1019	32-1020	32-1021	32-1022	32-1023	32-1024	32-1025	32-1026	32-1027	32-1028	32-1029
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968
MCNP ZAID.XS	Weight fraction														
1001.70c	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150	0.062150
1002.70c	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014	0.000014
8016.70c	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037	0.492037
8017.70c	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337	0.001337
26054.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
26056.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6000.70c	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462	0.444462
material densty (g/cm3)	0.123776	0.122576	0.122665	0.122818	0.123054	0.123379	0.123791	0.124287	0.124855	0.125474	0.126138	0.126722	0.127273	0.127769	0.128145

Table G-1 continued (10 of 13)

	6-inch Pipe														
material	33-1000	33-1001	33-1002	33-1003	33-1004	33-1005	33-1006	33-1007	33-1008	33-1009	33-1010	33-1011	33-1012	33-1013	33-1014
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	13814124	11725246	12130940	12543943	12964304	13392070	13827289	14270010	14720279	15178146	15643659	16116864	16597811	17086547	17583120
MCNP ZAID.XS	Weight fraction														
1001.70c	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805
1002.70c	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008
8016.70c	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400
8017.70c	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944
26054.70c	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294
26056.70c	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637
6000.70c	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911
material densty (g/cm3)	0.718947	0.831281	0.804733	0.780249	0.757822	0.737294	0.718423	0.700981	0.684687	0.669228	0.654458	0.639263	0.624135	0.608951	0.593315

material	33-1015	33-1016	33-1017	33-1018	33-1019	33-1020	33-1021	33-1022	33-1023	33-1024	33-1025	33-1026	33-1027	33-1028	33-1029
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	13814124	11725246	12130940	12543943	12964304	13392070	13827289	14270010	14720279	15178146	15643659	16116864	16597811	17086547	17583120
MCNP ZAID.XS	Weight fraction														
1001.70c	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805
1002.70c	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008
8016.70c	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400
8017.70c	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944
26054.70c	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294
26056.70c	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637
6000.70c	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911
material densty (g/cm3)	0.718947	0.831281	0.804733	0.780249	0.757822	0.737294	0.718423	0.700981	0.684687	0.669228	0.654458	0.639263	0.624135	0.608951	0.593315

Table G-1 continued (11 of 13)

6-inch Pipe															
material	34-1000	34-1001	34-1002	34-1003	34-1004	34-1005	34-1006	34-1007	34-1008	34-1009	34-1010	34-1011	34-1012	34-1013	34-1014
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968
MCNP ZAID.XS	Weight fraction														
1001.70c	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805
1002.70c	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008
8016.70c	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400
8017.70c	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944
26054.70c	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294
26056.70c	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637
6000.70c	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911
material densty (g/cm3)	0.368362	0.364792	0.365055	0.365512	0.366214	0.367181	0.368408	0.369884	0.371574	0.373417	0.375391	0.377130	0.378770	0.380245	0.381365

material	34-1015	34-1016	34-1017	34-1018	34-1019	34-1020	34-1021	34-1022	34-1023	34-1024	34-1025	34-1026	34-1027	34-1028	34-1029
total sphere volume (cm3)	270686	11977	31256	64580	115626	185655	273969	379451	499172	628517	765671	885231	997009	1096744	1171932
total reflector box volume (cm3)	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968	26703968
MCNP ZAID.XS	Weight fraction														
1001.70c	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805	0.034805
1002.70c	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008	0.000008
8016.70c	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400	0.347400
8017.70c	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944	0.000944
26054.70c	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294	0.021294
26056.70c	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637	0.346637
6000.70c	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911	0.248911
material densty (g/cm3)	0.368362	0.364792	0.365055	0.365512	0.366214	0.367181	0.368408	0.369884	0.371574	0.373417	0.375391	0.377130	0.378770	0.380245	0.381365

Table G-1 continued (12 of 13)

6-inch Pipe															
material	m35-1000	m35-1001	m35-1002	m35-1003	m35-1004	m35-1005	m35-1006	m35-1007	m35-1008	m35-1009	m35-1010	m35-1011	m35-1012	m35-1013	m35-1014
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	16857005	13017923	13422607	13820700	14208408	14581935	14937485	15271264	15579475	15858325	16104044	16318471	16520227	16723849	16965591
MCNP ZAID.XS	Weight fraction														
1001.70c	0.011348	0.014880	0.014315	0.013824	0.013395	0.013022	0.012699	0.012421	0.012182	0.011980	0.011812	0.011673	0.011547	0.011425	0.011287
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.234998	0.248897	0.246676	0.244739	0.243053	0.241586	0.240315	0.239218	0.238279	0.237484	0.236823	0.236274	0.235779	0.235300	0.234757
8017.70c	0.000639	0.000676	0.000670	0.000665	0.000660	0.000656	0.000653	0.000650	0.000647	0.000645	0.000644	0.000642	0.000641	0.000639	0.000638
26054.70c	0.012030	0.019418	0.018237	0.017208	0.016312	0.015532	0.014856	0.014273	0.013774	0.013352	0.013000	0.012709	0.012446	0.012191	0.011902
26056.70c	0.195838	0.316096	0.296879	0.280126	0.265533	0.252843	0.241841	0.232351	0.224225	0.217348	0.211629	0.206878	0.202599	0.198457	0.193753
6000.70c	0.056250	0.090792	0.085272	0.080461	0.076269	0.072624	0.069464	0.066738	0.064404	0.062429	0.060786	0.059422	0.058192	0.057003	0.055651
12024.70c	0.124155	0.077865	0.085262	0.091711	0.097328	0.102212	0.106447	0.110100	0.113228	0.115875	0.118077	0.119905	0.121552	0.123147	0.124958
12025.70c	0.016374	0.010269	0.011244	0.012095	0.012836	0.013480	0.014038	0.014520	0.014933	0.015282	0.015572	0.015813	0.016030	0.016241	0.016479
12026.70c	0.018747	0.011757	0.012874	0.013848	0.014696	0.015433	0.016073	0.016624	0.017097	0.017496	0.017829	0.018105	0.018354	0.018594	0.018868
4009.70c	0.002658	0.004290	0.004029	0.003801	0.003603	0.003431	0.003282	0.003153	0.003043	0.002950	0.002872	0.002807	0.002749	0.002693	0.002629
11023.70c	0.128619	0.080664	0.088327	0.095008	0.100827	0.105887	0.110274	0.114059	0.117299	0.120041	0.122322	0.124216	0.125922	0.127574	0.129450
17035.70c	0.148254	0.092979	0.101811	0.109512	0.116219	0.122052	0.127109	0.131471	0.135206	0.138367	0.140995	0.143179	0.145146	0.147050	0.149212
17037.70c	0.050089	0.031414	0.034398	0.037000	0.039266	0.041237	0.042945	0.044419	0.045681	0.046749	0.047637	0.048375	0.049039	0.049683	0.050413
material densty (g/cm3)	1.022408	0.820238	0.847001	0.871800	0.894616	0.915450	0.934314	0.951223	0.966193	0.979236	0.990355	0.999784	1.008432	1.016949	1.026795

Table G-1 continued (13 of 13)

	6-inch Pipe														
material	m35-1030	m35-1031	m35-1032	m35-1033	m35-1034	m35-1035	m35-1036	m35-1037	m35-1038	m35-1039	m35-1040	m35-1041	m35-1042	m35-1043	m35-1044
total sphere volume (cm3)	2066793	11977	31256	64580	115791	188733	287250	415185	576381	774681	1013901	1292252	1591160	1896136	2170974
total reflector box volume (cm3)	16857005	13017923	13422607	13820700	14208408	14581935	14937485	15271264	15579475	15858325	16104044	16318471	16520227	16723849	16965591
MCNP ZAID.XS	Weight fraction														
1001.70c	0.004833	0.004633	0.004659	0.004683	0.004705	0.004726	0.004744	0.004761	0.004776	0.004789	0.004800	0.004810	0.004818	0.004827	0.004837
1002.70c	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
8016.70c	0.205422	0.203611	0.203845	0.204064	0.204266	0.204452	0.204621	0.204774	0.204909	0.205028	0.205129	0.205215	0.205294	0.205372	0.205463
8017.70c	0.000558	0.000553	0.000554	0.000555	0.000555	0.000556	0.000556	0.000556	0.000557	0.000557	0.000557	0.000558	0.000558	0.000558	0.000558
26054.70c	0.006544	0.008251	0.008031	0.007825	0.007634	0.007459	0.007299	0.007156	0.007028	0.006916	0.006821	0.006740	0.006665	0.006591	0.006506
26056.70c	0.106525	0.134322	0.130726	0.127372	0.124267	0.121415	0.118820	0.116482	0.114404	0.112586	0.111032	0.109710	0.108495	0.107295	0.105905
6000.70c	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12024.70c	0.172270	0.165154	0.166075	0.166933	0.167728	0.168458	0.169123	0.169721	0.170253	0.170718	0.171116	0.171454	0.171765	0.172072	0.172428
12025.70c	0.022719	0.021781	0.021902	0.022015	0.022120	0.022216	0.022304	0.022383	0.022453	0.022514	0.022567	0.022612	0.022653	0.022693	0.022740
12026.70c	0.026012	0.024937	0.025076	0.025206	0.025326	0.025436	0.025536	0.025627	0.025707	0.025777	0.025837	0.025888	0.025935	0.025982	0.026035
4009.70c	0.001446	0.001823	0.001774	0.001729	0.001686	0.001648	0.001612	0.001581	0.001553	0.001528	0.001507	0.001489	0.001472	0.001456	0.001437
11023.70c	0.178463	0.171092	0.172045	0.172935	0.173758	0.174515	0.175203	0.175823	0.176374	0.176856	0.177268	0.177618	0.177941	0.178259	0.178627
17035.70c	0.205707	0.197211	0.198310	0.199335	0.200284	0.201156	0.201949	0.202664	0.203299	0.203855	0.204330	0.204734	0.205105	0.205472	0.205897
17037.70c	0.069501	0.066630	0.067001	0.067348	0.067668	0.067963	0.068231	0.068472	0.068687	0.068875	0.069035	0.069172	0.069297	0.069421	0.069565
material densty (g/cm3)	1.879612	1.930238	1.923536	1.917327	1.911613	1.906396	1.901672	1.897438	1.893689	1.890423	1.887639	1.885278	1.883112	1.880979	1.878514

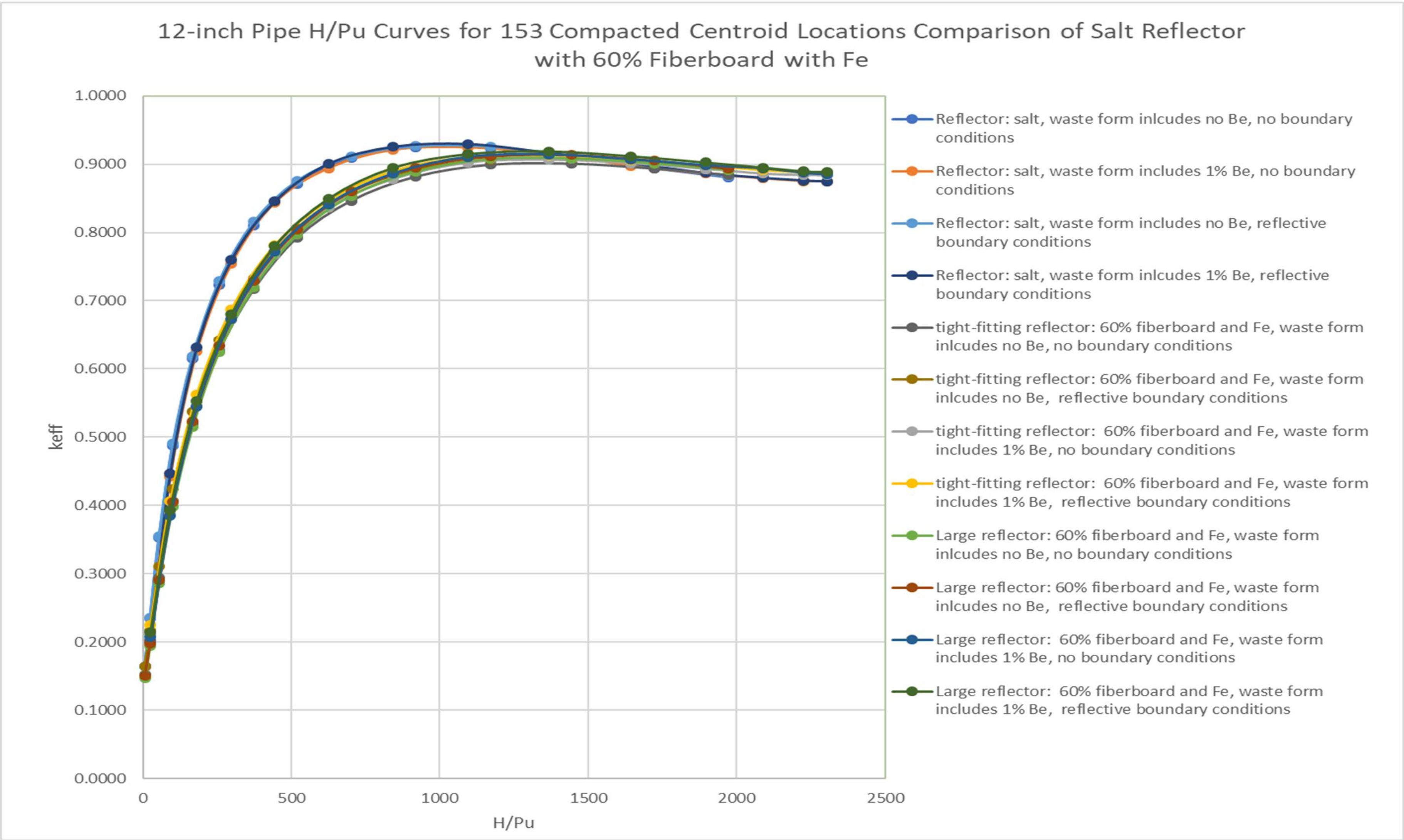


Figure G-1. 153 Centroid location comparison of salt with 60% fiberboard and Fe for the 12-inch pipes and various waste form compositions and boundary conditions.

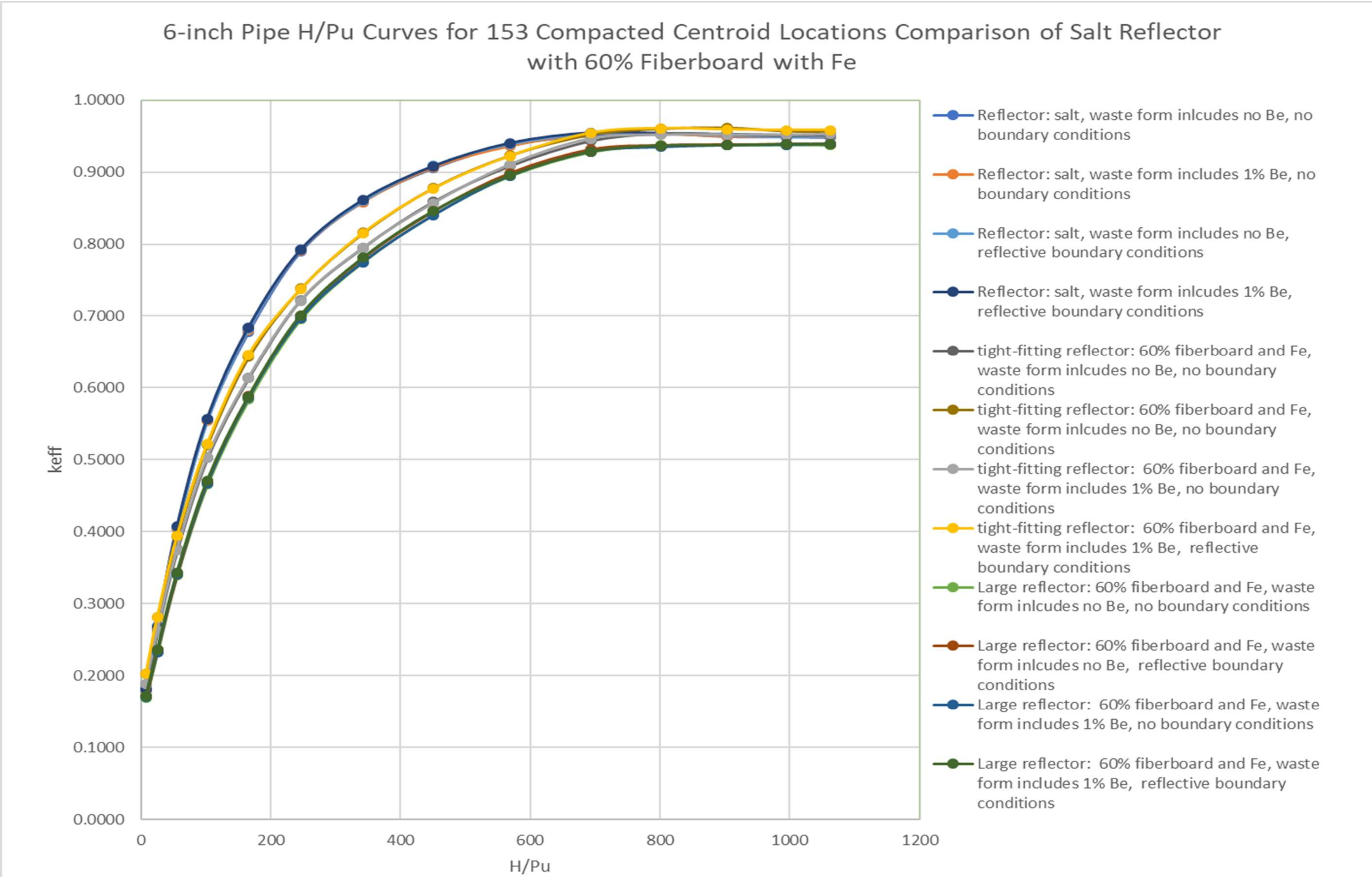


Figure G-2. 153 Centroid location comparison of salt with 60% fiberboard and Fe for the 6-inch pipes and various waste form compositions and boundary conditions.

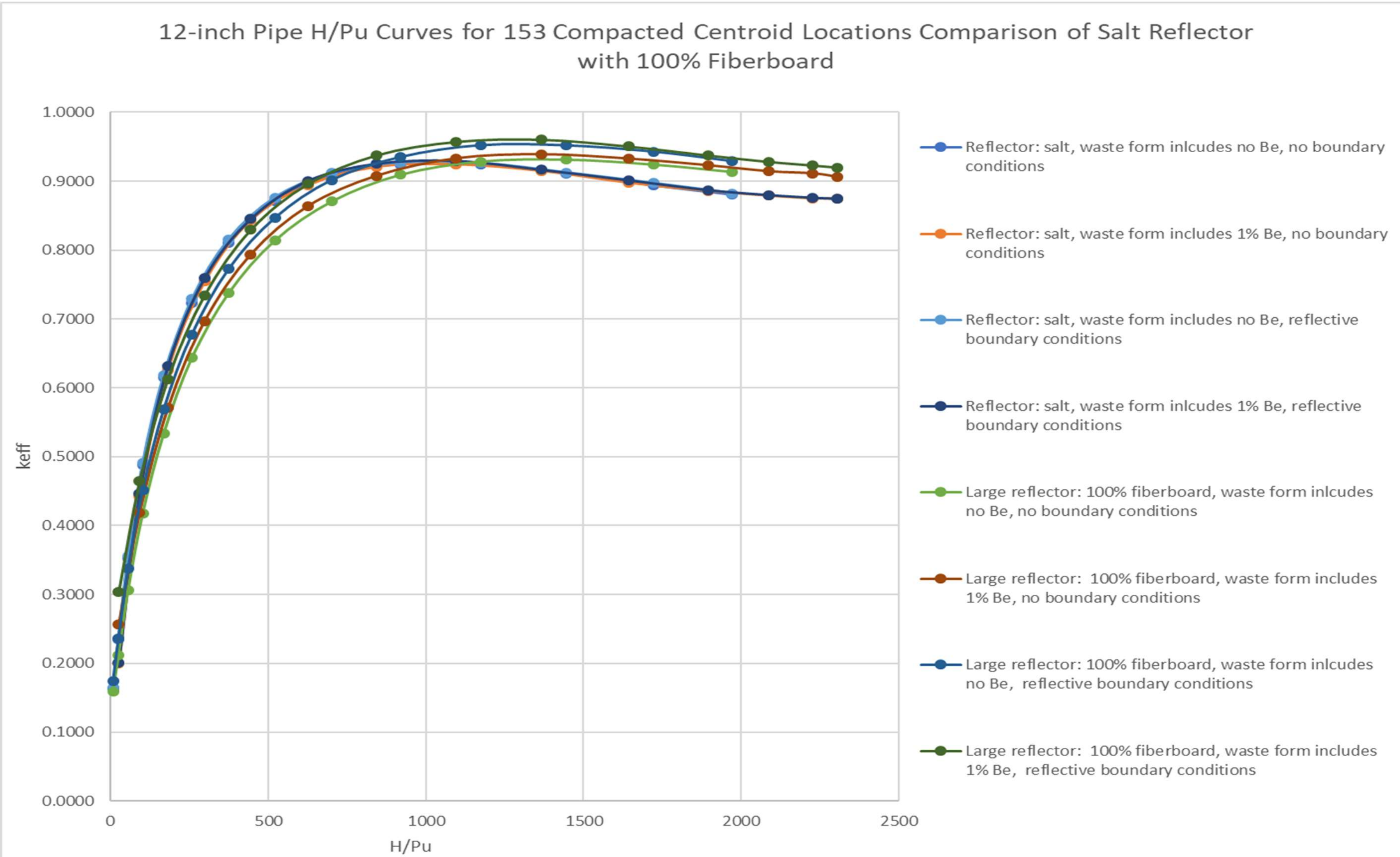


Figure G-3. 153 Centroid location comparison of salt with 100% fiberboard for the 12-inch pipes and various waste form compositions and boundary conditions.

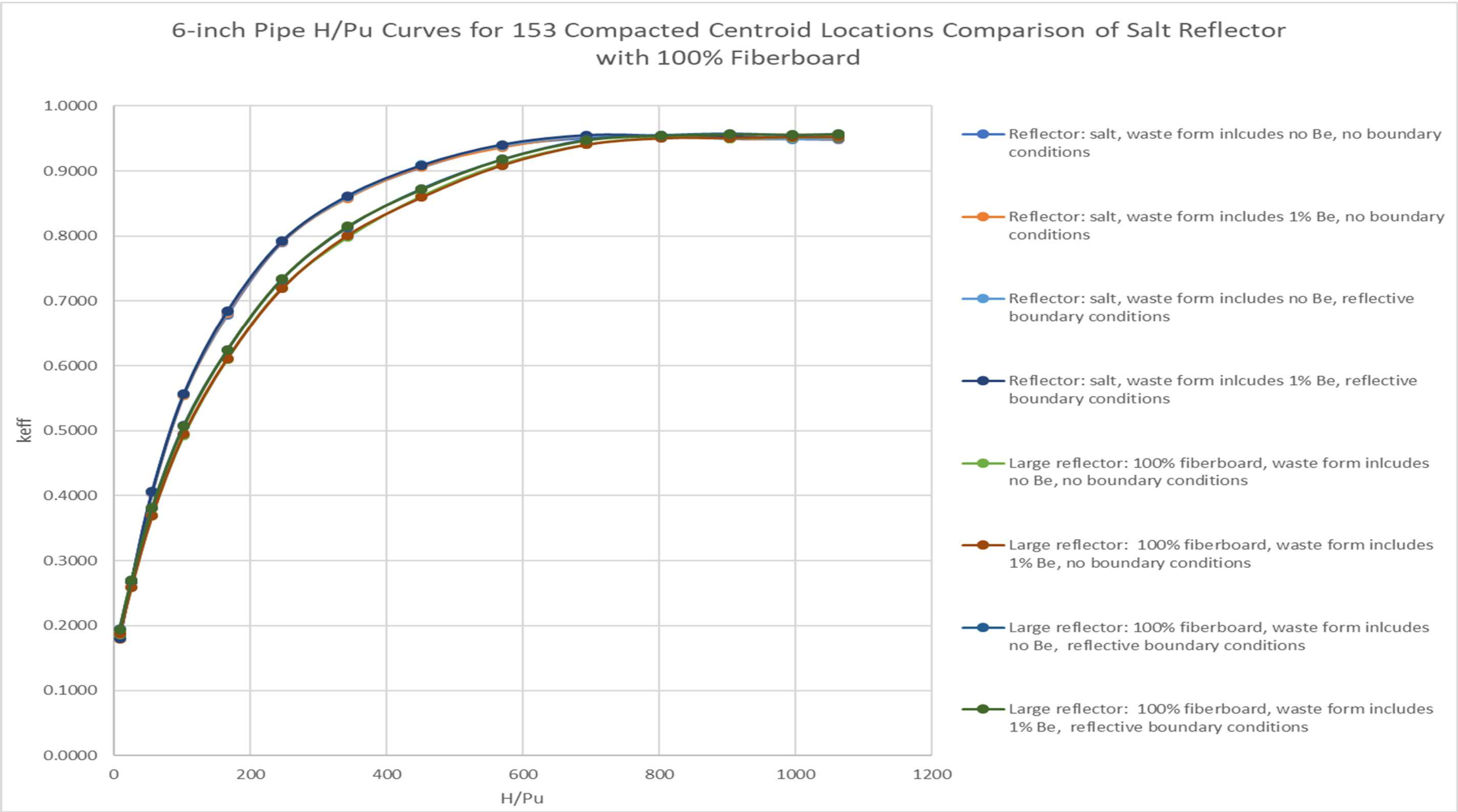


Figure G-4. 153 Centroid location comparison of salt with 100% fiberboard for the 6-inch pipes and various waste form compositions and boundary conditions.

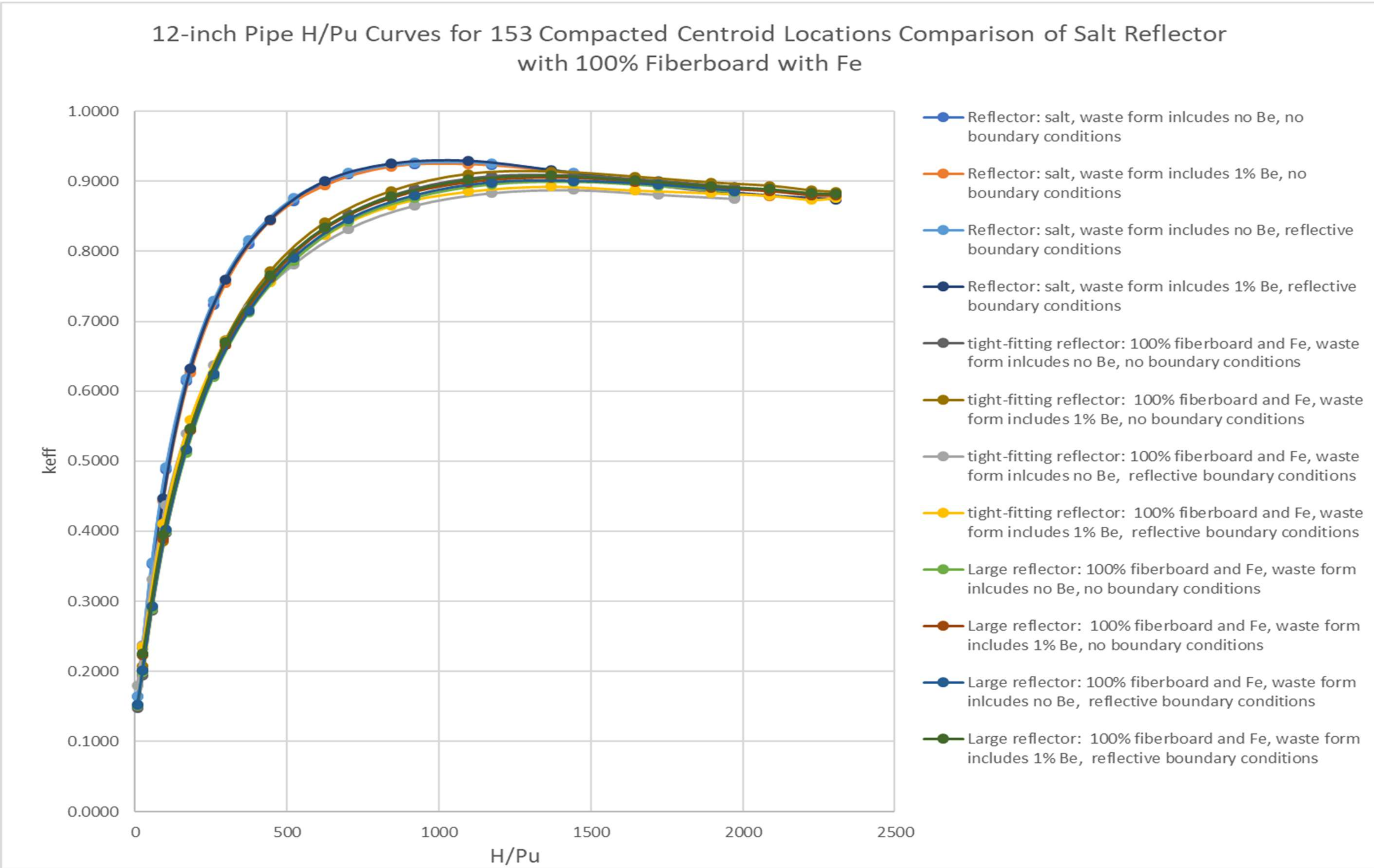


Figure G-5. 153 Centroid location comparison of salt with 100% fiberboard and Fe for the 12-inch pipes and various waste form compositions and boundary conditions.

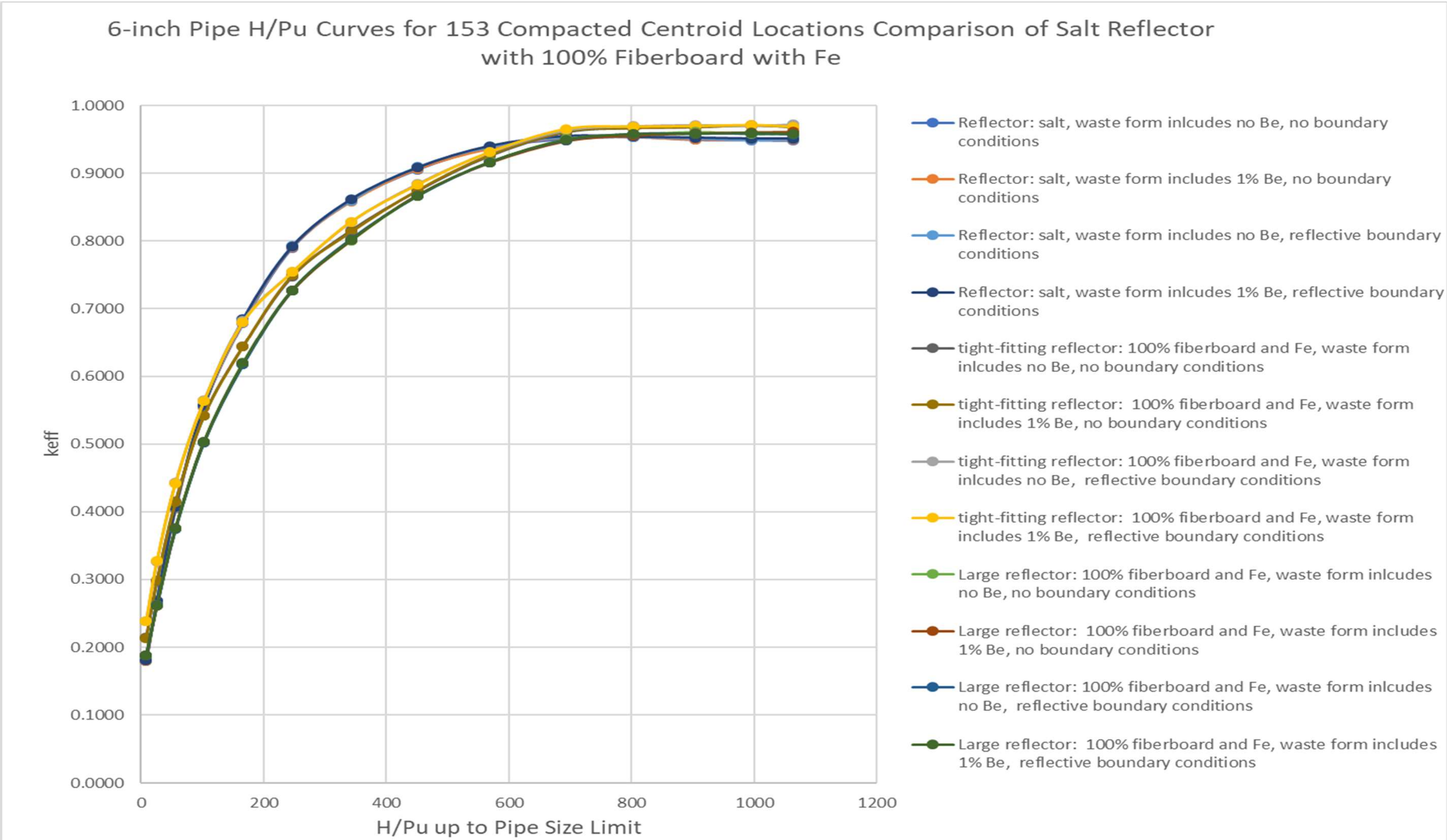


Figure G-6. 153 Centroid location comparison of salt with 100% fiberboard and Fe for the 6-inch pipes and various waste form compositions and boundary conditions.

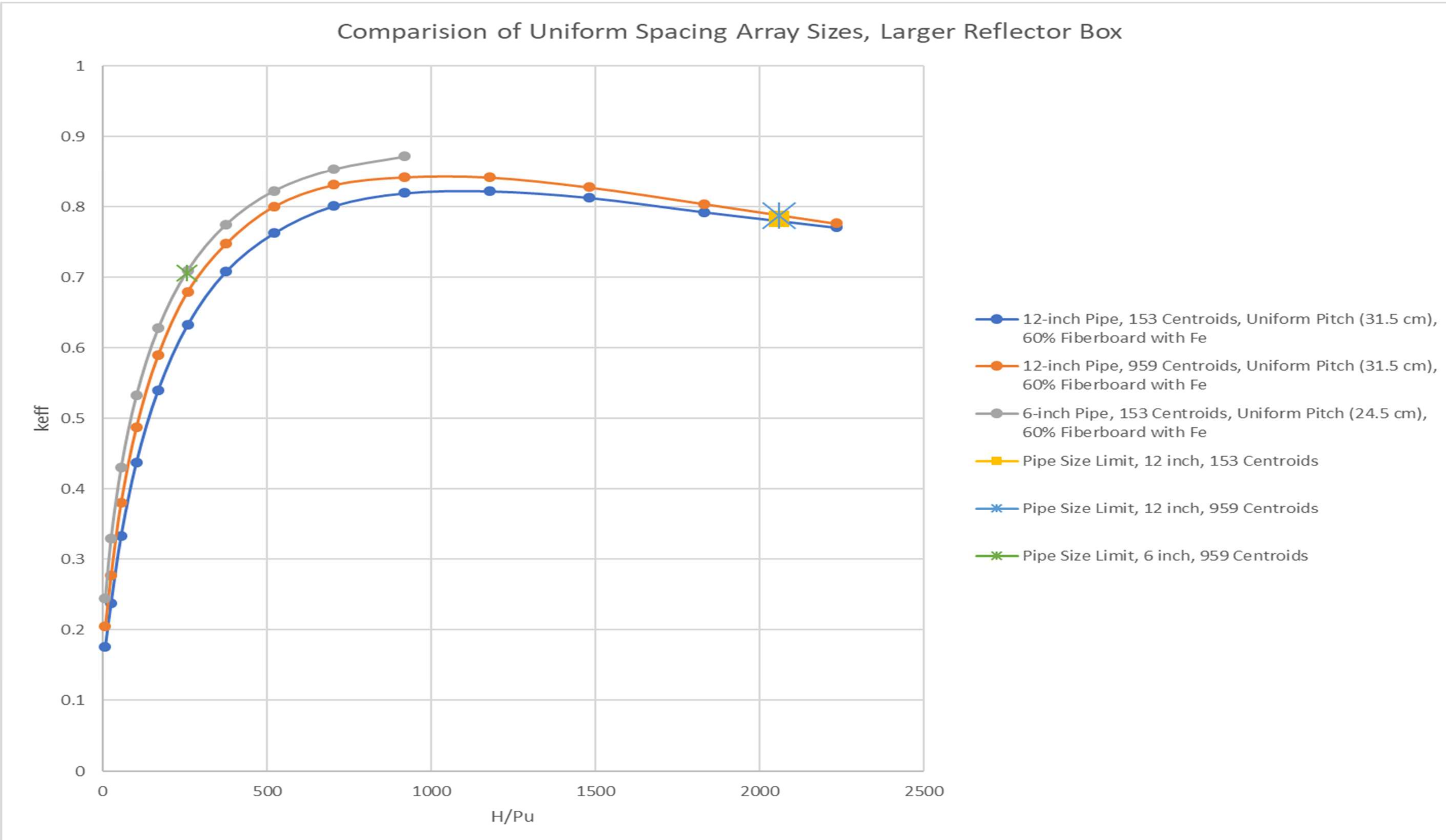


Figure G-7. Comparison of the various sphere arrays sizes with a uniform pitch.

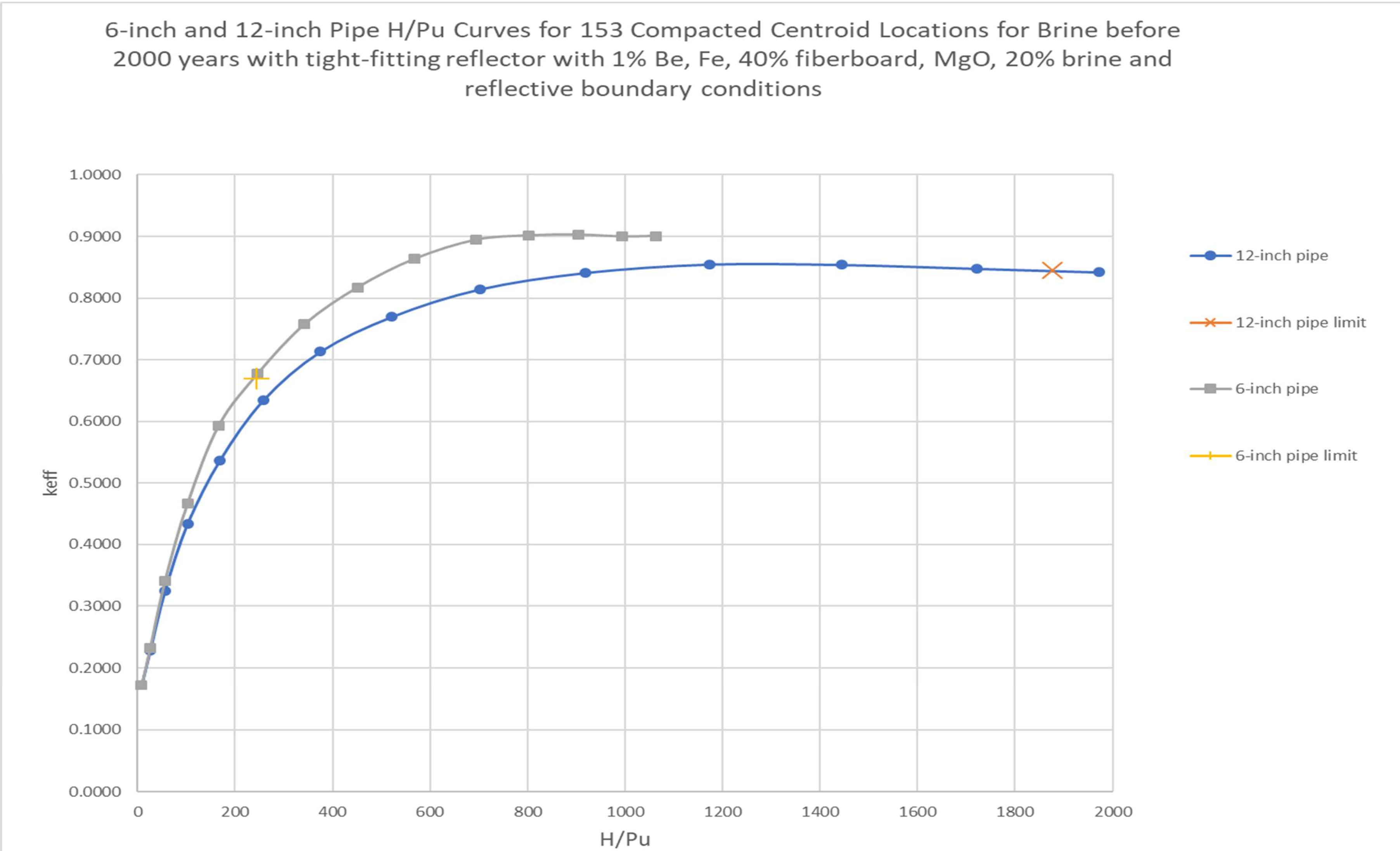


Figure G-8. 153 Centroid location calculations with brine before 2000 years.

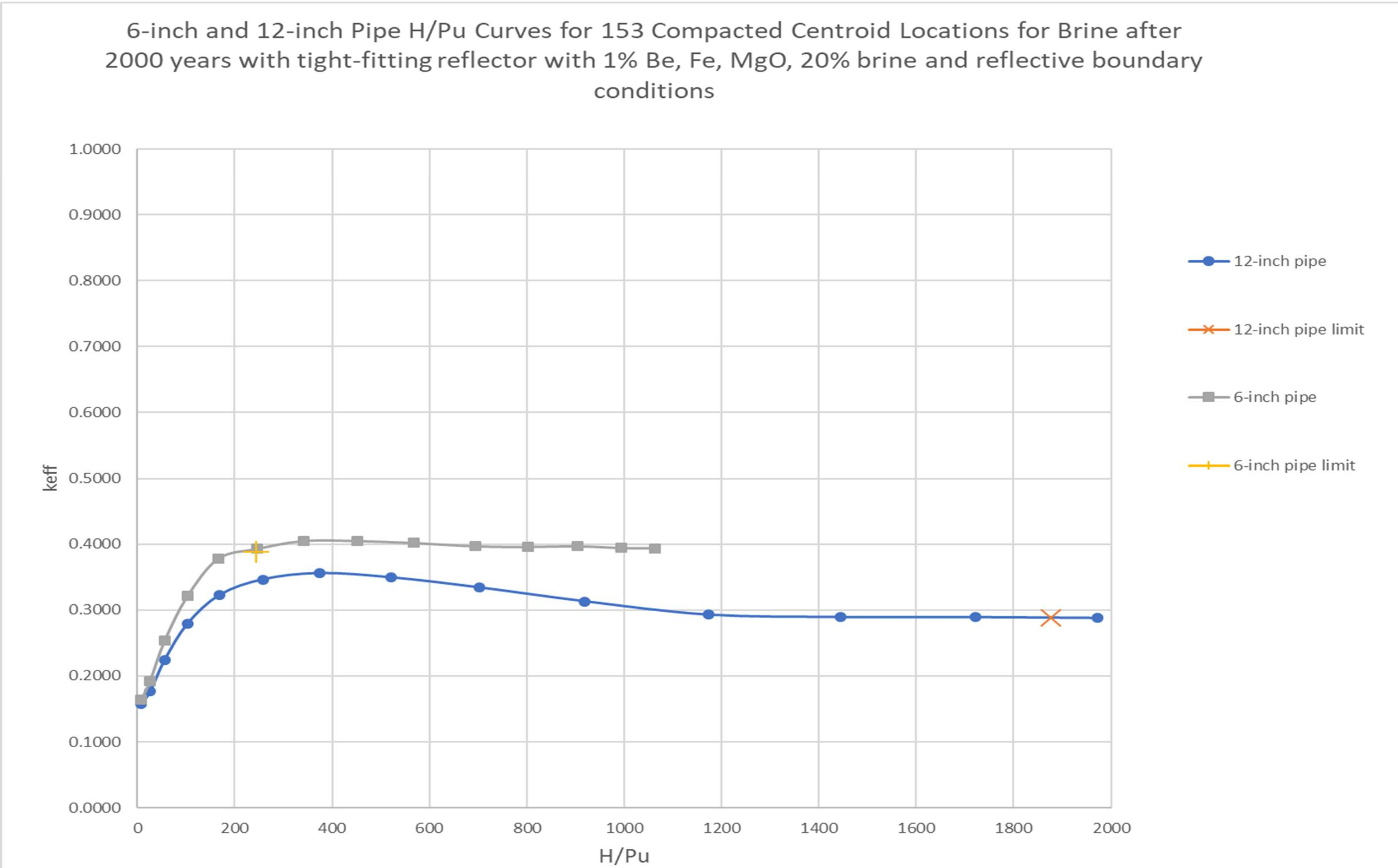


Figure G-9. 153 Centroid location calculations with brine after 2000 years.

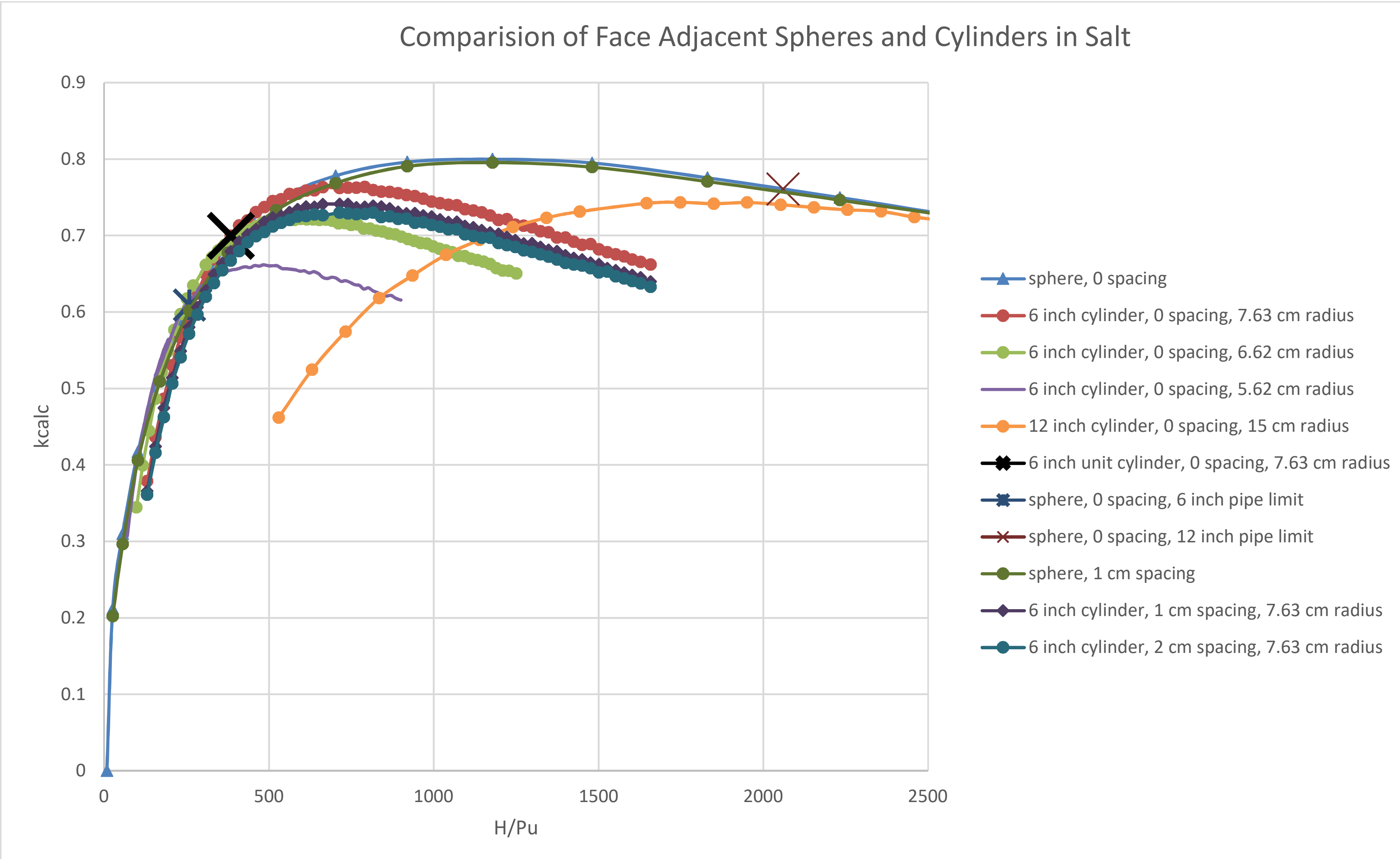


Figure G-10. Comparison of two spheres and two cylinders in salt.

APPENDIX H. STUDIES WITH 200 FGE SPHERES IN A 959 UNIFORM ARRAY WITH SPECIFIC SPACING

APPENDIX H. STUDIES WITH 200 FGE SPHERES IN A 959 UNIFORM ARRAY WITH SPECIFIC SPACING

Results of the cases presented in this appendix are from the studies discussed in Section 6.4 of the main report for 200 g fissile masses in the same 959 sphere array considered in Appendix B and Appendix C. The purpose of the calculations presented in this Appendix is to demonstrate the reactivity effect of randomly distributing variations in H/Pu (sphere size) when compared to all spheres using the maximum reactivity sphere size.

The cases in this appendix consider the compaction study data from Reedlunn [10] by setting the center to center pitch of the spheres for the minimum and average nearest neighbor distances for the 6- and 12-inch pipes.

The MCNP models are constructed as in the other array cases in this report such that the array of spheres is set in a reflector box which itself is set in a pure salt reflector. The only reflector material which varies is the reflector box which surrounds the spheres. The material composition of the reflector box is dependent upon the size of the reflector box and the total volume of the spheres within the reflector box. All cases use a tight fitting reflector box.

The cases in this appendix are as follows:

- Case H-1: Uniform H/Pu curves for 200 g POCs.
    - Calculations are performed for the 6- and 12-inch pipe minimum and average nearest neighbor spacing.
    - No Be or reflective boundary conditions are considered.
    - Tight fitting reflector box. For the reflector box material volume, the total volume of the spheres is calculated specifically for each H/Pu case.
    - For each pitch case, variations of H/Pu are evaluated.
    - The reflector box material considered is m31 from Appendix G (60% cellulose with Fe). In Table H-1, each material description is specified using the material number and the waste form designation. For example, "m31-9300" represents material 31 and a sphere radius of 11.65 cm. The waste form designations considered are as follows:
        - 12-inch pipe minimum nearest neighbor spacing (pitch = 23.3 cm):
            - 9300: 11.65 cm radius (maximum radius sphere size for pitch spacing).
            - 9301-9309: sphere radius decreases from 10.65 to 2.65 cm.
        - 12-inch pipe average nearest neighbor spacing (pitch = 31.8 cm):
            - 9310: 15.90 cm radius (maximum radius sphere size for pitch spacing).
            - 9311-9323: sphere size decreases from 14.90 to 2.90 cm.

        - 6- inch pipe minimum nearest neighbor spacing (pitch = 10.9 cm):
            - 93200: 5.45 cm radius (maximum radius sphere size for pitch spacing).
            - 93210-93212: sphere radius decreases from 4.45 to 2.45 cm.
        - 6- inch pipe average nearest neighbor spacing (pitch = 23.7 cm):
            - 9330: 11.85 cm radius (maximum radius sphere size for pitch spacing).
            - 9331-9340: sphere radius decreases from 10.85 to 1.85 cm.

- Case H-2: Randomly distributed H/Pu calculations.
    - Calculations are performed for the 6- and 12-inch pipe minimum and average nearest neighbor spacing.
    - No Be or reflective boundary conditions are considered.
    - Tight fitting reflector box. For the reflector box material volume, the total volume of the spheres is calculated as the average total volume of the spheres over all cases (base case and 300 randomly distributed H/Pu cases). Therefore, for each set of cases, the base case and the 300 variations, have the same reflector box material composition and density.
    - For each set of randomly distributed H/Pu cases, a set of 50 variations in H/Pu is used which varies from the maximum sphere radius for each nearest neighbor pitch spacing down to small sphere radius values.
    - The reflector box material considered is m31 from Appendix G (60% cellulose with Fe). In Table H-2, each material description is specified using the material number and the waste form designation. For example, "m31-930" represents material 31 and a sphere radius of 11.65 cm. The waste form designations considered are as follows:
        - 12-inch pipe minimum nearest neighbor spacing (pitch = 23.3 cm):
            - 930: 11.65 cm radius (maximum radius sphere size for pitch spacing).
            - RN_case_1 to RN_case_300: sphere radius is a random distribution from the 50 sets of H/Pu variations.
        - 12-inch pipe average nearest neighbor spacing (pitch = 31.8 cm):
            - 931: 15.90 cm radius (maximum radius sphere size for pitch spacing).
            - RN_case_1 to RN_case_300: sphere radius is a random distribution from the 50 sets of H/Pu variations.
        - 6- inch pipe minimum nearest neighbor spacing (pitch = 10.9 cm):
            - 932: 5.45 cm radius (maximum radius sphere size for pitch spacing).

        - RN_case_1 to RN_case_300: sphere radius is a random distribution from the 50 sets of H/Pu variations.

    - 6- inch pipe average nearest neighbor spacing (pitch = 23.7 cm):

        - 933: 11.85 cm radius (maximum radius sphere size for pitch spacing).

        - RN_case_1 to RN_case_300: sphere radius is a random distribution from the 50 sets of H/Pu variations.

The results of Case H-1 are presented in Figure H-1 and the results for Case H-2 are presented in Figures H-2 through H-5.

For Case H-1, the results in Figure H-1 show how reactivity changes as a function of spacing, H/Pu and pipe size. The results are limited by how large the moderated spheres may grow based on the radius of the pipe while every sphere in the uniform arrays have the same radius. The results show that for a room sized uniform array configuration with a tight-fitting reflector box material composition which models a representation of the container compositions interstitially, the reactivity is highly dependent upon the spacing scenarios and the sphere size assumptions.

For Case H-2, the results presented in Figures H-2 through H-5 show the reactivity effect of randomly varying the sphere sizes in the array while maintaining the spacing consistent with the calculations in Case H-1 for each pipe size and spacing combination. In each of the variations evaluated the reactivity decreases significantly from the uniform sphere radius reactivity, consistently about 14% delta-k for the minimum spacing and 5% delta-k for the average spacing. These results indicate that the approach of using the same sphere size in every location is a significantly conservative assumption.

Additionally, a comparison of the results between Case H-1 and the H-2 base cases show that the approach used to determine the reflector box material volume can have a significant impact on reactivity. In Case H-1, the volume of the reflector box material considers the volume of the spheres in the array for each calculation. For Case H-2, the volume of the reflector box material is calculated using the average volume over all the randomly distributed sphere size cases. A direct comparison between the “maximum sphere size” case in the results from Case H-2 and the results from Case H-1 shows that reducing the reflector box material density increases reactivity over the results in Case H-1 consistently among all configurations by about 3% delta-k.   Since the material density is held constant between all the randomly varied calculations then reactivity decrease seen is directly related to sphere size variation.

Table H-1. Specification of Reflector Material for Case H-1 (1 of 2)

12-inch Pipe (pitch = 23.3 cm)											
material	31-9300	31-9301	31-9302	31-9303	31-9304	31-9305	31-9306	31-9307	31-9308	31-9309	31-9310
total sphere volume (cm3)	6355285	4855682	3612740	2602368	1800476	1182975	725775	404784	195914	75074	16151876
total reflector box volume (cm3)	12312754	11846905	11388282	10936836	10492518	10055281	9625077	9201858	8785575	8376182	31289799
MCNP ZAID.XS	Weight fraction										
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
26054.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
material densty (g/cm3)	11.357288	9.677946	8.701732	8.118177	7.784211	7.626054	7.602920	7.691272	7.876991	8.150802	4.469615

12 inch Pipe (pitch = 31.8 cm)													
material	31-9311	31-9312	31-9313	31-9314	31-9315	31-9316	31-9317	31-9318	31-9319	31-9320	31-9321	31-9322	31-9323
total sphere volume (cm3)	13292710	10792587	8627418	6773112	5205580	3900731	2834475	1982722	1321381	826364	473580	238938	98349
total reflector box volume (cm3)	30420470	29561017	28711393	27871550	27041440	26221015	25410226	24609026	23817367	23035201	22262479	21499155	20745179
MCNP ZAID.XS	Weight fraction												
1001.70c	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296	0.013296
1002.70c	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003	0.000003
8016.70c	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625	0.233625
8017.70c	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635	0.000635
26054.70c	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045	0.038045
26056.70c	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311	0.619311
6000.70c	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086	0.095086
material densty (g/cm3)	3.950352	3.605026	3.368889	3.206905	3.098604	3.031354	2.997051	2.990355	3.007678	3.046566	3.105282	3.182502	3.277049

Table H-1 continued (2 of 2)

6-inch Pipe (pitch = 10.9 cm)				
material	31-93200	31-93210	31-93211	31-93212
total sphere volume (cm3)	651451	354812	165475	59350
total reflector box volume (cm3)	1262622	1161467	1063669	969179
MCNP ZAID.XS	Weight fraction			
1001.70c	0.026912	0.026912	0.026912	0.026912
1002.70c	0.000006	0.000006	0.000006	0.000006
8016.70c	0.305647	0.305647	0.305647	0.305647
8017.70c	0.000831	0.000831	0.000831	0.000831
26054.70c	0.027441	0.027441	0.027441	0.027441
26056.70c	0.446704	0.446704	0.446704	0.446704
6000.70c	0.192460	0.192460	0.192460	0.192460
material densty (g/cm3)	77.490031	58.711096	52.727601	52.053332

6 inch Pipe (pitch = 23.7 cm)											
material	31-9330	31-9331	31-9332	31-9333	31-9334	31-9335	31-9336	31-9337	31-9338	31-9339	31-9340
total sphere volume (cm3)	6688125	5134299	3841952	2786993	1945332	1292881	805547	459242	229875	93356	25595
total reflector box volume (cm3)	12957523	12475487	12000800	11533415	11073284	10620358	10174590	9735932	9304335	8879752	8462134
MCNP ZAID.XS	Weight fraction										
1001.70c	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912	0.026912
1002.70c	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006
8016.70c	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647	0.305647
8017.70c	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831	0.000831
26054.70c	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441	0.027441
26056.70c	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704	0.446704
6000.70c	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460	0.192460
material densty (g/cm3)	7.554098	6.451224	5.804697	5.414744	5.188420	5.077433	5.054907	5.105231	5.219004	5.390110	5.613634

Table H-2. Specification of Reflector Material for Case H-2

12-inch Pipe	pitch = 23.3 cm	pitch = 31.8 cm
material	31-930	31-931
total sphere volume (cm3)	1917066	4671360
total reflector box volume (cm3)	12312754	31289799
MCNP ZAID.XS	Weight fraction	
1001.70c	0.013296	0.013296
1002.70c	0.000003	0.000003
8016.70c	0.233625	0.233625
8017.70c	0.000635	0.000635
26054.70c	0.038045	0.038045
26056.70c	0.619311	0.619311
6000.70c	0.095086	0.095086
material densty (g/cm3)	6.508534	2.541873

6-inch Pipe	pitch = 10.9 cm	pitch = 23.7 cm
material	31-932	31-933
total sphere volume (cm3)	238386	2183767
total reflector box volume (cm3)	1262622	12957523
MCNP ZAID.XS	Weight fraction	
1001.70c	0.026912	0.026912
1002.70c	0.000006	0.000006
8016.70c	0.305647	0.305647
8017.70c	0.000831	0.000831
26054.70c	0.027441	0.027441
26056.70c	0.446704	0.446704
6000.70c	0.192460	0.192460
material densty (g/cm3)	46.239011	4.395834

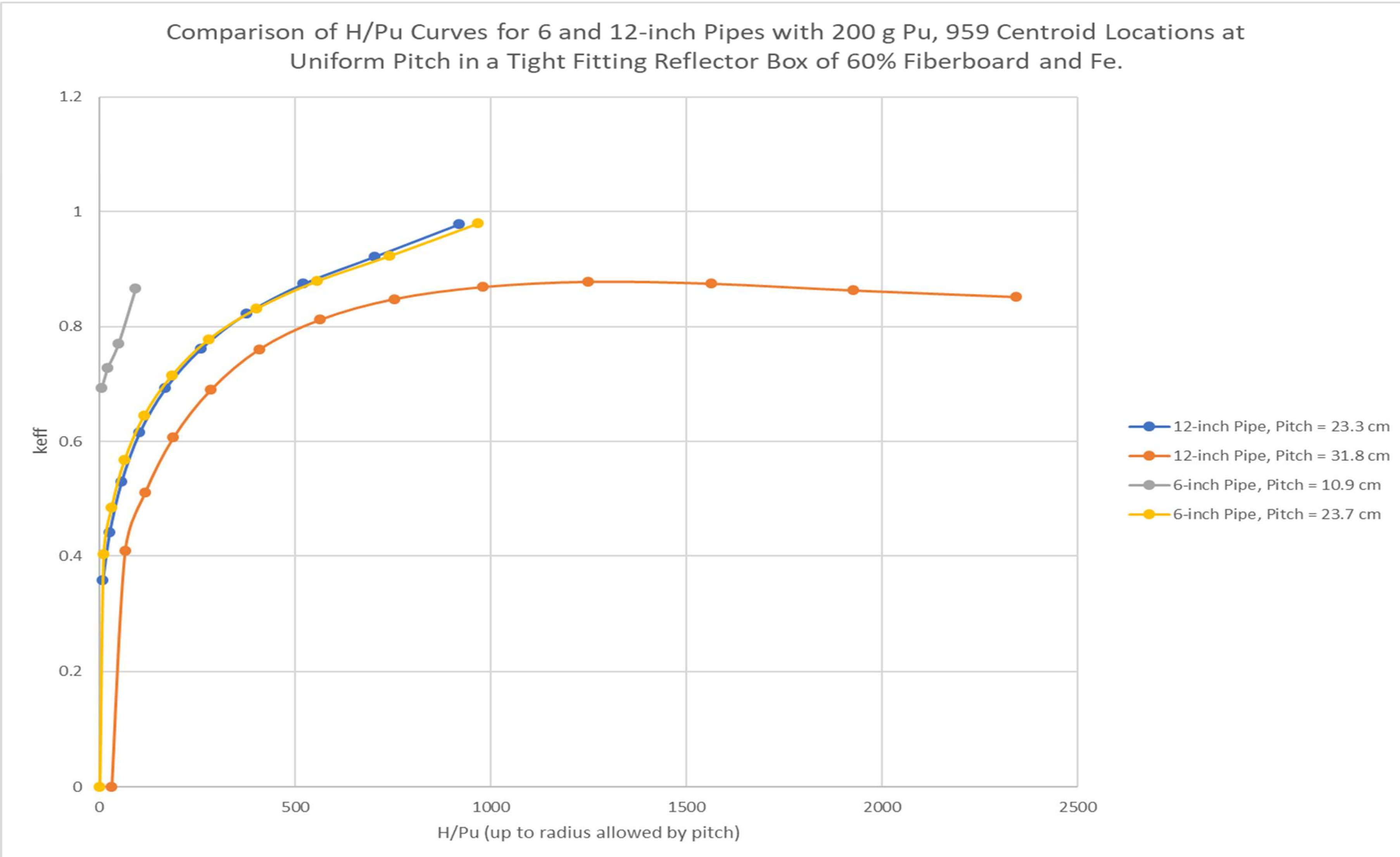


Figure H-1. Results for Case H-1

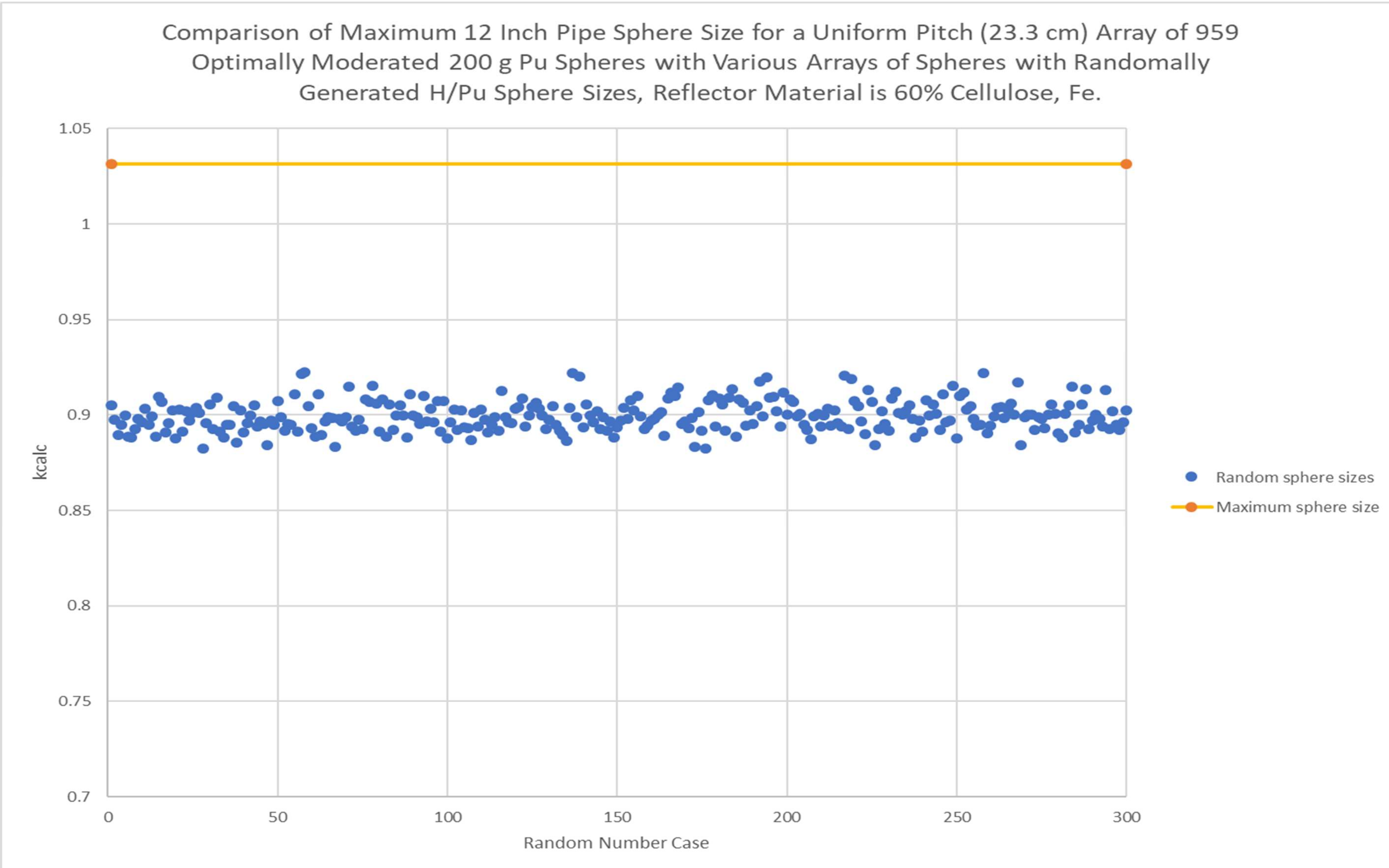


Figure H-2. Results for Case H-2 with 12-inch pipes and minimum nearest neighbor spacing.

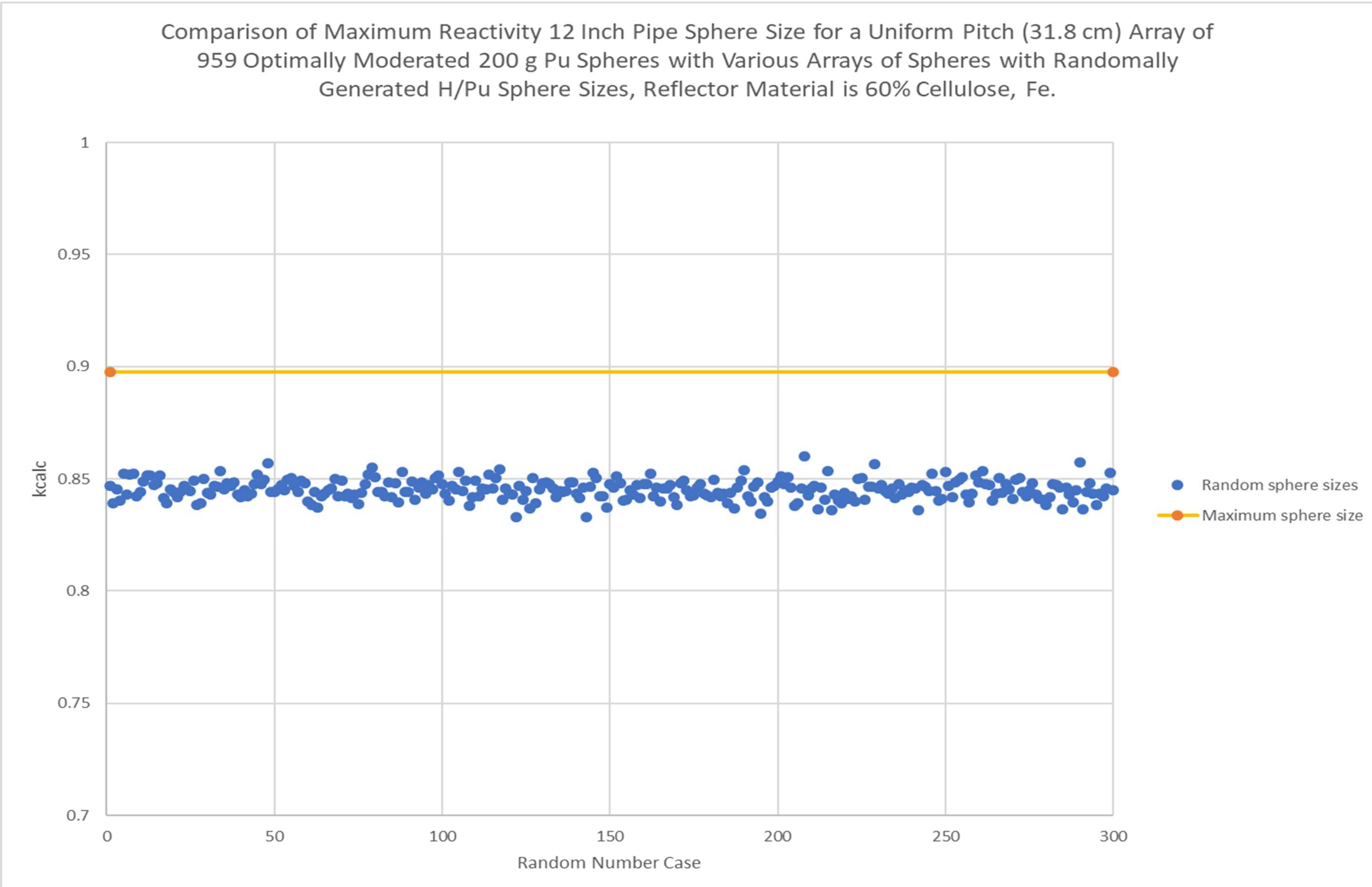


Figure H-3. Results for Case H-2 with 12-inch pipes and average nearest neighbor spacing.

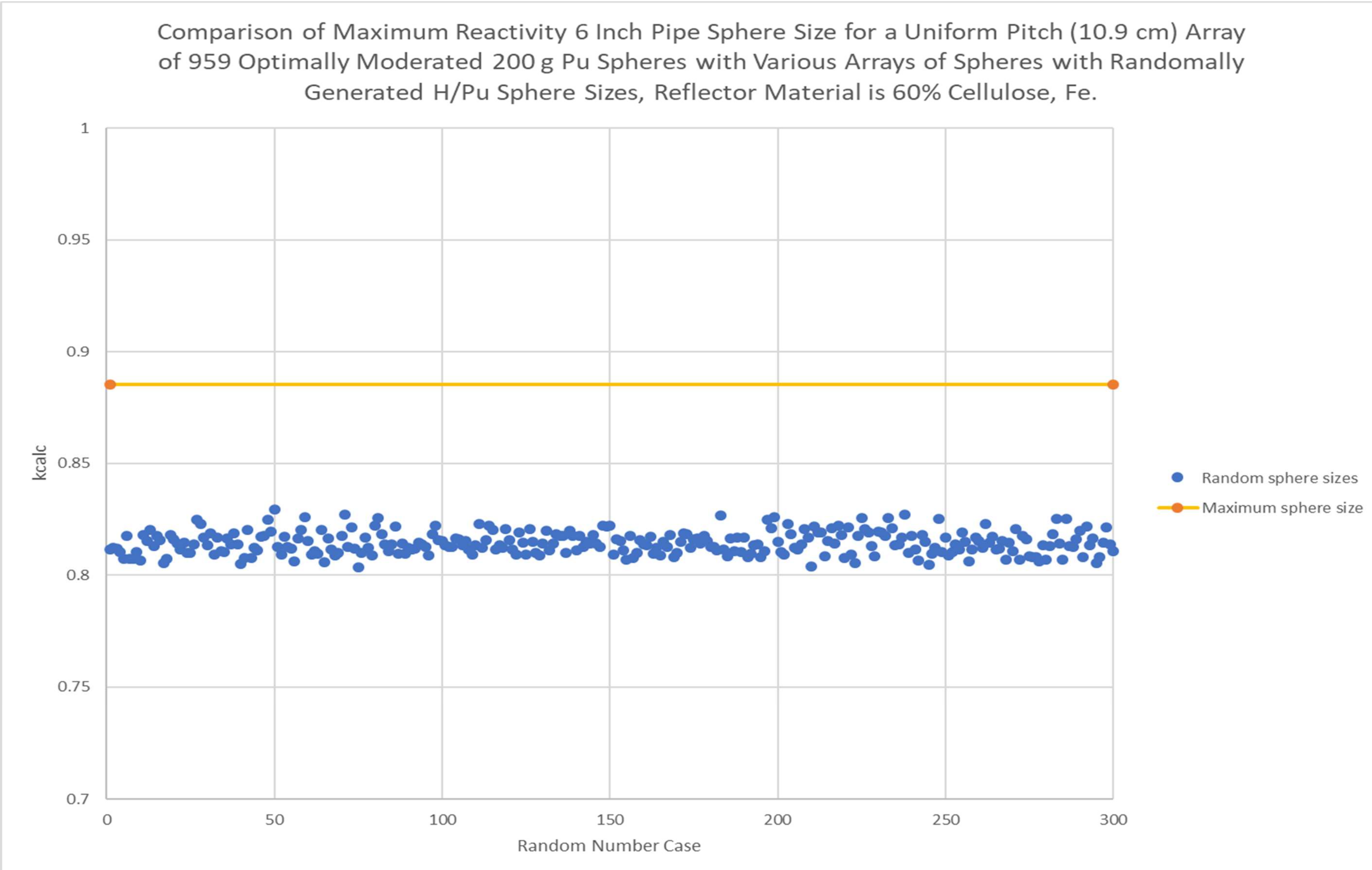


Figure H-4. Results for Case H-2 with 6-inch pipes and minimum nearest neighbor spacing.

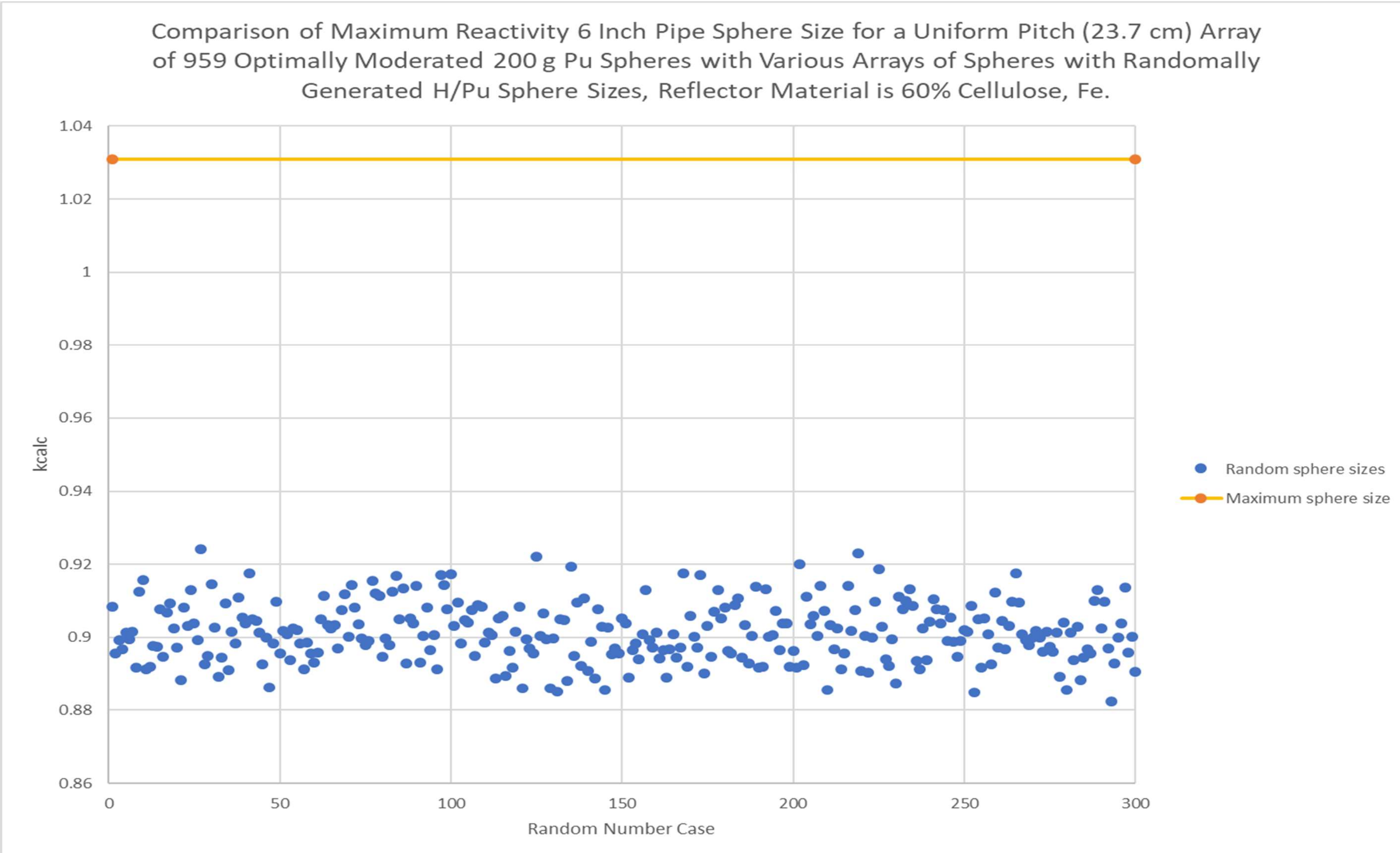


Figure H-5. Results for Case H-2 with 6-inch pipes and average nearest neighbor spacing.