S

ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 632081

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental ○ Direct Revision ● Change ECN ○ Temporary ○ Standby ○ Supersedure ○ Cancel/Void ○	J. Greenborg, FFS, B4-44, 376-3482	○ Yes ● No	4/30/01
	6. Project Title/No./Work Order No. Plutonium Finishing Plant	7. Bldg./Sys./Fac. No. PFP/234-5Z	8. Approval Designator S
	9. Document Numbers Changed by this ECN (includes sheet no. and rev.) HNF-4436, Rev. 0	10. Related ECN No(s). N/A	11. Related PO No. N/A

12a. Modification Work	12b. Work Package No.	12c. Modification Work Completed	12d. Restored to Original Condition (Temp. or Standby ECNs only)
○ Yes (fill out Blk. 12b) ● No (NA Blks. 12b, 12c, 12d)	N/A	N/A Design Authority/Cog. Engineer Signature & Date	N/A Design Authority/Cog. Engineer Signature & Date

13a. Description of Change

13b. Design Baseline Document? ○ Yes ● No

Revision to allow processing U-235 enriched >50% providing U-235 bulk density is greater than 1 g/cm3 and waste remain so if flooded. Thermal Stabilization materials; U metal, Pu/U alloys, and oxides fall in this category.

14a. Justification (mark one)	14b. Justification Details
Criteria Change ○ Design Improvement ○ Environmental ○ Facility Deactivation ○ As-Found ● Facilitate Const. ○ Const. Error/Omission ○ Design Error/Omission ○	Thermal Stabilization Metals and oxides are insoluble and fissile bulk density exceeds 1 g/cm3 (1000 g/L).

15. Distribution (include name, MSIN, and no. of copies)
See distribution list.

RELEASE STAMP

DATE: JUN 29 2001
STA: 5
HANFORD RELEASE
ID: 12

ENGINEERING CHANGE NOTICE

1. ECN (use no. from pg. 1): 632081

16. Design Verification Required
- ◯ Yes
- ◉ No

17. Cost Impact

ENGINEERING		CONSTRUCTION	
Additional ◯	$	Additional ◯	$
Savings ◯	$	Savings ◯	$

18. Schedule Impact (days)
- Improvement ◯
- Delay ◯

19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	☐	Seismic/Stress Analysis	☐	Tank Calibration Manual	☐
Functional Design Criteria	☐	Stress/Design Report	☐	Health Physics Procedure	☐
Operating Specification	☐	Interface Control Drawing	☐	Spares Multiple Unit Listing	☐
Criticality Specification	☒	Calibration Procedure	☐	Test Procedures/Specification	☐
Conceptual Design Report	☐	Installation Procedure	☐	Component Index	☐
Equipment Spec.	☐	Maintenance Procedure	☐	ASME Coded Item	☐
Const. Spec.	☐	Engineering Procedure	☐	Human Factor Consideration	☐
Procurement Spec.	☐	Operating Instruction	☐	Computer Software	☐
Vendor Information	☐	Operating Procedure	☐	Electric Circuit Schedule	☐
OM Manual	☐	Operational Safety Requirement	☐	ICRS Procedure	☐
FSAR/SAR	☐	IEFD Drawing	☐	Process Control Manual/Plan	☐
Safety Equipment List	☐	Cell Arrangement Drawing	☐	Process Flow Chart	☐
Radiation Work Permit	☐	Essential Material Specification	☐	Purchase Requisition	☐
Environmental Impact Statement	☐	Fac. Proc. Samp. Schedule	☐	Tickler File	☐
Environmental Report	☐	Inspection Plan	☐		☐
Environmental Permit	☐	Inventory Adjustment Request	☐		☐

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number/Revision
N/A		

21. Approvals

	Signature	Date
Design Authority	B. S. Mo [signature]	5/17/01
Cog. Eng.	H. R. Risenmay [signature]	5-17-01
Cog. Mgr.	D. G. Satterwhite [signature]	5/30/01
QA	N/A	
Safety	S. E. Nunn [signature]	5-23-01
Environ.	N/A	
Other		
Orig. Eng.	J. Greenborg [signature]	04/30/01
Orig. Mgr.	H. Toffer [signature]	5/3/01
Tech. Rev.	R. F. Richard [signature]	4/30/01
CSE	A. D. Wilkinson [signature]	5/17/01
Ops. Mgr.	M. D. Talbot [signature]	5/20/01
CSR	B. S. Mo [signature]	5/17/01

	Signature	Date
Design Agent		
PE		
QA		
Safety		
Design		
Environ.		
Other		

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	Criticality and Shielding FFS	Date 4/30/01
Project Title/Work Order		EDT No. N/A
CSER 99-003, Rev. 1 Criticality Mass of Uranium as Compared to Plutonium-Implications for PFP Processing Uranium		ECN No. 632081

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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Revision 1

CSER 99-003, Rev. 1 Criticality Mass of Uranium as Compared to Plutonium-Implications for PFP Processing Uranium

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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CSER 99-003, Rev. 1 Criticality Mass of Uranium as Compared to Plutonium-Implications for PFP Processing Uranium

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Fluor Federal Services

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(2) Title

CSER 99-003, Rev. 1 Criticality Mass of Uranium as Compared to Plutonium-Implications for PFP Processing Uranium

Change Control Record

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0	(7) Initial release, EDT 619979, dated 5/26/1999	RM Marusich	JP Estrellado
RS 1	Replace entire document per ECN 632081	J Greenborg J Greenborg 04/30/01	H Toffer H Toffer 5/3/01

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CSER 99-003, Rev. 1 Critical Mass of Uranium as Compared to Plutonium-Implications for PFP Processing Uranium

Key Words: Plutonium Finishing Plant (PFP), fissile material, fissionable material, criticality, metal Thermal Stabilization

Abstract: The purpose of this report is to provide information to be used in the evaluation of the CSER and CPS for equipment and activities involved in thermal stabilization. It is well known that for equal mass, ^{239}Pu is more reactive than ^{235}U except at fissile material concentrations of 100 g/L to 1,000 g/L. In this range of concentrations, spheres of highly enriched 94% uranium have a lower critical mass than spheres of ^{239}Pu. Within these same limits, infinite cylinders of highly enriched uranium (^{235}U in ^{238}U) have a smaller critical diameter than infinite cylinders of ^{239}Pu. This report determines the fissile concentrations between which ^{239}Pu is more reactive than uranium (^{235}U in ^{238}U). The information can be used for the revision of CSERs and CPS's to allow processing uranium using limits developed for plutonium.

CSER 99-003, Rev. 1
Critical Mass of Uranium as Compared to Plutonium – Implications for PFP Processing Uranium

April 2001

Prepared by
Fluor Federal Services
Richland, Washington

For
Fluor Hanford
In support of
Task Order No. 5240

Prepared by: ____________________ Date: 04/30/01
J. Greenborg, Criticality and Shielding

Prepared by: ____________________ Date: 04/30/01
D. G. Erickson, Criticality and Shielding

Reviewed by: ____________________ Date: 4/30/01
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Approved by: ____________________ Date: 5/3/01
H. Toffer, Manager, Criticality and Shielding

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1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The Plutonium Finishing Plant (PFP) has uranium-bearing materials in storage. These materials will require stabilization. The Criticality Safety Evaluation Reports (CSER) and Criticality Protection Specifications (CPS) are in place for plutonium stabilization and may need to be modified to allow uranium stabilization.

The purpose of this report is to provide information to be used in the evaluation of the CSER and CPS for equipment and activities involved in thermal stabilization or other PFP operations. It is well known that for equal mass, ^{239}Pu is more reactive than ^{235}U except at fissile material concentrations of 100 g/L to 1,000 g/L. In this range of concentrations, spheres of highly enriched 94% uranium have a lower critical mass than spheres of ^{239}Pu. Within these same limits, infinite cylinders of highly enriched uranium (^{235}U in ^{238}U) have a smaller critical diameter than infinite cylinders of ^{239}Pu. This report determines the fissile concentrations between which ^{239}Pu is more reactive than uranium (^{235}U in ^{238}U). The information can then be used for the revision of CSERs and CPS's to allow processing uranium using limits developed for plutonium.

1.2 CONCLUSIONS

The conclusion obtained from comparing the reactivity of uranium (^{235}U in ^{238}U) at different fissile concentrations and enrichments in water with 100% ^{239}Pu in water at the same fissile concentrations as the uranium is that:

> Uranium (^{235}U in ^{238}U) at fissile concentrations below 100 g/L (0.1 g/cm^3) <u>OR</u> above 1,000 g/L (1 g/cm^3) <u>OR</u> Uranium at enrichments up to 50 wt% ^{235}U in ^{238}U, is less reactive than an equal mass of ^{239}Pu for any concentration,

Therefore criticality safety limits established in CSERs for ^{239}Pu adequately covers uranium in the same application for ^{235}U concentrations in the range 100 g/L (0.1 g/cm^3) to 1,000 g/L (1 g/cm^3) <u>OR</u> for uranium enrichment of less than 50 wt% ^{235}U in ^{238}U. The uranium fissile isotope analyzed in this CSER is ^{235}U and not ^{233}U. The conclusions of this CSER are not applicable to ^{233}U.

Processing uranium enriched to greater than 50 wt% ^{235}U <u>AND</u> with a fissile concentrations in the range 100 g/L (0.1 g/cm^3) to 1,000 g/L (1 g/cm^3) will require additional CSER analysis to establish criticality safety limits for processing that uranium.

Consistent with the above, it is expected that most, if not all, of the uranium-bearing materials at the PFP with ^{235}U enrichment >50 wt% are suitable for processing based on existing glove box Pu limits (i.e., substituting ^{235}U content for ^{239}Pu on a gram for gram basis). See Section 4.3.

2.0 SYSTEM DESCRIPTION AND NORMAL OPERATIONS

No specific PFP system or operation is analyzed. The analysis provided is a parameter study with the results applied to all systems and operations involving uranium-bearing material.

3.0 LIMITS AND CONTROLS

The limits determined by the parameter study show where uranium is less reactive than plutonium. It is conservative to substitute ^{239}Pu for ^{235}U, gram-for-gram:

1. If ^{235}U concentration is below 100 g/L or above 1,000 g/L OR
2. ^{235}U in ^{238}U enrichment is less than 50 wt% OR
3. If material is insoluble and has a fissile bulk density in excess of 1 g/cm^3. These materials may include Pu/U metal alloy, corrosion products, oxidized metal, product quality oxide (See Section 4.3).

This information can be used in CSERs and CPSs to limit the uranium to allowed concentrations. Outside of the these limits, new analyses are necessary for operations with uranium.

4.0 METHODOLOGY

The first step in the analysis was to determine the upper and lower concentration where 94% enriched uranium is more reactive than 100% ^{239}Pu using critical mass handbooks. The high enrichment values (94% for ^{235}U and 100% ^{239}Pu) were chosen so that the analysis results would be bounding. PFP has some containers with uranium enrichments up to 94% as well as some plutonium with as little as 3% ^{240}Pu. The second step involved using computer analysis to find the fissile concentration crossover points.

4.1 USE OF CRITICAL MASS HANDBOOKS

The first investigation to determine the range where plutonium or uranium is the most reactive and the upper and lower concentration cross-over point involved consulting the various critical mass handbooks. Table 1 presents the results of that review for critical spheres. Similar upper and lower cross-over points were obtained for infinite cylinders. Table 1 shows the lower cross-over point to be between 100 and 200 g (fissile)/L. The upper cross-over point was found to be around 1,000 g, fissile/L. The critical masses as shown in ARH-600 are not directly comparable to those in LA-12808. The calculations performed for ARH-600 did not include bias or safety margin, whereas the calculations for LA-12808 include both. This means that the LA-12808 reported critical masses are conservative (smaller).

Table 1. Critical Mass of ^{235}U or ^{239}Pu Fully H_2O Reflected Spheres

Critical Mass, kg of Fissile Material				
Fissile Concentration	LA-12808		ARH-600	
kg/L	^{235}U (93.5)	^{239}Pu	^{235}U (93.5)	^{239}Pu
0.1	0.89	0.77	1.0	0.87
0.2	1.25	1.33	1.4	1.5
0.3	1.82	1.90	1.9	2.15
0.4	2.26	2.41	2.5	2.8
0.5	2.77	2.84	3.0	3.4
0.6	3.32	3.44	3.6	4.0
0.7	3.60	3.77	4.2	4.6
0.8	4.22	4.36	4.8	5.2
0.9	4.80	4.68	5.4	5.6
1.0	5.3	5.02	6.0	6.0
Figure within the Reference	Fig. 6	Fig. 10	III.B.6 (93.5)-2	III.A.6.100-3
1.35	7.8	7.5	-	-
2	11.0	7.9	10.8	8.5
4	17.0	10.0	-	-
5	-	-	19.7	10.7
10	24.0	7.3	21.5	8.8
Figure within the Reference	Fig. 6	Fig. 10	III.B.9 (93.5)-2	III.A.9.100-3

While the handbook values are reasonably accurate, a detailed analysis using an approved computer code is needed to determine the exact location of the upper and lower concentration. This analysis is described in the next section.

4.2 MCNP ANALYSIS

Pairs of uranium and plutonium fissile concentrations and critical mass from the critical mass handbooks were chosen for analysis in MCNP. The pairs were chosen on the basis that the approximate location of the upper and lower limit be surrounded. Pairs were also chosen in between and outside of the approximate location of the upper and lower concentration cross-over point.

The MCNP code provided the values of k_{eff} for each pair. Calculations of k_{eff} were made using the MCNP version 4B code (Breismeister 1997). Quality assurance verification documentation is contained in Schwinkendorf (1998). Erickson (1998) reports MCNP4B validation activities for plutonium systems, while Ruben (1998) covers low enriched uranium systems. The pairs and associated k_{eff} were arranged so that a straight-line interpolation of several data points could be used to determine the critical mass for each fissile concentration chosen. This analysis was performed for all 4 combinations of 94% enriched uranium and 100% ^{239}Pu spheres and infinite cylinders. An analysis was also performed to determine the critical mass as a function of fissile concentration for 50 wt%-enriched uranium.

The computer models used in this analysis are either fully water reflected spheres of fissile material/water mix, or fully water reflected infinite cylinders of fissile material/water mix. The fissile material was conservatively assumed to be fine metal particles. System dimensions were chosen such that the critical condition was bracketed. The actual critical dimension was determined by linear interpolation. Input parameters were calculated by Excel spreadsheets; a list of input files is given in the attached table. Sample input files and the explanation of the attached spreadsheet columns are given in Appendix A.

4.3 ENRICHED URANIUM > 50 WT% ^{235}U* BEARING MATERIALS THAT CAN BE SUBSTITUTED ^{239}PU TO ^{235}U GRAM-FOR-GRAM

Dry processing of Pu residues and Pu/U alloys (including contingencies) generally does not subject these materials to the moderation conditions identified in the previous section. Examples are:

URANIUM/PLUTONIUM METAL ALLOY TO BE PROCESSED BY THERMAL STABILIZATION

The density of these alloys typically exceeds 10 g/cm^3. When thermally stabilized, this material is converted to oxide with bulk densities in the range of 3 to 5 g/cm^3 (Moseley 1965, Felt 1967, and Barr 1971). In these forms, these materials are no more reactive than an equal mass of Pu.

Thermal stabilization materials are insoluable. When infiltrated with water, they do not mimic solutions, i.e., they do not suspend in water without a mechanism to accomplish that. At an oxide (or metal) density of 3 g/cm^3, or more, if infiltrated with water, ^{235}U (enriched > 50 wt%) in this material would be less reactive than ^{239}Pu (2650 g/L fissile, see Figures 1 and 2). Even if this material is less than 3 g/cm^3, any ^{235}U (enriched >50 wt%) present will be less reactive than ^{239}Pu providing the fissile concentration of the material is at least 1 g/cm^3 (1000 g/L, see Figures 1 and 2 and Section 5.0, Results). Should this material contain an insoluble non-hydrogenous diluent (or surrogate), the reactivity is further reduced. This is demonstrated in CSER 00-001, Ad 1 (Greenborg and Erickson 2001), which examined the reactivity of plutonium in silicon dioxide (SiO_2) sand infiltrated with water.

Thermal Stabilization is a dry process. Water intrusion in this process is evaluated in the double contingency analysis of each applicable glovebox or process criticality safety evaluation

* The enrichment at which ^{235}U is more reactive than ^{239}Pu is above 50%, perhaps about 75% (visual linear interpolation of Figure 1). However, the safety basis remains 50%; the limit of the analysis.

(CSER). If the assumptions in these CSERs are consistent with the above, the limits therein should apply to EU > 50 wt% ^{235}U gram-for-gram fissile.

The H/X range in which ^{235}U (enriched > 50 wt%) is more reactive than ^{239}Pu (gram for gram) i.e., the cross over points in Figures 1 and 2, is 35 to 150 (see Figure 3; H/X vs fissile concentration in water mixtures). At the limits, < 100 g/L and > 1000 g/L, H/X is 250 and 25, respectively. These observations are a basis for evaluating criticality limits of glove box operations which process uranium bearing materials which are damp and/or are subject to limited moderation contingencies.

GLOVE BOX INVENTORIES CONTAINING LESS THAN 15 GRAMS ^{235}U IN EU > 50 wt% ENRICHED

In the professional judgment of the authors, glovebox inventories less than 15 grams ^{235}U in EU > 50 wt%, are insignificant and can be treated on a gram-for-gram substitution basis.

5.0 RESULTS

The MCNP analysis showed that the lower concentration cross-over point for spheres of fissile isotopes ^{235}U and ^{239}Pu is at about 100 g (fissile)/L. The upper cross-over point is at about 850 g (fissile)/L. For infinite cylinders, the lower crossover point is the same as that for spheres and the upper crossover point is at about 700 g (fissile)/L. These concentration cross-over points are shown in Figures 1 and 2.

The conclusions obtained from the materials analysis of the fissile isotopes ^{235}U and ^{239}Pu are as follows:

1. Uranium enrichments of ^{235}U in ^{238}U equal to or less than 50 wt% have critical mass and dimensions larger than those containing 100% ^{239}Pu of equal moderation.

2. Uranium-235 concentration above 1,000 g/L (1 g/cm^3) is less reactive than an equal mass of ^{239}Pu for the same moderation.

3. 50 to 94% enriched ^{235}U in ^{238}U, in a ^{235}U concentration of greater than 100 g/L (0.1 g/cm^3) less than 1,000 g/L (1 g/cm^3) requires a specific separate analysis. Exceptions are listed in Section 4.3.

6.0 REFERENCES

LA-12808 stands for N. L. Pruvost, H. C. Paxton, 1996, *Nuclear Criticality Safety Guide*, LA-12808, Los Alamos National Laboratory, Albuquerque, New Mexico.

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Schwinkendorf, K. N., 1998, *Software Certification Report for MCNP4B*, Fluor Daniel Northwest, Inc., Richland, Washington.

Ruben, R. H. and K. N. Schwinkendorf, 1998, *MCNP4B Criticality Validation and Bias for Low-Enriched Uranium Systems*, HNF-SD-SNF-ANAL-013, Rev. 1, Fluor Daniel Northwest, Inc., Richland, Washington.

Figure 1. Critical Mass For Water Reflected Spheres

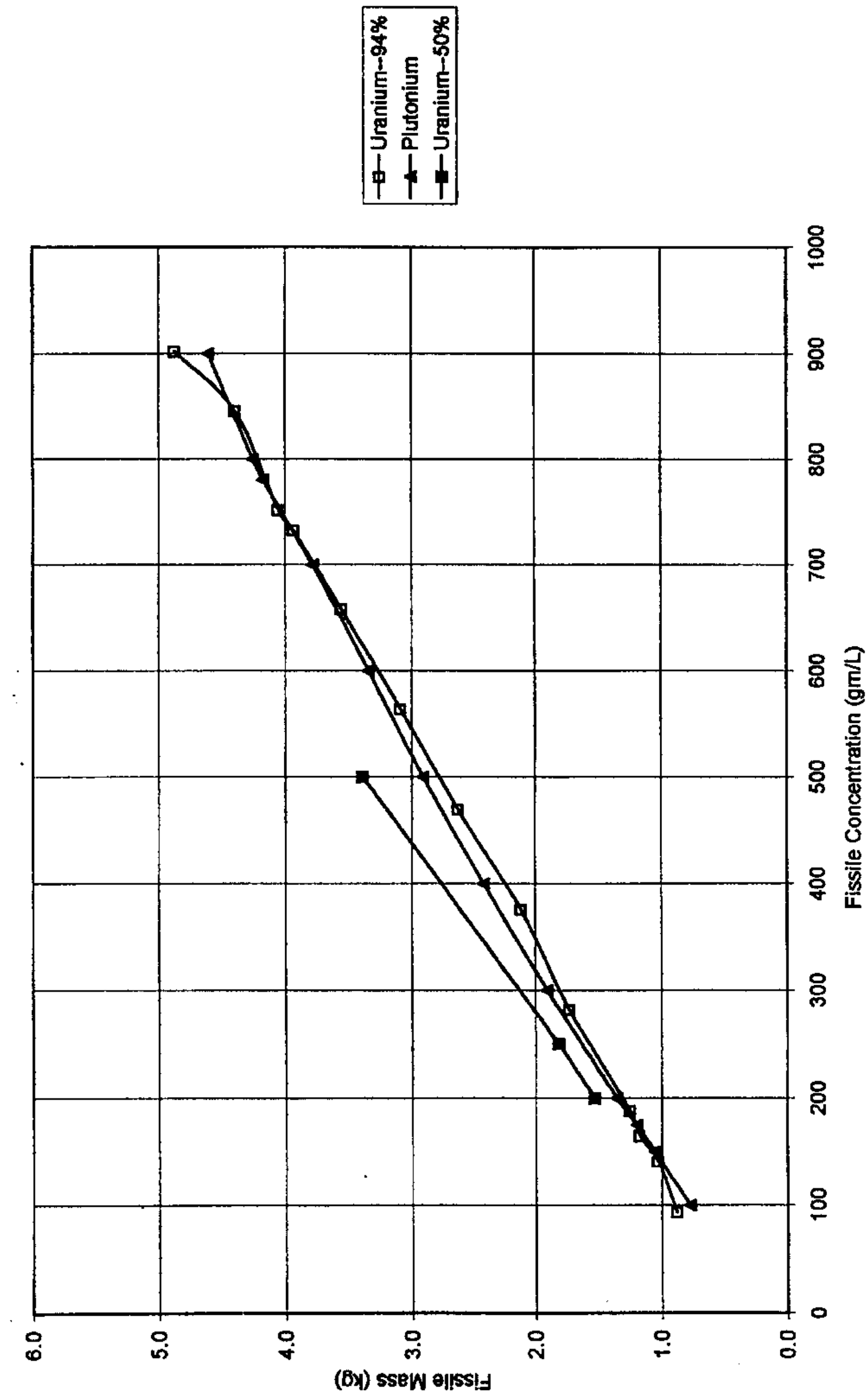


Figure 2. Critical Diameter For Water Reflected Infinite Cylinders

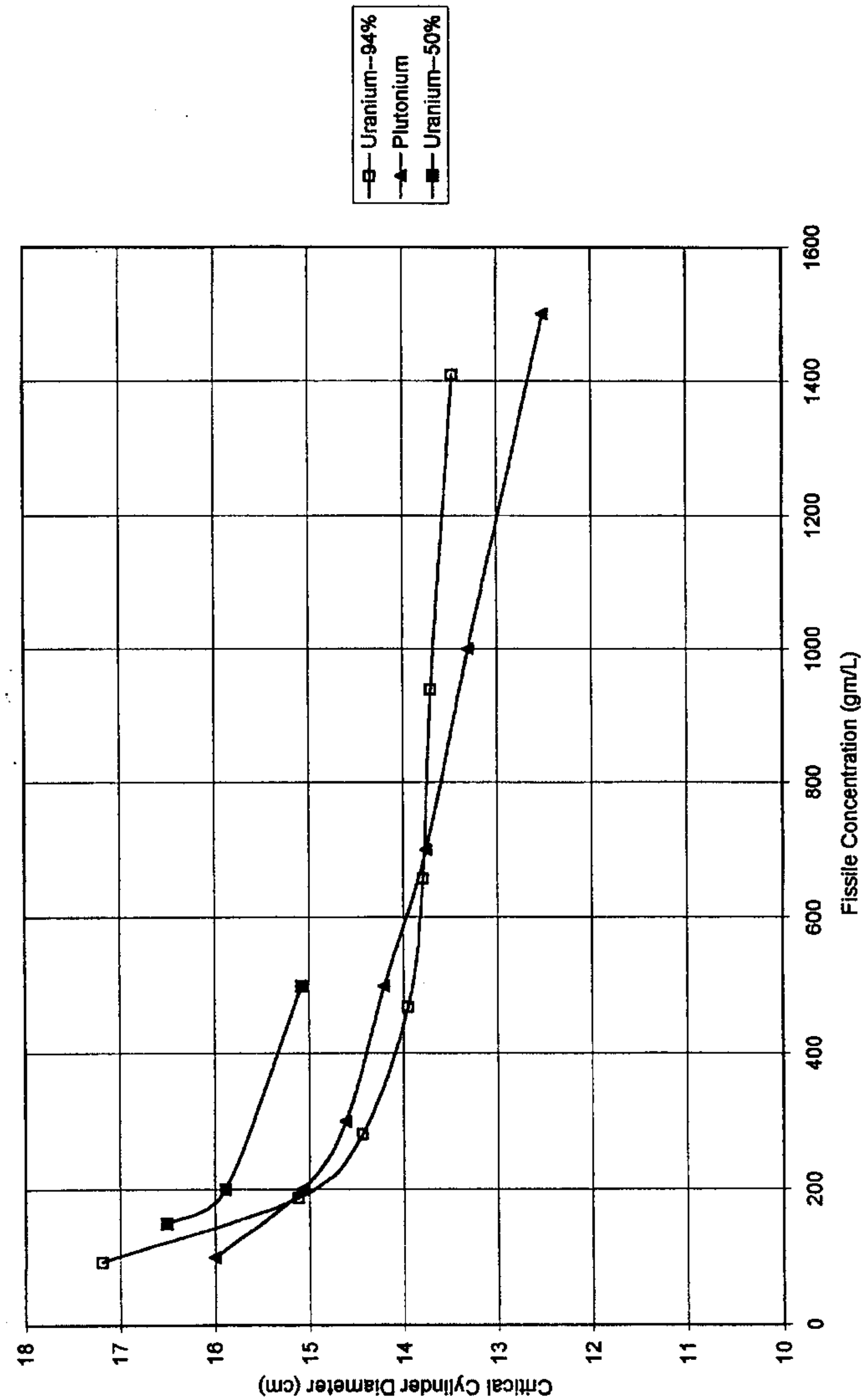
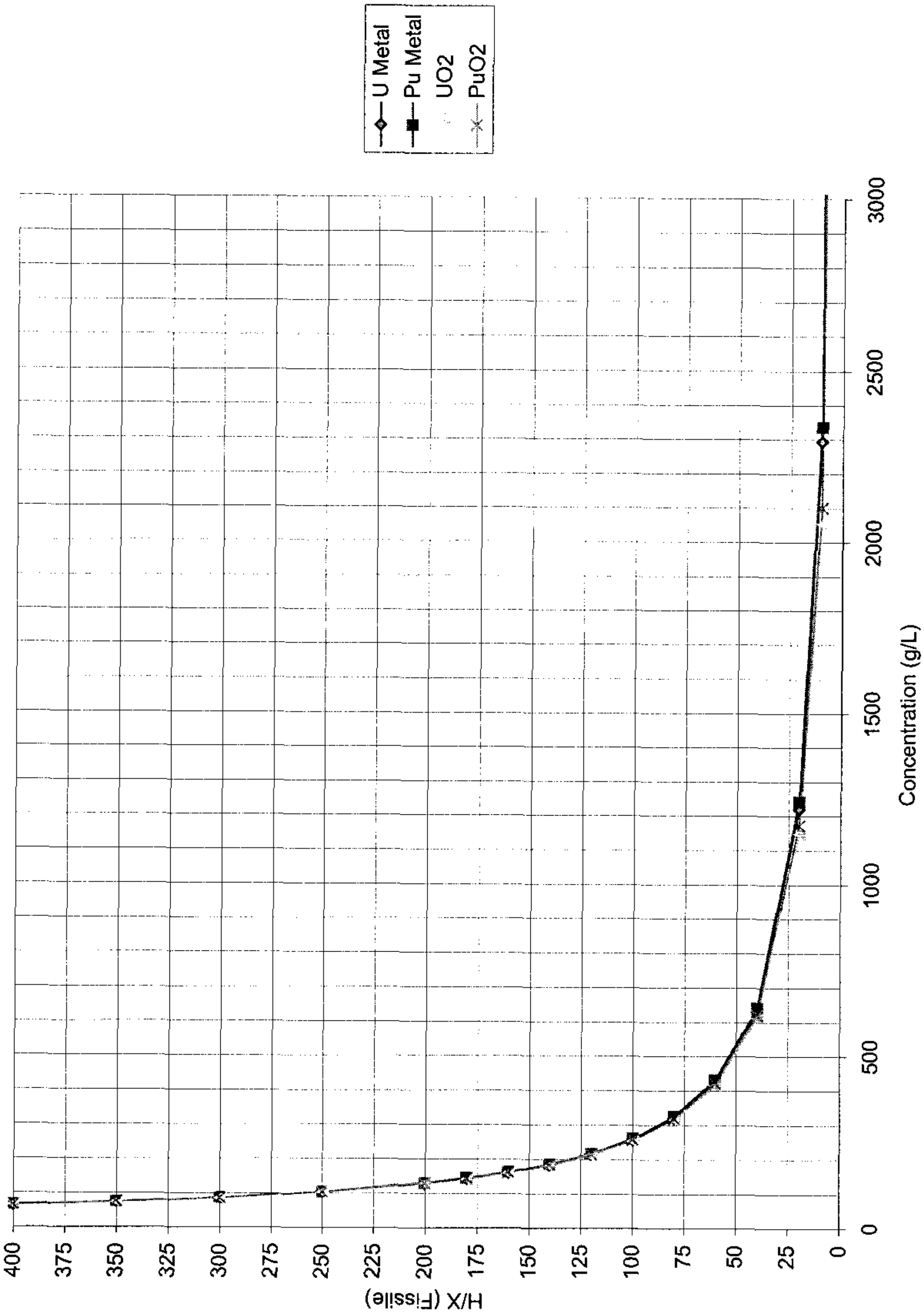


Figure 3. H/X vs Fissile Concentration in Water Mixtures



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APPENDIX A
MCNP ANALYSIS

Input and output file names consist of a letter, "r" for the spherical cases and "c" for the cylindrical cases, a sequence number, and a letter, "u" for uranium cases and "p" for plutonium cases. Input files have a ".inp" extension, outputs a "out" extension.

A1.0 MCNP Input

For the spherical systems, MCNP input data was calculated in the spreadsheet of Table A1-3. Starting point was the chosen fissile concentration, in grams per liter (column B), and the total fissile mass in the system (column C). Columns D and E are the enrichments, in weight percent, of ^{235}U in uranium and ^{239}Pu in plutonium, respectively. The metal volume fractions (columns F and G) of the water-metal mix were determined by dividing the heavy metal concentration by the appropriate metal density (and applying conversion factors as necessary). Water volume fractions (columns H and I) were calculated by subtracting the metal fraction from 1. Overall density of the water-metal mixes (columns J and K) were calculated by multiplying the component volume fraction by the appropriate component density and summing. The volume of the water-metal mix (column L) was calculated by dividing the metal mass (column C) by the metal concentration (column B) and applying the appropriate unit conversions. From the volume of the sphere, the radius of the fissile mix can be calculated (column N). The outer radius of the reflector region (column O) was obtained by adding 100 cm to the radius of the fueled region (column N). The metal masses (columns P, Q, and T) were calculated by multiplying the mix volume (column L) by the metal concentration (column B) and an appropriate factor derived from the enrichments of columns D and E. Hydrogen and oxygen masses (columns R, S, U and V) were calculated by multiplying the mix volume (column L) by the water volume fraction (column H or I), by the density of water, and finally by the weight fraction of oxygen or hydrogen in water.

For cylindrical systems, MCNP input data was calculated in the spreadsheet of Table A1-4. Starting point was the desired fissile concentration, in grams per liter (column B). Column C is the cylinder radius of that particular case. Columns D and E are the enrichments, in weight percent, of ^{235}U in uranium and ^{239}Pu in plutonium, respectively. The metal volume fractions (columns F and G) of the water-metal mix were determined by dividing the metal concentration by the appropriate metal density (and applying conversion factors as necessary). Water volume fractions (columns H and I) were calculated by subtracting the metal fraction from 1. Overall density of the water-metal mixes (columns J and K) were calculated by multiplying the component volume fraction by the appropriate component density and summing. The metal densities (columns L, M, and P) were calculated by multiplying the metal concentration (column B) by an appropriate factor derived from the enrichments of columns D and E. Hydrogen and oxygen densities (column N, O, Q and R) were calculated by multiplying the water volume fraction (column H or I) by the density of water, and finally by the weight fraction of oxygen or hydrogen in water.

The typical input file for a plutonium-water sphere with a water reflector is shown in Table A1-1. The italicized portions of this file change with the case being analyzed, with the new data taken from the spreadsheet of Table A1-3. The first two lines are the case title and comment cards—values from columns B through D are used to identify the case. The value in line 4 is the overall mix density from column J or K for uranium or plutonium system, respectively. The two variables in lines 7 and 8 are the outside radii of the fuel and reflector regions, from columns N and O. The variables in lines 10 and 11 are the masses of the elements in the fuel mix, given by columns P through S for uranium systems, and columns T through V for plutonium systems.

Table A1-1. MCNP Input For A Water Reflected Sphere.

```
Case r10p.inp

critical concentration homogeneous sphere Pu
c  conc   800   mass   4.20
c

  1   1  -1.75968     -1   imp:n=1
  2   2  -1.00         1   -2   imp:n=1
  3   0                2        imp:n=0

  1   so   10.78177     $ fuel region
  2   so   110.7818     $ reflector region

m1     94239.50  -4200.00    101.50    -563.758
                 -4474.55
mt1    lwtr.01t
m2      1001.50     2  8016.50     1
mt2    lwtr.01t
mode       n
kcode      1000   1    10
ksrc     0   0   0
print      40    50
prdmp      3j    3
ctme      10
```

The typical cylindrical geometry input file—in this case, a uranium system—is shown in Table A1-2 below. The case identifiers in lines 1 and 2 come from columns B through D of the spreadsheet in Table A1-4. The variable in line 4 is the overall fuel mix density from column J or K, for uranium or plutonium systems, respectively. The variable in line 8 is the radius of the fuel region, from column C. The variables of lines 13 and 14 are the elemental densities from columns L through O for uranium systems, and columns P through R for plutonium systems.

Table A1-2. MCNP Input for a Water Reflected Infinite Cylinder

```
Case c1u.inp

c  conc   100   dia = 13
c
  1   1   -1.094751  -1  2  -3       imp:n=1
  2   2   -1.00      1  2  -3  -4   imp:n=1
  3   0            -2 : 3 :  4       imp:n=0

  1   cz    6.50       $ fuel region
 *2   pz  -50.00
 *3   pz   50.00
  4   cz  106.50       $ reflector region

m1    92235.50  -0.09400  92238.50   -0.0060
      1001.50  -0.111307  8016.50   -0.883444
mt1   lwtr.01t
m2     1001.50     2  8016.50     1
mt2   lwtr.01t
mode      n
kcode     1000   1    10
ksrc   0  0  0
print      40    50
prdmp     3j    3
ctme      10
```

Table A1-3. Spreadsheet to obtain MCNP Input for Water Reflected Spheres.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
5		water reflected spheres																				
6																						
7																						
8	molecular wieghts			densities, gm/cm3				conversion factors														
9	U-235	235.044		U metal	19.05			1 litre=	1000 cm3													
10	U-238	238.051		Pu metal	19.84			1 kg=	1000 gm													
11	Pu-239	239.052		H2O	1.00																	
12	H	1.0079																				
13	O	15.9994																				
14																						
15																						
16				enrichment		volume fractions in mix				density of mix		volume of system		sphere ra	reflector	mass of various stuff, U system				mass of various stuff, Pu system		
17	case	HM conc	HM mass	U	Pu	U metal	Pu metal	H2O	H2O	w/U	w/ Pu	(both)		(both)	rad	U-235	U-238	H	O	Pu	H	O
18	desig	gm/L	kg	per cent				w/ U	w/ Pu	gm/cm3		cm3		cm	cm	gm						
19	r1	175	1.20	94	100	0.009186	0.008821	0.990814	0.991179	1.165814	1.166179	6857.143		11.7856	111.7856	1128.00	72.00	780.2274	6033.923	1200.00	780.5081	6036.151
20	r2	175	1.30	94	100	0.009186	0.008821	0.990814	0.991179	1.165814	1.166179	7428.571		12.10428	112.1043	1222.00	78.00	823.5797	6536.75	1300.00	823.8838	6539.163
21	r3	200	1.20	94	100	0.010499	0.010081	0.989501	0.989919	1.189501	1.189919	6000		11.27252	111.2725	1128.00	72.00	664.3179	5272.69	1200.00	664.5986	5274.918
22	r4	200	1.30	94	100	0.010499	0.010081	0.989501	0.989919	1.189501	1.189919	6500		11.57733	111.5773	1222.00	78.00	719.6778	5712.081	1300.00	719.9818	5714.494
23	r5	200	1.40	94	100	0.010499	0.010081	0.989501	0.989919	1.189501	1.189919	7000		11.86686	111.8669	1316.00	84.00	775.0376	6151.472	1400.00	775.365	6154.07
24	r6	780	3.80	94	100	0.040945	0.039315	0.959055	0.960685	1.739055	1.740685	4871.795		10.51639	110.5164	3572.00	228.00	522.8064	4149.513	3800.00	523.6952	4156.567
25	r7	780	4.00	94	100	0.040945	0.039315	0.959055	0.960685	1.739055	1.740685	5128.205		10.69775	110.6977	3760.00	240.00	550.3226	4367.909	4000.00	551.2581	4375.334
26	r8	780	4.20	94	100	0.040945	0.039315	0.959055	0.960685	1.739055	1.740685	5384.615		10.87315	110.8731	3948.00	252.00	577.8387	4586.304	4200.00	578.821	4594.101
27	r9	800	4.00	94	100	0.041995	0.040323	0.958005	0.959677	1.758005	1.759677	5000		10.60784	110.6078	3760.00	240.00	536.9771	4254.049	4000.00	536.9126	4261.474
28	r10	800	4.20	94	100	0.041995	0.040323	0.958005	0.959677	1.758005	1.759677	5250		10.78177	110.7818	3948.00	252.00	562.776	4466.752	4200.00	563.7583	4474.548
29	r11	800	4.40	94	100	0.041995	0.040323	0.958005	0.959677	1.758005	1.759677	5500		10.95027	110.9503	4136.00	264.00	589.5746	4679.454	4400.00	590.6039	4687.622
30	r12	800	4.60	94	100	0.041995	0.040323	0.958005	0.959677	1.758005	1.759677	5750		11.11373	111.1137	4324.00	276.00	616.3737	4892.157	4600.00	617.4495	4900.696
31	r13	300	1.70	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	5666.667		11.05978	111.0598	1598.00	102.00	624.0829	4953.345	1700.00	624.4805	4956.501
32	r14	300	1.80	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	6000		11.27252	111.2725	1692.00	108.00	660.7937	5244.718	1800.00	661.2147	5248.06
33	r15	300	1.90	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	6333.333		11.47752	111.4775	1786.00	114.00	697.5045	5536.091	1900.00	697.9488	5539.618
34	r16	300	2.00	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	6666.667		11.67544	111.6754	1880.00	120.00	734.2152	5827.465	2000.00	734.683	5831.177
35	r17	300	2.10	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	7000		11.86686	111.8669	1974.00	126.00	770.926	6118.838	2100.00	771.4171	6122.736
36	r18	500	2.70	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	5400		10.8835	110.8835	2538.00	162.00	588.3707	4669.897	2700.00	589.0022	4674.909
37	r19	500	2.80	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	5600		11.01623	111.0162	2632.00	168.00	610.1622	4842.856	2800.00	610.8171	4848.054
38	r20	500	2.90	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	5800		11.14586	111.1458	2726.00	174.00	631.9537	5015.815	2900.00	632.632	5021.199
39	r21	500	3.00	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	6000		11.27252	111.2725	2820.00	180.00	653.7452	5188.774	3000.00	654.4469	5194.343
40	r22	500	3.10	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	6200		11.3964	111.3964	2914.00	186.00	675.5367	5361.734	3100.00	676.2618	5367.488
41	r24	150	0.80	94	100	0.007874	0.007560	0.992126	0.992440	1.142126	1.142440	5333.333		10.83852	110.8385	752.00	48.00	592.0712	4699.267	800.00	592.2583	4700.752
42	r36	150	1.00	94	100	0.007874	0.007560	0.992126	0.992440	1.142126	1.142440	6666.667		11.67544	111.6754	940.00	60.00	740.0889	5874.084	1000.00	740.3228	5875.941
43	r25	400	2.30	94	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	5750		11.11373	111.1137	2162.00	138.00	629.8832	4999.382	2300.00	630.4212	5003.651
44	r26	400	2.40	94	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	6000		11.27252	111.2725	2256.00	144.00	657.2695	5216.746	2400.00	657.8308	5221.201
45	r27	600	3.20	94	100	0.031496	0.030242	0.968504	0.969758	1.568504	1.569758	5333.333		10.83852	110.8385	3008.00	192.00	577.9742	4587.38	3200.00	578.7227	4593.32
46	r28	600	3.30	94	100	0.031496	0.030242	0.968504	0.969758	1.568504	1.569758	5500		10.95027	110.9503	3102.00	198.00	596.0359	4730.736	3300.00	596.8077	4736.862
47	r29	700	3.70	94	100	0.036745	0.035282	0.963255	0.964718	1.663255	1.664718	5285.714		10.80617	110.8062	3478.00	222.00	569.7091	4521.78	3700.00	570.5744	4528.648
48	r30	700	3.80	94	100	0.036745	0.035282	0.963255	0.964718	1.663255	1.664718	5428.571		10.90266	110.9027	3572.00	228.00	585.1066	4643.99	3800.00	585.9954	4651.044
49	r31	900	4.50	94	100	0.047244	0.045363	0.952756	0.954637	1.852756	1.854637	5000		10.60784	110.6078	4230.00	270.00	533.0403	4230.739	4500.00	534.0927	4239.093
50	r32	900	4.60	94	100	0.047244	0.045363	0.952756	0.954637	1.852756	1.854637	5111.111		10.68585	110.6858	4324.00	276.00	544.8856	4324.756	4600.00	545.9615	4333.295
51	r33	100	0.75	94	100	0.005249	0.005040	0.994751	0.994960	1.094751	1.094960	7500		12.14295	112.143	705.00	45.00	834.8027	6625.827	750.00	834.9781	6627.219
52	r34	100	0.85	94	100	0.005249	0.005040	0.994751	0.994960	1.094751	1.094960	8500		12.66026	112.6603	799.00	51.00	946.1097	7509.271	850.00	946.3085	7510.849
53	r35	100	0.95	94	100	0.005249	0.005040	0.994751	0.994960	1.094751	1.094960	9500		13.13848	113.1385	893.00	57.00	1057.417	8392.714	950.00	1057.639	8394.478
54	r37	400	4.50	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	11250		13.90021	113.9002	2250.00	2250.00	1232.38	9781.399	4500.00	1233.433	9789.753
55	r38	400	5.00	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	12500		14.39708	114.3971	2500.00	2500.00	1369.311	10868.22	5000.00	1370.481	10877.5
56	r39	400	5.50	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	13750		14.8618	114.8618	2750.00	2750.00	1506.243	11955.04	5500.00	1507.529	11965.25
57	r40	500	5.50	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	11000		13.79647	113.7965	2750.00	2750.00	1198.533	9512.753	5500.00	1199.619	9522.963
58	r41	500	6.00	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	12000		14.20248	114.2025	3000.00	3000.00	1307.49	10377.55	6000.00	1308.694	10388.69
59	r42	500	6.50	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	13000		14.58652	114.5865	3250.00	3250.00	1416.448	11242.34	6500.00	1417.966	11254.41
60	r43	400	3.00	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	7500		12.14295	112.143	1500.00	1500.00	821.5869	6520.933	3000.00	822.2885	6526.502
61	r44	400	3.60	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	9000		12.90381	112.9038	1800.00	1800.00	985.9042	7825.119	3600.00	986.7462	7831.802
62	r45	400	4.00	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	10000		13.36505	113.365	2000.00	2000.00	1095.449	8694.577	4000.00	1096.385	8702.002
63	r46	1000	7.00	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	7000		11.86686	111.8669	3500.00	3500.00	742.1447	5890.401	7000.00	743.7819	5903.395
64	r47	1000	8.00	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	8000		12.40701	112.407	4000.00	4000.00	848.1654	6731.887	8000.00	850.0365	6746.738
65	r48	1000	9.00	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	9000		12.90381	112.9038	4500.00	4500.00	954.1861	7573.373	9000.00	956.2911	7590.06
66	r49	500	3.00	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	6000		11.27252	111.2725	1500.00	1500.00	653.7452	5188.774	3000.00	654.4469	5194.343
67	r50	500	3.50	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	7000		11.86686	111.8669	1750.00	1750.00	762.7028	6053.57	3500.00	763.5214	6060.067
68	r51	500	4.00	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	8000		12.40701	112.407	2000.00	2000.00	871.6603	6918.366	4000.00	872.5958	6925.791
69	r52	960	4.30	94	100	0.050394	0.048367	0.949606	0.951613	1.909606	1.911613	4479.167		10.22593	110.2259	4042.00	258.00	475.9367	3777.506	4300.00	476.9424	3785.49
70	r53	960	4.50	94	100	0.050394	0.048367	0.949606	0.951613	1.909606	1.911613	4687.5		10.38208	110.3821	4230.00	270.00	498.0733	3953.206	4500.00	499.1257	3961.56
71	r54	960	4.70	94	100	0.050394	0.048367	0.949606	0.951613	1.909606	1.911613	4895.833		10.53366	110.5337	4418.00	282.00	520.2098	4128.904	4700.00	521.3091	4137.629
72	r55	960	5.00	94	100	0.050394	0.048367	0.949606	0.951613	1.909606	1.911613	5208.333		10.75318	110.7532	4700.00	300.00	553.4147	4392.451	5000.00	554.5841	4401.733
73	r56	960	5.30	94	100	0.050394	0.048367	0.949606	0.951613	1.909606	1.911613	5520.833		10.95408	110.9641	4982.00	318.00	586.6198	4655.999	5300.00	587.8592	4665.837

Table A1-4. Spreadsheet to Obtain MCNP Input for Water Reflected Infinite Cylinders.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
5	critical water-reflected infinite cylinders																	
6																		
7																		
8	molecular wieghts			densities, gm/cm3				conversion factors										
9	U-235	235.0439		U metal	19.05			1 litre=	1000	cm3								
10	U-238	238.0508		Pu metal	19.84			1 kg=	1000	gm								
11	Pu-239	239.0522		H2O	1.00													
12	H	1.0079																
13	O	15.9994																
14																		
15																		
16				enrichment		volume fractions in mix				density of mix		mass in one cm^3				mass in one cm^3		
17	case	HM conc	cylinder	U	Pu	U metal	Pu metal	H2O	H2O	w/U	w/ Pu	uranium systems				plutonium systems		
18	desig	gm/L	radius, cm	per cent				w/ U	w/ Pu	gm/cm3		U235	U238	H	O	Pu239	H	O
19	c1	100	6.50	94	100	0.005249	0.005040	0.994751	0.994960	1.094751	1.094960	0.094000	0.006000	0.111307	0.883444	0.100000	0.111330	0.883629
20	c2	100	7.50	94	100	0.005249	0.005040	0.994751	0.994960	1.094751	1.094960	0.094000	0.006000	0.111307	0.883444	0.100000	0.111330	0.883629
21	c3	100	8.50	94	100	0.005249	0.005040	0.994751	0.994960	1.094751	1.094960	0.094000	0.006000	0.111307	0.883444	0.100000	0.111330	0.883629
22	c4	300	6.50	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.282000	0.018000	0.110132	0.874120	0.300000	0.110202	0.874677
23	c5	300	7.50	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.282000	0.018000	0.110132	0.874120	0.300000	0.110202	0.874677
24	c6	300	8.50	94	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.282000	0.018000	0.110132	0.874120	0.300000	0.110202	0.874677
25	c7	500	6.50	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	0.470000	0.030000	0.108958	0.864796	0.500000	0.109074	0.865724
26	c8	500	7.50	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	0.470000	0.030000	0.108958	0.864796	0.500000	0.109074	0.865724
27	c9	500	8.50	94	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	0.470000	0.030000	0.108958	0.864796	0.500000	0.109074	0.865724
28	c10	1000	6.50	94	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.940000	0.060000	0.106021	0.841486	1.000000	0.106255	0.843342
29	c11	1000	7.50	94	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.940000	0.060000	0.106021	0.841486	1.000000	0.106255	0.843342
30	c12	1000	8.50	94	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.940000	0.060000	0.106021	0.841486	1.000000	0.106255	0.843342
31	c13	1500	6.50	94	100	0.078740	0.075605	0.921260	0.924395	2.421260	2.424395	1.410000	0.090000	0.103084	0.818176	1.500000	0.103435	0.820961
32	c14	1500	7.50	94	100	0.078740	0.075605	0.921260	0.924395	2.421260	2.424395	1.410000	0.090000	0.103084	0.818176	1.500000	0.103435	0.820961
33	c15	1500	8.50	94	100	0.078740	0.075605	0.921260	0.924395	2.421260	2.424395	1.410000	0.090000	0.103084	0.818176	1.500000	0.103435	0.820961
34	c16	200	7.4000	94	100	0.010499	0.010081	0.989501	0.989919	1.189501	1.189919	0.188000	0.012000	0.110720	0.878782	0.200000	0.110766	0.879153
35	c17	200	7.5000	94	100	0.010499	0.010081	0.989501	0.989919	1.189501	1.189919	0.188000	0.012000	0.110720	0.878782	0.200000	0.110766	0.879153
36	c18	200	7.6250	94	100	0.010499	0.010081	0.989501	0.989919	1.189501	1.189919	0.188000	0.012000	0.110720	0.878782	0.200000	0.110766	0.879153
37	c19	700	6.7500	94	100	0.036745	0.035282	0.963255	0.964718	1.663255	1.664718	0.658000	0.042000	0.107783	0.855472	0.700000	0.107947	0.856771
38	c20	700	6.8750	94	100	0.036745	0.035282	0.963255	0.964718	1.663255	1.664718	0.658000	0.042000	0.107783	0.855472	0.700000	0.107947	0.856771
39	c21	700	7.0000	94	100	0.036745	0.035282	0.963255	0.964718	1.663255	1.664718	0.658000	0.042000	0.107783	0.855472	0.700000	0.107947	0.856771
40	c22	300	7.2000	50	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.150000	0.150000	0.110132	0.874120	0.300000	0.110202	0.874677
41	c23	300	7.3000	50	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.150000	0.150000	0.110132	0.874120	0.300000	0.110202	0.874677
42	c24	300	7.4000	50	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.150000	0.150000	0.110132	0.874120	0.300000	0.110202	0.874677
43	c25	500	7.0000	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	0.250000	0.250000	0.108958	0.864796	0.500000	0.109074	0.865724
44	c26	500	7.1250	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	0.250000	0.250000	0.108958	0.864796	0.500000	0.109074	0.865724
45	c27	500	7.2500	50	100	0.026247	0.025202	0.973753	0.974798	1.473753	1.474798	0.250000	0.250000	0.108958	0.864796	0.500000	0.109074	0.865724
46	c28	400	8.0000	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	0.200000	0.200000	0.109545	0.869458	0.400000	0.109638	0.870200
47	c29	400	8.2500	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	0.200000	0.200000	0.109545	0.869458	0.400000	0.109638	0.870200
48	c30	400	8.5000	50	100	0.020997	0.020161	0.979003	0.979839	1.379003	1.379839	0.200000	0.200000	0.109545	0.869458	0.400000	0.109638	0.870200
49	c31	1000	8.0000	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.500000	0.500000	0.106021	0.841486	1.000000	0.106255	0.843342
50	c32	1000	8.2500	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.500000	0.500000	0.106021	0.841486	1.000000	0.106255	0.843342
51	c33	1000	8.5000	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.500000	0.500000	0.106021	0.841486	1.000000	0.106255	0.843342
52	c34	300	7.7000	50	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.150000	0.150000	0.110132	0.874120	0.300000	0.110202	0.874677
53	c35	300	8.0000	50	100	0.015748	0.015121	0.984252	0.984879	1.284252	1.284879	0.150000	0.150000	0.110132	0.874120	0.300000	0.110202	0.874677
54	c36	1000	7.5000	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.500000	0.500000	0.106021	0.841486	1.000000	0.106255	0.843342
55	c37	1000	7.7000	50	100	0.052493	0.050403	0.947507	0.949597	1.947507	1.949597	0.500000	0.500000	0.106021	0.841486	1.000000	0.106255	0.843342

A2.0 MCNP Results

Spherical system results are tabulated in the spreadsheet shown in Table A2-1 and shown graphically in Figure –1. The MCNP-calculated k_{eff} and standard deviation for uranium and plutonium systems are given in columns F through I. The critical mass at a given concentration was calculated by straight-line interpolation between the mass data points closest to a k_{eff} of 1, and is reported in columns K through M. Note that the uranium results in columns K and L are corrected for enrichment and report the mass of ^{235}U. The results are repeated in columns O through T for ease of plotting-note again that the uranium concentration has been corrected for enrichment.

Cylindrical system results are tabulated in the spreadsheet shown in Table A2-2 and shown graphically in Figure1. The calculated k_{eff} and standard deviation for uranium and plutonium systems are given in columns E through H. The critical diameter at a given concentration was calculated by straight-line interpolation between the data points closest to a k_{eff} of 1, and is reported in columns J through L. The results are repeated in columns O through T for ease of plotting.

Table A2-1. MCNP Output For Water Reflected Spheres.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
5																				
6																				
7	Critical Reflected HM-Water Spheres																			
8																				
9																				
10																				
11																				
12																				
13											U-235 mass for		Pu-239 mass for							
14	case	HM conc	U-235 enrich	U-235 conc	HM mass	U	sigma	Pu	sigma		criticality		criticality			u235-94	pu	pu	u235-50	
15	desig	gm/L		gm/L	kg	keff		keff			94% enr	50% enr			u235 con	mass	conc	mass	conc	mass
16	r33	100	94	94.0	0.75	0.94704	0.00245	0.99470	0.00237				0.768861		94	0.875678	100	0.768861	200	1.530249
17	r34	100	94	94.0	0.85	0.98070	0.00220	1.02280	0.00209		0.875678				141.0	1.026193	150	1.051359	250	1.812988
18	r35	100	94	94.0	0.95	1.00438	0.00234	1.04875	0.00230						164.5	1.172445	175	1.198003	500	3.392364
19	r1	175	94	164.5	1.20	0.99028	0.00217	1.00040	0.00214		1.172445		1.198003		188.0	1.249614	200	1.349933		
20	r2	175	94	164.5	1.30	1.01088	0.00235	1.02043	0.00212						282.0	1.726226	300	1.904176		
21	r3	200	94	188.0	1.20	0.96728	0.00232	0.97174	0.00212						376.0	2.111564	400	2.412191		
22	r4	200	94	188.0	1.30	0.99453	0.00212	0.99259	0.00213		1.249614		1.349933		470.0	2.624205	500	2.904503		
23	r5	200	94	188.0	1.40	1.01315	0.00243	1.00743	0.00213						564.0	3.088031	600	3.342417		
24	r6	780	94	733.2	3.80	0.98051	0.00237	0.98049	0.00207						658.0	3.556551	700	3.786667		
25	r7	780	94	733.2	4.00	0.98729	0.00231	0.99011	0.00202		3.935956		4.175355		733.2	3.935956	780	4.175355		
26	r8	780	94	733.2	4.20	1.00067	0.00251	1.00139	0.00233						752.0	4.055262	800	4.255081		
27	r9	800	94	752.0	4.00	0.98617	0.00237	0.98889	0.00225						846.0	4.399241	900	4.604496		
28	r10	800	94	752.0	4.20	0.99632	0.00237	0.99607	0.00214		4.055262		4.255081		902.4	4.871024				
29	r11	800	94	752.0	4.40	1.00277	0.00246	1.01034	0.00211											
30	r12	800	94	752.0	4.60	1.01621	0.00222	1.02101	0.00220											
31	r13	300	94	282.0	1.70	0.98356	0.00237	0.97673	0.00223											
32	r14	300	94	282.0	1.80	0.99511	0.00225	0.98733	0.00224		1.726226									
33	r15	300	94	282.0	1.90	1.00864	0.00229	0.99942	0.00217				1.904176							
34	r16	300	94	282.0	2.00	1.02319	0.00223	1.01331	0.00221											
35	r17	300	94	282.0	2.10	1.03666	0.00250	1.02718	0.00228											
36	r18	500	94	470.0	2.70	0.98861	0.00238	0.98115	0.00218		2.624205									
37	r19	500	94	470.0	2.80	1.00103	0.00237	0.99472	0.00230											
38	r20	500	94	470.0	2.90	1.00802	0.00238	0.99971	0.00228				2.904503							
39	r21	500	94	470.0	3.00	1.01848	0.00227	1.00615	0.00226											
40	r22	500	94	470.0	3.10	1.02854	0.00220	1.01559	0.00213											
41	r23	150	94	141.0	0.70	0.88147	0.00245	0.90092	0.00231											
42	r24	150	94	141.0	0.80	0.92203	0.00246	0.93432	0.00253		1.026193		1.051359							
43	r36	150	94	141.0	1.00	0.97549	0.0022	0.98658	0.00239											
44	r25	400	94	376.0	2.30	1.00389	0.00245	0.98592	0.00197		2.111564		2.412191							
45	r26	400	94	376.0	2.40	1.01114	0.00238	0.99647	0.00242											
46	r27	600	94	564.0	3.20	0.99311	0.00245	0.98751	0.00221		3.088031		3.342417							
47	r28	600	94	564.0	3.30	1.00141	0.00217	0.99628	0.00207											
48	r29	700	94	658.0	3.70	0.99217	0.00237	0.98337	0.00236		3.556551		3.786667							
49	r30	700	94	658.0	3.80	1.00154	0.00249	1.00102	0.00217											
50	r31	900	94	846.0	4.50	0.98367	0.0022	0.99419	0.00221		4.399241		4.604496							
51	r32	900	94	846.0	4.60	0.99274	0.00229	0.99975	0.00225											
52	r37	400	50	200.0	4.50	1.09146	0.00219													
53	r38	400	50	200.0	5.00	1.11586	0.00224													
54	r39	400	50	200.0	5.50	1.13429	0.00224													
55	r40	500	50	250.0	5.50	1.09665	0.00209													
56	r41	500	50	250.0	6.00	1.1156	0.00219													
57	r42	500	50	250.0	6.50	1.13314	0.00213													
58	r43	400	50	200.0	3.00	0.99563	0.00216					1.530249								
59	r44	400	50	200.0	3.60	1.03697	0.00209													
60	r45	400	50	200.0	4.00	1.06806	0.00231													
61	r46	1000	50	500.0	7.00	1.00561	0.00209					3.392364								
62	r47	1000	50	500.0	8.00	1.03167	0.00215													
63	r48	1000	50	500.0	9.00	1.05621	0.00236													
64	r49	500	50	250.0	3.00	0.95479	0.00227													
65	r50	500	50	250.0	3.50	0.99226	0.00235					1.612988								
66	r51	500	50	250.0	4.00	1.02298	0.00211													
67	r52	960	94	902.4	4.30	0.95561	0.00220													
68	r53	960	94	902.4	4.50	0.96844	0.00222													
69	r54	960	94	902.4	4.70	0.98157	0.00242													
70	r55	960	94	902.4	5.00	0.99100	0.00244				4.871024									
71	r56	960	94	902.4	5.30	1.00584	0.00221													
72	r57	400	50	200.0	2.7	0.9715	0.00237					1.486233								
73	r58	400	50	200.0	2.8	0.98196	0.00237													

Figure A2-2. MCNP Output For Water Reflected Infinite Cylinders.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
9	Results: Infinite cylinders with water reflection																			
10																				
11	HM conc	U enrich	U-235 conc	cylinder	U		Pu		case	U crit~94%	50% U	Pu crit			U-235	94% enr	Pu		U-235	
12	gm/L			radius, cm		sigma		sigma	desig	diameter	crit dia	diameter			conc	dia	conc	dia	conc	u-50
13	100	94	94	6.50	0.82354	0.00243	0.87083	0.00229	c1											
14	100	94	94	7.50	0.90768	0.00207	0.96126	0.00246	c2						94	17.16328	100	16.00013	150	16.50706
15	100	94	94	8.50	0.99225	0.00205	1.03873	0.00231	c3	17.16328		16.00013			188	15.11378	200	15.06693	200	15.88934
16	200	94	188	7.4	0.96491	0.00230	0.96927	0.00215	c16						282	14.43513	300	14.61661	500	15.07589
17	200	94	188	7.5	0.99782	0.00238	0.99630	0.00233	c17						470	13.95076	500	14.20038		
18	200	94	188	7.625	1.00261	0.00215	1.01012	0.00219	c18	15.11378		15.06693			658	13.78387	700	13.75168		
19	300	94	282	6.50	0.93087	0.00257	0.93557	0.00259	c4						940	13.70114	1000	13.30738		
20	300	94	282	7.50	1.02721	0.00208	1.01528	0.00205	c5	14.43513		14.61661			1410	13.46915	1500	12.50327		
21	300	94	282	8.50	1.09977	0.00220	1.09062	0.00205	c6											
22	500	94	470	6.50	0.95984	0.00214	0.94926	0.00214	c7											
23	500	94	470	7.50	1.04432	0.00224	1.03380	0.00227	c8	13.95076		14.20038								
24	500	94	470	8.50	1.11932	0.00225	1.10862	0.00193	c9											
25	700	94	658	6.75	0.98782	0.00257	0.99034	0.00229	c19											
26	700	94	658	6.875	0.99606	0.00215	0.99994	0.00222	c20											
27	700	94	658	7	1.01238	0.00233	1.00685	0.00231	c21	13.78387		13.75168								
28	1000	94	940	6.50	0.97234	0.00224	0.96715	0.00248	c10											
29	1000	94	940	7.50	1.05124	0.00250	1.07076	0.00209	c11	13.70114		13.30738								
30	1000	94	940	8.50	1.12430	0.00209	1.14269	0.00211	c12											
31	1500	94	1410	6.50	0.98270	0.00202	1.02052	0.00235	c13											
32	1500	94	1410	7.50	1.05645	0.00227	1.10314	0.00216	c14	13.46915		12.50327								
33	1500	94	1410	8.50	1.12546	0.00200	1.17500	0.00197	c15											
34	300	50	150	7.2000	0.91920	0.00251			c22											
35	300	50	150	7.3000	0.92982	0.00216			c23											
36	300	50	150	7.4000	0.93783	0.00229			c24											
37	300	50	150	7.7000	0.96081	0.00232			c34											
38	300	50	150	8.0000	0.98205	0.00211			c35		16.50706									
39	500	50	250	7.0000	0.93658	0.00212			c25											
40	500	50	250	7.1250	0.95037	0.00234			c26											
41	500	50	250	7.2500	0.95619	0.00232			c27											
42	400	50	200	8.0000	1.00465	0.00244			c28											
43	400	50	200	8.2500	1.02566	0.00231			c29		15.88934									
44	400	50	200	8.5000	1.04301	0.00215			c30											
45	1000	50	500	8.0000	1.03620	0.00229			c31											
46	1000	50	500	8.2500	1.05225	0.00233			c32											
47	1000	50	500	8.5000	1.06416	0.00218			c33											
48	1000	50	500	7.5000	0.99719	0.00246			c36											
49	1000	50	500	7.7000	1.01200	0.00229			c37		15.07589									

A3.0 MCNP Validation

Several high-enriched uranium benchmark cases were run using the MCNP Code. The benchmark cases were six critical experiments chosen from NEA (1995). These six cases span the concentrations of concern. The results are shown in Table A3-1.

Table A3-1. Results of the Validation Runs

Validation Runs					
Case Number	Fissile Concentration kg/L	Actual k_{eff}	calc k_{eff}	std dev	Δk_{eff} Actual - calc.
HEU-SOL-THERM-018-1	0.3	1.0	0.99211	0.00100	-.00789
HEU-SOL-THERM-019-1	0.4	1.0	1.00303	0.00097	+.00303
HEU-SOL-THERM-009-1	0.65	1.0	1.00408	0.00068	+.00408
HEU-MET-THERM-003-4	4.6	0.9826	0.97735	0.00083	-.00525
HEU-SOL-THERM-016-1	0.15	1.0	0.99687	0.00096	-.00313
HEU-SOL-THERM-010-4	0.1	1.0	1.00047	0.00063	+.00047

The data for both the plutonium and uranium benchmarks are summarized in Table A3-2.

Table A3-2. Comparison of Bias between actual k_{eff} and MCNP calculated k_{eff}.

	Metal		Non-Metal	
Fissile	Mean k_{eff}	Range above and below the mean	Mean k_{eff}	Range above and below the mean
Plutonium	0.9956	-0.00081 to -0.0086	1.0125	-0.0020 to 0.0041
Uranium	0.9948	-0.0052	0.9929	-0.0079 to 0.0041

The benchmark for uranium metal matches the results for plutonium metal benchmark runs. The uranium solutions benchmarks have the same range as plutonium solutions, but the mean is lower than plutonium solution benchmark results. The mean value of k_{eff} for uranium solutions is about 0.02 lower than that for plutonium. This means that the calculated critical mass for uranium is too large. The impact of this bias is determined next. It was stated above that materials containing uranium having enrichments less than 50 wt% could be stored and processed using CPS for plutonium. Figure 1 shows that for spheres, the closest approach of the critical mass for 50 wt% enriched uranium to plutonium is at a fissile concentration of 200 g/L. The critical mass of plutonium at a fissile concentration of 200 g/L is 1.3499 kg. The critical mass for 50 wt% enriched uranium is 1.53025 kg. The critical mass for 50 wt% enriched uranium at a k_{eff} of 1.02 is 1.6681 kg. So the estimated critical mass at a k_{eff} of 0.98 is found from

$$1.53025 - (1.6681 - 1.53025) = 1.39 \text{ kg.}$$

Alternatively, using the MCNP code, the critical mass for 50 wt% enriched uranium at a k_{eff} of 0.98 is 1.39 kg. Both of the estimates of a mass of a 50 wt% enriched uranium at a k_{eff} of 0.98 are above the critical mass of plutonium. A similar calculation performed for infinite cylinders shows similar results. Therefore use of 50 wt% enriched uranium covers the bias.

APPENDIX B
STATEMENT OF WORK FOR REV. 1

-----Original Message-----
From: Greenborg, Jess
Sent: Tuesday, March 06, 2001 12:00 PM
To: Mo, Blaise S
Cc: Dobbin, Kenneth D; Wilkinson, Alan D; Erickson, David G; Toffer, Hans; Greenborg, Jess
Subject: EU>50%

Blaise;

Confirming our phone conversation, the following CSERs will be upgraded now:

98-005 (Canning thermally stabilized powder)
99-007 (Muffle furnace operations)
00-002 (Prep for thermal stabilization)
00-008 (18BS, packaging thermally stabilized materials)
00-010 (Bag less transfer)

The following CSERs will be upgraded if/when needed.

00-001 (HC46F)
00-006 (Storage in drums)

Jess
376-3482

Fluor Hanford

STATEMENT OF WORK

DATE: 1/12/01
REV. NUMBER: _0__

REFERENCE INFORMATION (Project Internal Use Only)

COST ACCOUNT CHARGE NUMBER (CACN): 110844
CODE OF ACCOUNT (COA): BA30
ORG/COST CENTER: 1AG00
TOTAL ESTIMATED COST:
AUTHORIZED AMOUNT FOR THIS ACTION or RELEASE:
PREFERRED VENDOR:
NONCOMPETITIVE JUSTIFICATION ATTACHED: N *(Criticality work is exclusive and assigned and monitored by Central FH Group. Therefore no NCJ is required.*
ISMS CHECKSHEET ATTACHED: Y
CONTRACT NUMBER:
RELEASE NUMBER:
MODIFICATION NUMBER:

1.0 WORK SCOPE TITLE or CONTRACT RELEASE TITLE

Provide a Criticality Safety Evaluation Report (CSER) that establishes volume and moderation limits so that fissile materials in the form of metal or oxides with a uranium enrichment greater than 50% can be managed under Pu limits on a gram per gram substitution basis with Pu mass limits. Revise CSERs 98-005, 99-007, 00-001, 00-002, 00-006, and 00-008 to remove the U-235 enrichment restriction.

2.0 INTRODUCTION

This Contract Release provides direction for Fluor Federal Services (FFS) to provide Criticality Safety services related to preparing and revising CSERs. The work performed under this Contract Release is in support of Fiscal Year (FY) 2001 activities.

3.0 WORK SCOPE / DESCRIPTION OF REQUIRED SERVICES

CSER 99-003 involved a parameter study that conservatively and generally concluded that mass limits applied to the handling of plutonium Pu could be used for U-235 if the U235 enrichment did not exceed 50% or if the U235 concentration was above 1000 g/l. The 50% enrichment restriction has since been promulgated in subsequent CSERs at PFP. It is relevant to note that the study only observed that U235 was more reactive than Pu as a moderated solution with a fissile concentration between 150 g/l and 850 g/l.

There is a small population of Pu and EU alloy materials that are to be opened, brushed, possibly stabilized, and then packaged in BTCs and stored by July 2001. These materials are stored in vaults and will be handled in Gloveboxes HC-21A, HC-21C, HC-18M, HC-18BS, HC-21I, and HC-20MB. U235 is only slightly more reactive than plutonium under a limited, specific range of moderated conditions. Therefore, the volume and moderation of fissile material can be limited such that CSER 99-003 shows it is conservative to use plutonium calculations and a one gram to one gram conversion for U-235. The scope for this work is:

1. Determine the container volume and moderation limits where the CSER 99-003 evaluation shows plutonium calculations are conservative for a uranium system of any enrichment. Hence, plutonium is

more reactive than U235 and consequently, U235 may be substituted for Pu metal on a gram for gram basis in mass limits. Assume the most conservative container dimensions so that geometry is not a control.

2. Revise CSERs 98-005, 99-007, 00-001, 00-002, 00-006, and 00-008 to remove the U-235 enrichment restriction.
3. Prepare a CSER based upon the CSER 99-003 evaluation that documents the volume and moderation limits established in item 1. Include a list of the contingencies that do not compromise the assumptions of CSER 99-003 (ie. The list of contingencies of the CSERs of item 2.).
4. Do not perform any additional computer calculations. Use results of CSER 99-003 or other CSERs as a basis for this work.

If it should be deemed necessary to perform an additional calculation, that work must first be agreed upon by the technical representative with concurrence of the cost account manager if such work exceeds the initial cost estimates and schedule.

In the conduct of performing this analysis FFS CSS review is sufficient, i.e., no additional outside CSS review is required. It is also expected that FFS CSS obtain reviews and signatures for the revised CSER and submit it to document control.

No work is authorized beyond 100 hours until the PFP Technical Representative and Cost Account Manager have approved a cost estimate and schedule.

4.0 DELIVERABLES / SCHEDULE OR OBJECTIVE ACCEPTANCE CRITERIA

The deliverables are to be detailed in proposal with completion dates for each deliverable based on priority previously established by BTR.

4.1 REPORTS

A FFS monthly status report is required for this release.

4.2 DOCUMENT CONTROL REQUIREMENTS

All documents generated under the Contract Release will be reviewed/approved and released as directed by the FH Project Technical Representative.

4.3 HOLD POINTS and/or SOURCE RECEIVING INSPECTION POINTS

N/A

4.4 MEETINGS

Kickoff Meetings

A kickoff meeting is required.

Progress Meetings

Contractor's personnel shall attend progress meetings as directed by the FH Project Technical Representative.

Weekly Review Meetings

Cost and schedule status shall be reported at a weekly review meeting as directed by the FH Project Technical Representative.

5.0 MINIMUM QUALIFICATION AND COMPETENCE REQUIREMENTS WHICH CONTRACTOR MUST MEET

REQUIRED TRAINING FOR CONTRACTOR (TO INCLUDE QUALIFICATION OR CERTIFICATION REQUIREMENTS IF NECESSARY)

6.0 Performance Period

Desired Start Date: 1/22/01 Completion Date: 04/15/01

7.0 Type of Service:

__ Staff Augmentation or Shared Resource (works at the direction of FH management)
The assigned staff shall comply with Project Hanford Management Contract, FH and PFP specific procedures. When in doubt regarding any direction or procedure, Staff Augmentation employees shall be accountable to stop and consult with the Point of Contact (POC) providing day to day direction or this contract's Buyers Technical Representative (BTR). It is the assigned Staff Augmentation employee's responsibility to know the PFP Casualty Response procedures, Emergency Response Guide, and the PFP Building Emergency Plan for PFP. All accidents (cuts, bumps, bruises, etc.) shall be reported immediately to the POC, BTR, or the cognizant PFP Management person.

Vendor Key Personnel:

X Managed Task (works at the direction of the Vendor)
The vendor shall comply with following FH or PFP Project specific procedures.

__ Other

8.0 General Project Specific Requirements, Codes, and Standards

Information of a sensitive nature which is obtained, accessed, referenced, handled, reproduced or stored as a result or consequence of work produced under this contract statement of work, shall be protected in accordance with FSP-PFP-5-8, Section 4.18. No such information shall be retained by the sub-contractor following completion of work under this contract statement of work.

Information regarding the quantity, identity, characteristics and locations of special nuclear materials, (e.g., plutonium, uranium, nuclear fuel, etc.) at PFP is of particular concern. Personnel performing work under this contract statement of work who will or may use or produce such information shall discuss the information intended for use with a FH Authorized Derivative Classifier before work commences.

1) Employees proposed to perform work in support of this contract release will be required to participate in a brief ONSITE interview with the FH Buyer Technical Representative and a PFP Authorized Derivative Classifier before work commences.
2) The purpose of the ONSITE interview is two fold: Identify and discuss sensitive information potentially available to be needed or produced during the performance of work under this contract statement of work.

3) Orient the employees to the requirements and key PFP points of contract for protection of sensitive information and prescribe the conditions under which such information will be used, handled, stored, reproduced, or delivered.

PFP is a security protected area and therefore requires an "L" (2) or "Q" (3) DOE security clearance for unescorted access to the PFP protected area. Employees who do not possess an approved DOE clearance shall be escorted at all times after passing through the PFP Operations Control Facility (OCF).

The PFP project requires specific training beyond the PHMC and DOE required training for access in the PFP protected area. All training beyond HGET and Building/Facility Orientation must have prior approval from the Contract Administrator. All no-show costs are the responsibility of the vendor.

9.0 FH NMS Project Points of Contact:

Buyers Technical Representative B.S. Mo
Cost Account Manager D.R. Speer______________________

10.0 QUALITY AND SAFETY REQUIREMENTS

10.1 Configuration Control

10.2 ISMS Requirement
10.2.1 SP-5A___(Full Implementation)
10.2.2 SP-5B_X_(Partial Implementation)

10.3 Quality Assurance (check the ones that apply)

The contractor is subject to the provision of 10-CFR-830.120 and 10-CFR-820.
X______ NQA-1, 1994 Edition, Basic Requirements: (list requirements) 1-7 and 15-18 ____________.
_______ NQA-1, 1994 Edition, Supplemental Requirements: (list requirements) ________________.
_______ Other: (list other requirements)____.

10.4 Safety Classification & Quality Level (check only one)

X______A) Quality Level 1 – SC
_______B) Quality Level 1 – SS
_______C) Quality Level 1 – GS
_______D) Quality Level 2 – SS
_______E) Quality Level 2 – GS
_______F) Quality Level 3 – GS
_______G) Quality Level 0 - GS

10.5 Approval Designator (check all that apply)

_______E) Environmental
X______S) Safety
X______Q) Quality

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APPENDIX C
PEER REVIEW CHECKLIST

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Practice 134 290 1112
Publication Date 22Nov99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: HNF-4436, Rev. 1
Title: CSER 99-003, Rev. 1 Criticality Mass of Uranium as Compared to Plutonium-Implications for PFP Processing Uranium
Author: J. Greenborg, D. G. Erickson
Date: April 26, 2001
Scope of Review: Revised limits for U-235 enrichments >5%

Yes	No*	NA	
[ ]	[ ]	[✓]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[✓]	[ ]	[ ]	Problem completely defined.
[ ]	[ ]	[✓]	Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[ ]	[ ]	[✓]	Computer codes and data files documented.
[ ]	[ ]	[✓]	Data used in calculations explicitly stated in document.
[ ]	[ ]	[✓]	Data checked for consistency with original source information as applicable.
[ ]	[ ]	[✓]	Mathematical derivations checked including dimensional consistency of results.
[ ]	[ ]	[✓]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[✓]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[ ]	[ ]	[✓]	Software input correct and consistent with document reviewed.
[ ]	[ ]	[✓]	Software output consistent with input and with results reported in document reviewed.
[✓]	[ ]	[ ]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[✓]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[✓]	[ ]	[ ]	Format consistent with applicable guides or other standards.
[ ]		[✓]**	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]	Document approved (i.e., the reviewer affirms the technical accuracy of the document).

R. F. Richard *R. F. Richard*
Reviewer: (Printed and Signed)

Date 4/26/01

* All "NO" responses must be explained below or on an additional page.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

NUCLEAR ENGINEERING

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