ENERGYSOLUTIONS

CD07-0301

September 13, 2007

Mr. Scott C. Flanders, Director
Environmental and Performance Assessment Directorate
Division of Waste management and Environmental Protection
Mail Stop T7-J8
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Re: Response to Request for Additional Information Concerning Modifications to NRC Order Exempting Energy*Solutions* From 10 CFR 70 Licensing Requirements

Dear Mr. Flanders:

In a letter to the U.S. Nuclear Regulatory Commission (NRC), dated July 16, 2007 (CD07-0231), Energy*Solutions* committed to provide the NRC with a Clive site-specific criticality analysis. This was in response to a Request for Additional Information from the NRC. Please find enclosed a report titled "Clive Nuclear Criticality Safety Evaluation: Disposal of K-25 Piping."

Energy*Solutions* would also propose to meet with the NRC, in several weeks after NRC review of the enclosed report, to answer questions and provide clarification, as necessary.

Please call me at 1-801-649-2000 with any questions.

Sincerely,

Tye Rogers
Senior Vice President of Regulatory Affairs

Cc:
Mr. Dane L. Finerfrock, Director, Utah Division of Radiation Control

Enclosure

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Clive

Nuclear Criticality Safety Evaluation: Disposal of K-25 Piping

Parallax INC.

Parallax Contract Number 3036

Signature Page

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A. V. Pearson, NSA Author	9/12/07 Date
B. R. Kerr, Parallax Technical Reviewer	9/12/07 Date
R. J. Bentley, Parallax Nuclear Safety Manager	9/12/07 Date
R. D. Shaffer, Parallax President	9/12/07 Date
M. Ledoux, Energy*Solutions* Corporate Radiation Safety Officer	9-13-07 Date

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1 Introduction

The U.S. Department of Energy (DOE) is performing decontamination and decommissioning activities at the Gaseous Diffusion Plant in Oak Ridge, Tennessee. The K-25 building was originally designed and built to house a full-gradient cascade to yield high-enriched uranium. The cascade enriched the ^{235}U isotope of uranium by the gaseous diffusion process, which utilized uranyl hexafluoride (UF_6) as the process gas.

The K-25 building contains many pieces of equipment and several thousand linear feet of process gas piping. In order to prepare the building for demolition, DOE is performing several prerequisite activities to demonstrate criticality is incredible. These prerequisite activities include visual inspection of equipment and process gas piping, removal of equipment from the building, analyzing the equipment and piping with non-destructive analysis (NDA) techniques to ensure high risk areas are removed, and foaming internal voids to fix any residual ^{235}U and preclude water entry.

DOE has developed several Nuclear Criticality Safety Evaluation (NCSE) documents addressing all activities associated with preparing the building for demolition, and packaging, transporting, and disposal of the waste at the local DOE disposal site in Oak Ridge, Tennessee (Environmental Management Waste Management Facility). Energy*Solutions* has submitted several of these NCSE documents to the U.S. Nuclear Regulatory Commission (NRC) for review.

Energy*Solutions* proposes to receive and dispose of the process gas piping at its Clive, Utah disposal facility.

1.1 Scope

This NCSE documents the criticality safety basis for the waste disposal and burial operations at the Clive, Utah facility. This NCSE specifically covers the receipt, on-site handling, and disposal of process piping removed from the K-25 building in Oak Ridge, TN. This NCSE includes consideration of highly unlikely assumptions and multiple layers of conservatism. It presents them as normal and credible abnormal process conditions and assumptions, and provides process limits and controls to justify that a criticality accident during disposal and burial operations is incredible. This NCSE provides the technical justification and requirements to demonstrate compliance with the Double Contingency Principle for this process.

The process piping from K-25 that is to be disposed of at Clive ranges in size from 2-inches to 16-inches nominal diameter. The chemical form of uranium within the equipment and gas piping is conservatively assumed to be uranyl fluoride since this form is more reactive than other chemical forms of uranium. Pipes 3-inches and larger will be filled with polyurethane foam to fix any residual ^{235}U deposits and preclude water entry. This report evaluates uranium distributed throughout the interior of the piping such that the mass ratio of steel in the pipe to ^{235}U is greater than 2000:1.

Transportation of the piping from Building K-25 to Clive is covered in a separate NCSE.

2 Description

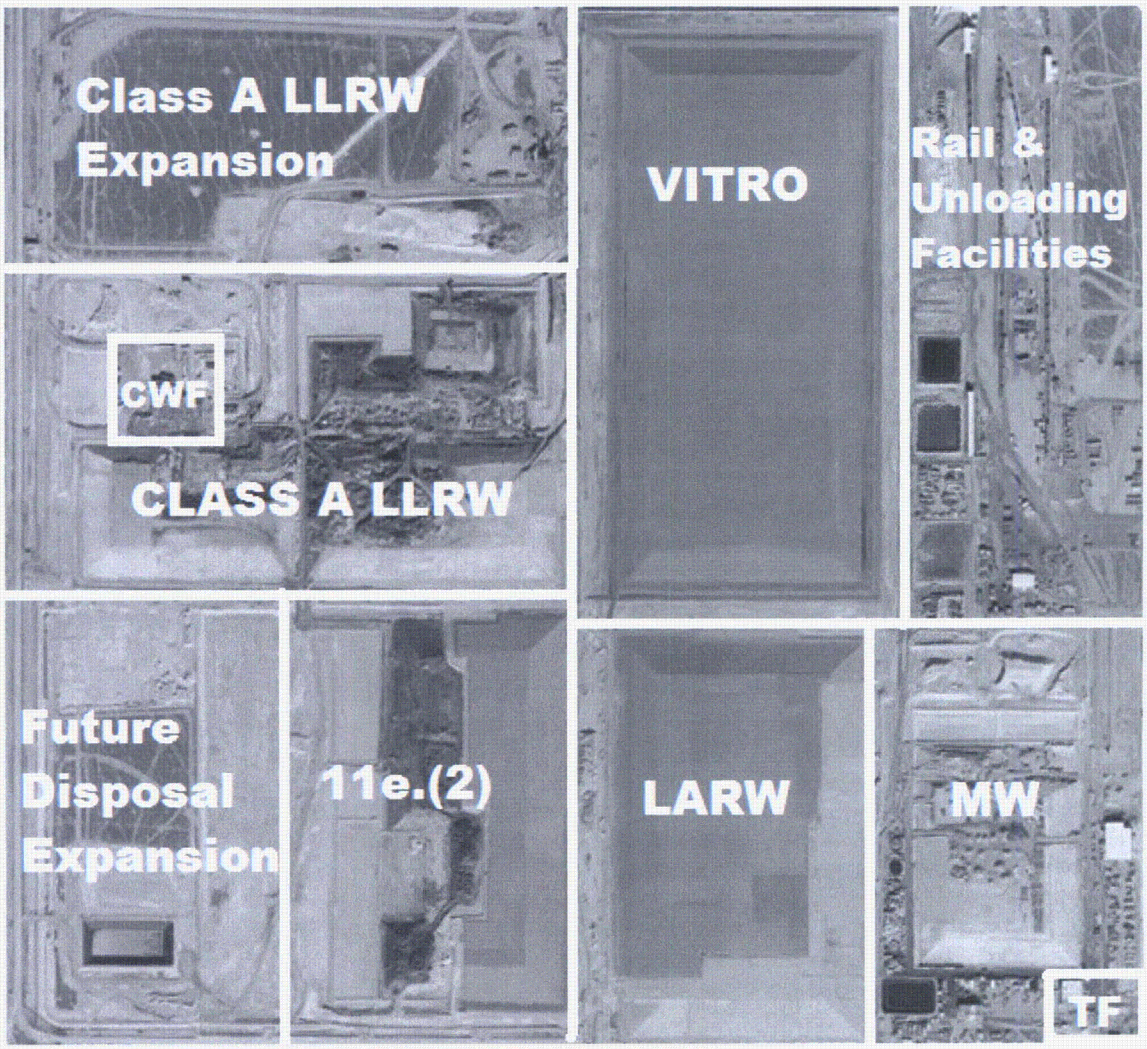
2.1 Clive Disposal and Treatment Facilities

The Clive site is located in Utah's West Desert approximately 75 miles west of Salt Lake City. The site's remote location, low precipitation, naturally poor groundwater, and low-permeability clay soils were some of the attractive qualities of the area. The disposal site is operated by Energy*Solutions*. The purpose of the Clive site is to provide a private disposal option for cleanups carried out across the country by the Environmental Protection Agency (EPA), DOE, Department of Defense, and private companies. Since 1988, Energy*Solutions*' Radioactive Material License (RML) has been amended several times, expanding the types of radioactive materials to include low-level radioactive waste (LLRW), in addition to Naturally Occurring Radioactive Materials (NORM).

Energy*Solutions* receives waste shipped via bulk truck, containerized truck, enclosed truck, bulk railcars, rail boxcars, and rail intermodals. Energy*Solutions* uses more than seven miles of track and three locomotives for railcar management. Covered railcar roll-over and covered railcar decontamination facilities allow for the efficient unloading, decontamination and return of rail shipments.

The locations of Energy*Solutions*' waste treatment, disposal, and operations areas are identified in Figure 2-1. Energy*Solutions*' waste operations are managed as three facilities: "Treatment Facility" (TF), "Bulk Waste Facility" (BWF), and "Containerized Waste Facility" (CWF).

Figure 2-1 Energy*Solutions*' Disposal and Treatment Facilities



2.1.1 Treatment Facility

Waste shipped to Energy*Solutions* for treatment or liquid solidification prior to disposal is managed at Energy*Solutions*' Treatment Facility. The Treatment Facility is shown in Figure 2-1 as "TF." The Treatment Facility is located within the Mixed Waste footprint. The facility is designed for radioactive waste that requires treatment for RCRA constituents and for liquid radioactive wastes requiring solidification prior to disposal. Currently, all waste processed at the Treatment Facility are disposed in the Mixed Waste disposal embankment. The Treatment Facility includes open and covered waste storage areas for storing, sampling, and staging Mixed Waste shipments.

EnergySolutions' treatment and solidification capabilities include the following:

- Chemical Stabilization, Neutralization, Deactivation, Oxidation, Reduction
- Macroencapsulation of hazardous debris or radioactive lead solids
- Debris Spray Washing
- Microencapsulation
- Thermal Treatment of Organics
- Mercury Treatment

2.1.2 Bulk Waste Facility

Waste shipped for direct disposal that is compliant with the ALARA Criteria described below is managed at Energy*Solutions*' "BWF by either removing the waste from the container or filling the container with a grout-like mixture to minimize void spaces. Waste that is removed from the shipping container is typically compacted into 24-inch waste lifts as shown in Figure 2-2. Waste that consists of debris items that do not have a dimension less than 10 inches is disposed of using grout in a different disposal area within the BWF. Waste is directly disposed at the Class A LLRW, Mixed Waste, or 11e.(2) disposal embankments. Bulk containers (e.g., intermodals, gondolas, etc.) and non-bulk containers (e.g., drums, boxes, etc.) are acceptable for receipt at the BWF.

The BWF includes the following disposal embankments and structures:

- Class A LLRW and NORM disposal embankment
- 11e.(2) Byproduct Material disposal embankment
- Mixed Waste disposal embankment for LDR compliant solid waste
- Intermodal unloading facility for unloading and staging bulk waste shipments for disposal
- Railcar Rollover facility for unloading and staging bulk waste shipments for disposal
- Rail Wash Facility for decontamination, surveying, and releasing of railcars
- Container Wash Facility for decontamination, surveying and releasing of bulk containers

2.1.3 Containerized Waste Facility

The Containerized Waste Facility (CWF) has been designed and constructed to handle disposal packages shipped in shielded casks with contact dose rates generally exceeding 200 mR/hr. Waste must be packaged in disposal containers (e.g., drums, boxes, liners, etc.) instead of bulk containers (e.g., intermodals, gondolas, etc.) for shipments to the CWF since Energy*Solutions* will not remove such waste from its container due to the elevated dose rates.

2.2 Description of Burial Process

The design and operation of the Energy*Solutions* disposal site provides a long-term disposal solution with a minimal need for active maintenance after closure. Energy*Solutions* uses an above-ground engineered disposal embankments. The design of these embankments is patterned after DOE and EPA specifications for the VITRO disposal embankment. Each licensed disposal embankment (Figure 2-2) meets or exceeds the applicable regulatory requirements.

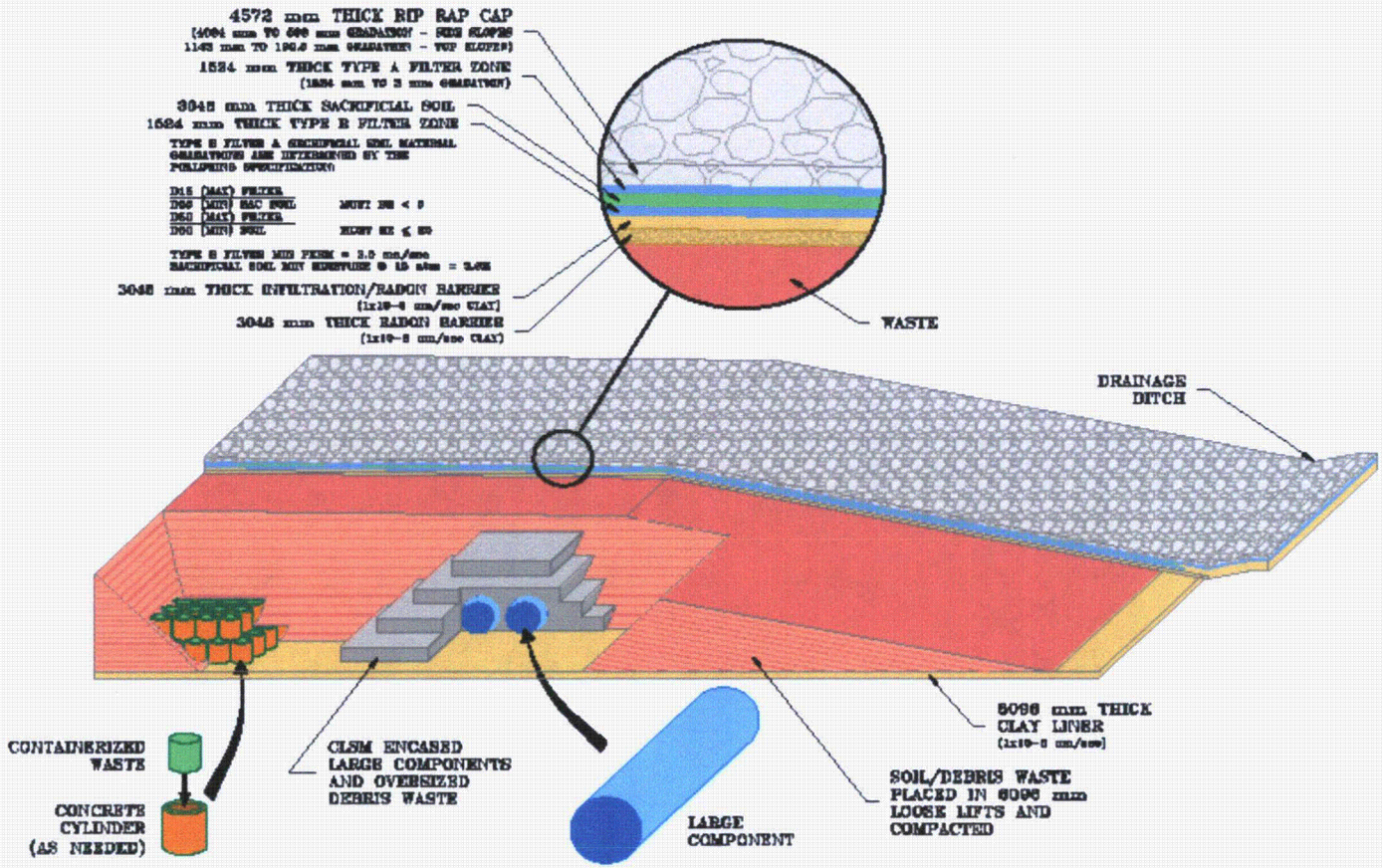


Figure 2-2 Disposal Embankment Diagram

Process piping in the K-25 building will be removed from their installed locations and transported to the Clive disposal facility. The piping is contaminated with uranyl fluoride compounds to some degree. This piping will be cut into smaller pieces and loaded into a transportation container.

The shipments of piping will meet applicable U.S. Department of Transportation (DOT) and DOE requirements. Piping will arrive at the Clive Site in gondola rail cars. Each gondola rail car is expected to contain less than 3 kg of ^{235}U.

The Clive Site will accept the process piping upon arrival based on certification that the waste meets the applicable Waste Acceptance Criteria (Reference 1). The process piping will be removed from the transportation container and placed into a disposal embankment.

During normal disposal operations, the waste will be mixed with soil or grout to minimize void spaces. Soil/debris waste is compacted in a series of lifts. Cover layers of clay, gravel, and rock are placed on top of the waste to provide long-term protection of the disposal embankment.

2.3 Description of K-25 Process Equipment to be Buried

The K-25 building was analyzed by Bechtel Jacobs Company LLC (BJC) using non-destructive assay (NDA) techniques to determine the location of any potential uranium deposits and quantities. Each component potentially exposed to uranium hexafluoride (UF_6) gas was scanned using NDA to determine if a measurable quantity of uranium was deposited within.

2.3.1 Fissile Material of Concern

The diffusion plants used UF_6, a compound of uranium and fluorine, as the process gas to increase the concentration of ^{235}U in the uranium up to 92 wt % ^{235}U. The properties of UF_6 are ideal for use in the diffusion process. Uranium hexafluoride can be a solid, liquid, or gas, depending on its temperature and pressure. At atmospheric pressure (14.7 psia); UF_6 can only be a solid or a gas regardless of temperature. Solid UF_6 is a nearly white, dense, crystalline material that resembles rock salt (Reference 2).

Uranium hexafluoride does not react with oxygen, nitrogen, carbon dioxide, or dry air. Gaseous UF_6 and the exposed surface of solid UF_6 do react rapidly with water vapor. At room temperature, depending upon the relative humidity of the air, the products of this reaction are uranyl fluoride (UO_2F_2) hydrides and HF-H_2O fog, which appear as a white cloud. The UF_6 compound reacts with moisture in the air to form UO_2F_2 and HF gas through the following equations:

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF + \text{heat}$$

The UO_2F_2 is water-soluble. It is possible to have other uranyl fluoride compounds as the result of other reactions with the UF_6. However, the predominant chemical reaction is the conversion of UF_6 to UO_2F_2. The HF-H_2O compound in liquid form is a hydrofluoric acid.

Uranium deposits in the K-25 building are expected to exist in either thin films distributed throughout the interior of process equipment or in concentrated areas. Bulk deposits may be present in pipes and equipment as a result of a large humid air leak into the process gas over a relatively short period of time (e.g., hours) or a small humid air leak into the process gas over a relatively long period of time (e.g., days). Uranium deposited in process gas piping or equipment as a film is expected to be a thin layer less than 0.05-cm thick (Reference 3). BNFL experience during D&D of the K-29, K-31, and K-33 buildings was that piping had at most a thin film of uranium visible as a slight discoloration of the pipe wall. The minimum estimated thickness for discoloration is 0.02 cm (Reference 3). A long section of pipe with a uniform film 0.02-cm thick would be atypical. Not all of the pipe and equipment in the K-25 building will have a film thickness of as much as 0.02 cm. This would result in many more kilograms of uranium than are known or expected to exist in the building. However, some limited areas may have films that meet or exceed 0.02-cm thickness.

The formation of UO_2F_2 could take place anywhere in the enrichment process, so that the uranyl fluoride film on the pipes can contain enrichment ranging from natural uranium (0.71 wt% ^{235}U) up to highly enriched uranium (92 wt% ^{235}U).

2.3.2 Foam Material

Prerequisite activities for removal of piping from K-25 include visual inspection and foaming, which will fix any residual ^{235}U deposits and preclude water entry (Reference 4). The visual inspection and foaming will only be performed on PGE&P that has greater than 3 in. nominal outer diameter (OD). The term 'deposit' is used throughout this document to signify any amount of uranium, regardless of size.

Polyurethane foam is an isocyanate/resin-based foam composed of carbon (69.6 wt.%), oxygen (10.2 wt.%), hydrogen (8.5 wt.%), nitrogen (5.5 wt.%), fluorine (4.5 wt.%), chlorine (1.2 wt.%), and phosphorus (0.5 wt.%) (Reference 3). Polyurethane foam is formed when isocyanate and resin components are combined prior to foam application. The isocyanate component has a density of about 77 lb/ft^3 (1.24 g/cm^3). The resin component density is about 72 lb/ft^3 (1.157 g/cm^3). Before the foam rises, the mixture density will be the average of the density of the two components, or about 75 lb/ft^3 (1.2 g/cm^3). After expansion, this foam has a density that can vary from 2-5 lb/ft^3 (0.032-0.080 g/cm^3). The density requested by the K-25 Project, 2 lb/ft^3 (0.032 g/cm^3).

2.3.3 Process Pipe

The K-25 building contains miles of process piping used to connect converters to compressors within a stage, stages within a cell, cells within a unit, and units within buildings.

The UF_6 process pipe diameters range from 2 inches up to 16 inches. Piping larger than 4-inch diameter was fabricated with ASTM A-53 steel. This pipe was also plated with nickel. Smaller-diameter piping was fabricated with Monel. The single most common pipe size in the facility is 6-inch, Schedule 40 pipe. Process piping greater than 3 inches diameter will be filled with polyurethane foam prior to removal from K-25 to prevent

moderator intrusion into the piping. The use of foam is intended to limit or preclude migration of ^{235}U during demolition activities.

Sections of piping that were determined to contain uranium deposits by scanning were measured using NDA to qualify the deposit.

3 Requirements Documentation

This NCSE is prepared in accordance with 10CFR70.61 (Reference 5) and applicable American National Standards Institute standards. DOE Standard 3007-2007 (Reference 6) is used for guidance in developing the format for this NCSE. Guidance on the implementation of regulatory orders and standards was taken form the Parallax Criticality Safety Methods Manual (Reference 7).

4 Methodology

4.1 Computer Codes

Criticality calculations for the disposal of K-25 Piping at the Clive Site were performed using the MCNP Monte-Carlo computer code [8, 9, 10]. MCNP is a general-purpose Monte Carlo N–Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori.

Pointwise cross-section data are used. For neutrons, all reactions given in a particular cross-section evaluation (such as ENDF/B-VI) are accounted for. Thermal neutrons are described by both the free gas and $S(\alpha,\beta)$ models

4.2 Validation

The validation for the criticality safety code, MCNP version 5 installed on the Parallax Criticality Safety Linux System (S/N: SD039P20000716F00375 and SD039P20000716F00361) is documented in two technical reports. The first, NSA-TR-07-07 (Reference 11), documents the benchmark experiments selected for the validation and the calculation results. The second document, NSA-TR-07-08 (Reference 12), discusses the development of the Upper Subcritical Limit (USL).

The USL includes a 0.05 Margin of Subcriticality (MOS) and a bias and bias uncertainty (σ_B) of 0.0160. The analyzed system k_{eff} is determined to be acceptable if:

$$k_s + 2\sigma_s \leq 0.9340$$

Where:

$k_s = k_{eff}$ from MCNP 5, and

σ_s = the standard deviation in k_{eff} from MCNP 5

The USL developed in Reference 12 is appropriate for homogeneous systems. Calculations for this analysis were performed on the Parallax Criticality Safety Linux System (S/N: SD039P20000716F00375 and SD039P20000716F00361) using cross-section data from the default MCNP library, primarily the ENDF/B-VI library. The actual nuclide sets used are listed in Table 4-2.

Table 4-1 Validation Parameter Range

Parameter	AOA from Experiments	Situation Analyzed	Discussion
Fissile Material	UO_2, U_3O_8, UF_4, UH_3, UO_2F_2, $UO_2(NO_3)_2$	UO_2F_2	Same Material
Fissile Material Form	Solid and Solution	Solid and Solution	Same Form
$H/^{235}U$ ratio	$0.07 \leq H/^{235}U \leq 1437.51$	0 to 1352	The cases with $H/^{235}U$ ratio of 0 are for pure dry UO_2F_2 and do not challenge the USL
Average Neutron Energy Causing Fission (MeV)	0.006 < ANECF < 0.800	0.001 < ANECF < 0.994	The cases with ANECF > 0.8 are mixtures of UO_2F_2 with small amounts of concrete or steel and do not challenge the USL
Enrichment	2 to 93 wt.% ^{235}U	100 wt.% ^{235}U	The enrichment is acceptably close to the evaluated range.
Moderating Materials	Water, Plexiglas, Paraffin, Fluorine, Polyethylene, Hydrogen, HNO_3	Water	Same Material
Reflecting Materials	Water, Plexiglas, Paraffin, Polyethylene, Concrete, Depleted Uranium Unreflected	Water and Concrete	Same Material
Absorber Materials	Aluminum, Steel, Stainless Steel, Boral, Teflon	Steel	Same Material
Geometry	Sphere, Cylinder, Cuboid, and Arrays	Sphere, Cylinder, and Arrays	Same Geometry

Table 4-2 Cross-Section Libraries Used

Element/ Isotope	Cross-Section Set ID	Temperature	Source
H-1	1001.62c	293.6K	ENDF-VI.8
C-nat	6000.66c	293.6K	ENDF-VI.6
N-14	7014.62c	293.6K	ENDF-VI.8
O-16	8016.62c	293.6K	ENDF-VI.8
F-19	9019.62c	293.6K	ENDF/B-VI.8
Na-23	11023.62c	293.6K	ENDF-VI.8
Al-27	13027.62c	293.6K	ENDF-VI.8
Si-nat	14000.60c		ENDF/B-VI
S-32	16032.62c	293.6K	ENDF/B-VI.8
Cl-nat	17000.66c	293.6K	ENDF-VI.0
P-nat	19000.62c	293.6K	ENDF/B-VI.8
Ca-nat	20000.62c	293.6K	ENDF-VI.8
Fe-54	26054.62c	293.6K	ENDF-VI.8
Fe-56	26056.62c	293.6K	ENDF-VI.8
Fe-57	26057.62c	293.6K	ENDF-VI.8
Fe-58	26058.62c	293.6K	ENDF-VI.8
U-235	92235.69c	293.6K	T16 u235la9d
U-238	92238.69c	293.6K	T16 u238la8h

4.3 Model Development

Detailed MCNP 5 models were developed to investigate the effect of various postulated scenarios on k_{eff}. The techniques used to develop these models are discussed in this section.

4.3.1 Mixture Density for Hydrated Uranyl Fluoride Complexes

The mixture density for hydrated uranyl fluoride complexes required for NCS calculations can be calculated by summing the densities of the individual elements (BNFL NCSE-208, Reference 13):

$$\rho_{Mixture}^{UO2F2} = \rho_U + \rho_H + \rho_F + \rho_O \qquad [1]$$

Where

ρ_U = Uranium Density

ρ_H = Hydrogen Density

ρ_F = Fluorine Density

ρ_O = Oxygen Density

The uranium density in the H-to-U range between 0 and 22.0 inclusive can be calculated from the predictive correlation presented above via the expression

$$\rho_U = \sum_{k=1}^{9} C_k \left(\frac{H}{U}\right)^{k-1} \qquad [2]$$

Where

C_1 = 4.8594728

C_2 = -0.68305026

C_3 = 0.057656201

C_4 = 0.0076415799

C_5 = -0.0027107264

C_6 = 0.00030087457

C_7 =-0.000016492638

C_8 = 0.00000045275879

C_9 =-0.0000000049768561

For the solution phase (i.e. H-to-U > 22) the uranium density can be computed from the expression:

$$\rho_U = \frac{MW_U}{9.0(\frac{H}{U}) - 1.128 * MW_U + MW_{UO2F2}} \qquad [3]$$

Once the uranium density is known, then the densities of the other components can be computed from the relationships:

$$\rho_H = \rho_U \left(\frac{H}{U}\right)\left(\frac{AW_H}{MW_U}\right) \qquad [4]$$

$$\rho_O = \left(2.0 + 0.5(\frac{H}{U})\right)\rho_U \left(\frac{AW_O}{MW_U}\right) \qquad [5]$$

And

$$\rho_F = 2.0\rho_U\left(\frac{AW_F}{MW_U}\right) \qquad [6]$$

Where

AW_x is the atomic weight of hydrogen, oxygen, and fluorine, and

MW_U represents the molecular weight of uranium.

For this analysis, the atomic weights are taken from the sixteenth edition of the Chart of Nuclides (Reference 14).

The UO_2F_2-water mixture is modeled at an enrichment of 100 wt% ^{235}U.

4.3.2 Mixing Fissile Material

Piping will arrive at the Clive Site in gondola rail cars. The contents of each gondola will be disposed of in one or more separate areas or disposal embankments. In the course of time it can not be guaranteed that the original configuration will be maintained. Some material may combine into a single mass of fissile material mixed with other material in the disposal embankment or geologic formation. A study of the effect of combining the material from adjacent embankmentss was performed assuming that the combining material is CLSM, salt, steel, dry sand, or polyurethane foam. The parameters of the combined sphere are calculated as:

$$\begin{aligned} frac_j &= \frac{\rho_j}{\rho^{mix}} \\ \rho_j &= wf_j^{UO2F2} Vf^{UO2F2} \rho^{UO2F2} + wf_j^{mat} Vf^{mat} \rho^{mat} \\ \rho^{mix} &= Vf^{UO2F2} \rho^{UO2F2} + Vf^{mat} \rho^{mat} \end{aligned} \qquad [7]$$

Where:

$frac_j$ is the weight fraction of constituent "j" in the mixed material

ρ_j is the partial density of constituent "j" in the mixed material

wf_j^{UO2F2} is the weight fraction of constituent "j" in UO_2F_2

Vf^{UO2F2} is the volume fraction of UO_2F_2

ρ^{UO2F2} is the density of UO_2F_2

wf_j^{mat} is the weight fraction of constituent "j" in the mixing material (e.g., CLSM)

Vf^{mat} is the volume fraction of the mixing material ($1 - Vf^{UO2F2}$)

ρ^{mat} is the density of the mixing material

ρ^{mix} is the density of the mixed material

The radius of the sphere of mixed material is calculated as:

$$r = \sqrt[3]{\frac{3V}{4\pi}} \qquad [8]$$

The volume of the material in the sphere (V) is calculated as:

$$V = \frac{M_{U-235}}{\rho_{U-235}} \qquad [9]$$

$$\rho_{U-235} = E_{U-235}\rho_U \qquad [10]$$

Where:

M_{U-235} is the mass of ^{235}U

ρ_{U-235} is the partial density of ^{235}U in the mixed material

ρ_U is the partial density of U, calculated using either equation 2 or 3 as appropriate

E_{U-235} is the enrichment of ^{235}U

The spheres are surrounded by a four foot thick consolidated low strength material (CLSM) reflector. The radii of the spheres are listed in Table 4-3 for UO_2F_2 mixed with CLSM; and in Table 4-4 for UO_2F_2 mixed with sand, steel or foam. The model used is shown in Figures 4-1and 4-2.

Table 4-3 Sphere Radius (CLSM)

v/o UO_2F_2	Radius (cm)						
	1 kg[1]	2 kg	3 kg	4 kg	5 kg	6 kg	7 kg
0.1	36.6247	46.1442	52.8220	58.1381	62.6274	66.5515	70.06053
0.2	29.0690	36.6247	41.9248	46.1442	49.7074	52.8220	55.60708
0.5	21.4183	26.9853	30.8905	33.9994	36.6247	38.9196	40.97165
1	16.9997	21.4183	24.5178	26.9853	29.0690	30.8905	32.51922
2	13.4927	16.9997	19.4598	21.4183	23.0721	24.5178	25.81052
5	9.9415	12.5255	14.3381	15.7811	16.9997	18.0649	19.01735
10	7.8906	9.9415	11.3801	12.5255	13.4927	14.3381	15.09408
20	6.2627	7.8906	9.0324	9.9415	10.7091	11.3801	11.98018
50	4.6144	5.8138	6.6551	7.3249	7.8906	8.3850	8.827074
100	3.6625	4.6144	5.2822	5.8138	6.2627	6.6551	7.006053

[1] Mass of ^{235}U in Sphere

Table 4-4 Sphere Radius (Sand, Steel, and Foam)

v/o UO_2F_2	Radius (cm)								
	1.01 kg[2]	4.03 kg	12.6 kg	25.2 kg	30.2 kg	35 kg	40 kg	45 kg	50 kg
0.1	36.7221	58.2927	85.2245	107.3761	114.1041	119.8018	125.2547	130.2702	134.9265
0.5	21.4752	34.0898	49.8396	62.7939	66.7285	70.0605	73.2494	76.1824	78.9055
1	17.0449	27.0571	39.5577	49.8396	52.9624	55.6071	58.1381	60.4660	62.6274
2	13.5285	21.4752	31.3970	39.5577	42.0363	44.1354	46.1442	47.9919	49.7074
3	11.8183	18.7603	27.4278	34.5568	36.7221	38.5558	40.3107	41.9248	43.4234
4	10.7376	17.0449	24.9198	31.3970	33.3642	35.0303	36.6247	38.0912	39.4528
5	9.9679	15.8231	23.1335	29.1464	30.9726	32.5192	33.9994	35.3608	36.6247
6	9.3802	14.8901	21.7694	27.4278	29.1464	30.6018	31.9946	33.2757	34.4652
7	8.9104	14.1443	20.6791	26.0540	27.6865	29.0690	30.3921	31.6091	32.7389
8	8.5224	13.5285	19.7788	24.9198	26.4812	27.8035	29.0690	30.2330	31.3137
9	8.1943	13.0077	19.0174	23.9604	25.4617	26.7331	27.9499	29.0690	30.1081
10	7.9115	12.5588	18.3611	23.1335	24.5830	25.8105	26.9853	28.0659	29.0690
20	6.2794	9.9679	14.5732	18.3611	19.5115	20.4858	21.4183	22.2759	23.0721
30	5.4856	8.7078	12.7308	16.0399	17.0449	17.8960	18.7106	19.4598	20.1553
40	4.9840	7.9115	11.5667	14.5732	15.4863	16.2596	16.9997	17.6804	18.3124
50	4.6267	7.3444	10.7376	13.5285	14.3762	15.0941	15.7811	16.4130	16.9997
60	4.3539	6.9114	10.1045	12.7308	13.5285	14.2041	14.8506	15.4452	15.9973
70	4.1358	6.5652	9.5984	12.0932	12.8510	13.4927	14.1068	14.6716	15.1961
80	3.9558	6.2794	9.1805	11.5667	12.2915	12.9053	13.4927	14.0329	14.5345
90	3.8035	6.0376	8.8271	11.1214	11.8183	12.4084	12.9732	13.4927	13.9749
100	3.6722	5.8293	8.5224	10.7376	11.4104	11.9802	12.5255	13.0270	13.4927

[2] Mass of ^{235}U in Sphere

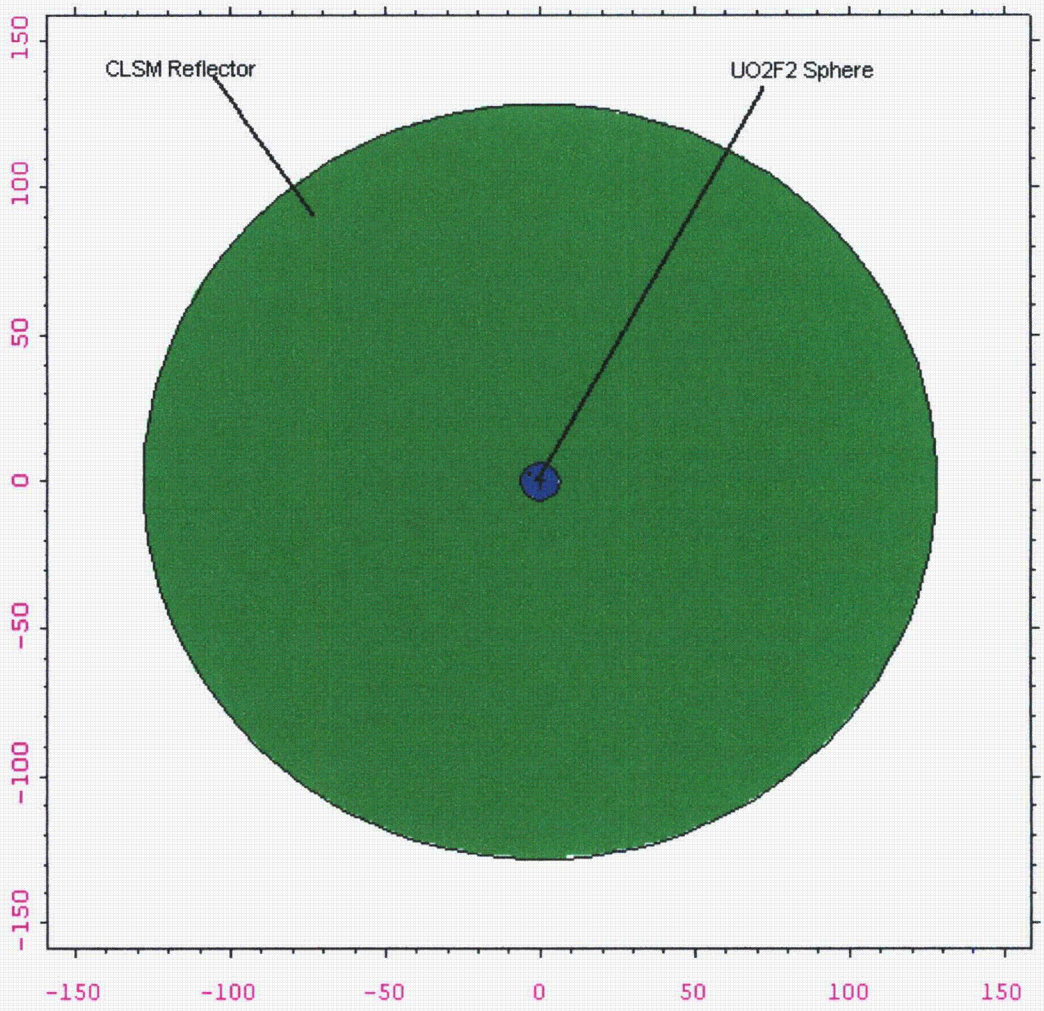


Figure 4-1 CLSM Reflected 5 kg UO_2F_2 Sphere

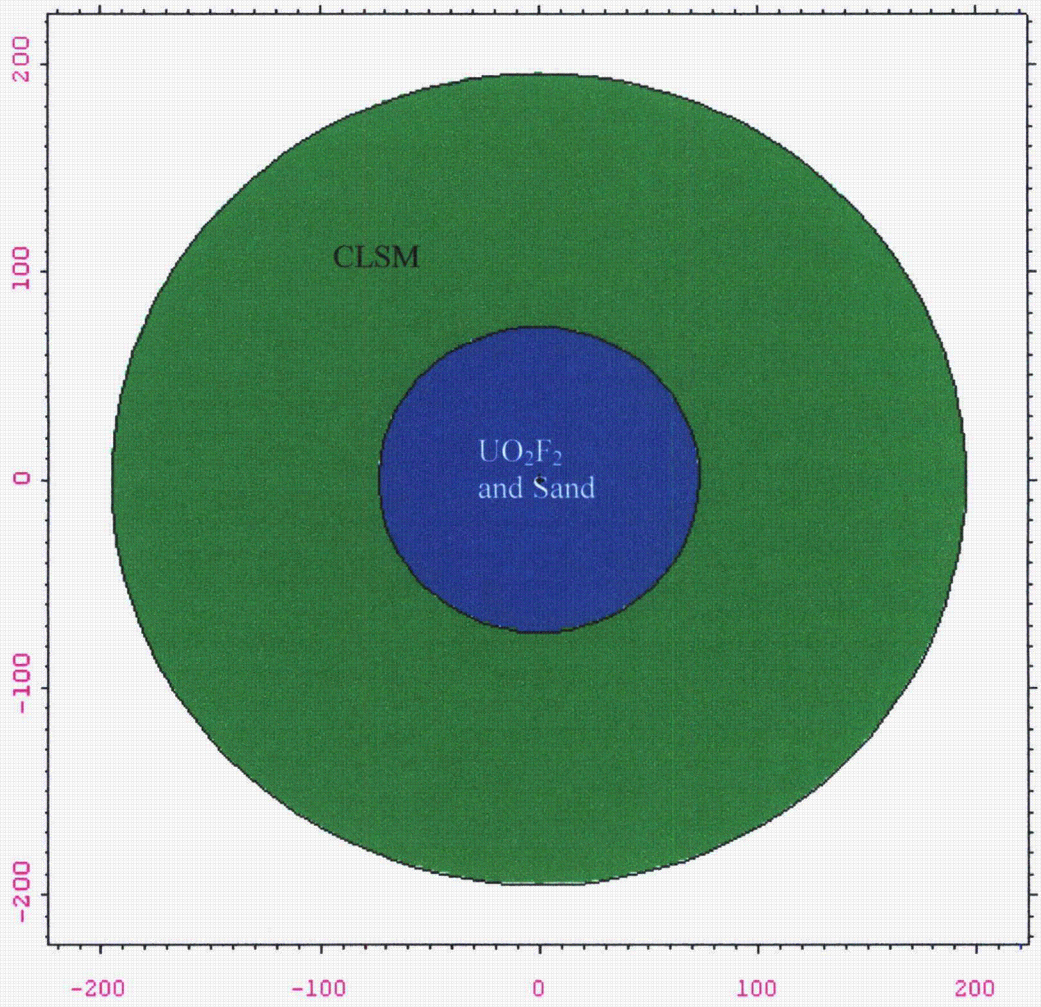


Figure 4-2 99.5 v/o Sand and UO_2F_2 Sphere Reflected by CLSM

4.3.3 Solutions of UO_2F_2

Solutions of UO_2F_2 are not expected to occur during normal operation of the Clive Site due to the precipitation rate being much lower than the evaporation rate. However, there is a ground water aquifer approximately 30 feet below the bottom surface of the burial region. In the course of time it can not be guaranteed that the original configuration will be maintained.

In order for the uranium to reconcentrate in the disposal embankment, the uranium would need to be mobilized in water. The uranium would then need to be immobilized at some point to reconcentrate. If the uranium remains in solution and mobile, its concentration does not increase and there is no increased likelihood of a criticality accident. Notwithstanding the extremely low probability of reconcentration of uranyl fluoride, a study of k_{eff} as a function of UO_2F_2 concentration (in terms of g/l of solution) was performed.

Using the equations from Section 4.3.1, the mixture density for hydrated uranyl fluoride complexes can be calculated by summing the densities of the individual elements:

The density of UO_2F_2 in the solution is:

$$\rho_{Solution}^{UO2F2} = \rho_U + \rho_F + \rho_{UO2F2}^{O} \qquad [11]$$

Where

ρ_{UO2F2}^{O} is the density of O in UO_2F_2 (not including the O from water of hydration is calculated as

$$\rho_{UO2F2}^{O} = 2\rho_U\left(\frac{AW_O}{MW_U}\right) \qquad [12]$$

Then, substituting equations 5, and 7 into equation 6 we get:

$$\rho_{Solution}^{UO2F2} = \rho_U + 2\rho_U\left(\frac{AWF}{MW_U}\right) + 2\rho_U\left(\frac{AW_O}{MW_U}\right) \qquad [13]$$

Factoring out ρ_U and substituting equation 2 into equation 8 yields:

$$\rho_{Solution}^{UO2F2} = \frac{MW_{UO2F2}}{9.0(\frac{H}{U}) - 1.128 * MW_U + MW_{UO2F2}} \qquad [14]$$

Solving for $\frac{H}{U}$

$$\left(\frac{H}{U}\right) = \frac{\frac{MW_{UO2F2}}{\rho_{Solution}^{UO2F2}} + 1.128 * MW_U - MW_{UO2F2}}{9.0} \qquad [15]$$

Equation 10 can then be used together with equations 1 through 5 to calculate the densities for all the constituents given a density of UO_2F_2 in the solution.

4.3.4 Arrays of Pipes

Piping will arrive at the Clive Site in gondola rail cars. Each gondola rail car is expected to contain less than 3 kg of ^{235}U based on an expected uranium activity level of 150 pCi/g. The uranium content is calculated as:

$$\begin{aligned} \hat{M}_U &= \frac{a_U}{sa_U}\hat{M}_{St} \\ &= \frac{a_U}{sa_U}\pi\rho_{St}\left(r_0^2 - r_i^2\right) \end{aligned} \qquad [16]$$

Where:

$\hat{M}_U$	is the mass of uranium per cm of pipe (g-U/cm)
$\hat{M}_{St}$	is the mass of steel per cm of pipe (g-steel/cm)
a_U	is the activity of uranium on the pipe (pCi/g-steel)
sa_U	is the specific activity of uranium (2.164 E6 pCi/g-U)
ρ_{St}	is the density of steel (7.86 g/cc)
r_o	is the outer radius of the pipe (cm)
r_i	is the inner radius of the pipe (cm)

The uranium is modeled as a thin layer of UO_2F_2 on the inside of the pipe. The radius of the layer is calculated as:

$$\begin{aligned} \hat{M}_U &= \pi\rho_U\left(r_i^2 - r_c^2\right) \\ r_c &= \sqrt{\left(r_i^2 - \frac{\hat{M}_U}{\pi\rho_U}\right)} \end{aligned} \qquad [17]$$

Where:

ρ_U	is the partial density of uranium in UO_2F_2 calculated using equation 2
r_c	is the inner radius of the coating (cm)

Substituting equation 16 into equation 17 yields:

$$r_c = \sqrt{\left(r_i^2 - \frac{a_U}{sa_U}\frac{\rho_{St}\left(r_0^2 - r_i^2\right)}{\rho_U}\right)} \qquad [18]$$

The pipe dimensions are listed in Table 4-5 and the coating thickness values are listed in Table 4-6.

Table 4-5 Pipe Dimensions

Pipe Size	Pipe OD (in)	Wall t (in)	Pipe IR (cm)	Pipe OR (cm)
2	2.375	0.154	2.625	3.01625
3	3.5	0.216	3.896	4.445
6	6.625	0.28	7.703	8.41375
8	8.625	0.322	10.136	10.95375
16	16	0.5	19.050	20.32

Note: Pipe dimensions from Reference 15.

Table 4-6 Coating Radius

Pipe	Steel	Uranium Mass (g/cm)		Coating IR (cm) – H/U = 0		Coating IR (cm) – H/U = 4	
Size[3]	gm/cm	150	1100	150	1100	150	1100
2	54.489037	0.003777	0.027698	2.624156	2.618235	2.624046	2.617424
3	113.00476	0.007833	0.057442	3.895055	3.886782	3.894901	3.885649
6	283.02807	0.019618	0.143868	7.700897	7.690421	7.700702	7.688987
8	425.92268	0.029523	0.216504	10.13398	10.122	10.13376	10.12036
16	1234.6434	0.085581	0.627591	19.04708	19.02861	19.04674	19.02608
			ρ_U	0.770557		0.689171	

The pipes are modeled as an array 9' 3¼" wide by 11' 5" high by 62' 8¼" long (roughly the size of a gondola rail car) to bound any possible waste disposal arrangement. The array is modeled with and without foam inside the pipes. Flooded and dry configurations are analyzed. A cross-sectional view of the pipe model for 16 inch pipes is shown in Figure 4-3 which shows the array as modeled in MCNP. The array contains fractions of a pipe to fill the cross-section of the rail car. This model is conservative since it includes extra fissile material in the array that can not be physically present in the rail car.

[3] Nominal pipe diameter in inches.

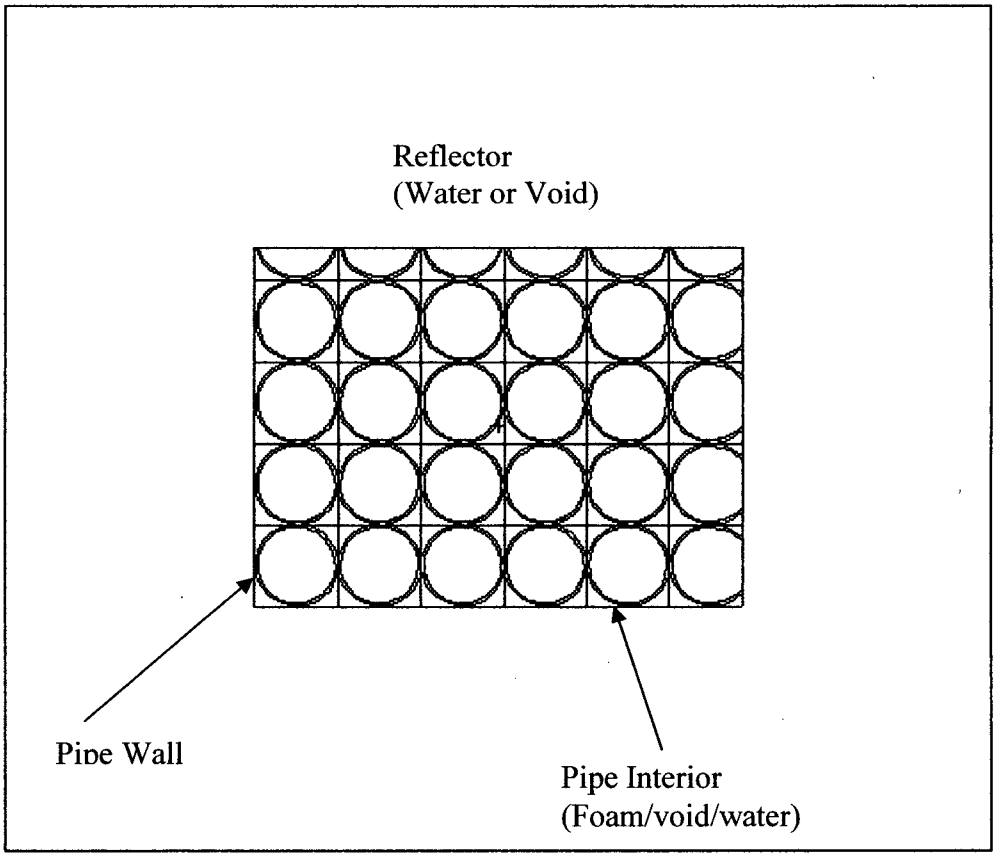


Figure 4-3 Array of 16 Inch Pipes

5 Discussion of Contingencies

Material from the K-25 Gaseous Diffusion Plant will arrive at the Clive Site in gondola rail cars. The material is stainless steel piping with surface contamination of UO_2F_2. Pipes larger than 3 inches in diameter are filled with polyurethane foam to prevent migration of the UO_2F_2 and to prevent infiltration of water.

Uranium deposits in the K-25 building are expected to exist in either thin films distributed throughout the interior of process equipment or in concentrated areas (such as areas near seal failures, where large quantities of humid air could have come in contact with the UF_6 process gas stream).

It is expected that the uranium will remain with the pipe during normal operations. However, over a geologic time scale (many thousands of years) this can not be assured. The effects of migration of the uranium into deposits with material used to fill in the waste lift have been analyzed. The possible effect of migration of the uranium into the ground water (located 30 feet below the waste deposits) has also been postulated.

5.1 Migration of Uranium mixed with Fill Material

The majority of the K-25 process piping will arrive at the Clive Site filled with polyurethane foam encapsulating the contamination. Over geological time, it can not be guaranteed that the surface contamination will not separate from the piping material or polyurethane foam. However, in order for migration of uranium to occur, solutions of UO_2F_2 would have to form.

Solutions of UO_2F_2 are not expected to occur during normal operation of the Clive Site due to minimal precipitation amounts for both rain and snow. Reference 16 gives 14-year precipitation averages of 7.62 millimeters (0.30 inches) to 31.75 millimeters (1.25 inches) each month or approximately nine inches annually. Twenty-four hour precipitation amounts in excess of 25.4 millimeters (one inch) are rare. Reference 16 also gives a 10-year mean evaporation of 50.8 inches. Due to the precipitation rate being much lower than the evaporation rate, precipitation is not expected to reach the depth of the buried fissile material. As an added defense, the engineered disposal embankments that hold the buried materials are designed to transfer any liquids away from the disposal embankment.

The mixing of uranium with consolidated low strength material (CLSM), dry sand, steel, or polyurethane foam was analyzed using the methodology described in Section 4.3.2. The mixture was modeled as a sphere of UO_2F_2 with the volume fraction of the mixing material varied to determine the most reactive combination. The results summarized in Section 6.1 show that 40 kg of ^{235}U as UO_2F_2 mixed with dry sand, steel, or polyurethane foam and reflected by CLSM will remain below the USL. If UO_2F_2 were to mix with CLSM (reflected by CLSM) the safe mass is shown in Section 6.1 to be 3.6 kg of ^{235}U.

However, the mixture assumes that UO_2F_2 migration would have to occur. The only credible mechanism for significant UO_2F_2 migration is when it is in a soluble state.

Because the Clive site has a precipitation rate that is much lower than the evaporation rate, precipitation is not expected to reach the buried fissile material.

Therefore, criticality is not credible for this scenario due to the inability to form a configuration that exceeds the USL.

5.2 Reconcentration of UO_2F_2

Although highly unlikely, if migration were to occur, the UO_2F_2 solution could form a slab-like geometry. Slabs of various combinations of UO_2F_2 concentration and thickness were analyzed using the methodology described in 4.3.3. The results summarized in Section 6.2 show that for concentrations of UO_2F_2 up to 200 g/l, slabs up to 5cm in thickness will remain below the USL. The migration of uranyl fluoride solution through the desert soil surrounding the disposal embankment would take place over a diffuse area. Conservatively, a slab 1,000 cm (32.8 ft) on a side and 1 cm thick would require over 4,900 kg of ^{235}U to reach this concentration. This is much greater than the mass of ^{235}U that will be shipped in a single gondola rail car.

Formation of a slab of solution assumes that UO_2F_2 migration would have to occur. The only credible mechanism for significant UO_2F_2 migration is when it is in a soluble state. Because the Clive site has a precipitation rate that is much lower than the evaporation rate (see Section 5.1), precipitation is not expected to reach the buried fissile material. Because the mechanism for forming a solution is not present and the mass required to cause k_{eff} to exceed the USL is not available, criticality is not credible for this scenario.

5.3 Unloading

After the material from the K-25 Gaseous Diffusion Plant arrives at the Clive Site in gondola rail cars it will be unloaded and may be placed into temporary storage before being transported to the waste lift for disposal. During this time, it is possible that the pipes could be subject to immersion in water due to rainfall or to leakage from liquids in use for other purposes.

The analysis summarized in Section 6.3 shows that an array of pipes with or without foam filling the interior of the pipe will be below the USL when flooded and reflected by water.

If the piping is not filled with foam, it is possible that the water flooding the pipes would dissolve the UO_2F_2 and form a critical solution. The ANSI/ANS-8.1 subcritical limit for solutions of UO_2F_2 is 760 grams of ^{235}U in an optimally moderated sphere fully reflected by water. In order to accumulate 760 grams of ^{235}U, the piping would have to be flooded with water which would then reconcentrate and form an optimally moderated sphere. It would take over 1,000 gallons of water to fill the necessary length of piping at the expected ^{235}U loading (150 pCi/g) or more than 150 gallons of water at the maximum loading (1100 pCi/g). No process activities that involve use of water are permitted during unloading.

The Operating Procedures for handling K-25 piping will include restrictions on the use of water and performing unloading operations in the event of rainfall to safeguard against this scenario.

Criticality during unloading operations is not considered a credible event due to the lack of sufficient water to dissolve 760 g of ^{235}U and the absence of mechanisms to reconcentrate the dissolved uranium into an optimally moderated geometry.

5.4 Interim Storage

After the material from the K-25 Gaseous Diffusion Plant arrives at the Clive Site in gondola rail cars it will be unloaded and may be placed into temporary storage before being transported to the waste lift for disposal. During this time, it is possible that the pipes could be subject to immersion in water due to rainfall or to leakage from liquids in use for other purposes.

The analysis summarized in Section 6.3 shows that an array of pipes with or without foam filling the interior of the pipe will be below the USL when flooded and reflected by water.

The evaluation presented for Unloading above bounds this scenario. Therefore, criticality during interim storage is not a credible event.

5.5 On-site Transportation

After the material from the K-25 Gaseous Diffusion Plant arrives at the Clive Site in gondola rail cars it will be unloaded and may be placed into temporary storage before being transported to the waste lift for disposal. During this time, it is possible that the pipes could be subject to immersion in water due to rainfall or to leakage from liquids in use for other purposes.

The analysis summarized in Section 6.3 shows that an array of pipes with or without foam filling the interior of the pipe will be below the USL when flooded and reflected by water.

The evaluation presented for Unloading above bounds this scenario. Therefore, criticality during on-site transportation is not a credible event.

5.6 Double Batching

During disposal of the K-25 piping, the operating procedures will limit the mass of ^{235}U placed in a waste lift to prevent the accumulation of a critical mass when mixed with CLSM.

Since the mass limit established by this analysis for mixing UO_2F_2 with CLSM is 3.6 kg, the limit in the unloading and placement areas will be managed to less than this ^{235}U mass limit.

The ^{235}U mass within each gondola rail car shipment will be tracked by unloading and disposal area to limit the number of gondola rail car loads that can be managed at the same time at a particular location.

In order for criticality to occur, the ^{235}U would have to be removed from the pipes, migrate, and uniformly mix with CLSM to form an optimally moderated geometry. The migration and reconcentration was analyzed in Section 5.1 and shown to be not credible. Therefore, criticality due to double batching during disposal is not a credible event.

6 Evaluation of Results

6.1 Mixing Fissile Material

The effect of mixing fissile material with CLSM, steel, sand, and polyurethane foam was calculated to evaluate the effects of migration of UO_2F_2 over a geologic time scale. Each case analyzed considered a sphere of a given mass of ^{235}U as UO_2F_2 mixed with the material and surrounded by a four foot thick CLSM reflector. The volume percent (v/o) of the material and mass of ^{235}U were varied parametrically. The methodology described in Section 4.3.2 was used. The model geometry is shown in Figures 4-1 and 4-2.

Detailed MCNP results are presented in Appendix B and representative input files are contained in Appendix C.

The results are summarized in Tables 6-1, through 6-5, and in Figures 6-1, through 6-7.

Table 6-1 and Figure 6-1 show the effect of mixing UO_2F_2 and CLSM for mass of ^{235}U from 1 kg to 7 kg. The mixing of CLSM with the UO_2F_2 increases the moderation available causing k_{eff} to increase because pure UO_2F_2 is under moderated. The peak k_{eff} is reached at a mixture of 99.5 v/o CLSM and 0.5 v/o UO_2F_2.

Table 6-2 and Figures 6-2 show the effect of mixing 1 kg of ^{235}U as UO_2F_2 with A-53 carbon steel as a function of packing fraction (PF). Figure 6-3 shows the effect of varying volume fraction of steel and packing fraction of steel pieces mixed with 30.2 kg of ^{235}U as UO_2F_2. The packing fraction (the volume fraction occupied by the steel pieces) was varied parametrically between 0.2 and 1.0. It accounts for the fact that random pieces of steel will not entirely fill the space.

Tables 6-3 and 6-4, and Figures 6-4 and 6-5 show the effect of mixing UO_2F_2 with sand at normal density (2.2 g/cc) and reduced density (1.6 g/cc) for mass of ^{235}U from 1 kg to 50 kg.

Table 6-5 and Figure 6-6 show the effect of UO_2F_2 mixing with the polyurethane foam that is in most of the pipes as a function of mass of ^{235}U between 1 kg and 50 kg.

Figure 6-7 is a cross-plot of k_{eff} vs. mass of ^{235}U to determine the limiting mass to ensure that k_{eff} is below the USL.

For mixtures of UO_2F_2 with CLSM, the mass of ^{235}U must be less than 3.6 kg to ensure that k_{eff} is less than the USL.

For mixtures of UO_2F_2 with steel, sand, or polyurethane foam, the mass limit is 40 kg of ^{235}U.

Table 6-1 Effect of Mixing CLSM on k_{eff}

Volume % UO_2F_2	k_{eff}+2 σ						
	1 kg	2 kg	3 kg	4 kg	5 kg	6 kg	7 kg
0.1	0.54293	0.65451	0.71397	0.75305	0.78072	0.80356	0.81969
0.2	0.61355	0.76095	0.84462	0.9019	0.94292	0.97432	1.00202
0.5	0.60981	0.78135	0.88227	0.95233	1.00737	1.0497	1.08429
1	0.5509	0.72067	0.82295	0.89931	0.95566	1.00173	1.04187
2	0.47661	0.6299	0.72594	0.80005	0.85548	0.90101	0.9411
5	0.37886	0.50745	0.59254	0.65374	0.7062	0.7486	0.78385
10	0.3193	0.43142	0.50479	0.56164	0.60647	0.64591	0.67814
20	0.27405	0.37048	0.43769	0.48804	0.5317	0.56687	0.59687
50	0.24343	0.32797	0.38821	0.43435	0.47243	0.50636	0.5347
100	0.24745	0.33111	0.38868	0.43448	0.47312	0.50482	0.53345

Table 6-2 Effect of Mixing Steel on k_{eff}

Volume % Steel	$k_{eff}+2\sigma$				
	PF = 0.2	PF = 0.4	PF = 0.6	PF = 0.8	PF = 1
0	0.22938	0.22938	0.22938	0.22938	0.22938
10	0.22226	0.22307	0.2224	0.22349	0.22352
20	0.21526	0.21545	0.21686	0.21675	0.21806
30	0.20805	0.20881	0.20972	0.21145	0.21159
40	0.20136	0.20213	0.20407	0.20475	0.20555
50	0.19439	0.19647	0.19736	0.1983	0.19887
60	0.18837	0.19051	0.19136	0.19307	0.1931
70	0.18472	0.18509	0.18565	0.18681	0.18674
80	0.18215	0.18181	0.18166	0.18078	0.18121
90	0.18452	0.18055	0.17678	0.17394	0.1722
91	0.18579	0.18143	0.17746	0.17297	0.17023
92	0.18637	0.18066	0.17647	0.17191	0.16829
93	0.18768	0.18068	0.1755	0.16992	0.16638
94	0.18852	0.18069	0.17321	0.16815	0.16392
95	0.18917	0.17864	0.17123	0.16461	0.15872
96	0.19063	0.17731	0.16677	0.15948	0.15147
97	0.18928	0.17286	0.1608	0.15068	0.14236
98	0.18543	0.16279	0.14728	0.13527	0.1266
99	0.16803	0.13696	0.11853	0.10513	0.09617
99.5	0.13992	0.10412	0.08619	0.07452	0.06656
99.9	0.06061	0.03942	0.03079	0.0259	0.02285

Table 6-3 Effect of Mixing Sand (ρ = 2.2 g/cc) on k_{eff}

Volume % UO_2F_2	k_{eff}+2 σ								
	1.0 kg	4.0 kg	12.6 kg	25.2 kg	30.2 kg	35 kg	40 kg	45 kg	50 kg
100	0.24464	0.42705	0.64033	0.79443	0.83807	0.8719	0.90579	0.9344	0.96207
90	0.23879	0.41796	0.62602	0.77763	0.82185	0.85528	0.88689	0.91608	0.94167
80	0.23448	0.40965	0.61294	0.76147	0.8027	0.83651	0.86759	0.89664	0.92091
70	0.22976	0.40106	0.60035	0.74389	0.78425	0.81611	0.84727	0.87502	0.89971
60	0.22567	0.39343	0.58639	0.72592	0.76504	0.79671	0.82778	0.85264	0.87732
50	0.22179	0.38558	0.57231	0.70767	0.74407	0.77677	0.80543	0.82928	0.85316
40	0.21907	0.37916	0.55927	0.68866	0.72356	0.75546	0.78232	0.80667	0.82856
30	0.22026	0.37554	0.54782	0.66943	0.70496	0.73376	0.76032	0.78193	0.80428
20	0.22308	0.37622	0.53943	0.65384	0.68706	0.71327	0.73535	0.75724	0.77868
10	0.23881	0.3888	0.54208	0.64597	0.67509	0.69828	0.72057	0.74127	0.75861
9	0.24094	0.39169	0.54428	0.64653	0.67557	0.69916	0.71987	0.74017	0.75664
8	0.24622	0.39505	0.54607	0.64845	0.67608	0.69871	0.72189	0.73909	0.7583
7	0.24994	0.39899	0.54777	0.64997	0.67675	0.69899	0.71975	0.73954	0.75649
6	0.25392	0.40462	0.55207	0.64987	0.67972	0.70144	0.72264	0.74012	0.75778
5	0.26004	0.40863	0.55608	0.65479	0.68122	0.70367	0.72631	0.74209	0.76034
4	0.26897	0.41952	0.56331	0.65793	0.68647	0.70859	0.73011	0.74733	0.76415
3	0.27768	0.42832	0.57156	0.66577	0.69451	0.71505	0.73566	0.75358	0.76987
2	0.29058	0.44133	0.58289	0.67859	0.70607	0.72752	0.74857	0.76735	0.78313
1	0.30768	0.45811	0.60109	0.70097	0.72995	0.75208	0.77324	0.79293	0.8109
0.5	0.31464	0.46597	0.61578	0.72508	0.75623	0.78187	0.80723	0.82793	0.84819
0.1	0.26897	0.42124	0.60319	0.73544	0.77245	0.80146	0.82696	0.84825	0.86846

Table 6-4 Effect of Mixing Sand (ρ = 1.6 g/cc) on k_{eff}

Volume % UO_2F_2	k_{eff}+2 σ									
	5 kg	10 kg	15 kg	20 kg	25 kg	30 kg	35 kg	40 kg	45 kg	50 kg
100	0.46305	0.59233	0.67655	0.74094	0.79307	0.83654	0.8719	0.90579	0.9344	0.96207
90	0.45258	0.57833	0.66181	0.72405	0.776	0.81682	0.85326	0.88445	0.91138	0.93796
80	0.44166	0.56598	0.64547	0.7061	0.75465	0.79586	0.83219	0.86246	0.89033	0.91504
70	0.43253	0.55129	0.62986	0.68857	0.73482	0.77594	0.81138	0.84026	0.86629	0.89056
60	0.42272	0.53768	0.61169	0.67046	0.71582	0.7532	0.78862	0.81514	0.84257	0.8655
50	0.41388	0.52328	0.59696	0.6514	0.69573	0.73274	0.76421	0.79238	0.81623	0.8393
40	0.40665	0.51129	0.58062	0.63276	0.67454	0.71028	0.73881	0.76568	0.79018	0.81049
30	0.39876	0.50149	0.56531	0.61483	0.65346	0.68752	0.71565	0.7412	0.76259	0.78227
20	0.39672	0.49311	0.55283	0.60001	0.63522	0.66571	0.6904	0.71471	0.73399	0.7529
10	0.40598	0.49546	0.54777	0.58825	0.62167	0.64875	0.67039	0.69087	0.70876	0.7252
9	0.40973	0.49604	0.54948	0.58922	0.62066	0.64728	0.6696	0.68858	0.70704	0.7241
8	0.41131	0.49664	0.55105	0.59064	0.62141	0.64694	0.66782	0.68916	0.70388	0.72152
7	0.4143	0.49962	0.55228	0.59026	0.62091	0.64679	0.66724	0.68735	0.70433	0.7216
6	0.41855	0.50286	0.55454	0.59259	0.62282	0.64537	0.66798	0.68675	0.70453	0.71917
5	0.42412	0.50645	0.55558	0.5946	0.62329	0.64773	0.66958	0.68858	0.70469	0.71853
4	0.42997	0.51202	0.56081	0.59774	0.62631	0.65113	0.66985	0.68837	0.70378	0.71955
3	0.43906	0.51761	0.56817	0.60154	0.63037	0.65316	0.67356	0.69223	0.7071	0.7219
2	0.44912	0.52844	0.57747	0.60976	0.63887	0.65874	0.6793	0.69649	0.71062	0.72619
1	0.46222	0.53949	0.58759	0.6214	0.64882	0.67127	0.69208	0.70758	0.72354	0.73744
0.5	0.46804	0.54272	0.59141	0.62622	0.65489	0.68006	0.70029	0.71973	0.73636	0.75126
0.1	0.41339	0.49771	0.55617	0.60273	0.64143	0.6728	0.70252	0.72669	0.74894	0.77002

Table 6-5 Effect of Mixing Polyurethane Foam on k_{eff}

Volume % UO_2F_2	$k_{eff}+2\sigma$								
	1.0 kg	4.0 kg	12.6 kg	25.2 kg	30.2 kg	35.0 kg	40.0 kg	45.0 kg	50.0 kg
100	0.24464	0.42705	0.64033	0.79443	0.83807	0.8719	0.90579	0.9344	0.96207
90	0.23879	0.41796	0.62602	0.77763	0.82185	0.85528	0.88689	0.91608	0.94167
80	0.23448	0.40965	0.61294	0.76147	0.8027	0.83651	0.86759	0.89664	0.92091
70	0.22976	0.40106	0.60035	0.74389	0.78425	0.81611	0.84727	0.87502	0.89971
60	0.22567	0.39343	0.58639	0.72592	0.76504	0.79671	0.82778	0.85264	0.87732
50	0.22179	0.38558	0.57231	0.70767	0.74407	0.77677	0.80543	0.82928	0.85316
40	0.21907	0.37916	0.55927	0.68866	0.72356	0.75546	0.78232	0.80667	0.82856
30	0.22026	0.37554	0.54782	0.66943	0.70496	0.73376	0.76032	0.78193	0.80428
20	0.22308	0.37622	0.53943	0.65384	0.68706	0.71327	0.73535	0.75724	0.77868
10	0.23881	0.3888	0.54208	0.64597	0.67509	0.69828	0.72057	0.74127	0.75861
9	0.24094	0.39169	0.54428	0.64653	0.67557	0.69916	0.71987	0.74017	0.75664
8	0.24622	0.39505	0.54607	0.64845	0.67608	0.69871	0.72189	0.73909	0.7583
7	0.24994	0.39899	0.54777	0.64997	0.67675	0.69899	0.71975	0.73954	0.75649
6	0.25392	0.40462	0.55207	0.64987	0.67972	0.70144	0.72264	0.74012	0.75778
5	0.26004	0.40863	0.55608	0.65479	0.68122	0.70367	0.72631	0.74209	0.76034
4	0.26897	0.41952	0.56331	0.65793	0.68647	0.70859	0.73011	0.74733	0.76415
3	0.27768	0.42832	0.57156	0.66577	0.69451	0.71505	0.73566	0.75358	0.76987
2	0.29058	0.44133	0.58289	0.67859	0.70607	0.72752	0.74857	0.76735	0.78313
1	0.30768	0.45811	0.60109	0.70097	0.72995	0.75208	0.77324	0.79293	0.8109
0.5	0.31464	0.46597	0.61578	0.72508	0.75623	0.78187	0.80723	0.82793	0.84819
0.1	0.26897	0.42124	0.60319	0.73544	0.77245	0.80146	0.82696	0.84825	0.86846

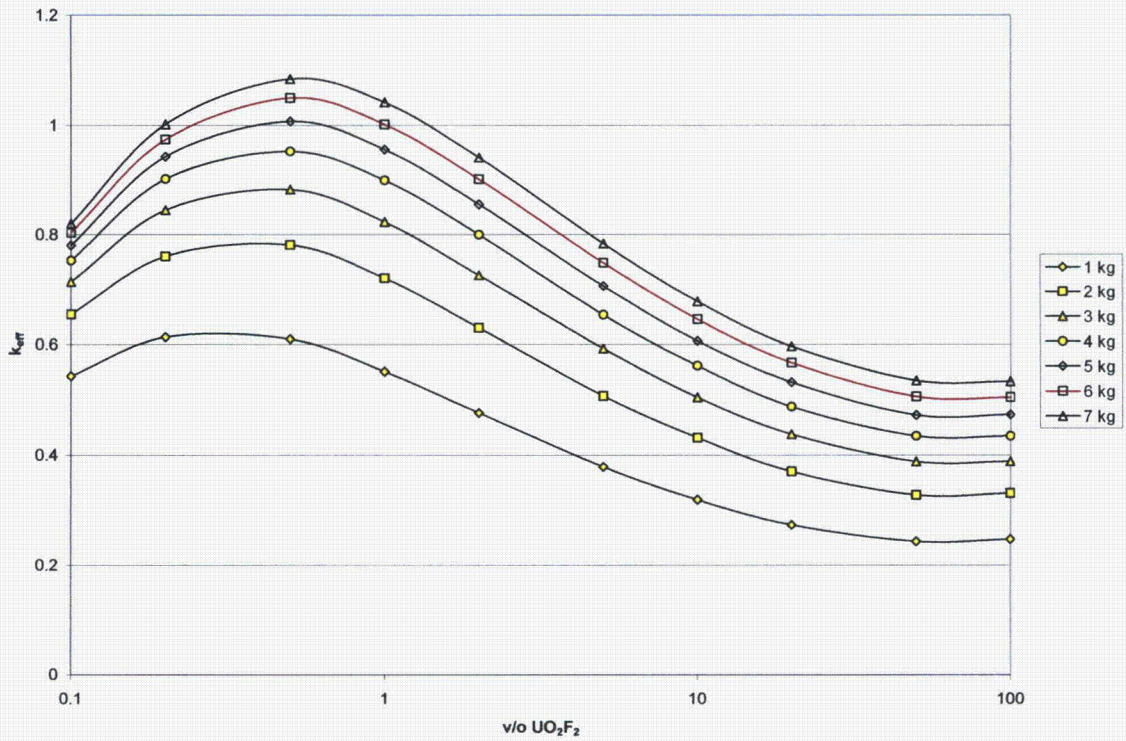


Figure 6-1 Effect of Mixing Fissile Material with CLSM

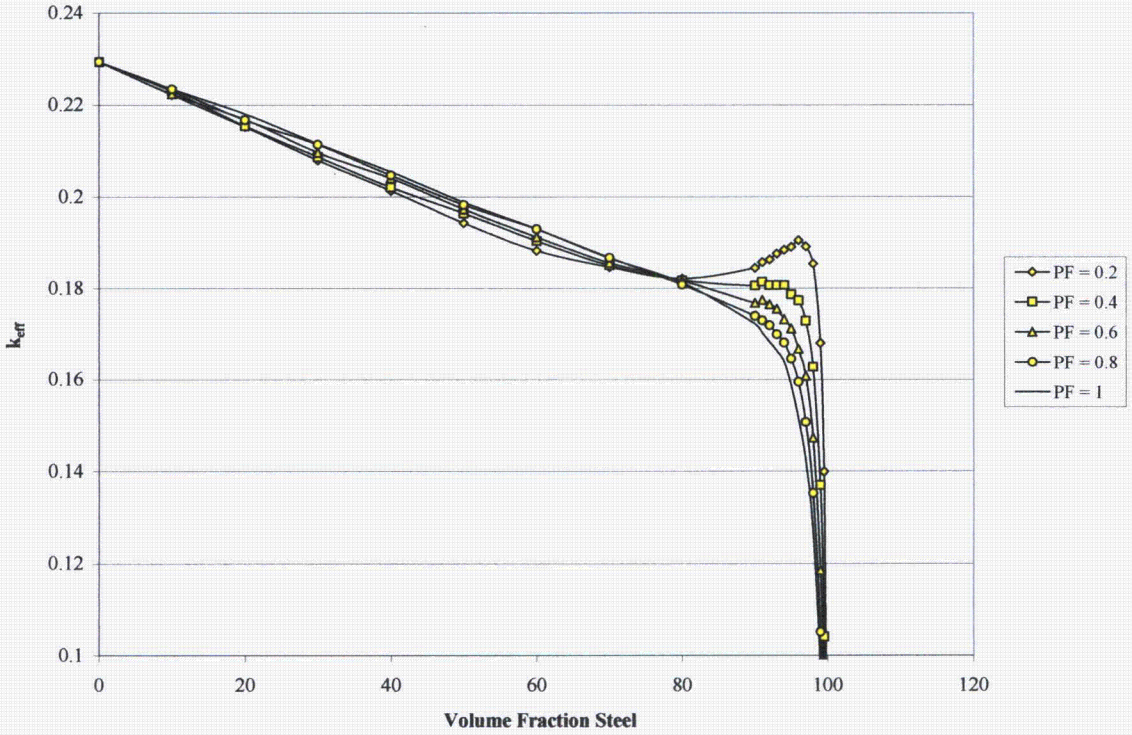


Figure 6-2 Effect of Mixing 4 Fissile Material with Steel

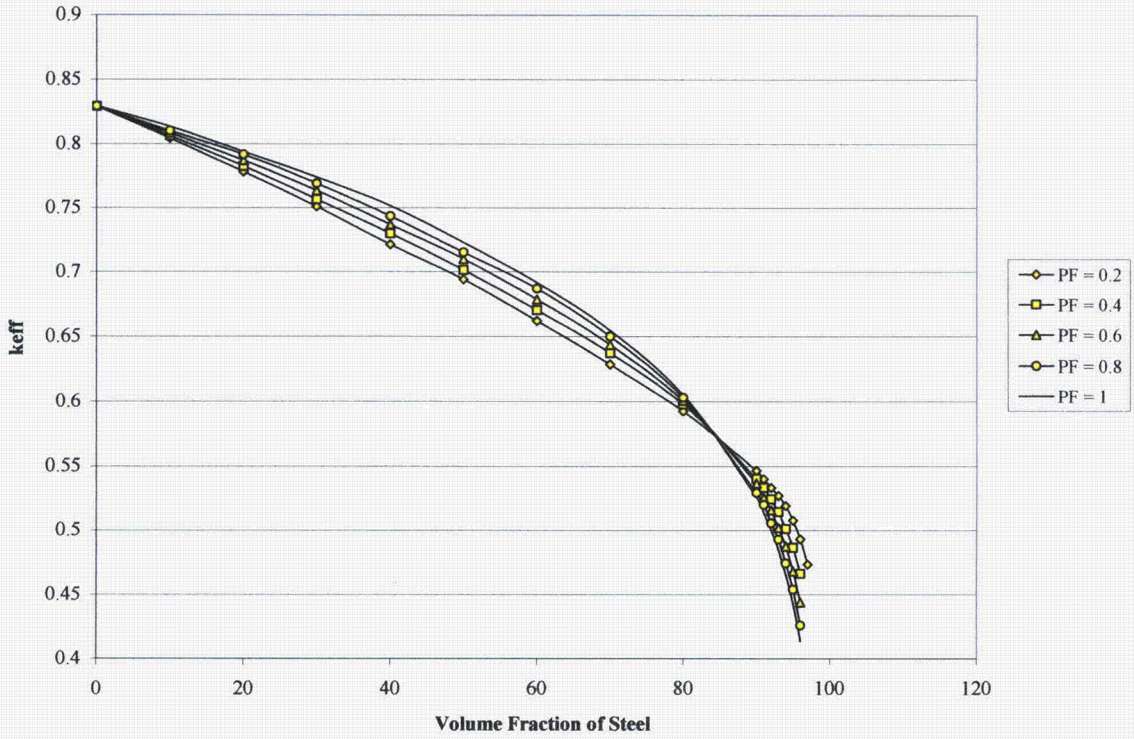


Figure 6-3 Effect of Mixing 30.2 kg of Fissile Material with Steel

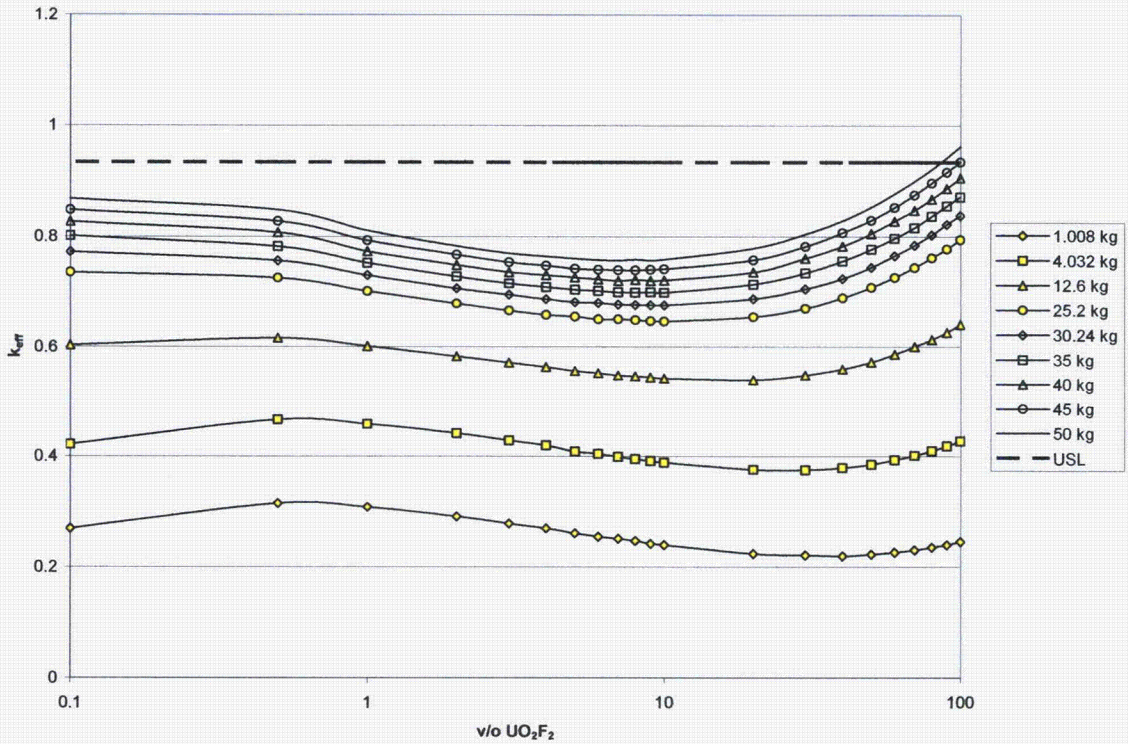


Figure 6-4 Effect of Mixing Fissile Material with Sand (ρ = 2.2 g/cc)

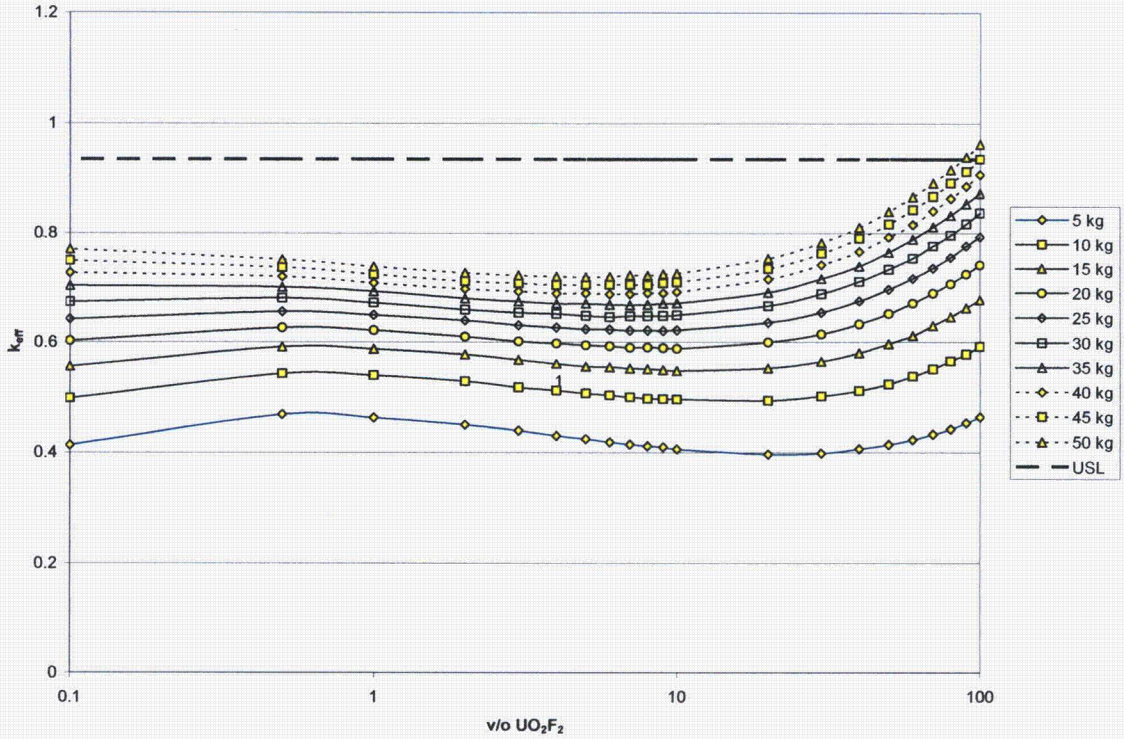


Figure 6-5 Effect of Mixing Fissile Material with Sand (ρ = 1.6 g/cc)

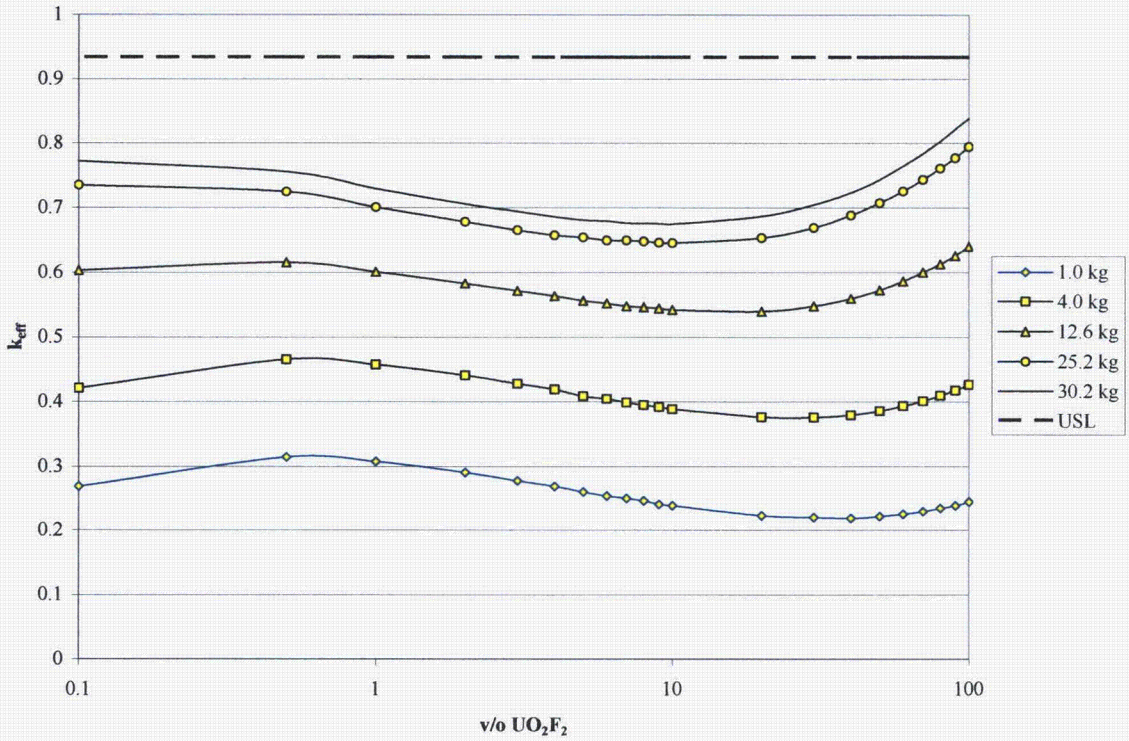


Figure 6-6 Effect of Mixing Fissile Material with Polyurethane Foam

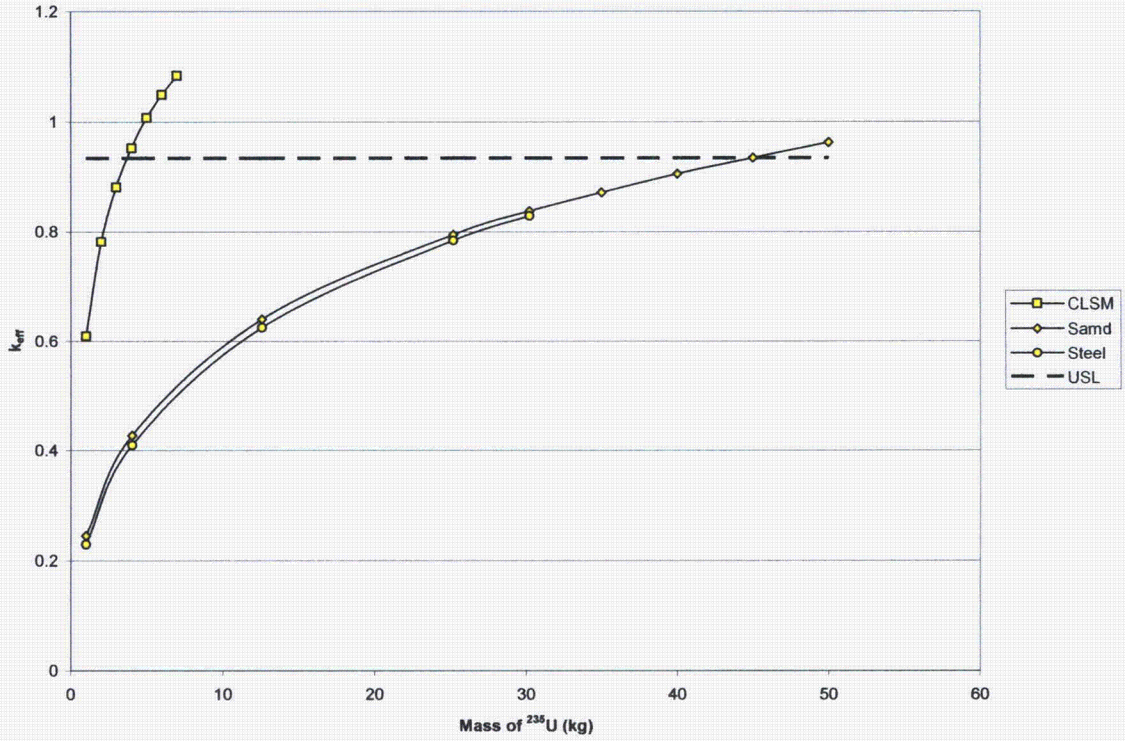


Figure 6-7 Effect of Mixing Fissile Material

6.2 Solutions of UO_2F_2

UO_2F_2 could migrate over time and re-concentrate into a layer of solution. Slabs of various combinations of UO_2F_2 concentration and thickness were evaluated using MCNP 5. Detailed MCNP results are presented in Appendix B and representative input files are contained in Appendix C.

The resulting k_{eff} as a function of thickness and concentration is summarized in Table 6-6 and Figure 6-8.

It can be seen from Table 6-6 and Figure 6-8 that k_{eff} will remain below the USL for solutions of less than 200 g/L UO_2F_2 and slabs (1,000 cm on a side) less than 5 cm thick.

Table 6-6 Effect of UO_2F_2 Concentration on k_{eff}

Concentration of UO_2F_2 (g/L)	$k_{eff} + 2\sigma$						
	1 cm[4]	2 cm	5 cm	10 cm	20 cm	50 cm	100 cm
25	0.14419	0.24798	0.46974	0.70681	0.94838	1.14677	1.20619
50	0.23909	0.3779	0.64724	0.92687	1.20632	1.43789	1.50785
100	0.35609	0.51266	0.8005	1.09796	1.39107	1.64047	1.7156
150	0.42622	0.58218	0.87053	1.16721	1.46382	1.71514	1.79323
200	0.47313	0.62495	0.90834	1.20534	1.49996	1.75051	1.82604
250	0.50555	0.65558	0.93478	1.22659	1.52042	1.77087	1.8464
300	0.5323	0.67584	0.95115	1.24162	1.53137	1.77991	1.85579
350	0.55147	0.69261	0.96443	1.25181	1.5396	1.78533	1.86204
400	0.56785	0.70526	0.97163	1.25711	1.54266	1.7877	1.86285
450	0.58033	0.71522	0.98022	1.26115	1.54555	1.78837	1.8632
500	0.59289	0.72477	0.98591	1.26364	1.54318	1.7879	1.86252

[4] Thickness of slab

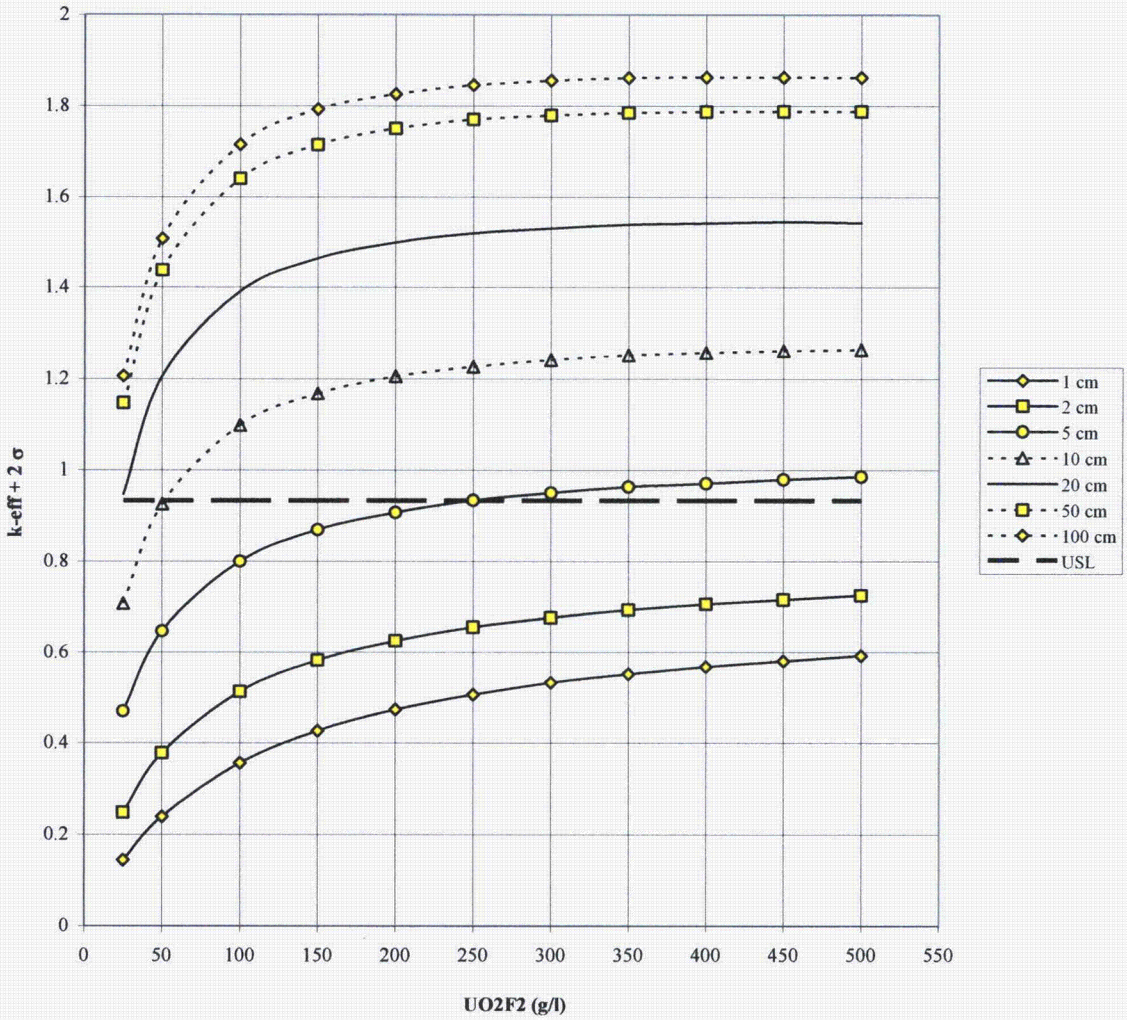


Figure 6-8 Effect of Solution Density on k_{eff}

6.3 Arrays of Pipes

During the unloading, interim storage, on-site transportation, and disposal the pipes from K-25 may be in an array like configuration. The model used is described in Section 4.3.4 and is shown in Figure 4-3. Detailed MCNP results are presented in Appendix B and representative input files are contained in Appendix C.

An array 9' 3¼" wide by 11' 5" high by 62' 8¼" long (roughly the size of a gondola rail car) was modeled to bound any possible waste disposal arrangement. The array was modeled with and without foam inside the pipes. Flooded and dry configurations were analyzed. An additional set of cases were run where the wall thickness was reduced to half its specification to account for possible corrosion of the pipe wall. The results are

summarized in Table 6-7. It can be seen from Table 6-7 that k_{eff} is far below the USL for all pipe sizes whether flooded or dry.

Table 6-7 Array of Pipes

Case \ Pipe OD	$k_{eff} + 2\sigma$				
	2.375 "	3.5 "	6.625 "	8.625 "	16 "
H/U=0, 150 pCi/g					
Flooded w/water reflector	0.01731	0.01624	0.01195	0.01070	
Flooded foam in pipe w/water reflector		0.01887	0.01540		0.01081
H/U=4, 150 pCi/g					
Flooded w/water reflector	0.01754		0.01190	0.01068	
Void foam in pipe				0.02658	
Flooded foam in pipe w/water reflector	0.02013	0.01895	0.01545	0.01387	0.01088
H/U=0, 1100 pCi/g					
Flooded w/water reflector	0.11956	0.11042	0.08091	0.07222	0.06463
Void foam in pipe	0.04534	0.04276	0.02976		
Flooded foam in pipe w/water reflector	0.13494	0.12638	0.10244	0.09147	0.07009
H/U=4, 1100 pCi/g					
Flooded w/water reflector	0.11957	0.11103	0.08091	0.07244	0.06485
Void w/o reflector	0.00675	0.00608	0.00327		
Void foam in pipe w/o reflector	0.04632	0.04380	0.03024	0.02658	0.02249
Flooded foam in pipe w/water reflector	0.13549	0.12700	0.10316	0.09193	0.07095
Flooded foam in pipe w/water reflector with reduced pipe wall thickness	0.23780	0.22463	0.17818	0.15897	0.12342

Note: Blanks indicate cases where MCNP could not calculate k_{eff} due to small thickness of insufficient fissile material.

7 Design Features (Active and Passive) and Administratively Controlled Limits & Requirements

7.1 Assumptions

The following assumptions are used in this criticality safety evaluation:

7.1.1 Unrestricted Bounding Assumptions

The fissile material is ^{235}U enriched to 100% as UO_2F_2 surface contamination.

7.1.2 Restricted Process Assumptions

The analyses presented in this NCSE are predicated on the piping from the K-25 Gaseous Diffusion Plant being internally surface contaminated with UO_2F_2 with the following characteristics:

- The waste will be received in gondola rail cars containing a maximum of 3.6 kg of ^{235}U.
- Pipes with nominal diameter 3 inches or greater are filled with polyurethane foam with a density of 0.032 g/cc.
- Fissile material from other sources needs to be accounted for in the disposal waste lift to ensure the total fissile mass limits in Section 7.2 are not exceeded.

7.1.3 Unrestricted Process Assumptions

- The average rain fall at the Clive Site is 9 inches per year and the average evaporation rate 51 inches per year.
- The water table is more than 30 feet below the surface.
- The material will be transported in gondola rail cars that have nominal dimensions of 9' 3¼" wide by 11' 5" high by 62' 8¼" long.

7.2 Limits

The analysis performed in support of this NCSE determined that criticality events during disposal of the K-25 piping at the Clive Facility are not credible provide that the following conditions are met:

- No more than 40 kg of ^{235}U is placed in a single disposal emplacement filled with dry sand or scrap steel.
- No more than 3.6 kg of ^{235}U is placed in a single disposal emplacement filled with CLSM.

7.3 Administrative & Programmatic Controls

- Waste Lifts containing K-25 piping shall not be stacked.

- Waste Lifts containing K-25 piping shall be placed in a single waste emplacement area within the Class A disposal embankment. [Scenario 5.1]
- Single disposal emplacement areas will consist of one continuous CLSM filled waste lift and will be limited to ^{235}U mass limits established in Section 7.2. [Scenario 5.1]
- Piping with a diameter less than 10 inches and no longer than 12 feet in length will be placed in separate soil lifts as to not exceed the limits established in Section 7.2 for a single waste emplacement area. [Scenario 5.1]
- Liquids shall not be used as part of the process in areas where K-25 piping is being unloaded, moved on-site, or placed in interim storage. [Scenario 5.3]
- Piping shall be covered to prevent inleakage of rain water when rainfall is expected to exceed one inch. [Scenario 5.3]
- Piping that is stock-piled or placed in disposal waste lifts shall not exceed the most restrictive mass limits established in Section 7.2. [Scenarios 5.1 and 5.4]
- Fissile material from other sources shall be accounted for in the disposal waste lift to ensure the total fissile mass limits in Section 7.2 are not exceeded. [Scenario 5.1]

7.4 Design Features

The Clive Site design features relied upon to ensure that criticality is incredible are (1) the location of the site in an arid region and (2) the water table location more than 30 feet below the surface.

8 Summary and Conclusions

The analyses presented in this NCSE demonstrate that criticality is not credible during disposal of piping from the K-25 Gaseous Diffusion Plant at the Clive Site as long as the limits presented in Section 7.2 are met.

Since criticality is not credible, a Criticality Accident Alarm System is not required.

9 References

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Appendix A – Material and Compositions

A.1 Standard Materials

Five standard materials are used in this analysis: A-53 carbon steel, consolidated low strength material (CLSM), polyurethane foam, sand, and salt. The composition of these materials is shown in Table A-1. The composition of the isotopes of iron was computed based on the atom fractions of the isotope as:

$$wf_j = \frac{af_j AW_j}{\sum_j af_j AW_j} wf^{Fe} \tag{1}$$

Where:

wf_j	is the weight fraction of isotope j in the material
af_j	is the atom fraction of isotope j in iron
AW_j	is the atomic weight of isotope j
wf^{Fe}	is the weight fraction of iron in the material

Table A-1 Standard Material Composition

Element	ZAID	Atom Fraction	Steel	Salt	CLSM Fill	CLSM Cap	Foam	Sand
			Weight Fraction					
Hydrogen	1001				1.0010E-02	9.3352E-03	8.5000E-02	
Carbon	6000		3.0000E-03				6.9600E-01	
Nitrogen	7014						5.5000E-02	
Oxygen	8016				5.5419E-01	5.5041E-01	1.0200E-01	5.3257E-01
Fluorine	9019						4.5000E-02	
Sodium	11023			3.9337E-01	6.1911E-04	7.0374E-04		
Magnesium	12000				1.7614E-03	2.0022E-03		
Aluminum	13027				1.1523E-02	1.3156E-02		
Silicon	14000		1.0000E-04		3.9780E-01	3.9606E-01		4.6743E-01
Phosphorus	15031		4.8000E-04				5.0000E-03	
Sulfur	16032		5.4000E-04		5.6197E-04	6.5606E-04		
Chlorine	17000			6.0663E-01			1.2000E-02	
Potassium	19000				1.3856E-03	1.5750E-03		
Calcium	20000				1.7700E-02	2.0990E-02		
Manganese	25055		6.7500E-03					
Iron	26054	5.9006E-02	5.6374E-02		2.4453E-04	2.8030E-04		
	26056	9.1718E-01	9.0869E-01		4.0873E-03	4.6852E-03		
	26057	2.1007E-02	2.1185E-02		9.6994E-05	1.1118E-04		
	26058	2.8060E-03	2.8793E-03		1.3414E-05	1.5376E-05		
Density (g/cc)			7.86	2.17	2.11	2.12	0.032	2.2
Reference:		A.1	A.2	A.3	A.4	A.4	A.5	Note 1

Notes:

1. Dry sand was modeled as pure SiO_2 with density 2.2 g/cc or 1.6 g/cc.

A.2 UO_2F_2 Spheres

The composition of UO_2F_2 spheres mixed concrete, steel, and salt was calculated using the formulae presented in Section 4.3.2 and is presented for representative cases in Tables A-2, A-3, and A-4 respectively.

Table A-2 Representative UO_2F_2/CLSM Sphere Properties

Element	ZAID	Weight Fraction					
	VF UO_2F_2	100	50	10	1	0.5	0.1
Hydrogen	1001		2.52E-03	7.52E-03	9.72E-03	9.86E-03	9.98E-03
Oxygen	8016	1.05E-01	2.18E-01	4.43E-01	5.41E-01	5.48E-01	5.53E-01
Fluorine	9019	1.25E-01	9.32E-02	3.09E-02	3.63E-03	1.83E-03	3.70E-04
Sodium	11023		1.56E-04	4.65E-04	6.01E-04	6.10E-04	6.17E-04
Aluminum	13027		4.43E-04	1.32E-03	1.71E-03	1.74E-03	1.76E-03
Silicon	14000		2.90E-03	8.66E-03	1.12E-02	1.14E-02	1.15E-02
Potassium	19000		1.00E-01	2.99E-01	3.86E-01	3.92E-01	3.97E-01
Calcium	20000		1.41E-04	4.22E-04	5.46E-04	5.54E-04	5.60E-04
Iron	26054		3.49E-04	1.04E-03	1.35E-03	1.37E-03	1.38E-03
	26056		4.45E-03	1.33E-02	1.72E-02	1.74E-02	1.76E-02
	26057		6.15E-05	1.84E-04	2.37E-04	2.41E-04	2.44E-04
	26058		1.03E-03	3.07E-03	3.97E-03	4.03E-03	4.08E-03
Uranium	92235	7.71E-01	2.44E-05	7.29E-05	9.42E-05	9.56E-05	9.67E-05
UO_2F_2 Radius (cm)		3.66247	4.61442	7.89055	16.99968	21.41825	36.6247
CLSM Radius (cm)		125.58247	126.5344	129.8106	138.9197	143.3383	158.5447

Note: Properties are for 1 kg of ^{235}U as UO_2F_2 mixed with CLSM

Table A-3 Representative UO_2F_2/Steel Sphere Properties

Element	ZAID	Weight Fraction					
	V%/PF steel	0	50/20	50/40	50/60	50/80	50/100
Hydrogen	1001						
	6000		3.81E-04	3.17E-04	2.72E-04	2.38E-04	2.12E-04
Oxygen	8016	1.05E-01	8.40E-02	7.00E-02	6.00E-02	5.25E-02	4.67E-02
Fluorine	9019	1.25E-01	9.97E-02	8.31E-02	7.13E-02	6.24E-02	5.55E-02
Silicon	14000		1.83E-05	3.06E-05	3.93E-05	4.59E-05	5.10E-05
Phosphorus	15031		9.58E-05	1.60E-04	2.05E-04	2.40E-04	2.66E-04
Sulfur	16000		1.08E-04	1.80E-04	2.31E-04	2.70E-04	3.00E-04
Manganese	25055		1.35E-03	2.25E-03	2.89E-03	3.37E-03	3.75E-03
Iron	26054		1.11E-02	1.85E-02	2.38E-02	2.78E-02	3.08E-02
	26056		1.81E-01	3.02E-01	3.89E-01	4.53E-01	5.04E-01
	26057		4.41E-03	7.35E-03	9.45E-03	1.10E-02	1.23E-02
	26058		6.76E-04	1.13E-03	1.45E-03	1.69E-03	1.88E-03
Uranium	92235	7.71E-01	6.17E-01	5.14E-01	4.41E-01	3.86E-01	3.43E-01
UO_2F_2 Radius (cm)		3.67221	4.6267	4.6267	4.6267	4.6267	4.6267
Concrete Radius (cm)		125.59221	126.5467	126.5467	126.5467	126.5467	126.5467

Note: Properties are for 1.008 kg of ^{235}U as UO_2F_2 mixed with Steel

Table A-4 Representative UO_2F_2/Salt Sphere Composition

Element	ZAID	Weight Fraction			
	v/o salt	0	50	90	99
Hydrogen	1001	1.59E-26	2.36E-26	3.87E-26	4.52E-26
Oxygen	8016	1.05E-01	7.80E-02	2.56E-02	2.99E-03
Fluorine	9019	1.25E-01	9.27E-02	3.04E-02	3.55E-03
Sodium	11023	1.59E-26	1.01E-01	2.97E-01	3.82E-01
Chlorine	17000	1.59E-26	1.55E-01	4.59E-01	5.89E-01
Uranium	92235	7.71E-01	5.73E-01	1.88E-01	2.20E-02
UO_2F_2 Radius (cm)		3.67221	4.6267	7.91154	17.04489
Concrete Radius (cm)		125.59221	126.5467	129.8315	138.9649

Note: Properties are for 1.008 kg of ^{235}U as UO_2F_2 mixed with Salt

A.3 UO_2F_2 Solutions

The composition of UO_2F_2 solutions with varying concentration of UO_2F_2 was calculated using the methodology in Section 4.3.3. The resulting weight fractions are presented in Table A-5 .

Table A-5 UO_2F_2 Solution Composition

Element	Hydrogen	Oxygen	Fluorine	Uranium		
	Weight Fraction					
ZAID / C UO_2F_2 (g/L)	1001	8016	9019	92235	Density (g/cc)	H/U
25	1.09E-01	8.69E-01	3.05E-03	1.88E-02	1.02234	1351.26
50	1.07E-01	8.51E-01	5.97E-03	3.69E-02	1.04407	673.41
100	1.02E-01	8.16E-01	1.15E-02	7.09E-02	1.08752	334.49
150	9.71E-02	7.84E-01	1.65E-02	1.02E-01	1.13098	221.52
200	9.29E-02	7.55E-01	2.12E-02	1.31E-01	1.17443	165.03
250	8.89E-02	7.27E-01	2.56E-02	1.58E-01	1.21789	131.14
300	8.53E-02	7.02E-01	2.96E-02	1.83E-01	1.26134	108.54
350	8.19E-02	6.78E-01	3.34E-02	2.07E-01	1.30480	92.4
400	7.87E-02	6.56E-01	3.70E-02	2.29E-01	1.34825	80.3
450	7.57E-02	6.35E-01	4.03E-02	2.49E-01	1.39171	70.88
500	7.29E-02	6.15E-01	4.34E-02	2.68E-01	1.43517	63.35

A.4 References for Appendix A

A.1 E. M. Baum, H. D. Knox, and T. R. Miller, *Nuclides and Isotopes Chart of the Nuclides*, 16th Edition, KAPL Inc, Schenectady, NY (2002).

A.2 Steels for Nuclear Reactor Applications, Chapter 3, *Mechanical and Physical Properties of Steels for Nuclear Reactor Applications*, United States Steel Corporation, Pittsburgh, PA (1967).

A.3 WebElements™, the periodic table on the WWW, http://www.webelements.com/webelements/compounds/text/Na/Cl1Na1-7647145.html.

A.4 *Concrete Mix* Design, Mix ID: CLSM CAP, Energy*Solutions*, Salt Lake City, UT (January 8, 2007).

A.5 A. G., Goslen and J. Bullington, *Nuclear Criticality Safety Review of Foams for D&D*, NCSR-ET-K25-0021, Rev 2, Bechtel Jacobs Company, LLC, Oak Ridge, TN (August 17, 2004).

Appendix B – Calculation Results

Piping will arrive at the Clive Site in gondola rail cars with a maximum of 3.6 kg of fissile material in each package. The contents of each container will be disposed of in multiple areas. In the course of time it can not be guaranteed that the original configuration will be maintained. Some material from adjacent embankments may migrate and combine into a single mass of fissile material mixed with other material in the disposal embankment on geologic formation. Calculations were performed using the methodology described in Chapter 4 to determine the limits that must be applied to ensure criticality safety.

Input files for cases marked with an * are included in Appendix C as representative input files.

B.1 Mixing of UO_2F_2 with Other Material

A study of the effect of combining the material from adjacent embankments was performed assuming that the combining material is CLSM, steel, sand, or foam using the methodology described in Section 4.3.2. The calculated values of k_{eff} are listed in Tables B-1, B-2, B-4, B-5, and B-6. The column headings common to all tables are:

Column Heading	Description
File Name	Name of the MCNP input file
v/o X	Volume Percent of material "X" mixed with the UO_2F_2
k_{eff}	K effective calculated by MCNP
σ	Standard deviation on k_{eff} calculated by MCNP
$k_{eff} + 2\sigma$	95% confidence level for k_{eff}
average E	Average energy of neutron causing fission (eV)

Table B-1 contains the calculated k_{eff} for UO_2F_2 mixed with CLSM and reflected by CLSM. Table B-2 contains the results for UO_2F_2 mixed with steel pieces and reflected by CLSM. Since the steel would be randomly sized pieces, a packing fraction (PF in column 3) was applied to the density of the steel mixed with the UO_2F_2. Tables B-4 and B-5 contain the calculated k_{eff} for UO_2F_2 mixed with sand and reflected by CLSM. Table B-4 is based on sand at its normal density of 2.2 g/cc, while table B-5 is based on a reduced sand density of 1.6 g/cc. Table B-6 contains the calculated k_{eff} for UO_2F_2 mixed with polyurethane foam and reflected by CLSM.

Although validation results do not exist for salt (sodium chloride), a set of cases were run to demonstrate that k_{eff} would be much lower if the mixing material were salt since the area surrounding the Clive Site is a salt flat. The results are presented in Table B-3. This table is presented for information only and is not used as the basis for any conclusions in the body of this NCSE.

Table B-1 CLSM Spheres

File Name	v/o UO_2F_2	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
1 kg ^{235}U as UO_2F_2					
clsm_1_1_in	0.1	0.54199	0.00047	0.54293	2.78E-03
clsm_2_1_in	0.2	0.61235	0.00060	0.61355	4.04E-03
clsm_3_1_in	0.5	0.60825	0.00078	0.60981	8.59E-03
clsm_4_1_in	1	0.54946	0.00072	0.55090	1.63E-02
clsm_5_1_in	2	0.47513	0.00074	0.47661	3.10E-02
clsm_6_1_in	5	0.37746	0.00070	0.37886	7.48E-02
clsm_7_1_in	10	0.31810	0.00060	0.31930	1.41E-01
clsm_8_1_in	20	0.27291	0.00057	0.27405	2.60E-01
clsm_9_1_in	50	0.24249	0.00047	0.24343	5.49E-01
clsm_10_1_in*	100	0.24661	0.00042	0.24745	8.79E-01
2 kg ^{235}U as UO_2F_2					
clsm_1_2_in	0.1	0.65351	0.00050	0.65451	2.33E-03
clsm_2_2_in	0.2	0.75967	0.00064	0.76095	3.81E-03
clsm_3_2_in	0.5	0.77979	0.00078	0.78135	7.93E-03
clsm_4_2_in	1	0.71905	0.00081	0.72067	1.45E-02
clsm_5_2_in	2	0.62820	0.00085	0.62990	2.80E-02
clsm_6_2_in	5	0.50601	0.00072	0.50745	6.68E-02
clsm_7_2_in	10	0.43006	0.00068	0.43142	1.28E-01
clsm_8_2_in	20	0.36922	0.00063	0.37048	2.38E-01
clsm_9_2_in	50	0.32687	0.00055	0.32797	5.09E-01
clsm_10_2_in	100	0.33007	0.00052	0.33111	8.21E-01
3 kg ^{235}U as UO_2F_2					
clsm_1_3_in	0.1	0.71297	0.00050	0.71397	2.20E-03
clsm_2_3_in	0.2	0.84326	0.00068	0.84462	3.50E-03
clsm_3_3_in	0.5	0.88065	0.00081	0.88227	7.44E-03
clsm_4_3_in	1	0.82127	0.00084	0.82295	1.42E-02
clsm_5_3_in	2	0.72414	0.00090	0.72594	2.68E-02
clsm_6_3_in	5	0.59092	0.00081	0.59254	6.42E-02
clsm_7_3_in	10	0.50327	0.00076	0.50479	1.23E-01
clsm_8_3_in	20	0.43641	0.00064	0.43769	2.30E-01
clsm_9_3_in	50	0.38697	0.00062	0.38821	4.87E-01
clsm_10_3_in	100	0.38762	0.00053	0.38868	7.95E-01
4 kg ^{235}U as UO_2F_2					
clsm_1_4_in	0.1	0.75211	0.00047	0.75305	2.16E-03
clsm_2_4_in	0.2	0.90060	0.00065	0.90190	3.53E-03
clsm_3_4_in*	0.5	0.95067	0.00083	0.95233	7.24E-03
clsm_4_4_in	1	0.89761	0.00085	0.89931	1.35E-02
clsm_5_4_in	2	0.79833	0.00086	0.80005	2.57E-02
clsm_6_4_in	5	0.65212	0.00081	0.65374	6.31E-02
clsm_7_4_in	10	0.56014	0.00075	0.56164	1.20E-01
clsm_8_4_in	20	0.48662	0.00071	0.48804	2.25E-01
clsm_9_4_in	50	0.43307	0.00064	0.43435	4.75E-01

Table B-1 CLSM Spheres

File Name	v/o UO_2F_2	k_{eff}	σ	k_{eff}+2*σ	average E
clsm_10_4_in	100	0.43336	0.00056	0.43448	7.79E-01
5 kg ^{235}U as UO_2F_2					
clsm_1_5_in	0.1	0.77968	0.00052	0.78072	2.13E-03
clsm_2_5_in	0.2	0.94156	0.00068	0.94292	3.40E-03
clsm_3_5_in	0.5	1.00569	0.00084	1.00737	7.06E-03
clsm_4_5_in	1	0.95386	0.00090	0.95566	1.33E-02
clsm_5_5_in	2	0.85366	0.00091	0.85548	2.53E-02
clsm_6_5_in	5	0.70440	0.00090	0.70620	6.19E-02
clsm_7_5_in	10	0.60493	0.00077	0.60647	1.17E-01
clsm_8_5_in	20	0.53022	0.00074	0.53170	2.19E-01
clsm_9_5_in	50	0.47107	0.00068	0.47243	4.69E-01
clsm_10_5_in	100	0.47192	0.00060	0.47312	7.65E-01
6 kg ^{235}U as UO_2F_2					
clsm_1_6_in	0.1	0.80256	0.00050	0.80356	2.19E-03
clsm_2_6_in	0.2	0.97294	0.00069	0.97432	3.28E-03
clsm_3_6_in	0.5	1.04806	0.00082	1.04970	7.16E-03
clsm_4_6_in	1	0.99993	0.00090	1.00173	1.30E-02
clsm_5_6_in	2	0.89927	0.00087	0.90101	2.52E-02
clsm_6_6_in	5	0.74684	0.00088	0.74860	6.08E-02
clsm_7_6_in	10	0.64415	0.00088	0.64591	1.15E-01
clsm_8_6_in	20	0.56537	0.00075	0.56687	2.17E-01
clsm_9_6_in	50	0.50504	0.00066	0.50636	4.62E-01
clsm_10_6_in	100	0.50356	0.00063	0.50482	7.58E-01
7 kg ^{235}U as UO_2F_2					
clsm_1_7_in	0.1	0.81871	0.00049	0.81969	2.14E-03
clsm_2_7_in	0.2	1.00070	0.00066	1.00202	3.28E-03
clsm_3_7_in	0.5	1.08261	0.00084	1.08429	7.05E-03
clsm_4_7_in	1	1.04007	0.00090	1.04187	1.30E-02
clsm_5_7_in	2	0.93932	0.00089	0.94110	2.50E-02
clsm_6_7_in	5	0.78209	0.00088	0.78385	5.98E-02
clsm_7_7_in	10	0.67646	0.00084	0.67814	1.14E-01
clsm_8_7_in	20	0.59529	0.00079	0.59687	2.14E-01
clsm_9_7_in	50	0.53330	0.00070	0.53470	4.58E-01
clsm_10_7_in	100	0.53217	0.00064	0.53345	7.52E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	k_{eff}+2*σ	average E
psteel_1_1_1_in	0	0.2	1.0	0.22864	0.00037	0.22938	9.94E-01
psteel_2_1_1_in	10	0.2	1.0	0.22152	0.00037	0.22226	9.57E-01
psteel_3_1_1_in	20	0.2	1.0	0.21452	0.00037	0.21526	9.10E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_4_1_1_in	30	0.2	1.0	0.20727	0.00039	0.20805	8.65E-01
psteel_5_1_1_in	40	0.2	1.0	0.2006	0.00038	0.20136	8.07E-01
psteel_6_1_1_in	50	0.2	1.0	0.19355	0.00042	0.19439	7.39E-01
psteel_7_1_1_in	60	0.2	1.0	0.18759	0.00039	0.18837	6.58E-01
psteel_8_1_1_in	70	0.2	1.0	0.1839	0.00041	0.18472	5.54E-01
psteel_9_1_1_in	80	0.2	1.0	0.18133	0.00041	0.18215	4.34E-01
psteel_10_1_1_in	90	0.2	1.0	0.1837	0.00041	0.18452	2.78E-01
psteel_11_1_1_in	91	0.2	1.0	0.18493	0.00043	0.18579	2.58E-01
psteel_12_1_1_in	92	0.2	1.0	0.18545	0.00046	0.18637	2.40E-01
psteel_13_1_1_in	93	0.2	1.0	0.1868	0.00044	0.18768	2.17E-01
psteel_14_1_1_in	94	0.2	1.0	0.18764	0.00044	0.18852	1.99E-01
psteel_15_1_1_in	95	0.2	1.0	0.18827	0.00045	0.18917	1.75E-01
psteel_16_1_1_in	96	0.2	1.0	0.18977	0.00043	0.19063	1.50E-01
psteel_17_1_1_in	97	0.2	1.0	0.18838	0.00045	0.18928	1.27E-01
psteel_18_1_1_in	98	0.2	1.0	0.18463	0.0004	0.18543	1.01E-01
psteel_19_1_1_in	99	0.2	1.0	0.16733	0.00035	0.16803	6.97E-02
psteel_20_1_1_in	99.5	0.2	1.0	0.13936	0.00028	0.13992	5.38E-02
psteel_21_1_1_in	99.9	0.2	1.0	0.06039	0.00011	0.06061	3.95E-02
psteel_1_2_1_in	0	0.4	1.0	0.22864	0.00037	0.22938	9.94E-01
psteel_2_2_1_in	10	0.4	1.0	0.22233	0.00037	0.22307	9.51E-01
psteel_3_2_1_in	20	0.4	1.0	0.21469	0.00038	0.21545	9.08E-01
psteel_4_2_1_in	30	0.4	1.0	0.20801	0.0004	0.20881	8.58E-01
psteel_5_2_1_in	40	0.4	1.0	0.20139	0.00037	0.20213	8.00E-01
psteel_6_2_1_in	50	0.4	1.0	0.19567	0.0004	0.19647	7.27E-01
psteel_7_2_1_in	60	0.4	1.0	0.18969	0.00041	0.19051	6.48E-01
psteel_8_2_1_in	70	0.4	1.0	0.18427	0.00041	0.18509	5.48E-01
psteel_9_2_1_in	80	0.4	1.0	0.18097	0.00042	0.18181	4.25E-01
psteel_10_2_1_in	90	0.4	1.0	0.17969	0.00043	0.18055	2.77E-01
psteel_11_2_1_in	91	0.4	1.0	0.18065	0.00039	0.18143	2.55E-01
psteel_12_2_1_in	92	0.4	1.0	0.17986	0.0004	0.18066	2.38E-01
psteel_13_2_1_in	93	0.4	1.0	0.17986	0.00041	0.18068	2.19E-01
psteel_14_2_1_in	94	0.4	1.0	0.17983	0.00043	0.18069	1.98E-01
psteel_15_2_1_in	95	0.4	1.0	0.1778	0.00042	0.17864	1.78E-01
psteel_16_2_1_in	96	0.4	1.0	0.17655	0.00038	0.17731	1.56E-01
psteel_17_2_1_in	97	0.4	1.0	0.1721	0.00038	0.17286	1.33E-01
psteel_18_2_1_in	98	0.4	1.0	0.16213	0.00033	0.16279	1.06E-01
psteel_19_2_1_in	99	0.4	1.0	0.1364	0.00028	0.13696	7.95E-02
psteel_20_2_1_in	99.5	0.4	1.0	0.10372	0.0002	0.10412	6.38E-02
psteel_21_2_1_in	99.9	0.4	1.0	0.03928	0.00007	0.03942	5.12E-02
psteel_1_3_1_in	0	0.6	1.0	0.22864	0.00037	0.22938	9.94E-01
psteel_2_3_1_in	10	0.6	1.0	0.2217	0.00035	0.2224	9.52E-01
psteel_3_3_1_in	20	0.6	1.0	0.21604	0.00041	0.21686	9.04E-01
psteel_4_3_1_in	30	0.6	1.0	0.20894	0.00039	0.20972	8.55E-01
psteel_5_3_1_in	40	0.6	1.0	0.20329	0.00039	0.20407	7.89E-01
psteel_6_3_1_in	50	0.6	1.0	0.1966	0.00038	0.19736	7.19E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_7_3_1_in	60	0.6	1.0	0.19058	0.00039	0.19136	6.41E-01
psteel_8_3_1_in	70	0.6	1.0	0.18489	0.00038	0.18565	5.43E-01
psteel_9_3_1_in	80	0.6	1.0	0.18086	0.0004	0.18166	4.24E-01
psteel_10_3_1_in	90	0.6	1.0	0.176	0.00039	0.17678	2.72E-01
psteel_11_3_1_in	91	0.6	1.0	0.17666	0.0004	0.17746	2.55E-01
psteel_12_3_1_in	92	0.6	1.0	0.17569	0.00039	0.17647	2.36E-01
psteel_13_3_1_in	93	0.6	1.0	0.1747	0.0004	0.1755	2.16E-01
psteel_14_3_1_in	94	0.6	1.0	0.17247	0.00037	0.17321	2.00E-01
psteel_15_3_1_in	95	0.6	1.0	0.17049	0.00037	0.17123	1.79E-01
psteel_16_3_1_in	96	0.6	1.0	0.16603	0.00037	0.16677	1.58E-01
psteel_17_3_1_in	97	0.6	1.0	0.1601	0.00035	0.1608	1.34E-01
psteel_18_3_1_in	98	0.6	1.0	0.14666	0.00031	0.14728	1.10E-01
psteel_19_3_1_in	99	0.6	1.0	0.11807	0.00023	0.11853	8.42E-02
psteel_20_3_1_in	99.5	0.6	1.0	0.08587	0.00016	0.08619	6.96E-02
psteel_21_3_1_in	99.9	0.6	1.0	0.03069	0.00005	0.03079	5.72E-02
psteel_1_4_1_in	0	0.8	1.0	0.22864	0.00037	0.22938	9.94E-01
psteel_2_4_1_in	10	0.8	1.0	0.22275	0.00037	0.22349	9.52E-01
psteel_3_4_1_in	20	0.8	1.0	0.21599	0.00038	0.21675	9.02E-01
psteel_4_4_1_in	30	0.8	1.0	0.21063	0.00041	0.21145	8.44E-01
psteel_5_4_1_in	40	0.8	1.0	0.20397	0.00039	0.20475	7.83E-01
psteel_6_4_1_in	50	0.8	1.0	0.19754	0.00038	0.1983	7.12E-01
psteel_7_4_1_in	60	0.8	1.0	0.19227	0.0004	0.19307	6.27E-01
psteel_8_4_1_in	70	0.8	1.0	0.18605	0.00038	0.18681	5.31E-01
psteel_9_4_1_in	80	0.8	1.0	0.17996	0.00041	0.18078	4.16E-01
psteel_10_4_1_in	90	0.8	1.0	0.17318	0.00038	0.17394	2.70E-01
psteel_11_4_1_in	91	0.8	1.0	0.17221	0.00038	0.17297	2.54E-01
psteel_12_4_1_in	92	0.8	1.0	0.17115	0.00038	0.17191	2.36E-01
psteel_13_4_1_in	93	0.8	1.0	0.16916	0.00038	0.16992	2.17E-01
psteel_14_4_1_in	94	0.8	1.0	0.16741	0.00037	0.16815	1.97E-01
psteel_15_4_1_in	95	0.8	1.0	0.16393	0.00034	0.16461	1.76E-01
psteel_16_4_1_in	96	0.8	1.0	0.15876	0.00036	0.15948	1.58E-01
psteel_17_4_1_in	97	0.8	1.0	0.15004	0.00032	0.15068	1.37E-01
psteel_18_4_1_in	98	0.8	1.0	0.13473	0.00027	0.13527	1.12E-01
psteel_19_4_1_in	99	0.8	1.0	0.10473	0.0002	0.10513	8.92E-02
psteel_20_4_1_in	99.5	0.8	1.0	0.07426	0.00013	0.07452	7.33E-02
psteel_21_4_1_in	99.9	0.8	1.0	0.02582	0.00004	0.0259	6.20E-02
psteel_1_5_1_in	0	1	1.0	0.22864	0.00037	0.22938	9.94E-01
psteel_2_5_1_in	10	1	1.0	0.22274	0.00039	0.22352	9.44E-01
psteel_3_5_1_in	20	1	1.0	0.2173	0.00038	0.21806	8.92E-01
psteel_4_5_1_in	30	1	1.0	0.21081	0.00039	0.21159	8.40E-01
psteel_5_5_1_in	40	1	1.0	0.20477	0.00039	0.20555	7.75E-01
psteel_6_5_1_in	50	1	1.0	0.19809	0.00039	0.19887	7.09E-01
psteel_7_5_1_in	60	1	1.0	0.19228	0.00041	0.1931	6.21E-01
psteel_8_5_1_in	70	1	1.0	0.18594	0.0004	0.18674	5.26E-01
psteel_9_5_1_in	80	1	1.0	0.18049	0.00036	0.18121	4.09E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_10_5_1_in	90	1	1.0	0.17148	0.00036	0.1722	2.65E-01
psteel_11_5_1_in	91	1	1.0	0.16947	0.00038	0.17023	2.51E-01
psteel_12_5_1_in	92	1	1.0	0.16755	0.00037	0.16829	2.32E-01
psteel_13_5_1_in	93	1	1.0	0.16566	0.00036	0.16638	2.15E-01
psteel_14_5_1_in	94	1	1.0	0.16324	0.00034	0.16392	1.95E-01
psteel_15_5_1_in	95	1	1.0	0.15804	0.00034	0.15872	1.79E-01
psteel_16_5_1_in	96	1	1.0	0.15079	0.00034	0.15147	1.58E-01
psteel_17_5_1_in	97	1	1.0	0.14174	0.00031	0.14236	1.39E-01
psteel_18_5_1_in	98	1	1.0	0.12608	0.00026	0.1266	1.13E-01
psteel_19_5_1_in	99	1	1.0	0.09581	0.00018	0.09617	9.12E-02
psteel_20_5_1_in	99.5	1	1.0	0.06632	0.00012	0.06656	7.74E-02
psteel_21_5_1_in	99.9	1	1.0	0.02279	0.00003	0.02285	6.36E-02
psteel_1_1_2_in	0	0.2	4.0	0.40861	0.00054	0.40969	8.67E-01
psteel_2_1_2_in	10	0.2	4.0	0.39574	0.00053	0.3968	8.35E-01
psteel_3_1_2_in	20	0.2	4.0	0.38326	0.00054	0.38434	8.02E-01
psteel_4_1_2_in	30	0.2	4.0	0.3721	0.00052	0.37314	7.55E-01
psteel_5_1_2_in	40	0.2	4.0	0.35857	0.00054	0.35965	7.15E-01
psteel_6_1_2_in	50	0.2	4.0	0.34635	0.00053	0.34741	6.57E-01
psteel_7_1_2_in	60	0.2	4.0	0.33463	0.00052	0.33567	5.89E-01
psteel_8_1_2_in	70	0.2	4.0	0.32378	0.00054	0.32486	5.08E-01
psteel_9_1_2_in	80	0.2	4.0	0.31537	0.00053	0.31643	4.03E-01
psteel_10_1_2_in	90	0.2	4.0	0.30903	0.00055	0.31013	2.65E-01
psteel_11_1_2_in	91	0.2	4.0	0.30776	0.00054	0.30884	2.50E-01
psteel_12_1_2_in	92	0.2	4.0	0.30765	0.00054	0.30873	2.30E-01
psteel_13_1_2_in	93	0.2	4.0	0.30649	0.00051	0.30751	2.13E-01
psteel_14_1_2_in	94	0.2	4.0	0.30578	0.00054	0.30686	1.93E-01
psteel_15_1_2_in	95	0.2	4.0	0.30386	0.00053	0.30492	1.74E-01
psteel_16_1_2_in	96	0.2	4.0	0.30117	0.00052	0.30221	1.51E-01
psteel_17_1_2_in	97	0.2	4.0	0.29622	0.00052	0.29726	1.28E-01
psteel_18_1_2_in	98	0.2	4.0	0.2834	0.00048	0.28436	1.03E-01
psteel_19_1_2_in	99	0.2	4.0	0.24766	0.0004	0.24846	7.32E-02
psteel_20_1_2_in	99.5	0.2	4.0	0.19774	0.00033	0.1984	5.74E-02
psteel_21_1_2_in	99.9	0.2	4.0	0.07949	0.00011	0.07971	4.54E-02
psteel_1_2_2_in	0	0.4	4.0	0.40861	0.00054	0.40969	8.67E-01
psteel_2_2_2_in	10	0.4	4.0	0.39671	0.00053	0.39777	8.33E-01
psteel_3_2_2_in	20	0.4	4.0	0.38507	0.00052	0.38611	7.97E-01
psteel_4_2_2_in	30	0.4	4.0	0.3727	0.00054	0.37378	7.53E-01
psteel_5_2_2_in	40	0.4	4.0	0.3614	0.0005	0.3624	7.01E-01
psteel_6_2_2_in	50	0.4	4.0	0.34928	0.00054	0.35036	6.44E-01
psteel_7_2_2_in	60	0.4	4.0	0.33842	0.00054	0.3395	5.79E-01
psteel_8_2_2_in	70	0.4	4.0	0.32667	0.00052	0.32771	4.92E-01
psteel_9_2_2_in	80	0.4	4.0	0.3155	0.00056	0.31662	3.89E-01
psteel_10_2_2_in	90	0.4	4.0	0.30376	0.00055	0.30486	2.58E-01
psteel_11_2_2_in	91	0.4	4.0	0.30167	0.00053	0.30273	2.41E-01
psteel_12_2_2_in	92	0.4	4.0	0.30026	0.00054	0.30134	2.23E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_13_2_2_in	93	0.4	4.0	0.29713	0.00051	0.29815	2.07E-01
psteel_14_2_2_in	94	0.4	4.0	0.2936	0.00053	0.29466	1.89E-01
psteel_15_2_2_in	95	0.4	4.0	0.29024	0.0005	0.29124	1.70E-01
psteel_16_2_2_in	96	0.4	4.0	0.28302	0.00051	0.28404	1.49E-01
psteel_17_2_2_in	97	0.4	4.0	0.27092	0.00047	0.27186	1.29E-01
psteel_18_2_2_in	98	0.4	4.0	0.25063	0.00041	0.25145	1.04E-01
psteel_19_2_2_in	99	0.4	4.0	0.20224	0.00033	0.2029	7.83E-02
psteel_20_2_2_in*	99.5	0.4	4.0	0.14772	0.00024	0.1482	6.52E-02
psteel_21_2_2_in	99.9	0.4	4.0	0.05196	0.00007	0.0521	5.34E-02
psteel_1_3_2_in	0	0.6	4.0	0.40861	0.00054	0.40969	8.67E-01
psteel_2_3_2_in	10	0.6	4.0	0.39728	0.00053	0.39834	8.29E-01
psteel_3_3_2_in	20	0.6	4.0	0.38733	0.00053	0.38839	7.90E-01
psteel_4_3_2_in	30	0.6	4.0	0.37478	0.00053	0.37584	7.45E-01
psteel_5_3_2_in	40	0.6	4.0	0.36454	0.00052	0.36558	6.91E-01
psteel_6_3_2_in	50	0.6	4.0	0.35186	0.00051	0.35288	6.32E-01
psteel_7_3_2_in	60	0.6	4.0	0.34073	0.00053	0.34179	5.61E-01
psteel_8_3_2_in	70	0.6	4.0	0.32885	0.00053	0.32991	4.78E-01
psteel_9_3_2_in	80	0.6	4.0	0.31584	0.00051	0.31686	3.77E-01
psteel_10_3_2_in	90	0.6	4.0	0.29868	0.0005	0.29968	2.50E-01
psteel_11_3_2_in	91	0.6	4.0	0.29683	0.00053	0.29789	2.32E-01
psteel_12_3_2_in	92	0.6	4.0	0.29337	0.00048	0.29433	2.17E-01
psteel_13_3_2_in	93	0.6	4.0	0.28947	0.00049	0.29045	2.00E-01
psteel_14_3_2_in	94	0.6	4.0	0.28447	0.00048	0.28543	1.83E-01
psteel_15_3_2_in	95	0.6	4.0	0.27772	0.00046	0.27864	1.65E-01
psteel_16_3_2_in	96	0.6	4.0	0.2673	0.00046	0.26822	1.47E-01
psteel_17_3_2_in	97	0.6	4.0	0.25205	0.00041	0.25287	1.25E-01
psteel_18_3_2_in	98	0.6	4.0	0.2264	0.00038	0.22716	1.05E-01
psteel_19_3_2_in	99	0.6	4.0	0.17444	0.0003	0.17504	8.23E-02
psteel_20_3_2_in	99.5	0.6	4.0	0.12232	0.00019	0.1227	6.85E-02
psteel_21_3_2_in	99.9	0.6	4.0	0.04078	0.00006	0.0409	5.66E-02
psteel_1_4_2_in	0	0.8	4.0	0.40861	0.00054	0.40969	8.67E-01
psteel_2_4_2_in	10	0.8	4.0	0.39904	0.00054	0.40012	8.25E-01
psteel_3_4_2_in	20	0.8	4.0	0.38861	0.00051	0.38963	7.81E-01
psteel_4_4_2_in	30	0.8	4.0	0.37712	0.00053	0.37818	7.34E-01
psteel_5_4_2_in	40	0.8	4.0	0.36651	0.00055	0.36761	6.79E-01
psteel_6_4_2_in	50	0.8	4.0	0.35523	0.00054	0.35631	6.19E-01
psteel_7_4_2_in	60	0.8	4.0	0.34255	0.00052	0.34359	5.47E-01
psteel_8_4_2_in	70	0.8	4.0	0.33076	0.00052	0.3318	4.63E-01
psteel_9_4_2_in	80	0.8	4.0	0.31657	0.00052	0.31761	3.64E-01
psteel_10_4_2_in	90	0.8	4.0	0.29546	0.00048	0.29642	2.38E-01
psteel_11_4_2_in	91	0.8	4.0	0.29133	0.00047	0.29227	2.24E-01
psteel_12_4_2_in	92	0.8	4.0	0.28725	0.0005	0.28825	2.10E-01
psteel_13_4_2_in	93	0.8	4.0	0.28229	0.00048	0.28325	1.95E-01
psteel_14_4_2_in	94	0.8	4.0	0.27591	0.00045	0.27681	1.77E-01
psteel_15_4_2_in	95	0.8	4.0	0.26695	0.00045	0.26785	1.60E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_16_4_2_in	96	0.8	4.0	0.25474	0.00043	0.2556	1.42E-01
psteel_17_4_2_in	97	0.8	4.0	0.23709	0.00038	0.23785	1.24E-01
psteel_18_4_2_in	98	0.8	4.0	0.20959	0.00033	0.21025	1.04E-01
psteel_19_4_2_in	99	0.8	4.0	0.15558	0.00024	0.15606	8.34E-02
psteel_20_4_2_in	99.5	0.8	4.0	0.10605	0.00017	0.10639	7.22E-02
psteel_21_4_2_in	99.9	0.8	4.0	0.03529	0.00005	0.03539	5.95E-02
psteel_1_5_2_in	0	1	4.0	0.40861	0.00054	0.40969	8.67E-01
psteel_2_5_2_in	10	1	4.0	0.3991	0.0005	0.4001	8.25E-01
psteel_3_5_2_in	20	1	4.0	0.38871	0.00053	0.38977	7.80E-01
psteel_4_5_2_in	30	1	4.0	0.37893	0.00056	0.38005	7.28E-01
psteel_5_5_2_in	40	1	4.0	0.36825	0.00051	0.36927	6.70E-01
psteel_6_5_2_in	50	1	4.0	0.35717	0.00054	0.35825	6.07E-01
psteel_7_5_2_in	60	1	4.0	0.3459	0.0005	0.3469	5.34E-01
psteel_8_5_2_in	70	1	4.0	0.33251	0.00054	0.33359	4.51E-01
psteel_9_5_2_in	80	1	4.0	0.31575	0.00054	0.31683	3.55E-01
psteel_10_5_2_in	90	1	4.0	0.29054	0.00048	0.2915	2.33E-01
psteel_11_5_2_in	91	1	4.0	0.28673	0.00047	0.28767	2.19E-01
psteel_12_5_2_in	92	1	4.0	0.28263	0.00045	0.28353	2.03E-01
psteel_13_5_2_in	93	1	4.0	0.27515	0.00044	0.27603	1.88E-01
psteel_14_5_2_in	94	1	4.0	0.26772	0.00042	0.26856	1.74E-01
psteel_15_5_2_in	95	1	4.0	0.25881	0.00043	0.25967	1.57E-01
psteel_16_5_2_in	96	1	4.0	0.24474	0.00039	0.24552	1.40E-01
psteel_17_5_2_in	97	1	4.0	0.22599	0.00036	0.22671	1.22E-01
psteel_18_5_2_in	98	1	4.0	0.1955	0.00031	0.19612	1.03E-01
psteel_19_5_2_in	99	1	4.0	0.14253	0.00021	0.14295	8.43E-02
psteel_20_5_2_in	99.5	1	4.0	0.09584	0.00014	0.09612	7.25E-02
psteel_21_5_2_in	99.9	1	4.0	0.03255	0.00004	0.03263	5.93E-02
psteel_1_1_3_in	0	0.2	12.6	0.62378	0.00064	0.62506	7.99E-01
psteel_2_1_3_in	10	0.2	12.6	0.60552	0.00063	0.60678	7.77E-01
psteel_3_1_3_in	20	0.2	12.6	0.58581	0.00061	0.58703	7.47E-01
psteel_4_1_3_in	30	0.2	12.6	0.56473	0.00064	0.56601	7.15E-01
psteel_5_1_3_in	40	0.2	12.6	0.54482	0.00065	0.54612	6.74E-01
psteel_6_1_3_in	50	0.2	12.6	0.52432	0.00063	0.52558	6.26E-01
psteel_7_1_3_in	60	0.2	12.6	0.50276	0.00065	0.50406	5.69E-01
psteel_8_1_3_in	70	0.2	12.6	0.48313	0.00067	0.48447	4.94E-01
psteel_9_1_3_in	80	0.2	12.6	0.46084	0.00066	0.46216	4.01E-01
psteel_10_1_3_in	90	0.2	12.6	0.43714	0.00061	0.43836	2.74E-01
psteel_11_1_3_in	91	0.2	12.6	0.43248	0.00067	0.43382	2.58E-01
psteel_12_1_3_in	92	0.2	12.6	0.43013	0.00061	0.43135	2.39E-01
psteel_13_1_3_in	93	0.2	12.6	0.42522	0.00061	0.42644	2.22E-01
psteel_14_1_3_in	94	0.2	12.6	0.42106	0.00063	0.42232	2.04E-01
psteel_15_1_3_in	95	0.2	12.6	0.41525	0.0006	0.41645	1.82E-01
psteel_16_1_3_in	96	0.2	12.6	0.40653	0.00059	0.40771	1.62E-01
psteel_17_1_3_in	97	0.2	12.6	0.39357	0.00057	0.39471	1.37E-01
psteel_18_1_3_in	98	0.2	12.6	0.3718	0.00054	0.37288	1.11E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_19_1_3_in	99	0.2	12.6	0.31718	0.00046	0.3181	8.07E-02
psteel_20_1_3_in	99.5	0.2	12.6	0.2472	0.00034	0.24788	6.39E-02
psteel_21_1_3_in	99.9	0.2	12.6	0.09546	0.00014	0.09574	4.87E-02
psteel_1_2_3_in	0	0.4	12.6	0.62378	0.00064	0.62506	7.99E-01
psteel_2_2_3_in	10	0.4	12.6	0.60671	0.00067	0.60805	7.72E-01
psteel_3_2_3_in	20	0.4	12.6	0.58783	0.00063	0.58909	7.38E-01
psteel_4_2_3_in	30	0.4	12.6	0.57	0.00066	0.57132	7.01E-01
psteel_5_2_3_in	40	0.4	12.6	0.55064	0.00066	0.55196	6.58E-01
psteel_6_2_3_in	50	0.4	12.6	0.52963	0.00063	0.53089	6.06E-01
psteel_7_2_3_in	60	0.4	12.6	0.51001	0.00061	0.51123	5.44E-01
psteel_8_2_3_in	70	0.4	12.6	0.48664	0.0006	0.48784	4.75E-01
psteel_9_2_3_in	80	0.4	12.6	0.46254	0.00061	0.46376	3.79E-01
psteel_10_2_3_in	90	0.4	12.6	0.43128	0.00064	0.43256	2.55E-01
psteel_11_2_3_in	91	0.4	12.6	0.4264	0.00061	0.42762	2.40E-01
psteel_12_2_3_in	92	0.4	12.6	0.41977	0.0006	0.42097	2.24E-01
psteel_13_2_3_in	93	0.4	12.6	0.41548	0.00062	0.41672	2.08E-01
psteel_14_2_3_in	94	0.4	12.6	0.40603	0.00056	0.40715	1.91E-01
psteel_15_2_3_in	95	0.4	12.6	0.39665	0.00058	0.39781	1.73E-01
psteel_16_2_3_in	96	0.4	12.6	0.38433	0.00054	0.38541	1.53E-01
psteel_17_2_3_in	97	0.4	12.6	0.36353	0.00052	0.36457	1.30E-01
psteel_18_2_3_in	98	0.4	12.6	0.32988	0.00045	0.33078	1.08E-01
psteel_19_2_3_in	99	0.4	12.6	0.25993	0.00036	0.26065	8.20E-02
psteel_20_2_3_in	99.5	0.4	12.6	0.18595	0.00025	0.18645	6.80E-02
psteel_21_2_3_in	99.9	0.4	12.6	0.063	0.00008	0.06316	5.54E-02
psteel_1_3_3_in	0	0.6	12.6	0.62378	0.00064	0.62506	7.99E-01
psteel_2_3_3_in	10	0.6	12.6	0.60742	0.00064	0.6087	7.67E-01
psteel_3_3_3_in	20	0.6	12.6	0.59219	0.00067	0.59353	7.30E-01
psteel_4_3_3_in	30	0.6	12.6	0.57406	0.00066	0.57538	6.88E-01
psteel_5_3_3_in	40	0.6	12.6	0.55641	0.0006	0.55761	6.42E-01
psteel_6_3_3_in	50	0.6	12.6	0.53529	0.00063	0.53655	5.88E-01
psteel_7_3_3_in	60	0.6	12.6	0.51387	0.00062	0.51511	5.26E-01
psteel_8_3_3_in	70	0.6	12.6	0.49125	0.00063	0.49251	4.52E-01
psteel_9_3_3_in	80	0.6	12.6	0.4646	0.00058	0.46576	3.60E-01
psteel_10_3_3_in	90	0.6	12.6	0.42617	0.00054	0.42725	2.40E-01
psteel_11_3_3_in	91	0.6	12.6	0.41854	0.00056	0.41966	2.27E-01
psteel_12_3_3_in	92	0.6	12.6	0.41248	0.00055	0.41358	2.10E-01
psteel_13_3_3_in	93	0.6	12.6	0.40331	0.00056	0.40443	1.96E-01
psteel_14_3_3_in	94	0.6	12.6	0.39404	0.00056	0.39516	1.79E-01
psteel_15_3_3_in	95	0.6	12.6	0.38101	0.00054	0.38209	1.63E-01
psteel_16_3_3_in	96	0.6	12.6	0.36412	0.00051	0.36514	1.45E-01
psteel_17_3_3_in	97	0.6	12.6	0.33839	0.00049	0.33937	1.25E-01
psteel_18_3_3_in	98	0.6	12.6	0.29954	0.0004	0.30034	1.04E-01
psteel_19_3_3_in	99	0.6	12.6	0.22514	0.00032	0.22578	8.23E-02
psteel_20_3_3_in	99.5	0.6	12.6	0.15448	0.00021	0.1549	7.02E-02
psteel_21_3_3_in	99.9	0.6	12.6	0.05158	0.00006	0.0517	5.74E-02

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_1_4_3_in	0	0.8	12.6	0.62378	0.00064	0.62506	7.99E-01
psteel_2_4_3_in	10	0.8	12.6	0.60977	0.00065	0.61107	7.64E-01
psteel_3_4_3_in	20	0.8	12.6	0.59441	0.00065	0.59571	7.22E-01
psteel_4_4_3_in	30	0.8	12.6	0.57733	0.00064	0.57861	6.78E-01
psteel_5_4_3_in	40	0.8	12.6	0.56075	0.00059	0.56193	6.27E-01
psteel_6_4_3_in	50	0.8	12.6	0.54011	0.00059	0.54129	5.72E-01
psteel_7_4_3_in	60	0.8	12.6	0.51956	0.00065	0.52086	5.06E-01
psteel_8_4_3_in	70	0.8	12.6	0.49491	0.0006	0.49611	4.33E-01
psteel_9_4_3_in	80	0.8	12.6	0.4654	0.00061	0.46662	3.43E-01
psteel_10_4_3_in	90	0.8	12.6	0.42097	0.00057	0.42211	2.27E-01
psteel_11_4_3_in	91	0.8	12.6	0.41356	0.00055	0.41466	2.15E-01
psteel_12_4_3_in	92	0.8	12.6	0.40507	0.00057	0.40621	1.99E-01
psteel_13_4_3_in	93	0.8	12.6	0.3941	0.00055	0.3952	1.86E-01
psteel_14_4_3_in	94	0.8	12.6	0.38227	0.00053	0.38333	1.71E-01
psteel_15_4_3_in	95	0.8	12.6	0.36848	0.00049	0.36946	1.55E-01
psteel_16_4_3_in	96	0.8	12.6	0.34778	0.00048	0.34874	1.38E-01
psteel_17_4_3_in	97	0.8	12.6	0.31974	0.00046	0.32066	1.21E-01
psteel_18_4_3_in	98	0.8	12.6	0.27746	0.00037	0.2782	1.02E-01
psteel_19_4_3_in	99	0.8	12.6	0.20251	0.00027	0.20305	8.24E-02
psteel_20_4_3_in	99.5	0.8	12.6	0.13676	0.00018	0.13712	7.01E-02
psteel_21_4_3_in	99.9	0.8	12.6	0.04709	0.00006	0.04721	5.81E-02
psteel_1_5_3_in	0	1	12.6	0.62378	0.00064	0.62506	7.99E-01
psteel_2_5_3_in	10	1	12.6	0.61101	0.00066	0.61233	7.61E-01
psteel_3_5_3_in	20	1	12.6	0.59802	0.00063	0.59928	7.14E-01
psteel_4_5_3_in	30	1	12.6	0.58168	0.00061	0.5829	6.66E-01
psteel_5_5_3_in	40	1	12.6	0.56363	0.00065	0.56493	6.14E-01
psteel_6_5_3_in	50	1	12.6	0.54465	0.00064	0.54593	5.57E-01
psteel_7_5_3_in	60	1	12.6	0.52237	0.00059	0.52355	4.91E-01
psteel_8_5_3_in	70	1	12.6	0.49991	0.00063	0.50117	4.13E-01
psteel_9_5_3_in	80	1	12.6	0.46522	0.00061	0.46644	3.28E-01
psteel_10_5_3_in	90	1	12.6	0.41458	0.00054	0.41566	2.17E-01
psteel_11_5_3_in	91	1	12.6	0.40743	0.00058	0.40859	2.03E-01
psteel_12_5_3_in	92	1	12.6	0.399	0.00052	0.40004	1.90E-01
psteel_13_5_3_in	93	1	12.6	0.3872	0.00053	0.38826	1.77E-01
psteel_14_5_3_in	94	1	12.6	0.37286	0.00054	0.37394	1.63E-01
psteel_15_5_3_in	95	1	12.6	0.35637	0.00049	0.35735	1.48E-01
psteel_16_5_3_in	96	1	12.6	0.33484	0.00045	0.33574	1.32E-01
psteel_17_5_3_in	97	1	12.6	0.30583	0.00042	0.30667	1.16E-01
psteel_18_5_3_in	98	1	12.6	0.26187	0.00036	0.26259	9.91E-02
psteel_19_5_3_in	99	1	12.6	0.18812	0.00024	0.1886	8.06E-02
psteel_20_5_3_in	99.5	1	12.6	0.12684	0.00016	0.12716	6.94E-02
psteel_21_5_3_in	99.9	1	12.6	0.0454	0.00005	0.0455	5.54E-02
psteel_1_1_4_in	0	0.2	25.2	0.78218	0.00065	0.78348	7.76E-01
psteel_2_1_4_in	10	0.2	25.2	0.75769	0.00072	0.75913	7.52E-01
psteel_3_1_4_in	20	0.2	25.2	0.73408	0.0007	0.73548	7.27E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_4_1_4_in	30	0.2	25.2	0.70894	0.00073	0.7104	6.95E-01
psteel_5_1_4_in	40	0.2	25.2	0.68324	0.00072	0.68468	6.60E-01
psteel_6_1_4_in	50	0.2	25.2	0.65533	0.00069	0.65671	6.17E-01
psteel_7_1_4_in	60	0.2	25.2	0.62697	0.00069	0.62835	5.64E-01
psteel_8_1_4_in	70	0.2	25.2	0.59691	0.00067	0.59825	4.95E-01
psteel_9_1_4_in	80	0.2	25.2	0.56237	0.00067	0.56371	4.09E-01
psteel_10_1_4_in	90	0.2	25.2	0.52158	0.00067	0.52292	2.84E-01
psteel_11_1_4_in	91	0.2	25.2	0.51588	0.00069	0.51726	2.67E-01
psteel_12_1_4_in	92	0.2	25.2	0.51018	0.00064	0.51146	2.50E-01
psteel_13_1_4_in	93	0.2	25.2	0.50492	0.00064	0.5062	2.31E-01
psteel_14_1_4_in	94	0.2	25.2	0.49709	0.00061	0.49831	2.13E-01
psteel_15_1_4_in	95	0.2	25.2	0.4879	0.00065	0.4892	1.91E-01
psteel_16_1_4_in	96	0.2	25.2	0.47467	0.00065	0.47597	1.70E-01
psteel_17_1_4_in	97	0.2	25.2	0.45658	0.00061	0.4578	1.45E-01
psteel_18_1_4_in	98	0.2	25.2	0.42649	0.00057	0.42763	1.18E-01
psteel_19_1_4_in	99	0.2	25.2	0.3609	0.00047	0.36184	8.53E-02
psteel_20_1_4_in	99.5	0.2	25.2	0.27619	0.00035	0.27689	6.78E-02
psteel_21_1_4_in	99.9	0.2	25.2	0.10514	0.00014	0.10542	5.21E-02
psteel_1_2_4_in	0	0.4	25.2	0.78218	0.00065	0.78348	7.76E-01
psteel_2_2_4_in	10	0.4	25.2	0.76084	0.00069	0.76222	7.47E-01
psteel_3_2_4_in	20	0.4	25.2	0.73832	0.00073	0.73978	7.17E-01
psteel_4_2_4_in	30	0.4	25.2	0.71536	0.0007	0.71676	6.81E-01
psteel_5_2_4_in	40	0.4	25.2	0.69019	0.0007	0.69159	6.41E-01
psteel_6_2_4_in	50	0.4	25.2	0.6625	0.00069	0.66388	5.93E-01
psteel_7_2_4_in	60	0.4	25.2	0.63433	0.00067	0.63567	5.36E-01
psteel_8_2_4_in	70	0.4	25.2	0.60225	0.00066	0.60357	4.70E-01
psteel_9_2_4_in	80	0.4	25.2	0.5676	0.00069	0.56898	3.79E-01
psteel_10_2_4_in	90	0.4	25.2	0.51765	0.00066	0.51897	2.59E-01
psteel_11_2_4_in	91	0.4	25.2	0.5095	0.00061	0.51072	2.44E-01
psteel_12_2_4_in	92	0.4	25.2	0.50133	0.00062	0.50257	2.28E-01
psteel_13_2_4_in	93	0.4	25.2	0.4924	0.00063	0.49366	2.11E-01
psteel_14_2_4_in	94	0.4	25.2	0.48211	0.0006	0.48331	1.93E-01
psteel_15_2_4_in	95	0.4	25.2	0.46681	0.00056	0.46793	1.74E-01
psteel_16_2_4_in	96	0.4	25.2	0.44891	0.0006	0.45011	1.56E-01
psteel_17_2_4_in	97	0.4	25.2	0.42137	0.00055	0.42247	1.35E-01
psteel_18_2_4_in	98	0.4	25.2	0.37905	0.00047	0.37999	1.10E-01
psteel_19_2_4_in	99	0.4	25.2	0.29538	0.00037	0.29612	8.34E-02
psteel_20_2_4_in	99.5	0.4	25.2	0.20921	0.00027	0.20975	6.95E-02
psteel_21_2_4_in	99.9	0.4	25.2	0.07121	0.00009	0.07139	5.64E-02
psteel_1_3_4_in	0	0.6	25.2	0.78218	0.00065	0.78348	7.76E-01
psteel_2_3_4_in	10	0.6	25.2	0.763	0.00068	0.76436	7.43E-01
psteel_3_3_4_in	20	0.6	25.2	0.74186	0.00073	0.74332	7.08E-01
psteel_4_3_4_in	30	0.6	25.2	0.72079	0.0007	0.72219	6.65E-01
psteel_5_3_4_in	40	0.6	25.2	0.69649	0.0007	0.69789	6.22E-01
psteel_6_3_4_in	50	0.6	25.2	0.66991	0.0007	0.67131	5.73E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_7_3_4_in	60	0.6	25.2	0.64272	0.00069	0.6441	5.14E-01
psteel_8_3_4_in	70	0.6	25.2	0.60941	0.00065	0.61071	4.42E-01
psteel_9_3_4_in	80	0.6	25.2	0.56857	0.00066	0.56989	3.55E-01
psteel_10_3_4_in	90	0.6	25.2	0.51116	0.00059	0.51234	2.38E-01
psteel_11_3_4_in	91	0.6	25.2	0.50243	0.00061	0.50365	2.24E-01
psteel_12_3_4_in	92	0.6	25.2	0.49166	0.00059	0.49284	2.11E-01
psteel_13_3_4_in	93	0.6	25.2	0.48031	0.00055	0.48141	1.96E-01
psteel_14_3_4_in	94	0.6	25.2	0.46643	0.00055	0.46753	1.79E-01
psteel_15_3_4_in	95	0.6	25.2	0.44944	0.00056	0.45056	1.63E-01
psteel_16_3_4_in	96	0.6	25.2	0.42561	0.00057	0.42675	1.44E-01
psteel_17_3_4_in	97	0.6	25.2	0.39514	0.0005	0.39614	1.25E-01
psteel_18_3_4_in	98	0.6	25.2	0.34704	0.00045	0.34794	1.05E-01
psteel_19_3_4_in	99	0.6	25.2	0.25763	0.00031	0.25825	8.22E-02
psteel_20_3_4_in	99.5	0.6	25.2	0.17665	0.00022	0.17709	6.95E-02
psteel_21_3_4_in	99.9	0.6	25.2	0.06086	0.00007	0.061	5.62E-02
psteel_1_4_4_in	0	0.8	25.2	0.78218	0.00065	0.78348	7.76E-01
psteel_2_4_4_in	10	0.8	25.2	0.76617	0.00072	0.76761	7.39E-01
psteel_3_4_4_in	20	0.8	25.2	0.74691	0.00076	0.74843	6.97E-01
psteel_4_4_4_in	30	0.8	25.2	0.72523	0.00067	0.72657	6.53E-01
psteel_5_4_4_in	40	0.8	25.2	0.70228	0.00067	0.70362	6.05E-01
psteel_6_4_4_in	50	0.8	25.2	0.67756	0.00072	0.679	5.50E-01
psteel_7_4_4_in	60	0.8	25.2	0.64845	0.0007	0.64985	4.90E-01
psteel_8_4_4_in	70	0.8	25.2	0.61524	0.00069	0.61662	4.20E-01
psteel_9_4_4_in	80	0.8	25.2	0.5722	0.00066	0.57352	3.35E-01
psteel_10_4_4_in	90	0.8	25.2	0.5051	0.00061	0.50632	2.24E-01
psteel_11_4_4_in	91	0.8	25.2	0.49533	0.00053	0.49639	2.11E-01
psteel_12_4_4_in	92	0.8	25.2	0.48321	0.00058	0.48437	1.96E-01
psteel_13_4_4_in	93	0.8	25.2	0.47054	0.00058	0.4717	1.83E-01
psteel_14_4_4_in	94	0.8	25.2	0.45412	0.00057	0.45526	1.69E-01
psteel_15_4_4_in	95	0.8	25.2	0.43431	0.00055	0.43541	1.53E-01
psteel_16_4_4_in	96	0.8	25.2	0.40898	0.00049	0.40996	1.36E-01
psteel_17_4_4_in	97	0.8	25.2	0.37387	0.00044	0.37475	1.20E-01
psteel_18_4_4_in	98	0.8	25.2	0.32215	0.0004	0.32295	1.02E-01
psteel_19_4_4_in	99	0.8	25.2	0.23456	0.0003	0.23516	8.15E-02
psteel_20_4_4_in	99.5	0.8	25.2	0.15957	0.00019	0.15995	6.97E-02
psteel_21_4_4_in	99.9	0.8	25.2	0.05748	0.00006	0.0576	5.50E-02
psteel_1_5_4_in	0	1	25.2	0.78218	0.00065	0.78348	7.76E-01
psteel_2_5_4_in	10	1	25.2	0.76809	0.0007	0.76949	7.32E-01
psteel_3_5_4_in	20	1	25.2	0.75016	0.00073	0.75162	6.88E-01
psteel_4_5_4_in	30	1	25.2	0.7299	0.00072	0.73134	6.41E-01
psteel_5_5_4_in	40	1	25.2	0.70795	0.00072	0.70939	5.92E-01
psteel_6_5_4_in	50	1	25.2	0.68456	0.00067	0.6859	5.33E-01
psteel_7_5_4_in	60	1	25.2	0.6539	0.00069	0.65528	4.71E-01
psteel_8_5_4_in	70	1	25.2	0.6184	0.00068	0.61976	3.99E-01
psteel_9_5_4_in	80	1	25.2	0.57501	0.00066	0.57633	3.14E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_10_5_4_in	90	1	25.2	0.50111	0.00058	0.50227	2.11E-01
psteel_11_5_4_in	91	1	25.2	0.49034	0.00058	0.4915	1.98E-01
psteel_12_5_4_in	92	1	25.2	0.47661	0.00057	0.47775	1.86E-01
psteel_13_5_4_in	93	1	25.2	0.46315	0.00056	0.46427	1.72E-01
psteel_14_5_4_in	94	1	25.2	0.44498	0.00053	0.44604	1.59E-01
psteel_15_5_4_in	95	1	25.2	0.42364	0.0005	0.42464	1.46E-01
psteel_16_5_4_in	96	1	25.2	0.39601	0.00045	0.39691	1.30E-01
psteel_17_5_4_in	97	1	25.2	0.35915	0.00041	0.35997	1.15E-01
psteel_18_5_4_in	98	1	25.2	0.30774	0.00036	0.30846	9.86E-02
psteel_19_5_4_in	99	1	25.2	0.22219	0.00027	0.22273	7.91E-02
psteel_20_5_4_in	99.5	1	25.2	0.15212	0.00017	0.15246	6.79E-02
psteel_21_5_4_in	99.9	1	25.2	0.05563	0.00005	0.05573	5.18E-02
psteel_1_1_5_in	0	0.2	30.2	0.82787	0.00068	0.82923	7.68E-01
psteel_2_1_5_in	10	0.2	30.2	0.80297	0.00068	0.80433	7.47E-01
psteel_3_1_5_in	20	0.2	30.2	0.77685	0.00068	0.77821	7.23E-01
psteel_4_1_5_in	30	0.2	30.2	0.7496	0.00068	0.75096	6.92E-01
psteel_5_1_5_in	40	0.2	30.2	0.71999	0.00072	0.72143	6.56E-01
psteel_6_1_5_in*	50	0.2	30.2	0.6927	0.00071	0.69412	6.15E-01
psteel_7_1_5_in	60	0.2	30.2	0.66045	0.00073	0.66191	5.64E-01
psteel_8_1_5_in	70	0.2	30.2	0.62733	0.00066	0.62865	4.97E-01
psteel_9_1_5_in	80	0.2	30.2	0.59103	0.00067	0.59237	4.10E-01
psteel_10_1_5_in	90	0.2	30.2	0.54525	0.00069	0.54663	2.85E-01
psteel_11_1_5_in	91	0.2	30.2	0.53872	0.00067	0.54006	2.71E-01
psteel_12_1_5_in	92	0.2	30.2	0.53206	0.00064	0.53334	2.54E-01
psteel_13_1_5_in	93	0.2	30.2	0.52553	0.0007	0.52693	2.35E-01
psteel_14_1_5_in	94	0.2	30.2	0.51786	0.0007	0.51926	2.15E-01
psteel_15_1_5_in	95	0.2	30.2	0.50644	0.00066	0.50776	1.95E-01
psteel_16_1_5_in	96	0.2	30.2	0.49172	0.00064	0.493	1.73E-01
psteel_17_1_5_in	97	0.2	30.2	0.47226	0.00061	0.47348	1.48E-01
psteel_18_1_5_in	98	0.2	30.2	0.44028	0.00057	0.44142	1.20E-01
psteel_19_1_5_in	99	0.2	30.2	0.37101	0.00049	0.37199	8.70E-02
psteel_20_1_5_in	99.5	0.2	30.2	0.28481	0.00037	0.28555	6.85E-02
psteel_21_1_5_in	99.9	0.2	30.2	0.10786	0.00014	0.10814	5.15E-02
psteel_1_2_5_in	0	0.4	30.2	0.82787	0.00068	0.82923	7.68E-01
psteel_2_2_5_in	10	0.4	30.2	0.80495	0.00069	0.80633	7.41E-01
psteel_3_2_5_in	20	0.4	30.2	0.78115	0.00074	0.78263	7.12E-01
psteel_4_2_5_in	30	0.4	30.2	0.75541	0.00067	0.75675	6.78E-01
psteel_5_2_5_in	40	0.4	30.2	0.72861	0.00073	0.73007	6.40E-01
psteel_6_2_5_in	50	0.4	30.2	0.70018	0.00071	0.7016	5.92E-01
psteel_7_2_5_in	60	0.4	30.2	0.66884	0.00067	0.67018	5.37E-01
psteel_8_2_5_in	70	0.4	30.2	0.63598	0.00069	0.63736	4.67E-01
psteel_9_2_5_in	80	0.4	30.2	0.59637	0.00068	0.59773	3.79E-01
psteel_10_2_5_in	90	0.4	30.2	0.5391	0.00066	0.54042	2.61E-01
psteel_11_2_5_in	91	0.4	30.2	0.53213	0.00067	0.53347	2.45E-01
psteel_12_2_5_in	92	0.4	30.2	0.52316	0.00061	0.52438	2.29E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_13_2_5_in	93	0.4	30.2	0.51318	0.00061	0.5144	2.12E-01
psteel_14_2_5_in	94	0.4	30.2	0.49984	0.00065	0.50114	1.95E-01
psteel_15_2_5_in	95	0.4	30.2	0.48513	0.00057	0.48627	1.77E-01
psteel_16_2_5_in	96	0.4	30.2	0.46528	0.00059	0.46646	1.57E-01
psteel_17_2_5_in	97	0.4	30.2	0.43813	0.00053	0.43919	1.35E-01
psteel_18_2_5_in	98	0.4	30.2	0.39295	0.0005	0.39395	1.11E-01
psteel_19_2_5_in	99	0.4	30.2	0.30513	0.00039	0.30591	8.40E-02
psteel_20_2_5_in	99.5	0.4	30.2	0.21577	0.00027	0.21631	7.08E-02
psteel_21_2_5_in	99.9	0.4	30.2	0.07365	0.00009	0.07383	5.53E-02
psteel_1_3_5_in	0	0.6	30.2	0.82787	0.00068	0.82923	7.68E-01
psteel_2_3_5_in	10	0.6	30.2	0.80695	0.00078	0.80851	7.37E-01
psteel_3_3_5_in	20	0.6	30.2	0.78565	0.00073	0.78711	7.01E-01
psteel_4_3_5_in	30	0.6	30.2	0.76211	0.00073	0.76357	6.62E-01
psteel_5_3_5_in	40	0.6	30.2	0.73567	0.00072	0.73711	6.20E-01
psteel_6_3_5_in	50	0.6	30.2	0.70883	0.00067	0.71017	5.68E-01
psteel_7_3_5_in	60	0.6	30.2	0.67704	0.0007	0.67844	5.10E-01
psteel_8_3_5_in	70	0.6	30.2	0.64227	0.00067	0.64361	4.40E-01
psteel_9_3_5_in	80	0.6	30.2	0.59939	0.00063	0.60065	3.53E-01
psteel_10_3_5_in	90	0.6	30.2	0.53548	0.00064	0.53676	2.39E-01
psteel_11_3_5_in	91	0.6	30.2	0.52426	0.00061	0.52548	2.25E-01
psteel_12_3_5_in	92	0.6	30.2	0.51459	0.00061	0.51581	2.11E-01
psteel_13_3_5_in	93	0.6	30.2	0.50076	0.0006	0.50196	1.96E-01
psteel_14_3_5_in	94	0.6	30.2	0.48632	0.00057	0.48746	1.79E-01
psteel_15_3_5_in	95	0.6	30.2	0.46724	0.00054	0.46832	1.64E-01
psteel_16_3_5_in	96	0.6	30.2	0.44282	0.00054	0.4439	1.46E-01
psteel_17_3_5_in	97	0.6	30.2	0.41019	0.00054	0.41127	1.26E-01
psteel_18_3_5_in	98	0.6	30.2	0.35907	0.00045	0.35997	1.05E-01
psteel_19_3_5_in	99	0.6	30.2	0.26691	0.00035	0.26761	8.30E-02
psteel_20_3_5_in	99.5	0.6	30.2	0.18263	0.00024	0.18311	7.03E-02
psteel_21_3_5_in	99.9	0.6	30.2	0.06364	0.00007	0.06378	5.58E-02
psteel_1_4_5_in	0	0.8	30.2	0.82787	0.00068	0.82923	7.68E-01
psteel_2_4_5_in	10	0.8	30.2	0.80871	0.00075	0.81021	7.31E-01
psteel_3_4_5_in	20	0.8	30.2	0.79011	0.00075	0.79161	6.92E-01
psteel_4_4_5_in	30	0.8	30.2	0.76763	0.00073	0.76909	6.47E-01
psteel_5_4_5_in	40	0.8	30.2	0.74221	0.00069	0.74359	6.01E-01
psteel_6_4_5_in	50	0.8	30.2	0.71397	0.0007	0.71537	5.47E-01
psteel_7_4_5_in	60	0.8	30.2	0.68554	0.00068	0.6869	4.87E-01
psteel_8_4_5_in	70	0.8	30.2	0.64859	0.00069	0.64997	4.17E-01
psteel_9_4_5_in	80	0.8	30.2	0.60183	0.00067	0.60317	3.30E-01
psteel_10_4_5_in	90	0.8	30.2	0.52814	0.00062	0.52938	2.23E-01
psteel_11_4_5_in	91	0.8	30.2	0.51896	0.00058	0.52012	2.09E-01
psteel_12_4_5_in	92	0.8	30.2	0.50452	0.0006	0.50572	1.96E-01
psteel_13_4_5_in	93	0.8	30.2	0.49166	0.00058	0.49282	1.83E-01
psteel_14_4_5_in	94	0.8	30.2	0.47325	0.00057	0.47439	1.68E-01
psteel_15_4_5_in	95	0.8	30.2	0.45283	0.00055	0.45393	1.52E-01

Table B-2 Steel Spheres

File Name	v/o Steel	Packing Fraction	^{235}U Mass (kg)	k_{eff}	σ	$k_{eff}+2*\sigma$	average E
psteel_16_4_5_in	96	0.8	30.2	0.42486	0.0005	0.42586	1.37E-01
psteel_17_4_5_in	97	0.8	30.2	0.38922	0.00046	0.39014	1.19E-01
psteel_18_4_5_in	98	0.8	30.2	0.33535	0.00039	0.33613	1.01E-01
psteel_19_4_5_in	99	0.8	30.2	0.24455	0.0003	0.24515	8.11E-02
psteel_20_4_5_in	99.5	0.8	30.2	0.16627	0.0002	0.16667	6.93E-02
psteel_21_4_5_in	99.9	0.8	30.2	0.06057	0.00006	0.06069	5.38E-02
psteel_1_5_5_in	0	1	30.2	0.82787	0.00068	0.82923	7.68E-01
psteel_2_5_5_in	10	1	30.2	0.81208	0.0007	0.81348	7.25E-01
psteel_3_5_5_in	20	1	30.2	0.79248	0.0007	0.79388	6.83E-01
psteel_4_5_5_in	30	1	30.2	0.77254	0.00067	0.77388	6.34E-01
psteel_5_5_5_in	40	1	30.2	0.75026	0.00071	0.75168	5.83E-01
psteel_6_5_5_in	50	1	30.2	0.72157	0.00072	0.72301	5.29E-01
psteel_7_5_5_in	60	1	30.2	0.6903	0.00069	0.69168	4.66E-01
psteel_8_5_5_in	70	1	30.2	0.65325	0.00063	0.65451	3.95E-01
psteel_9_5_5_in	80	1	30.2	0.60392	0.00066	0.60524	3.11E-01
psteel_10_5_5_in	90	1	30.2	0.52475	0.00061	0.52597	2.08E-01
psteel_11_5_5_in	91	1	30.2	0.51227	0.00059	0.51345	1.97E-01
psteel_12_5_5_in	92	1	30.2	0.49876	0.00059	0.49994	1.84E-01
psteel_13_5_5_in	93	1	30.2	0.48342	0.00056	0.48454	1.71E-01
psteel_14_5_5_in	94	1	30.2	0.46428	0.00055	0.46538	1.58E-01
psteel_15_5_5_in	95	1	30.2	0.44186	0.00051	0.44288	1.44E-01
psteel_16_5_5_in	96	1	30.2	0.41265	0.00049	0.41363	1.29E-01
psteel_17_5_5_in	97	1	30.2	0.37525	0.00045	0.37615	1.14E-01
psteel_18_5_5_in	98	1	30.2	0.32065	0.00038	0.32141	9.70E-02
psteel_19_5_5_in	99	1	30.2	0.23224	0.00027	0.23278	7.83E-02
psteel_20_5_5_in	99.5	1	30.2	0.16003	0.00018	0.16039	6.74E-02
psteel_21_5_5_in	99.9	1	30.2	0.05855	0.00005	0.05865	5.06E-02

Table B-3 Salt Spheres

Case	v/o Salt	k_{eff}	σ	$k_{eff}+2\sigma$
		1 kg ^{235}U		
salt_1_in	0	0.1564	0.00014	0.15668
salt_2_in	10	0.14685	0.00013	0.14711
salt_3_in	20	0.13733	0.00014	0.13761
salt_4_in	30	0.12697	0.00012	0.12721
salt_5_in	40	0.11626	0.00012	0.1165
salt_6_in	50	0.10494	0.0001	0.10514
salt_7_in	60	0.09286	0.0001	0.09306
salt_8_in*	70	0.07958	0.00008	0.07974
salt_9_in	80	0.06475	0.00008	0.06491
salt_10_in	90	0.04654	0.00006	0.04666
salt_11_in	91	0.04428	0.00006	0.0444
salt_12_in	92	0.04206	0.00006	0.04218
salt_13_in	93	0.03963	0.00006	0.03975
salt_14_in	94	0.03726	0.00006	0.03738
salt_15_in	95	0.03462	0.00005	0.03472
salt_16_in	96	0.0316	0.00005	0.0317
salt_17_in	97	0.02834	0.00005	0.02844
salt_18_in	98	0.02453	0.00005	0.02463
salt_19_in	99	0.01951	0.00004	0.01959

Table B-4 Dry Sand Spheres (ρ = 2.2 g/cc)

File Name	v/o Sand	k_{eff}	σ	k_{eff} +2 σ	average E
1.0 kg					
sand_1_1_in	0	0.24384	0.00040	0.24464	8.956E-01
sand_2_1_in	10	0.23795	0.00042	0.23879	8.585E-01
sand_3_1_in	20	0.23366	0.00041	0.23448	8.051E-01
sand_4_1_in	30	0.22888	0.00044	0.22976	7.558E-01
sand_5_1_in	40	0.22477	0.00045	0.22567	6.916E-01
sand_6_1_in	50	0.22093	0.00043	0.22179	6.254E-01
sand_7_1_in	60	0.21813	0.00047	0.21907	5.463E-01
sand_8_1_in	70	0.21932	0.00047	0.22026	4.548E-01
sand_9_1_in	80	0.22214	0.00047	0.22308	3.445E-01
sand_10_1_in	90	0.23781	0.00050	0.23881	2.091E-01
sand_11_1_in	91	0.23996	0.00049	0.24094	1.929E-01
sand_12_1_in	92	0.24514	0.00054	0.24622	1.764E-01
sand_13_1_in	93	0.24888	0.00053	0.24994	1.584E-01
sand_14_1_in	94	0.25296	0.00048	0.25392	1.414E-01
sand_15_1_in	95	0.25894	0.00055	0.26004	1.227E-01
sand_16_1_in	96	0.26787	0.00055	0.26897	1.032E-01
sand_17_1_in	97	0.27652	0.00058	0.27768	8.294E-02
sand_18_1_in	98	0.28940	0.00059	0.29058	6.128E-02
sand_19_1_in	99	0.30650	0.00059	0.30768	3.666E-02
sand_20_1_in	99.5	0.31356	0.00054	0.31464	2.222E-02
sand_21_1_in	99.9	0.26809	0.00044	0.26897	7.959E-03
4.0 kg					
sand_1_2_in	0	0.42595	0.00055	0.42705	8.022E-01
sand_2_2_in	10	0.41688	0.00054	0.41796	7.662E-01
sand_3_2_in	20	0.40855	0.00055	0.40965	7.250E-01
sand_4_2_in	30	0.39994	0.00056	0.40106	6.806E-01
sand_5_2_in	40	0.39229	0.00057	0.39343	6.265E-01
sand_6_2_in	50	0.38444	0.00057	0.38558	5.682E-01
sand_7_2_in	60	0.37796	0.00060	0.37916	5.004E-01
sand_8_2_in	70	0.37434	0.00060	0.37554	4.184E-01
sand_9_2_in	80	0.37504	0.00059	0.37622	3.227E-01
sand_10_2_in	90	0.38750	0.00065	0.38880	1.999E-01
sand_11_2_in	91	0.39043	0.00063	0.39169	1.841E-01
sand_12_2_in	92	0.39375	0.00065	0.39505	1.697E-01
sand_13_2_in	93	0.39765	0.00067	0.39899	1.535E-01
sand_14_2_in	94	0.40336	0.00063	0.40462	1.377E-01
sand_15_2_in	95	0.40733	0.00065	0.40863	1.201E-01
sand_16_2_in	96	0.41820	0.00066	0.41952	1.008E-01
sand_17_2_in	97	0.42694	0.00069	0.42832	8.122E-02
sand_18_2_in	98	0.43993	0.00070	0.44133	6.005E-02
sand_19_2_in	99	0.45667	0.00072	0.45811	3.557E-02
sand_20_2_in	99.5	0.46463	0.00067	0.46597	2.066E-02
sand_21_2_in	99.9	0.42022	0.00051	0.42124	6.226E-03

Table B-4 Dry Sand Spheres (ρ = 2.2 g/cc)

File Name	v/o Sand	k_{eff}	σ	k_{eff} +2 σ	average E
12.6 kg					
sand_1_3_in	0	0.63901	0.00066	0.64033	7.564E-01
sand_2_3_in	10	0.62468	0.00067	0.62602	7.240E-01
sand_3_3_in	20	0.61162	0.00066	0.61294	6.876E-01
sand_4_3_in	30	0.59893	0.00071	0.60035	6.454E-01
sand_5_3_in	40	0.58501	0.00069	0.58639	5.999E-01
sand_6_3_in	50	0.57095	0.00068	0.57231	5.452E-01
sand_7_3_in	60	0.55791	0.00068	0.55927	4.858E-01
sand_8_3_in	70	0.54646	0.00068	0.54782	4.119E-01
sand_9_3_in	80	0.53803	0.00070	0.53943	3.200E-01
sand_10_3_in	90	0.54064	0.00072	0.54208	1.989E-01
sand_11_3_in	91	0.54286	0.00071	0.54428	1.848E-01
sand_12_3_in	92	0.54463	0.00072	0.54607	1.700E-01
sand_13_3_in	93	0.54633	0.00072	0.54777	1.552E-01
sand_14_3_in	94	0.55063	0.00072	0.55207	1.393E-01
sand_15_3_in	95	0.55464	0.00072	0.55608	1.212E-01
sand_16_3_in	96	0.56181	0.00075	0.56331	1.018E-01
sand_17_3_in	97	0.57004	0.00076	0.57156	8.117E-02
sand_18_3_in	98	0.58151	0.00069	0.58289	5.941E-02
sand_19_3_in	99	0.59961	0.00074	0.60109	3.378E-02
sand_20_3_in	99.5	0.61430	0.00074	0.61578	1.958E-02
sand_21_3_in	99.9	0.60197	0.00061	0.60319	5.329E-03
25.2 kg					
sand_1_4_in	0	0.79295	0.00074	0.79443	7.380E-01
sand_2_4_in	10	0.77625	0.00069	0.77763	7.074E-01
sand_3_4_in	20	0.76003	0.00072	0.76147	6.752E-01
sand_4_4_in	30	0.74241	0.00074	0.74389	6.376E-01
sand_5_4_in	40	0.72450	0.00071	0.72592	5.928E-01
sand_6_4_in	50	0.70623	0.00072	0.70767	5.429E-01
sand_7_4_in	60	0.68726	0.00070	0.68866	4.834E-01
sand_8_4_in	70	0.66801	0.00071	0.66943	4.125E-01
sand_9_4_in	80	0.65234	0.00075	0.65384	3.228E-01
sand_10_4_in	90	0.64449	0.00074	0.64597	2.025E-01
sand_11_4_in	91	0.64501	0.00076	0.64653	1.878E-01
sand_12_4_in	92	0.64687	0.00079	0.64845	1.721E-01
sand_13_4_in	93	0.64843	0.00077	0.64997	1.555E-01
sand_14_4_in	94	0.64823	0.00082	0.64987	1.391E-01
sand_15_4_in	95	0.65327	0.00076	0.65479	1.206E-01
sand_16_4_in	96	0.65641	0.00076	0.65793	1.030E-01
sand_17_4_in	97	0.66423	0.00077	0.66577	8.208E-02
sand_18_4_in	98	0.67699	0.00080	0.67859	5.914E-02
sand_19_4_in	99	0.69943	0.00077	0.70097	3.339E-02
sand_20_4_in	99.5	0.72356	0.00076	0.72508	1.869E-02
sand_21_4_in	99.9	0.73412	0.00066	0.73544	4.656E-03

Table B-4 Dry Sand Spheres (ρ = 2.2 g/cc)

File Name	v/o Sand	k_{eff}	σ	k_{eff} +2 σ	average E
30.2 kg					
sand_1_5_in	0	0.83669	0.00069	0.83807	7.333E-01
sand_2_5_in	10	0.82047	0.00069	0.82185	7.049E-01
sand_3_5_in	20	0.80122	0.00074	0.80270	6.717E-01
sand_4_5_in	30	0.78275	0.00075	0.78425	6.345E-01
sand_5_5_in	40	0.76362	0.00071	0.76504	5.915E-01
sand_6_5_in	50	0.74263	0.00072	0.74407	5.422E-01
sand_7_5_in	60	0.72214	0.00071	0.72356	4.846E-01
sand_8_5_in	70	0.70362	0.00067	0.70496	4.120E-01
sand_9_5_in	80	0.68552	0.00077	0.68706	3.222E-01
sand_10_5_in	90	0.67353	0.00078	0.67509	2.027E-01
sand_11_5_in	91	0.67403	0.00077	0.67557	1.873E-01
sand_12_5_in	92	0.67458	0.00075	0.67608	1.728E-01
sand_13_5_in	93	0.67527	0.00074	0.67675	1.567E-01
sand_14_5_in	94	0.67816	0.00078	0.67972	1.397E-01
sand_15_5_in	95	0.67974	0.00074	0.68122	1.220E-01
sand_16_5_in	96	0.68491	0.00078	0.68647	1.023E-01
sand_17_5_in	97	0.69303	0.00074	0.69451	8.138E-02
sand_18_5_in	98	0.70453	0.00077	0.70607	5.887E-02
sand_19_5_in	99	0.72839	0.00078	0.72995	3.321E-02
sand_20_5_in	99.5	0.75471	0.00076	0.75623	1.850E-02
sand_21_5_in	99.9	0.77117	0.00064	0.77245	4.501E-03
35.0 kg					
sandkg_1_35_in	0	0.87032	0.00079	0.87190	7.330E-01
sandkg_2_35_in	10	0.85380	0.00074	0.85528	7.024E-01
sandkg_3_35_in	20	0.83489	0.00081	0.83651	6.717E-01
sandkg_4_35_in	30	0.81463	0.00074	0.81611	6.360E-01
sandkg_5_35_in	40	0.79527	0.00072	0.79671	5.923E-01
sandkg_6_35_in	50	0.77529	0.00074	0.77677	5.431E-01
sandkg_7_35_in	60	0.75402	0.00072	0.75546	4.845E-01
sandkg_8_35_in	70	0.73230	0.00073	0.73376	4.127E-01
sandkg_9_35_in	80	0.71189	0.00069	0.71327	3.226E-01
sandkg_10_35_in	90	0.69678	0.00075	0.69828	2.030E-01
sandkg_11_35_in	91	0.69770	0.00073	0.69916	1.881E-01
sandkg_12_35_in	92	0.69717	0.00077	0.69871	1.731E-01
sandkg_13_35_in	93	0.69747	0.00076	0.69899	1.577E-01
sandkg_14_35_in	94	0.69984	0.00080	0.70144	1.397E-01
sandkg_15_35_in	95	0.70209	0.00079	0.70367	1.214E-01
sandkg_16_35_in	96	0.70705	0.00077	0.70859	1.026E-01
sandkg_17_35_in	97	0.71343	0.00081	0.71505	8.187E-02
sandkg_18_35_in	98	0.72602	0.00075	0.72752	5.872E-02
sandkg_19_35_in	99	0.75054	0.00077	0.75208	3.319E-02
sandkg_20_35_in	99.5	0.78019	0.00084	0.78187	1.828E-02
sandkg_21_35_in	99.9	0.80010	0.00068	0.80146	4.465E-03

Table B-4 Dry Sand Spheres (ρ = 2.2 g/cc)

File Name	v/o Sand	k_{eff}	σ	k_{eff} +2 σ	average E
40.0 kg					
sandkg_1_40_in*	0	0.90423	0.00078	0.90579	7.308E-01
sandkg_2_40_in	10	0.88539	0.00075	0.88689	7.044E-01
sandkg_3_40_in	20	0.86607	0.00076	0.86759	6.712E-01
sandkg_4_40_in	30	0.84571	0.00078	0.84727	6.335E-01
sandkg_5_40_in	40	0.82618	0.00080	0.82778	5.929E-01
sandkg_6_40_in	50	0.80391	0.00076	0.80543	5.416E-01
sandkg_7_40_in	60	0.78088	0.00072	0.78232	4.853E-01
sandkg_8_40_in	70	0.75882	0.00075	0.76032	4.120E-01
sandkg_9_40_in	80	0.73383	0.00076	0.73535	3.238E-01
sandkg_10_40_in	90	0.71907	0.00075	0.72057	2.038E-01
sandkg_11_40_in	91	0.71833	0.00077	0.71987	1.892E-01
sandkg_12_40_in	92	0.72039	0.00075	0.72189	1.734E-01
sandkg_13_40_in	93	0.71827	0.00074	0.71975	1.580E-01
sandkg_14_40_in	94	0.72114	0.00075	0.72264	1.398E-01
sandkg_15_40_in	95	0.72469	0.00081	0.72631	1.220E-01
sandkg_16_40_in	96	0.72855	0.00078	0.73011	1.021E-01
sandkg_17_40_in	97	0.73406	0.00080	0.73566	8.185E-02
sandkg_18_40_in	98	0.74701	0.00078	0.74857	5.889E-02
sandkg_19_40_in	99	0.77166	0.00079	0.77324	3.291E-02
sandkg_20_40_in	99.5	0.80563	0.00080	0.80723	1.806E-02
sandkg_21_40_in	99.9	0.82566	0.00065	0.82696	4.439E-03
45.0 kg					
sandkg_1_45_in	0	0.93284	0.00078	0.93440	7.318E-01
sandkg_2_45_in	10	0.91448	0.00080	0.91608	7.024E-01
sandkg_3_45_in	20	0.89514	0.00075	0.89664	6.696E-01
sandkg_4_45_in	30	0.87346	0.00078	0.87502	6.342E-01
sandkg_5_45_in	40	0.85112	0.00076	0.85264	5.902E-01
sandkg_6_45_in	50	0.82784	0.00072	0.82928	5.443E-01
sandkg_7_45_in	60	0.80513	0.00077	0.80667	4.847E-01
sandkg_8_45_in	70	0.78043	0.00075	0.78193	4.134E-01
sandkg_9_45_in	80	0.75574	0.00075	0.75724	3.250E-01
sandkg_10_45_in	90	0.73979	0.00074	0.74127	2.037E-01
sandkg_11_45_in	91	0.73867	0.00075	0.74017	1.889E-01
sandkg_12_45_in	92	0.73753	0.00078	0.73909	1.736E-01
sandkg_13_45_in	93	0.73802	0.00076	0.73954	1.571E-01
sandkg_14_45_in	94	0.73856	0.00078	0.74012	1.406E-01
sandkg_15_45_in	95	0.74051	0.00079	0.74209	1.222E-01
sandkg_16_45_in	96	0.74573	0.00080	0.74733	1.027E-01
sandkg_17_45_in	97	0.75194	0.00082	0.75358	8.197E-02
sandkg_18_45_in	98	0.76573	0.00081	0.76735	5.866E-02
sandkg_19_45_in	99	0.79131	0.00081	0.79293	3.274E-02
sandkg_20_45_in	99.5	0.82643	0.00075	0.82793	1.791E-02
sandkg_21_45_in	99.9	0.84687	0.00069	0.84825	4.356E-03

Table B-4 Dry Sand Spheres (ρ = 2.2 g/cc)

File Name	v/o Sand	k_{eff}	σ	k_{eff} +2 σ	average E
50.0 kg					
sandkg_1_50_in	0	0.96051	0.00078	0.96207	7.287E-01
sandkg_2_50_in	10	0.94017	0.00075	0.94167	7.016E-01
sandkg_3_50_in	20	0.91937	0.00077	0.92091	6.693E-01
sandkg_4_50_in	30	0.89819	0.00076	0.89971	6.325E-01
sandkg_5_50_in	40	0.87580	0.00076	0.87732	5.917E-01
sandkg_6_50_in	50	0.85170	0.00073	0.85316	5.431E-01
sandkg_7_50_in	60	0.82708	0.00074	0.82856	4.840E-01
sandkg_8_50_in	70	0.80282	0.00073	0.80428	4.136E-01
sandkg_9_50_in	80	0.77712	0.00078	0.77868	3.267E-01
sandkg_10_50_in	90	0.75703	0.00079	0.75861	2.038E-01
sandkg_11_50_in	91	0.75518	0.00073	0.75664	1.900E-01
sandkg_12_50_in	92	0.75682	0.00074	0.75830	1.736E-01
sandkg_13_50_in	93	0.75493	0.00078	0.75649	1.574E-01
sandkg_14_50_in	94	0.75618	0.00080	0.75778	1.407E-01
sandkg_15_50_in	95	0.75878	0.00078	0.76034	1.220E-01
sandkg_16_50_in	96	0.76255	0.00080	0.76415	1.027E-01
sandkg_17_50_in	97	0.76833	0.00077	0.76987	8.118E-02
sandkg_18_50_in	98	0.78163	0.00075	0.78313	5.849E-02
sandkg_19_50_in	99	0.80922	0.00084	0.81090	3.241E-02
sandkg_20_50_in	99.5	0.84651	0.00084	0.84819	1.778E-02
sandkg_21_50_in	99.9	0.86708	0.00069	0.86846	4.260E-03

Table B-5 Dry Sand Spheres (ρ = 1.6 g/cc)

File Name	v/o sand	k_{eff}	σ	k_{eff} +2 σ	average E
5.0 kg					
sandld_5_1_in	0	0.46185	0.0006	0.46305	7.87E-01
sandld_5_2_in	10	0.45142	0.00058	0.45258	7.56E-01
sandld_5_3_in	20	0.4405	0.00058	0.44166	7.17E-01
sandld_5_4_in	30	0.43137	0.00058	0.43253	6.77E-01
sandld_5_5_in	40	0.4216	0.00056	0.42272	6.28E-01
sandld_5_6_in	50	0.41266	0.00061	0.41388	5.70E-01
sandld_5_7_in	60	0.40541	0.00062	0.40665	5.03E-01
sandld_5_8_in	70	0.39754	0.00061	0.39876	4.28E-01
sandld_5_9_in	80	0.39546	0.00063	0.39672	3.32E-01
sandld_5_10_in	90	0.4047	0.00064	0.40598	2.09E-01
sandld_5_11_in	91	0.40841	0.00066	0.40973	1.93E-01
sandld_5_12_in	92	0.41011	0.0006	0.41131	1.78E-01
sandld_5_13_in	93	0.41298	0.00066	0.4143	1.63E-01
sandld_5_14_in	94	0.41725	0.00065	0.41855	1.47E-01
sandld_5_15_in	95	0.42276	0.00068	0.42412	1.27E-01
sandld_5_16_in	96	0.42863	0.00067	0.42997	1.10E-01
sandld_5_17_in	97	0.43778	0.00064	0.43906	8.83E-02
sandld_5_18_in	98	0.44776	0.00068	0.44912	6.59E-02
sandld_5_19_in	99	0.46084	0.00069	0.46222	4.00E-02
sandld_5_20_in	99.5	0.46674	0.00065	0.46804	2.41E-02
sandld_5_21_in	99.9	0.41231	0.00054	0.41339	7.69E-03
10.0 kg					
sandld_10_1_in	0	0.59107	0.00063	0.59233	7.64E-01
sandld_10_2_in	10	0.57697	0.00068	0.57833	7.30E-01
sandld_10_3_in	20	0.56472	0.00063	0.56598	6.95E-01
sandld_10_4_in	30	0.54999	0.00065	0.55129	6.57E-01
sandld_10_5_in	40	0.53634	0.00067	0.53768	6.16E-01
sandld_10_6_in	50	0.5219	0.00069	0.52328	5.62E-01
sandld_10_7_in	60	0.50997	0.00066	0.51129	5.01E-01
sandld_10_8_in	70	0.50015	0.00067	0.50149	4.24E-01
sandld_10_9_in	80	0.49185	0.00063	0.49311	3.33E-01
sandld_10_10_in	90	0.49414	0.00066	0.49546	2.12E-01
sandld_10_11_in	91	0.49468	0.00068	0.49604	1.98E-01
sandld_10_12_in	92	0.49522	0.00071	0.49664	1.83E-01
sandld_10_13_in	93	0.4982	0.00071	0.49962	1.67E-01
sandld_10_14_in	94	0.50142	0.00072	0.50286	1.50E-01
sandld_10_15_in	95	0.50507	0.00069	0.50645	1.32E-01
sandld_10_16_in	96	0.51058	0.00072	0.51202	1.12E-01
sandld_10_17_in	97	0.51617	0.00072	0.51761	9.15E-02
sandld_10_18_in	98	0.527	0.00072	0.52844	6.80E-02
sandld_10_19_in	99	0.53803	0.00073	0.53949	4.02E-02
sandld_10_20_in	99.5	0.54122	0.00075	0.54272	2.41E-02
sandld_10_21_in	99.9	0.49653	0.00059	0.49771	7.29E-03

Table B-5 Dry Sand Spheres (ρ = 1.6 g/cc)

File Name	v/o sand	k_{eff}	σ	k_{eff} +2 σ	average E
15.0 kg					
sandld_15_1_in	0	0.67517	0.00069	0.67655	7.49E-01
sandld_15_2_in	10	0.66049	0.00066	0.66181	7.20E-01
sandld_15_3_in	20	0.64415	0.00066	0.64547	6.89E-01
sandld_15_4_in	30	0.62854	0.00066	0.62986	6.53E-01
sandld_15_5_in	40	0.61035	0.00067	0.61169	6.08E-01
sandld_15_6_in	50	0.59562	0.00067	0.59696	5.59E-01
sandld_15_7_in	60	0.57928	0.00067	0.58062	4.98E-01
sandld_15_8_in	70	0.56389	0.00071	0.56531	4.28E-01
sandld_15_9_in	80	0.55151	0.00066	0.55283	3.37E-01
sandld_15_10_in	90	0.54639	0.00069	0.54777	2.16E-01
sandld_15_11_in	91	0.54802	0.00073	0.54948	2.01E-01
sandld_15_12_in	92	0.54961	0.00072	0.55105	1.86E-01
sandld_15_13_in	93	0.55084	0.00072	0.55228	1.70E-01
sandld_15_14_in	94	0.55306	0.00074	0.55454	1.52E-01
sandld_15_15_in	95	0.55414	0.00072	0.55558	1.35E-01
sandld_15_16_in	96	0.55945	0.00068	0.56081	1.15E-01
sandld_15_17_in	97	0.56669	0.00074	0.56817	9.24E-02
sandld_15_18_in	98	0.57599	0.00074	0.57747	6.84E-02
sandld_15_19_in	99	0.58603	0.00078	0.58759	4.06E-02
sandld_15_20_in	99.5	0.58989	0.00076	0.59141	2.39E-02
sandld_15_21_in	99.9	0.55497	0.0006	0.55617	6.97E-03
20.0 kg					
sandld_20_1_in	0	0.73954	0.0007	0.74094	7.42E-01
sandld_20_2_in	10	0.72269	0.00068	0.72405	7.15E-01
sandld_20_3_in	20	0.7047	0.0007	0.7061	6.83E-01
sandld_20_4_in	30	0.68713	0.00072	0.68857	6.50E-01
sandld_20_5_in	40	0.66908	0.00069	0.67046	6.05E-01
sandld_20_6_in	50	0.64996	0.00072	0.6514	5.57E-01
sandld_20_7_in	60	0.63134	0.00071	0.63276	5.00E-01
sandld_20_8_in	70	0.61339	0.00072	0.61483	4.29E-01
sandld_20_9_in	80	0.59861	0.0007	0.60001	3.38E-01
sandld_20_10_in	90	0.58669	0.00078	0.58825	2.19E-01
sandld_20_11_in	91	0.58772	0.00075	0.58922	2.04E-01
sandld_20_12_in	92	0.58912	0.00076	0.59064	1.88E-01
sandld_20_13_in	93	0.58874	0.00076	0.59026	1.72E-01
sandld_20_14_in	94	0.59117	0.00071	0.59259	1.54E-01
sandld_20_15_in	95	0.59306	0.00077	0.5946	1.36E-01
sandld_20_16_in	96	0.59624	0.00075	0.59774	1.16E-01
sandld_20_17_in	97	0.6	0.00077	0.60154	9.44E-02
sandld_20_18_in	98	0.60834	0.00071	0.60976	6.98E-02
sandld_20_19_in	99	0.61992	0.00074	0.6214	4.11E-02
sandld_20_20_in	99.5	0.62472	0.00075	0.62622	2.44E-02
sandld_20_21_in	99.9	0.60137	0.00068	0.60273	6.72E-03

Table B-5 Dry Sand Spheres (ρ = 1.6 g/cc)

File Name	v/o sand	k_{eff}	σ	k_{eff} +2 σ	average E
25.0 kg					
sandld_25_1_in	0	0.79163	0.00072	0.79307	7.39E-01
sandld_25_2_in	10	0.7745	0.00075	0.776	7.11E-01
sandld_25_3_in	20	0.75317	0.00074	0.75465	6.80E-01
sandld_25_4_in	30	0.73336	0.00073	0.73482	6.45E-01
sandld_25_5_in	40	0.7144	0.00071	0.71582	6.06E-01
sandld_25_6_in	50	0.69431	0.00071	0.69573	5.56E-01
sandld_25_7_in	60	0.6731	0.00072	0.67454	5.01E-01
sandld_25_8_in	70	0.65192	0.00077	0.65346	4.31E-01
sandld_25_9_in	80	0.63378	0.00072	0.63522	3.42E-01
sandld_25_10_in	90	0.62015	0.00076	0.62167	2.22E-01
sandld_25_11_in	91	0.61922	0.00072	0.62066	2.06E-01
sandld_25_12_in	92	0.61989	0.00076	0.62141	1.90E-01
sandld_25_13_in	93	0.61935	0.00078	0.62091	1.74E-01
sandld_25_14_in	94	0.62128	0.00077	0.62282	1.56E-01
sandld_25_15_in	95	0.62193	0.00068	0.62329	1.38E-01
sandld_25_16_in	96	0.62481	0.00075	0.62631	1.16E-01
sandld_25_17_in	97	0.62881	0.00078	0.63037	9.52E-02
sandld_25_18_in	98	0.63741	0.00073	0.63887	6.98E-02
sandld_25_19_in	99	0.64732	0.00075	0.64882	4.12E-02
sandld_25_20_in	99.5	0.65341	0.00074	0.65489	2.39E-02
sandld_25_21_in	99.9	0.64011	0.00066	0.64143	6.64E-03
30.0 kg					
sandld_30_1_in	0	0.835	0.00077	0.83654	7.37E-01
sandld_30_2_in	10	0.8154	0.00071	0.81682	7.07E-01
sandld_30_3_in	20	0.7944	0.00073	0.79586	6.79E-01
sandld_30_4_in	30	0.77444	0.00075	0.77594	6.44E-01
sandld_30_5_in	40	0.75178	0.00071	0.7532	6.05E-01
sandld_30_6_in	50	0.73122	0.00076	0.73274	5.57E-01
sandld_30_7_in	60	0.70888	0.0007	0.71028	5.02E-01
sandld_30_8_in	70	0.68606	0.00073	0.68752	4.32E-01
sandld_30_9_in	80	0.66417	0.00077	0.66571	3.43E-01
sandld_30_10_in	90	0.64723	0.00076	0.64875	2.23E-01
sandld_30_11_in	91	0.64576	0.00076	0.64728	2.08E-01
sandld_30_12_in	92	0.64546	0.00074	0.64694	1.91E-01
sandld_30_13_in	93	0.64527	0.00076	0.64679	1.75E-01
sandld_30_14_in	94	0.64387	0.00075	0.64537	1.57E-01
sandld_30_15_in	95	0.64623	0.00075	0.64773	1.39E-01
sandld_30_16_in	96	0.64973	0.0007	0.65113	1.18E-01
sandld_30_17_in	97	0.65166	0.00075	0.65316	9.59E-02
sandld_30_18_in	98	0.6571	0.00082	0.65874	7.04E-02
sandld_30_19_in	99	0.66969	0.00079	0.67127	4.10E-02
sandld_30_20_in	99.5	0.67858	0.00074	0.68006	2.40E-02
sandld_30_21_in	99.9	0.67148	0.00066	0.6728	6.48E-03

Table B-5 Dry Sand Spheres (ρ = 1.6 g/cc)

File Name	v/o sand	k_{eff}	σ	k_{eff} +2 σ	average E
35.0 kg					
sandld_35_1_in	0	0.87032	0.00079	0.8719	7.33E-01
sandld_35_2_in	10	0.8517	0.00078	0.85326	7.05E-01
sandld_35_3_in	20	0.83069	0.00075	0.83219	6.78E-01
sandld_35_4_in	30	0.8099	0.00074	0.81138	6.43E-01
sandld_35_5_in	40	0.78706	0.00078	0.78862	6.04E-01
sandld_35_6_in	50	0.76275	0.00073	0.76421	5.59E-01
sandld_35_7_in	60	0.73733	0.00074	0.73881	5.02E-01
sandld_35_8_in	70	0.71419	0.00073	0.71565	4.35E-01
sandld_35_9_in	80	0.68896	0.00072	0.6904	3.45E-01
sandld_35_10_in	90	0.66895	0.00072	0.67039	2.24E-01
sandld_35_11_in	91	0.6681	0.00075	0.6696	2.10E-01
sandld_35_12_in	92	0.66628	0.00077	0.66782	1.94E-01
sandld_35_13_in	93	0.66574	0.00075	0.66724	1.76E-01
sandld_35_14_in	94	0.66644	0.00077	0.66798	1.59E-01
sandld_35_15_in	95	0.66804	0.00077	0.66958	1.40E-01
sandld_35_16_in	96	0.66823	0.00081	0.66985	1.19E-01
sandld_35_17_in	97	0.67202	0.00077	0.67356	9.62E-02
sandld_35_18_in	98	0.67776	0.00077	0.6793	7.09E-02
sandld_35_19_in	99	0.6905	0.00079	0.69208	4.09E-02
sandld_35_20_in*	99.5	0.69875	0.00077	0.70029	2.36E-02
sandld_35_21_in	99.9	0.70118	0.00067	0.70252	6.26E-03
40.0 kg					
sandld_40_1_in	0	0.90423	0.00078	0.90579	7.31E-01
sandld_40_2_in	10	0.88295	0.00075	0.88445	
sandld_40_3_in	20	0.86096	0.00075	0.86246	6.78E-01
sandld_40_4_in	30	0.83876	0.00075	0.84026	6.43E-01
sandld_40_5_in	40	0.8136	0.00077	0.81514	6.07E-01
sandld_40_6_in	50	0.79096	0.00071	0.79238	5.59E-01
sandld_40_7_in	60	0.76426	0.00071	0.76568	5.05E-01
sandld_40_8_in	70	0.73966	0.00077	0.7412	4.35E-01
sandld_40_9_in	80	0.71327	0.00072	0.71471	3.48E-01
sandld_40_10_in	90	0.68939	0.00074	0.69087	2.26E-01
sandld_40_11_in	91	0.68708	0.00075	0.68858	2.10E-01
sandld_40_12_in	92	0.68762	0.00077	0.68916	1.94E-01
sandld_40_13_in	93	0.68583	0.00076	0.68735	1.77E-01
sandld_40_14_in	94	0.68525	0.00075	0.68675	1.59E-01
sandld_40_15_in	95	0.68698	0.0008	0.68858	1.40E-01
sandld_40_16_in	96	0.68681	0.00078	0.68837	1.20E-01
sandld_40_17_in	97	0.69075	0.00074	0.69223	9.65E-02
sandld_40_18_in	98	0.69497	0.00076	0.69649	7.09E-02
sandld_40_19_in	99	0.70612	0.00073	0.70758	4.08E-02
sandld_40_20_in	99.5	0.71817	0.00078	0.71973	2.33E-02
sandld_40_21_in	99.9	0.72531	0.00069	0.72669	6.11E-03

Table B-5 Dry Sand Spheres (ρ = 1.6 g/cc)

File Name	v/o sand	k_{eff}	σ	k_{eff} +2 σ	average E
45.0 kg					
sandld_45_1_in	0	0.93284	0.00078	0.9344	7.32E-01
sandld_45_2_in	10	0.90998	0.0007	0.91138	7.06E-01
sandld_45_3_in	20	0.88881	0.00076	0.89033	6.76E-01
sandld_45_4_in	30	0.86477	0.00076	0.86629	6.43E-01
sandld_45_5_in	40	0.84105	0.00076	0.84257	6.05E-01
sandld_45_6_in	50	0.81467	0.00078	0.81623	5.59E-01
sandld_45_7_in	60	0.78872	0.00073	0.79018	5.04E-01
sandld_45_8_in	70	0.76103	0.00078	0.76259	4.37E-01
sandld_45_9_in	80	0.73251	0.00074	0.73399	3.48E-01
sandld_45_10_in	90	0.70722	0.00077	0.70876	2.27E-01
sandld_45_11_in	91	0.70548	0.00078	0.70704	2.13E-01
sandld_45_12_in	92	0.70236	0.00076	0.70388	1.96E-01
sandld_45_13_in	93	0.70283	0.00075	0.70433	1.79E-01
sandld_45_14_in	94	0.70303	0.00075	0.70453	1.60E-01
sandld_45_15_in	95	0.70313	0.00078	0.70469	1.41E-01
sandld_45_16_in	96	0.70224	0.00077	0.70378	1.19E-01
sandld_45_17_in	97	0.70558	0.00076	0.7071	9.72E-02
sandld_45_18_in	98	0.70912	0.00075	0.71062	7.09E-02
sandld_45_19_in	99	0.72198	0.00078	0.72354	4.13E-02
sandld_45_20_in	99.5	0.73482	0.00077	0.73636	2.37E-02
sandld_45_21_in	99.9	0.74756	0.00069	0.74894	5.98E-03
50.0 kg					
sandld_50_1_in	0	0.96051	0.00078	0.96207	7.29E-01
sandld_50_2_in	10	0.93642	0.00077	0.93796	7.04E-01
sandld_50_3_in	20	0.91356	0.00074	0.91504	6.78E-01
sandld_50_4_in	30	0.88908	0.00074	0.89056	6.44E-01
sandld_50_5_in	40	0.86404	0.00073	0.8655	6.07E-01
sandld_50_6_in	50	0.83784	0.00073	0.8393	5.59E-01
sandld_50_7_in	60	0.80893	0.00078	0.81049	5.07E-01
sandld_50_8_in	70	0.78075	0.00076	0.78227	4.37E-01
sandld_50_9_in	80	0.75136	0.00077	0.7529	3.51E-01
sandld_50_10_in	90	0.72366	0.00077	0.7252	2.29E-01
sandld_50_11_in	91	0.72248	0.00081	0.7241	2.12E-01
sandld_50_12_in	92	0.72006	0.00073	0.72152	1.96E-01
sandld_50_13_in	93	0.72006	0.00077	0.7216	1.79E-01
sandld_50_14_in	94	0.71765	0.00076	0.71917	1.61E-01
sandld_50_15_in	95	0.71705	0.00074	0.71853	1.41E-01
sandld_50_16_in	96	0.71801	0.00077	0.71955	1.20E-01
sandld_50_17_in	97	0.7204	0.00075	0.7219	9.74E-02
sandld_50_18_in	98	0.72461	0.00079	0.72619	7.16E-02
sandld_50_19_in	99	0.73596	0.00074	0.73744	4.10E-02
sandld_50_20_in	99.5	0.74978	0.00074	0.75126	2.32E-02
sandld_50_21_in	99.9	0.76858	0.00072	0.77002	5.90E-03

Table B-6 Polyurethane Foam Spheres

File Name	v/o Foam	k_{eff}	σ	$k_{eff}+2\sigma$	average E
1.0 kg					
foam_1_1_in	0	0.24384	0.00040	0.24464	8.96E-01
foam_2_1_in	10	0.23664	0.00039	0.23742	8.63E-01
foam_3_1_in	20	0.23043	0.00043	0.23129	8.12E-01
foam_4_1_in	30	0.22590	0.00040	0.22670	7.60E-01
foam_5_1_in	40	0.22134	0.00045	0.22224	7.03E-01
foam_6_1_in	50	0.21681	0.00043	0.21767	6.36E-01
foam_7_1_in	60	0.21399	0.00045	0.21489	5.55E-01
foam_8_1_in	70	0.21348	0.00046	0.21440	4.61E-01
foam_9_1_in	80	0.21706	0.00050	0.21806	3.51E-01
foam_10_1_in	90	0.23373	0.00051	0.23475	2.13E-01
foam_11_1_in	91	0.23584	0.00051	0.23686	2.00E-01
foam_12_1_in	92	0.23936	0.00049	0.24034	1.80E-01
foam_13_1_in	93	0.24300	0.00054	0.24408	1.66E-01
foam_14_1_in	94	0.24847	0.00056	0.24959	1.45E-01
foam_15_1_in	95	0.25523	0.00056	0.25635	1.27E-01
foam_16_1_in	96	0.26201	0.00054	0.26309	1.08E-01
foam_17_1_in	97	0.27489	0.00057	0.27603	8.47E-02
foam_18_1_in	98	0.28689	0.00060	0.28809	6.38E-02
foam_19_1_in	99	0.30527	0.00056	0.30639	3.96E-02
foam_20_1_in	99.5	0.31700	0.00061	0.31822	2.46E-02
foam_21_1_in	99.9	0.28912	0.00046	0.29004	9.20E-03
4.0 kg					
foam_1_2_in	0	0.42595	0.00055	0.42705	8.02E-01
foam_2_2_in	10	0.41447	0.00052	0.41551	7.70E-01
foam_3_2_in	20	0.40360	0.00056	0.40472	7.34E-01
foam_4_2_in	30	0.39346	0.00055	0.39456	6.89E-01
foam_5_2_in	40	0.38355	0.00059	0.38473	6.41E-01
foam_6_2_in	50	0.37557	0.00056	0.37669	5.81E-01
foam_7_2_in	60	0.36812	0.00055	0.36922	5.15E-01
foam_8_2_in	70	0.36165	0.00058	0.36281	4.40E-01
foam_9_2_in	80	0.36263	0.00061	0.36385	3.40E-01
foam_10_2_in	90	0.37346	0.00064	0.37474	2.15E-01
foam_11_2_in	91	0.37605	0.00068	0.37741	2.00E-01
foam_12_2_in	92	0.37895	0.00064	0.38023	1.85E-01
foam_13_2_in	93	0.38284	0.00065	0.38414	1.69E-01
foam_14_2_in	94	0.38790	0.00065	0.38920	1.50E-01
foam_15_2_in	95	0.39460	0.00066	0.39592	1.33E-01
foam_16_2_in	96	0.40261	0.00066	0.40393	1.14E-01
foam_17_2_in	97	0.41250	0.00069	0.41388	9.16E-02
foam_18_2_in	98	0.42636	0.00067	0.42770	6.94E-02
foam_19_2_in	99	0.44503	0.00069	0.44641	4.27E-02
foam_20_2_in*	99.5	0.45703	0.00066	0.45835	2.68E-02
foam_21_2_in	99.9	0.42928	0.00064	0.43056	9.62E-03

Table B-6 Polyurethane Foam Spheres

File Name	v/o Foam	k_{eff}	σ	k_{eff} +2 σ	average E
12.6 kg					
foam_1_3_in	0	0.63901	0.00066	0.64033	7.56E-01
foam_2_3_in	10	0.62099	0.00066	0.62231	7.28E-01
foam_3_3_in	20	0.60314	0.00067	0.60448	6.98E-01
foam_4_3_in	30	0.58574	0.00065	0.58704	6.63E-01
foam_5_3_in	40	0.56833	0.00064	0.56961	6.23E-01
foam_6_3_in	50	0.55178	0.00068	0.55314	5.74E-01
foam_7_3_in	60	0.53695	0.00068	0.53831	5.17E-01
foam_8_3_in	70	0.52255	0.00071	0.52397	4.43E-01
foam_9_3_in	80	0.51267	0.00073	0.51413	3.52E-01
foam_10_3_in	90	0.51028	0.00074	0.51176	2.32E-01
foam_11_3_in	91	0.51303	0.00073	0.51449	2.16E-01
foam_12_3_in	92	0.51526	0.00074	0.51674	2.00E-01
foam_13_3_in	93	0.51558	0.00072	0.51702	1.84E-01
foam_14_3_in	94	0.52091	0.00071	0.52233	1.65E-01
foam_15_3_in	95	0.52333	0.00071	0.52475	1.47E-01
foam_16_3_in	96	0.52874	0.00075	0.53024	1.26E-01
foam_17_3_in	97	0.53679	0.00073	0.53825	1.04E-01
foam_18_3_in	98	0.54978	0.00074	0.55126	7.84E-02
foam_19_3_in	99	0.56744	0.00075	0.56894	4.86E-02
foam_20_3_in	99.5	0.57909	0.00075	0.58059	2.98E-02
foam_21_3_in	99.9	0.55693	0.00071	0.55835	1.03E-02
25.2 kg					
foam_1_4_in	0	0.79295	0.00074	0.79443	7.38E-01
foam_2_4_in	10	0.77121	0.00073	0.77267	7.17E-01
foam_3_4_in	20	0.74778	0.00071	0.74920	6.89E-01
foam_4_4_in	30	0.72368	0.00070	0.72508	6.60E-01
foam_5_4_in	40	0.70207	0.00071	0.70349	6.25E-01
foam_6_4_in	50	0.67868	0.00068	0.68004	5.80E-01
foam_7_4_in	60	0.65557	0.00072	0.65701	5.26E-01
foam_8_4_in	70	0.63395	0.00070	0.63535	4.57E-01
foam_9_4_in	80	0.61429	0.00071	0.61571	3.70E-01
foam_10_4_in	90	0.60338	0.00074	0.60486	2.46E-01
foam_11_4_in	91	0.60311	0.00074	0.60459	2.31E-01
foam_12_4_in	92	0.60218	0.00077	0.60372	2.15E-01
foam_13_4_in	93	0.60222	0.00073	0.60368	1.97E-01
foam_14_4_in	94	0.60339	0.00071	0.60481	1.79E-01
foam_15_4_in	95	0.60531	0.00077	0.60685	1.59E-01
foam_16_4_in	96	0.60913	0.00077	0.61067	1.38E-01
foam_17_4_in	97	0.61541	0.00075	0.61691	1.13E-01
foam_18_4_in	98	0.62501	0.00077	0.62655	8.56E-02
foam_19_4_in	99	0.64336	0.00080	0.64496	5.28E-02
foam_20_4_in	99.5	0.65611	0.00081	0.65773	3.29E-02
foam_21_4_in	99.9	0.64226	0.00072	0.64370	1.06E-02

Table B-6 Polyurethane Foam Spheres

File Name	v/o Foam	k_{eff}	σ	k_{eff} +2 σ	average E
30.2 kg					
foam_1_5_in	0	0.83669	0.00069	0.83807	7.33E-01
foam_2_5_in	10	0.81317	0.00075	0.81467	7.15E-01
foam_3_5_in	20	0.78789	0.00073	0.78935	6.89E-01
foam_4_5_in	30	0.76313	0.00074	0.76461	6.59E-01
foam_5_5_in	40	0.73797	0.00075	0.73947	6.24E-01
foam_6_5_in	50	0.71300	0.00072	0.71444	5.82E-01
foam_7_5_in	60	0.68842	0.00074	0.68990	5.29E-01
foam_8_5_in	70	0.66493	0.00076	0.66645	4.60E-01
foam_9_5_in	80	0.64130	0.00073	0.64276	3.75E-01
foam_10_5_in	90	0.62539	0.00074	0.62687	2.51E-01
foam_11_5_in	91	0.62575	0.00075	0.62725	2.36E-01
foam_12_5_in	92	0.62658	0.00076	0.62810	2.19E-01
foam_13_5_in	93	0.62556	0.00077	0.62710	2.02E-01
foam_14_5_in	94	0.62495	0.00078	0.62651	1.83E-01
foam_15_5_in	95	0.62877	0.00076	0.63029	1.62E-01
foam_16_5_in	96	0.63255	0.00076	0.63407	1.41E-01
foam_17_5_in	97	0.63674	0.00080	0.63834	1.15E-01
foam_18_5_in	98	0.64508	0.00076	0.64660	8.80E-02
foam_19_5_in	99	0.66215	0.00081	0.66377	5.44E-02
foam_20_5_in	99.5	0.67758	0.00081	0.67920	3.35E-02
foam_21_5_in	99.9	0.66514	0.00078	0.66670	1.07E-02

B.2 Solutions of UO_2F_2

Table B-7 contains the calculated k_{eff} for UO_2F_2 solutions. The column headings are similar to those for the sphere case described above. The column labeled "t" is the thickness of the slab. The results presented are for square slabs 10,000 cm on each side.

Table B-7 Solutions

File Name	t (cm)	k_{eff}	σ	k_{eff} +2 σ	average E
25 g/L UO_2F_2					
slab_1_1_in	1	0.14375	0.00022	0.14419	3.47E-03
slab_1_2_in	2	0.24730	0.00034	0.24798	3.25E-03
slab_1_3_in	5	0.46874	0.00050	0.46974	2.76E-03
slab_1_4_in	10	0.70571	0.00055	0.70681	2.61E-03
slab_1_5_in	20	0.94736	0.00051	0.94838	2.37E-03
slab_1_6_in	50	1.14603	0.00037	1.14677	2.41E-03
slab_1_7_in	100	1.20563	0.00028	1.20619	2.34E-03
50 g/L UO_2F_2					
slab_2_1_in	1	0.23839	0.00035	0.23909	4.11E-03
slab_2_2_in	2	0.37690	0.00050	0.37790	4.22E-03
slab_2_3_in	5	0.64594	0.00065	0.64724	4.17E-03
slab_2_4_in	10	0.92555	0.00066	0.92687	4.08E-03
slab_2_5_in	20	1.20500	0.00066	1.20632	3.82E-03
slab_2_6_in	50	1.43693	0.00048	1.43789	3.80E-03
slab_2_7_in	100	1.50725	0.00030	1.50785	3.86E-03
100 g/L UO_2F_2					
slab_3_1_in	1	0.35509	0.00050	0.35609	5.62E-03
slab_3_2_in	2	0.51144	0.00061	0.51266	6.30E-03
slab_3_3_in	5	0.79896	0.00077	0.80050	6.87E-03
slab_3_4_in	10	1.09638	0.00079	1.09796	6.74E-03
slab_3_5_in	20	1.38959	0.00074	1.39107	6.77E-03
slab_3_6_in	50	1.63941	0.00053	1.64047	6.80E-03
slab_3_7_in	100	1.71484	0.00038	1.71560	6.73E-03
150 g/L UO_2F_2					
slab_4_1_in*	1	0.42504	0.00059	0.42622	7.35E-03
slab_4_2_in	2	0.58080	0.00069	0.58218	8.22E-03
slab_4_3_in	5	0.86887	0.00083	0.87053	9.56E-03
slab_4_4_in	10	1.16559	0.00081	1.16721	9.64E-03
slab_4_5_in	20	1.46234	0.00074	1.46382	9.69E-03
slab_4_6_in	50	1.71406	0.00054	1.71514	9.64E-03
slab_4_7_in	100	1.79241	0.00041	1.79323	9.66E-03

Table B-7 Solutions

File Name	t (cm)	k_{eff}	σ	k_{eff} +2 σ	average E
200 g/L UO_2F_2					
slab_5_1_in	1	0.47187	0.00063	0.47313	8.51E-03
slab_5_2_in	2	0.62353	0.00071	0.62495	1.03E-02
slab_5_3_in	5	0.90672	0.00081	0.90834	1.18E-02
slab_5_4_in	10	1.20362	0.00086	1.20534	1.24E-02
slab_5_5_in	20	1.49836	0.00080	1.49996	1.25E-02
slab_5_6_in	50	1.74939	0.00056	1.75051	1.27E-02
slab_5_7_in	100	1.82512	0.00046	1.82604	1.29E-02
250 g/L UO_2F_2					
slab_6_1_in	1	0.50421	0.00067	0.50555	1.02E-02
slab_6_2_in	2	0.65404	0.00077	0.65558	1.24E-02
slab_6_3_in	5	0.93310	0.00084	0.93478	1.45E-02
slab_6_4_in	10	1.22485	0.00087	1.22659	1.52E-02
slab_6_5_in*	20	1.51884	0.00079	1.52042	1.56E-02
slab_6_6_in	50	1.76965	0.00061	1.77087	1.60E-02
slab_6_7_in	100	1.84538	0.00051	1.84640	1.58E-02
300 g/L UO_2F_2					
slab_7_1_in	1	0.53094	0.00068	0.53230	1.19E-02
slab_7_2_in	2	0.67428	0.00078	0.67584	1.43E-02
slab_7_3_in	5	0.94943	0.00086	0.95115	1.71E-02
slab_7_4_in	10	1.23976	0.00093	1.24162	1.81E-02
slab_7_5_in	20	1.52981	0.00078	1.53137	1.84E-02
slab_7_6_in	50	1.77875	0.00058	1.77991	1.90E-02
slab_7_7_in	100	1.85485	0.00047	1.85579	1.90E-02
350 g/L UO_2F_2					
slab_8_1_in	1	0.55007	0.00070	0.55147	1.31E-02
slab_8_2_in	2	0.69109	0.00076	0.69261	1.65E-02
slab_8_3_in	5	0.96265	0.00089	0.96443	1.99E-02
slab_8_4_in	10	1.24999	0.00091	1.25181	2.09E-02
slab_8_5_in	20	1.53802	0.00079	1.53960	2.16E-02
slab_8_6_in	50	1.78409	0.00062	1.78533	2.21E-02
slab_8_7_in	100	1.86102	0.00051	1.86204	2.21E-02
400 g/L UO_2F_2					
slab_9_1_in	1	0.56637	0.00074	0.56785	1.46E-02
slab_9_2_in	2	0.70370	0.00078	0.70526	1.82E-02
slab_9_3_in	5	0.96987	0.00088	0.97163	2.26E-02
slab_9_4_in	10	1.25533	0.00089	1.25711	2.37E-02
slab_9_5_in	20	1.54102	0.00082	1.54266	2.47E-02
slab_9_6_in	50	1.78650	0.00060	1.78770	2.53E-02
slab_9_7_in	100	1.86187	0.00049	1.86285	2.53E-02

Table B-7 Solutions					
File Name	t (cm)	k_{eff}	σ	$k_{eff}+2\sigma$	average E
450 g/L UO_2F_2					
slab_10_1_in	1	0.57899	0.00067	0.58033	1.58E-02
slab_10_2_in	2	0.71366	0.00078	0.71522	2.05E-02
slab_10_3_in	5	0.97840	0.00091	0.98022	2.52E-02
slab_10_4_in	10	1.25947	0.00084	1.26115	2.69E-02
slab_10_5_in	20	1.54391	0.00082	1.54555	2.77E-02
slab_10_6_in	50	1.78713	0.00062	1.78837	2.87E-02
slab_10_7_in	100	1.86222	0.00049	1.86320	2.88E-02
500 g/L UO_2F_2					
slab_11_1_in	1	0.59149	0.00070	0.59289	1.72E-02
slab_11_2_in	2	0.72317	0.00080	0.72477	2.25E-02
slab_11_3_in	5	0.98409	0.00091	0.98591	2.75E-02
slab_11_4_in	10	1.26182	0.00091	1.26364	2.98E-02
slab_11_5_in	20	1.54158	0.00080	1.54318	3.09E-02
slab_11_6_in	50	1.78664	0.00063	1.78790	3.19E-02
slab_11_7_in	100	1.86144	0.00054	1.86252	3.19E-02

B.3 Arrays of Pipes Coated with UO_2F_2

Cases for arrays of pipes under normal and flooded storage conditions are presented in Table B-8. The column headings are:

Column Heading	Description
File Name	Name of the MCNP input file
Pipe	Nominal pile size (inches)
Activity	Assumed uranium activity level (pCi-U/g-steel)
H/U	Hydrogen to Uranium atom ration
k_{eff}	K effective calculated by MCNP
σ	Standard deviation on k_{eff} calculated by MCNP
$k_{eff}+2\sigma$	95% confidence level for k_{eff}
average E	Average energy of neutron causing fission (eV)

Table B-8 Pipe Storage

File Name	Pipe	Activity (pCi/g)	H/U	k_{eff}	σ	k_{eff} +2 σ	average E
Void w/o reflector							
void_1_1_1_in	2	150	0	MCNP could not calculate k_{eff}			
void_1_1_2_in	2	150	4	MCNP could not calculate k_{eff}			
void_1_2_1_in	2	1100	0	MCNP could not calculate k_{eff}			
void_1_2_2_in	2	1100	4	0.00671	0.00002	0.00675	6.02E-01
void_2_1_1_in	3	150	0	MCNP could not calculate k_{eff}			
void_2_1_2_in	3	150	4	MCNP could not calculate k_{eff}			
void_2_2_1_in	3	1100	0	MCNP could not calculate k_{eff}			
void_2_2_2_in	3	1100	4	0.00604	0.00002	0.00608	6.71E-01
void_3_1_1_in	6	150	0	MCNP could not calculate k_{eff}			
void_3_1_2_in	6	150	4	MCNP could not calculate k_{eff}			
void_3_2_1_in	6	1100	0	MCNP could not calculate k_{eff}			
void_3_2_2_in	6	1100	4	0.00325	0.00001	0.00327	1.03E+00
void_4_1_1_in	8	150	0	MCNP could not calculate k_{eff}			
void_4_1_2_in	8	150	4	MCNP could not calculate k_{eff}			
void_4_2_1_in	8	1100	0	MCNP could not calculate k_{eff}			
void_4_2_2_in	8	1100	4	MCNP could not calculate k_{eff}			
void_5_1_1_in	16	150	0	MCNP could not calculate k_{eff}			
void_5_1_2_in	16	150	4	MCNP could not calculate k_{eff}			
void_5_2_1_in	16	1100	0	MCNP could not calculate k_{eff}			
void_5_2_2_in	16	1100	4	MCNP could not calculate k_{eff}			
Void with foam in pipe							
foamv_1_1_1_in	2	150	0	MCNP could not calculate k_{eff}			
foamv_1_1_2_in	2	150	4	MCNP could not calculate k_{eff}			
foamv_1_2_1_in	2	1100	0	0.04512	0.00011	0.04534	7.61E-02
foamv_1_2_2_in	2	1100	4	0.04612	0.00010	0.04632	7.36E-02
foamv_2_1_1_in	3	150	0	MCNP could not calculate k_{eff}			
foamv_2_1_2_in	3	150	4	MCNP could not calculate k_{eff}			
foamv_2_2_1_in	3	1100	0	0.04254	0.00011	0.04276	8.23E-02
foamv_2_2_2_in	3	1100	4	0.04360	0.00010	0.04380	7.67E-02
foamv_3_1_1_in	6	150	0	MCNP could not calculate k_{eff}			
foamv_3_1_2_in	6	150	4	MCNP could not calculate k_{eff}			
foamv_3_2_1_in	6	1100	0	0.02958	0.00009	0.02976	9.79E-02
foamv_3_2_2_in	6	1100	4	0.03006	0.00009	0.03024	9.23E-02
foamv_4_1_1_in	8	150	0	MCNP could not calculate k_{eff}			
foamv_4_1_2_in	8	150	4	0.00385	0.00002	0.00389	1.02E-01
foamv_4_2_1_in	8	1100	0	MCNP could not calculate k_{eff}			
foamv_4_2_2_in	8	1100	4	0.02642	0.00008	0.02658	1.02E-01
foamv_5_1_1_in	16	150	0	MCNP could not calculate k_{eff}			
foamv_5_1_2_in	16	150	4	MCNP could not calculate k_{eff}			
foamv_5_2_1_in	16	1100	0	0.02192	0.00008	0.02208	1.30E-01
foamv_5_2_2_in*	16	1100	4	0.02233	0.00008	0.02249	1.24E-01

Table B-8 Pipe Storage

File Name	Pipe	Activity (pCi/g)	H/U	k_{eff}	σ	k_{eff} +2 σ	average E
Water in pipe with water reflector							
flood_1_1_1_in	2	150	0	0.01727	0.00002	0.01731	5.73E-03
flood_1_1_2_in	2	150	4	0.01750	0.00002	0.01754	5.91E-03
flood_1_2_1_in	2	1100	0	0.11938	0.00009	0.11956	6.18E-03
flood_1_2_2_in*	2	1100	4	0.11939	0.00009	0.11957	6.28E-03
flood_2_1_1_in	3	150	0	0.01620	0.00002	0.01624	8.16E-03
flood_2_1_2_in	3	150	4	MCNP could not calculate k_{eff}			
flood_2_2_1_in	3	1100	0	0.11022	0.00010	0.11042	7.70E-03
flood_2_2_2_in	3	1100	4	0.11083	0.00010	0.11103	7.13E-03
flood_3_1_1_in	6	150	0	0.01191	0.00002	0.01195	1.25E-02
flood_3_1_2_in	6	150	4	0.01186	0.00002	0.01190	8.91E-03
flood_3_2_1_in	6	1100	0	0.08083	0.00010	0.08103	1.09E-02
flood_3_2_2_in	6	1100	4	0.08071	0.00010	0.08091	1.05E-02
flood_4_1_1_in	8	150	0	0.01066	0.00002	0.01070	1.40E-02
flood_4_1_2_in	8	150	4	0.01064	0.00002	0.01068	1.41E-02
flood_4_2_1_in	8	1100	0	0.07202	0.00010	0.07222	1.30E-02
flood_4_2_2_in	8	1100	4	0.07224	0.00010	0.07244	1.18E-02
flood_5_1_1_in	16	150	0	MCNP could not calculate k_{eff}			
flood_5_1_2_in	16	150	4	MCNP could not calculate k_{eff}			
flood_5_2_1_in	16	1100	0	0.06441	0.00011	0.06463	2.07E-02
flood_5_2_2_in	16	1100	4	0.06461	0.00012	0.06485	1.94E-02
Foam in pipe with water reflector							
foamw_1_1_1_in	2	150	0	MCNP could not calculate k_{eff}			
foamw_1_1_2_in	2	150	4	0.02007	0.00003	0.02013	8.84E-03
foamw_1_2_1_in	2	1100	0	0.13468	0.00013	0.13494	1.02E-02
foamw_1_2_2_in	2	1100	4	0.13525	0.00012	0.13549	9.90E-03
foamw_2_1_1_in	3	150	0	0.01881	0.00003	0.01887	1.13E-02
foamw_2_1_2_in	3	150	4	0.01889	0.00003	0.01895	1.12E-02
foamw_2_2_1_in	3	1100	0	0.12612	0.00013	0.12638	1.24E-02
foamw_2_2_2_in*	3	1100	4	0.12676	0.00012	0.12700	1.15E-02
foamw_3_1_1_in	6	150	0	0.01534	0.00003	0.01540	1.69E-02
foamw_3_1_2_in	6	150	4	0.01539	0.00003	0.01545	1.54E-02
foamw_3_2_1_in	6	1100	0	0.10220	0.00012	0.10244	1.50E-02
foamw_3_2_2_in	6	1100	4	0.10294	0.00011	0.10316	1.43E-02
foamw_4_1_1_in	8	150	0	MCNP could not calculate k_{eff}			
foamw_4_1_2_in	8	150	4	0.01381	0.00003	0.01387	1.74E-02
foamw_4_2_1_in	8	1100	0	0.09123	0.00012	0.09147	1.74E-02
foamw_4_2_2_in	8	1100	4	0.09167	0.00013	0.09193	1.68E-02
foamw_5_1_1_in	16	150	0	0.01075	0.00003	0.01081	2.75E-02
foamw_5_1_2_in	16	150	4	0.01082	0.00003	0.01088	2.96E-02
foamw_5_2_1_in	16	1100	0	0.06985	0.00012	0.07009	2.97E-02
foamw_5_2_2_in	16	1100	4	0.07069	0.00013	0.07095	2.75E-02

Appendix C – Sample Input Files

This Appendix provides sample files for selected cases. The input files included are:

Case	Description
clsm_10_1_in	Sphere with 1 kg ^{235}U as UO_2F_2 mixed with 0 v/o CLSM surrounded by a 4 foot CLSM reflector
clsm_3_4_in	Sphere with 4 kg ^{235}U as UO_2F_2 mixed with 99.5 v/o CLSM surrounded by a 4 foot CLSM reflector
psteel_20_2_2_in	Sphere with 5 kg ^{235}U as UO_2F_2 mixed with 99.5 v/o steel at 0.4 packing fraction surrounded by a 4 foot CLSM reflector
psteel_6_1_5_in	Sphere with 30 kg ^{235}U as UO_2F_2 mixed with 50 v/o steel at 0.2 packing fraction surrounded by a 4 foot CLSM reflector
salt_8_in	Sphere with 1 kg ^{235}U as UO_2F_2 mixed with 70 v/o salt surrounded by a 4 foot salt reflector
sandkg_1_40_in	Sphere with 40 kg ^{235}U as UO_2F_2 mixed with 0 v/o sand surrounded by a 4 foot CLSM reflector
sandld_35_20_in	Sphere with 35 kg ^{235}U as UO_2F_2 mixed with 99.5v/o sand (ρ = 1.6 g/cc) surrounded by a 4 foot CLSM reflector
slab_4_1_in	Slab of 150 g/L UO_2F_2 solution 1 cm thick reflected by 4 feet of water.
slab_6_5_in	Slab of 250 g/L UO_2F_2 solution 20 cm thick reflected by 4 feet of water.
foamv_5_2_1_in	Array of 16-inch pipes with 1100 pCi/g coating of UO_2F_2 H/U = 0, foam inside pipe, void in interstitial spaces, no reflector
flood_1_2_2_in	Array of 2-inch pipes with 1100 pCi/g coating of UO_2F_2 H/U = 0, water in pipes and in interstitial spaces surrounded by a 4 foot water reflector
foamw_2_2_2_in	Array of 3-inch pipes with 1100 pCi/g coating of UO_2F_2 H/U = 0, foam in pipes, water in interstitial spaces surrounded by a 4 foot water reflector

file: clsm_10_1_in

```
MCNP calc of clsm_10__1_in
C    0.0 % NRC Concrete Mixed with 100 %UO2F2
C   1 kg of U-235
C   H/U = 0
C   E = 100 %
C   NRC Concrete Reflector
C
C  Cell Data
C
   10  2 -6.30644e+000   -3          imp:n=1    $ UO2F2 sphere
   20  5 -2.12100e+000       3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so       3.66247  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     125.58247  $ OR Of Concrete (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0     3.66247
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 +  0.0 % NRC concrete, H/U=0 , 100% U-235
m2     92235  -7.70557e-001
       92238  -1.58568e-026
        9019  -1.24566e-001
        8016  -1.04877e-001
        1001  -1.58568e-026
       14000  -1.58568e-026
       13027  -1.58568e-026
       11023  -1.58568e-026
       20000  -1.58568e-026
       26054  -1.58568e-026
       26056  -1.58568e-026
       26057  -1.58568e-026
       26058  -1.58568e-026
       12000   -1.58568e-026
       16032   -1.58568e-026
       19000   -1.58568e-026
mt2 lwtr.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
       14000  -0001
       26054  -0.056374435
       26056  -0.908691408
       26057  -0.02118481
       26058  -0.002879347
c
c m4 is CLSM cap
m4      1001  -0.009335234
        8016  -0.550411595
       11023  -0.000703736
       12000  -0.002002168
```

```
      13027  -0.013156298
      14000  -0.396055707
      16032  -0.000656064
      19000  -0.001574979
      20000  -0.020989636
      26054  -0.0002803
      26056  -0.004685245
      26057  -0.000111183
      26058  -1.53764E-05
mt4 lwtr.60t
c
c m5 is CLSM mix
c
m5    1001   -0.010010189
      8016   -0.554193707
     11023   -0.00061911
     12000   -0.001761401
     13027   -0.011523487
     14000   -0.397802179
     16032   -0.000561971
     19000   -0.001385583
     20000   -0.017700402
     26054   -0.000244528
     26056   -0.00408731
     26057   -9.6994E-05
     26058   -1.34141E-05

mt5 lwtr.60t
```

file: clsm_3_4_in

```
MCNP calc of clsm_3__4_in
C   99.5 % NRC Concrete Mixed with 0.5 %UO2F2
C   4 kg of U-235
C   H/U = 0
C   E = 100 %
C   NRC Concrete Reflector
C
C  Cell Data
C
   10  2 -2.14193e+000   -3          imp:n=1    $ UO2F2 sphere
   20  5 -2.12100e+000       3 -2       imp:n=1    $ Reflector
  999  0            2      imp:n=0    $ outside

C
C  Surface Data
C
    3  so      33.99936  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     155.91936  $ 0R Of Concrete (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0    33.99936
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 99.5 % NRC concrete, H/U=0 , 100% U-235
m2    92235  -1.13437e-002
      92238  -4.66868e-026
       9019  -1.83378e-003
       8016  -5.47579e-001
```

```
       1001  -9.86283e-003
      14000  -3.91946e-001
      13027  -1.13538e-002
      11023  -6.09996e-004
      20000  -1.74398e-002
      26054  -2.40928e-004
      26056  -4.02714e-003
      26057  -9.55661e-005
      26058  -1.32166e-005
      12000   -1.73547e-003
      16032   -5.53698e-004
      19000   -1.36519e-003
mt2 lwtr.60t
c
c m3 is steel A53
m3     6012  -0.003
      25055  -0.00675
      15031  -0.00048
      16000  -0.00054
      14000  -0001
      26054  -0.056374435
      26056  -0.908691408
      26057  -0.02118481
      26058  -0.002879347
c
c m4 is CLSM cap
m4     1001  -0.009335234
       8016  -0.550411595
      11023  -0.000703736
      12000  -0.002002168
      13027  -0.013156298
      14000  -0.396055707
      16032  -0.000656064
      19000  -0.001574979
      20000  -0.020989636
      26054  -0.0002803
      26056  -0.004685245
      26057  -0.000111183
      26058  -1.53764E-05
mt4 lwtr.60t
c
c m5 is CLSM mix
c
m5    1001   -0.010010189
      8016   -0.554193707
     11023   -0.00061911
     12000   -0.001761401
     13027   -0.011523487
     14000   -0.397802179
     16032   -0.000561971
     19000   -0.001385583
     20000   -0.017700402
     26054   -0.000244528
     26056   -0.00408731
     26057   -9.6994E-05
     26058   -1.34141E-05

mt5 lwtr.60t
```

file: psteel_20_2_2_in

```
MCNP calc of psteel_20_2 _2 _in

C   99 % Steel Mixed with 0.5 %UO2F2
C   Steeel density = 3.144 g/cc
C   16  Fissile units at 252 g U-235 each
C   H/U = 0
```

```
C   E = 100 %
C   Concrete Reflector
C
C  Cell Data
C
   10  2 -3.15981e+000   -3          imp:n=1    $ UO2F2 sphere
   20  4 -2.35000e+000     3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so      34.08978  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     156.00978  $ OR Of Steel (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0    34.08978
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 99 % Steel, H/U=0 , 100% U-235
m2     92235  -7.68950e-003
       92238  -3.16475e-026
        9019  -1.24306e-003
        8016  -1.04658e-003
        1001  -3.16475e-026
        6000  -9.44676e-004
       25055  -6.68264e-003
       15031  -4.75210e-004
       16000  -5.34611e-004
       14000  -9.09366e-005
       26054  -5.50462e-002
       26056  -8.98997e-001
       26057  -2.18637e-002
       26058  -3.35231e-003
mt2 lwtr.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
       14000  -0001
       26054  -0.056374435
       26056  -0.908691408
       26057  -0.02118481
       26058  -0.002879347
c
c m4 is concrete
m4      1001  -0.006
        8016  -0.5
       14028  -0.315
       13027  -0.048
       11023  -0.017
       20000  -0.083
       26054  -0.000683928
       26056  -0.011024129
       26057  -0.000257011
       26058  -3.49319E-05
       19000  -0.019
mt4 lwtr.60t
```

file: psteel_6_1_5_in

```
MCNP calc of psteel_6 _1 _5 _in

C   50 % Steel Mixed with 50  %UO2F2
C   Steeel density = 1.572 g/cc
C   120 Fissile units at 252 g U-235 each
C   H/U = 0
C   E = 100 %
C   Concrete Reflector
C
C  Cell Data
C
   10  2 -3.93922e+000   -3          imp:n=1    $ UO2F2 sphere
   20  4 -2.35000e+000     3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so      14.37622  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     136.29622  $ 0R Of Steel (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0    14.37622
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 50 % Steel, H/U=0 , 100% U-235
m2    92235  -6.16806e-001
      92238  -2.53857e-026
       9019  -9.97108e-002
       8016  -8.39508e-002
       1001  -2.53857e-026
       6000  -3.80786e-004
      25055  -1.34684e-003
      15031  -9.57753e-005
      16000  -1.07747e-004
      14000  -1.83276e-005
      26054  -1.10942e-002
      26056  -1.81187e-001
      26057  -4.40647e-003
      26058  -6.75634e-004
mt2 lwtr.60t
c
c m3 is steel A53
m3     6012  -0.003
      25055  -0.00675
      15031  -0.00048
      16000  -0.00054
      14000  -0001
      26054  -0.056374435
      26056  -0.908691408
      26057  -0.02118481
      26058  -0.002879347
c
c m4 is concrete
m4     1001  -0.006
```

```
       8016  -0.5
      14028  -0.315
      13027  -0.048
      11023  -0.017
      20000  -0.083
      26054  -0.000683928
      26056  -0.011024129
      26057  -0.000257011
      26058  -3.49319E-05
      19000  -0.019
mt4 lwtr.60t
```

file: salt_8_in

```
MCNP calc of Salt_8 _in

C   70 % Salt Mixed with 30  %UO2F2
C   H/U = 0
C   E = 100 %
C   Salt Reflector
C
C  Cell Data
C
   10  2 -3.41093e+000   -3          imp:n=1    $ UO2F2 sphere
   20  4 -2.17000e+000       3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so       5.48555  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     127.40555  $ 0R Of Salt (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0     5.48555
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 70 % Salt, H/U=0 , 100% U-235
m2     92235  -4.27403e-001
       92238  -2.93175e-026
        9019  -6.90925e-002
        8016  -5.81719e-002
        1001  -2.93175e-026
       11023  -1.75182e-001
       17000  -2.70150e-001
mt2 lwtr.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
       14000  -0001
       14029  -4.84909E-06
       14030  -3.29774E-06
       26054  -0.056374435
       26056  -0.908691408
       26057  -0.02118481
       26058  -0.002879347
```

```
c
c
c m4 is Salt
m4     11023  -0.393374115
       17000  -0.606625885
c m5 is concrete
m5      1001  -0.006
        8016  -0.5
       14028  -0.315
       13027  -0.048
       11023  -0.017
       20000  -0.083
       26054  -0.000683928
       26056  -0.011024129
       26057  -0.000257011
       26058  -3.49319E-05
       19000  -0.019
mt5 lwtr.60t
```

file: sand_1_40_in

```
MCNP calc of sandkg_1 _40_in
C   0  % sand Mixed with 100 %UO2F2
C   Sand density = den_sand|1.3> g/cc
C   40 kg U-235
C   H/U = 0
C   E = 100 %
C   Concrete Reflector
C
C  Cell Data
C
   10  2 -6.30644e+000   -3          imp:n=1    $ UO2F2 sphere
   20  4 -2.12100e+000     3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so      12.52547  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     134.44547  $ OR Of sand (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0    12.52547
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 0  % sand, H/U=0 , 100% U-235
m2     92235  -7.70557e-001
       92238  -1.58568e-026
        9019  -1.24566e-001
        8016  -1.04877e-001
        1001  -1.58568e-026
       14000  -1.58568e-026
mt2 lwtr.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
```

```
      14000  -0001
      26054  -0.056374435
      26056  -0.908691408
      26057  -0.02118481
      26058  -0.002879347
c
c m4 is clsm
m4     1001  -0.009335234
       8016  -0.550411595
      11023  -0.000703736
      12000  -0.002002168
      13027  -0.013156298
      14000  -0.396055707
      16032  -0.000656064
      19000  -0.001574979
      20000  -0.020989636
      26054  -0.0002803
      26056  -0.004685245
      26057  -0.000111183
      26058  -1.53764E-05
mt4 lwtr.60t
c
c m5 is polyurethane foam
c
m5    6000   -0.696
      8016   -0.102
      1001   -0.085
      7014   -0.055
      9019   -0.045
     17000   -0.012
     15031   -0.005
c
c m6 is sand
c
m6   14000   -0.467434921
      8016   -0.532565079
```

file: sandld_35_20_in

```
MCNP calc of sandld_35_20_in
C   99 % sand Mixed with 0.5 %UO2F2
C   Sand density = den_sand|1.3> g/cc
C   35 kg U-235
C   H/U = 0
C   E = 100 %
C   Concrete Reflector
C
C  Cell Data
C
   10  2 -1.62353e+000   -3          imp:n=1    $ UO2F2 sphere
   20  4 -2.12100e+000     3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so      70.06053  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     191.98053  $ 0R Of sand (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0    70.06053
C
C m1 is water
```

```
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 99 % sand, H/U=0 , 100% U-235
m2     92235  -1.49657e-002
       92238  -6.15941e-026
        9019  -2.41931e-003
        8016  -5.24259e-001
        1001  -6.15941e-026
       14000  -4.58356e-001
mt2 lwtr.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
       14000  -0001
       26054  -0.056374435
       26056  -0.908691408
       26057  -0.02118481
       26058  -0.002879347
c
c m4 is clsm
m4      1001  -0.009335234
        8016  -0.550411595
       11023  -0.000703736
       12000  -0.002002168
       13027  -0.013156298
       14000  -0.396055707
       16032  -0.000656064
       19000  -0.001574979
       20000  -0.020989636
       26054  -0.0002803
       26056  -0.004685245
       26057  -0.000111183
       26058  -1.53764E-05
mt4 lwtr.60t
c
c m5 is polyurethane foam
c
m5     6000   -0.696
       8016   -0.102
       1001   -0.085
       7014   -0.055
       9019   -0.045
      17000   -0.012
      15031   -0.005
c
c m6 is sand
c
m6   14000   -0.467434921
      8016   -0.532565079
```

file: foam_20_2_in

```
MCNP calc of pfoam_20_2 _in
C   99 % foam Mixed with 0.5 %UO2F2
C   foam density = den_foam|1.3> g/cc
C   4.03200e+000  kg U-235
C   H/U = 0
C   E = 100 %
C   Concrete Reflector
C
C  Cell Data
```

```
C
   10  2 -6.33722e-002   -3          imp:n=1    $ UO2F2 sphere
   20  4 -2.12100e+000     3 -2       imp:n=1    $ Reflector
  999  0            2          imp:n=0    $ outside

C
C  Surface Data
C
    3  so      34.08978  $ OR Of UO2F2 Sphere (4*252 g)
    2  so     156.00978  $ 0R Of foam (4 foot thick)

C
C Misc Data
C
kcode 2000 1 50  550
sdef rad d2 pos  0   0  0
si2   0    34.08978
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 + 99 % foam, H/U=0 , 100% U-235
m2     92235  -3.83407e-001
       92238  -1.57798e-024
        9019  -8.45896e-002
        8016  -1.03432e-001
        1001  -4.27064e-002
       14000  -1.62987e-024
        6000  -3.49690e-001
        7014  -2.76336e-002
       17000  -6.02914e-003
       15031  -2.51214e-003
mt2 poly.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
       14000  -0001
       26054  -0.056374435
       26056  -0.908691408
       26057  -0.02118481
       26058  -0.002879347
c
c m4 is clsm
m4      1001  -0.009335234
        8016  -0.550411595
       11023  -0.000703736
       12000  -0.002002168
       13027  -0.013156298
       14000  -0.396055707
       16032  -0.000656064
       19000  -0.001574979
       20000  -0.020989636
       26054  -0.0002803
       26056  -0.004685245
       26057  -0.000111183
       26058  -1.53764E-05
mt4 lwtr.60t
c
c m5 is polyurethane foam
c
m5     6000   -0.696
       8016   -0.102
       1001   -0.085
```

```
      7014   -0.055
      9019   -0.045
     17000   -0.012
     15031   -0.005
mt5 poly.60t
c
c m6 is sand
c
m6   14000   -0.467434921
      8016   -0.532565079
```

file: slab_4_1_in

```
MCNP calc of slab_4 _1_in
C   150 g/l UO2F2
C   H/U =  221.52
C   E = 100 %
C     1.00 cm thick slab
C
C  Cell Data
C
   10  2 -1.13098e+000   -10   imp:n=1    $ UO2F2 slab
   20  1 -1.0      10 -20      imp:n=1    $ Reflector
  999  0            20         imp:n=0    $ outside

C
C  Surface Data
C
   10  rpp   -10000.00  10000.00  -10000.00  10000.00   0.00    1.00 $ Solution
   20  rpp   -10121.92  10121.92  -10121.92  10121.92  -121.92  122.92 $ water reflector

C
C Misc Data
C
kcode 2000 1 50  550
sdef x d1 y d2 z d3 pos  0   0  0
si1   -10000.00  10000.00
sp1    0   1
si2   -10000.00  10000.00
sp2    0   1
si3   0    1.00
sp3    0   1
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 Solution
m2    92235  -1.02198e-001
      92238  -1.00000e-025
       9019  -1.65210e-002
       8016  -7.84214e-001
       1001  -9.70670e-002
mt2 lwtr.60t
c
c m3 is steel A53
m3     6012  -0.003
      25055  -0.00675
      15031  -0.00048
      16000  -0.00054
      14028  -9.18532E-05
      14029  -4.84909E-06
      14030  -3.29774E-06
      26054  -0.055601068
      26056  -0.908058795
```

```
      26057  -0.02208404
      26058  -0.003386097
c
c m4 is concrete
m4     1001  -0.006
       8016  -0.5
      14028  -0.289401342
      14029  -0.015220127
      14030  -0.010378531
      13027  -0.048
      11023  -0.017
      20000  -0.083
      26054  -0.000677467
      26056  -0.011028183
      26057  -0.000259244
      26058  -3.51053E-05
      19000  -0.019
```

file: slab_6_5_in

```
MCNP calc of slab_6 _5_in
C   250 g/l UO2F2
C   H/U =  131.14
C   E = 100 %
C    20.00 cm thick slab
C
C  Cell Data
C
   10  2 -1.21789e+000   -10   imp:n=1    $ UO2F2 slab
   20  1 -1.0      10 -20      imp:n=1    $ Reflector
  999  0            20         imp:n=0    $ outside

C
C  Surface Data
C
   10  rpp   -10000.00  10000.00  -10000.00  10000.00   0.00   20.00 $ Solution
   20  rpp   -10121.92  10121.92  -10121.92  10121.92  -121.92  141.92 $ water reflector

C
C Misc Data
C
kcode 2000 1 50  550
sdef x d1 y d2 z d3 pos  0   0  0
si1   -10000.00  10000.00
sp1    0   1
si2   -10000.00  10000.00
sp2    0   1
si3   0   20.00
sp3    0   1
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 Solution
m2    92235  -1.58175e-001
      92238  -1.00000e-025
       9019  -2.55700e-002
       8016  -7.27318e-001
       1001  -8.89374e-002
mt2 lwtr.60t
c
c m3 is steel A53
m3     6012  -0.003
      25055  -0.00675
      15031  -0.00048
```

```
      16000  -0.00054
      14028  -9.18532E-05
      14029  -4.84909E-06
      14030  -3.29774E-06
      26054  -0.055601068
      26056  -0.908058795
      26057  -0.02208404
      26058  -0.003386097
c
c m4 is concrete
m4     1001  -0.006
       8016  -0.5
      14028  -0.289401342
      14029  -0.015220127
      14030  -0.010378531
      13027  -0.048
      11023  -0.017
      20000  -0.083
      26054  -0.000677467
      26056  -0.011028183
      26057  -0.000259244
      26058  -3.51053E-05
      19000  -0.019
```

file: foamv_5_2_2_in

```
MCNP calc of foamv_5_2_2_in
C   16 Inch Pipe
C   UO2F2 Coating based on 1100 pCi/g
C   H/U = 4
C   E = 100 wt-%
C   foam 4.48730e+000  g/cc as Moderator inside pipe
C   concret reflector
C   void between pipes
C
C  Cell Data
C
   10  5 -3.20000e-002   -3 u=10 imp:n=1            $ center of pipe
   20  2 -4.48730e+000  3 -2 u=10 imp:n=1    $ UO2F2 H/U=22
   30  3 -7.86000e+000  2 -1 u=10 imp:n=1 imp:n=1 $ Steel A-53
   40  0  1  u=10  imp:n=1           $ rest of universe 10
   50  0  -5  4  -7  6 u=20 lat=1
       fill 0:5    0:4    0:0  10    29r
       imp:n=1                          $ Lattice
  100  0  -10 fill=20  imp:n=1       $ container
  120  0  -20 10 imp:n=1             $ no reflector
  999  0        20    imp:n=0             $ outside

C
C  Surface Data
C
    1  c/z    20.33  20.33  20.320000  $ OR Of Pipe  (6 Inch)
    2  c/z    20.33  20.33  19.050000  $ IR Of Pipe  (6 Inch)
    3  c/z    20.33  20.33  19.044673  $ IR Of UO2F2 (.2 cm)
    4  px     0
    5  px    40.66
    6  py     0
    7  py    40.66
   10  rpp    0        238.76    0.0     177.80   0.0    474.98 $ gondola
   20  rpp    -121.92    360.68   -121.92    299.72   -121.92    596.90 $  reflector

C
C Misc Data
C
kcode 2000 1 50  550 200000
sdef cell 100:50:20  rad d2 ext d3  pos 20.33  20.33  0  axs 0 0 1
si2  19.044673  19.050000
```

```
si3  0    474.98
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 H/U=22  100% U-235
m2    92235  -6.89171e-001
      92238  -1.00000e-025
       9019  -1.11409e-001
       8016  -1.87600e-001
       1001  -1.18199e-002
mt2 lwtr.60t
c
c m3 is steel A53
m3     6012  -0.003
      25055  -0.00675
      15031  -0.00048
      16000  -0.00054
      14000  -0.0001
      26054  -0.056374435
      26056  -0.908691408
      26057  -0.02118481
      26058  -0.002879347
c
c m4 is concrete
m4     1001  -0.006
       8016  -0.5
      14028  -0.315
      13027  -0.048
      11023  -0.017
      20000  -0.083
      26054  -0.000683928
      26056  -0.011024129
      26057  -0.000257011
      26058  -3.49319E-05
      19000  -0.019
mt4 lwtr.60t
c
c m5 is polyurethane foam
m5    6000   -0.696
      8016   -0.102
      1001   -0.085
      7014   -0.055
      9019   -0.045
     17000   -0.012
     15031   -0.005
mt5 poly.60t
```

file: flood_1_2_2_in

```
MCNP calc of flood_1_2_2_in
C   2  Inch Pipe
C   UO2F2 Coating based on 1100 pCi/g
C   H/U = 4
C   E = 100 wt-%
C   water as Moderator inside pipe
C   water reflector
C   water between pipes
C
C  Cell Data
C
   10  1 -1.0  -3 u=10 imp:n=1            $ center of pipe
   20  2 -4.48730e+000  3 -2 u=10 imp:n=1    $ UO2F2 H/U=22
   30  3 -7.86000e+000  2 -1 u=10 imp:n=1 imp:n=1 $ Steel A-53
```

```
   40  1 -1.0  1  u=10  imp:n=1          $ rest of universe 10
   50  0  -5  4  -7  6 u=20 lat=1
       fill 0:39   0:29   0:0  10  1199r
       imp:n=1                           $ Lattice
  100  1 -1.0  -10 fill=20  imp:n=1      $ container
  120  1 -1.0  -20 10 imp:n=1            $ concrete reflector
  999  0        20    imp:n=0            $ outside

C
C  Surface Data
C
    1  c/z     3.02   3.02   3.016250  $ OR Of Pipe  (6 Inch)
    2  c/z     3.02   3.02   2.625090  $ IR Of Pipe  (6 Inch)
    3  c/z     3.02   3.02   2.623384  $ IR Of UO2F2 (.2 cm)
    4  px     0
    5  px     6.04
    6  py     0
    7  py     6.04
   10  rpp    0         238.76    0.0     177.80   0.0    474.98 $ gondola
   20  rpp    -121.92    360.68   -121.92    299.72   -121.92    596.90 $  reflector

C
C Misc Data
C
kcode 2000 1 50  550 200000
sdef cell 100:50:20  rad d2 ext d3  pos  3.02   3.02  0  axs 0 0 1
si2   2.623384   2.625090
si3  0    474.98
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 H/U=22  100% U-235
m2     92235  -6.89171e-001
       92238  -1.00000e-025
        9019  -1.11409e-001
        8016  -1.87600e-001
        1001  -1.18199e-002
mt2 lwtr.60t
c
c m3 is steel A53
m3      6012  -0.003
       25055  -0.00675
       15031  -0.00048
       16000  -0.00054
       14000  -0.0001
       26054  -0.056374435
       26056  -0.908691408
       26057  -0.02118481
       26058  -0.002879347
c
c m4 is concrete
m4      1001  -0.006
        8016  -0.5
       14028  -0.315
       13027  -0.048
       11023  -0.017
       20000  -0.083
       26054  -0.000683928
       26056  -0.011024129
       26057  -0.000257011
       26058  -3.49319E-05
       19000  -0.019
mt4 lwtr.60t
```

file: foamw_2_2_2_in

```
MCNP calc of foamw_2_2_2_in
C   3  Inch Pipe
C   UO2F2 Coating based on 1100 pCi/g
C   H/U = 4
C   E = 100 wt-%
C   foam 4.48730e+000  g/cc  as Moderator inside pipe
C   water reflector
C   water between pipes
C
C  Cell Data
C
   10  5 -3.20000e-002   -3 u=10 imp:n=1            $ center of pipe
   20  2 -4.48730e+000  3 -2 u=10 imp:n=1    $ UO2F2 H/U=22
   30  3 -7.86000e+000  2 -1 u=10 imp:n=1 imp:n=1 $ Steel A-53
   40  1 -1.0  1  u=10  imp:n=1           $ rest of universe 10
   50  0  -5  4  -7  6 u=20 lat=1
       fill 0:26   0:19   0:0  10   539r
       imp:n=1                            $ Lattice
  100  1 -1.0  -10 fill=20  imp:n=1       $ container
  120  1 -1.0  -20 10 imp:n=1             $ concrete reflector
  999  0        20    imp:n=0             $ outside

C
C  Surface Data
C
    1  c/z     4.45   4.45   4.445000  $ OR Of Pipe  (6 Inch)
    2  c/z     4.45   4.45   3.896360  $ IR Of Pipe  (6 Inch)
    3  c/z     4.45   4.45   3.893976  $ IR Of UO2F2 (.2 cm)
    4  px     0
    5  px     8.90
    6  py     0
    7  py     8.90
   10  rpp    0        238.76    0.0     177.80   0.0    474.98 $ gondola
   20  rpp   -121.92    360.68   -121.92    299.72   -121.92    596.90 $  reflector

C
C Misc Data
C
kcode 2000 1 50  550 200000
sdef cell 100:50:20  rad d2 ext d3  pos  4.45   4.45  0  axs 0 0 1
si2   3.893976   3.896360
si3  0    474.98
C
C m1 is water
c
m1 1001 2 8016 1
mt1 lwtr.60t
c
c m2 is UO2F2 H/U=22  100% U-235
m2    92235  -6.89171e-001
      92238  -1.00000e-025
       9019  -1.11409e-001
       8016  -1.87600e-001
       1001  -1.18199e-002
mt2 lwtr.60t
c
c m3 is steel A53
m3     6012  -0.003
      25055  -0.00675
      15031  -0.00048
      16000  -0.00054
      14000  -0.0001
      26054  -0.056374435
      26056  -0.908691408
      26057  -0.02118481
```

```
      26058  -0.002879347
c
c m4 is concrete
m4     1001  -0.006
       8016  -0.5
      14028  -0.315
      13027  -0.048
      11023  -0.017
      20000  -0.083
      26054  -0.000683928
      26056  -0.011024129
      26057  -0.000257011
      26058  -3.49319E-05
      19000  -0.019
mt4 lwtr.60t
c
c m5 is polyurethane foam
m5    6000   -0.696
      8016   -0.102
      1001   -0.085
      7014   -0.055
      9019   -0.045
     17000   -0.012
     15031   -0.005
mt5 poly.60t
```