**CALCULATED CRITICAL PARAMETERS IN SIMPLE
GEOMETRIES FOR OXIDE AND NITRATE WATER MIXTURES
OF U-233, U-235 and Pu-239 WITH THORIUM**

FINAL REPORT

**W. E. Converse
S. R. Bierman**

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BASE TECHNOLOGY

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy**

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ABSTRACT

Calculations have been performed on water mixtures of oxides and nitrates of U-233, U-235 and Pu-239 with chemically similar thorium compounds to determine critical dimensions for simple geometries (sphere, cylinder and slab). Uranium enrichments calculated were 100%, 20%, 10% and 5%; plutonium calculations assumed 100% Pu-239. Thorium to uranium or plutonium weight ratios (Th: U or Pu) calculated were 0, 1, 4 and 8. Both bare and full water reflection conditions were calculated.

The results of the calculations are plotted showing a critical dimension versus the uranium or plutonium concentration. Plots of K-infinity and material buckling for each material type are also shown.

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INTRODUCTION

Experimental and analytical data are needed to establish safety guidelines for chemical processing of advanced nuclear reactor fuels involving uranium, plutonium and thorium compounds in solution.⁽¹⁾ Processing of such fuels may involve oxides, nitrates or other compounds of ^{233}U , ^{235}U and/or ^{239}Pu in the presence of thorium. The Thorium Fuel Cycle Technology (TFCT) Program was initiated in 1977 at Savannah River Laboratory (SRL) to study recycle facilities for thorium based fuels. Pacific Northwest Laboratory (PNL) was contracted by SRL to set up an experimental program to study these fuels. Preliminary to the experiments, calculations were performed at PNL to determine the types and quantities of nuclear materials and sizes of experimental vessels for the program.

PNL funding for the TFCT Program was terminated at the end of FY-1978. The calculations completed as of that time are presented in this document.

DESCRIPTION OF CALCULATIONS

ATOM DENSITIES

Atom densities for the mixtures of interest were calculated assuming that compounds in solution occupy a volume in the solution proportional to the ratio of the actual density of the compound to the theoretical density of the compound in solution (e.g., the portion of each cm^3 occupied by UO_2 at a density of 5 g/cm^3 would be $5/10.96 \text{ cm}^3$ since the theoretical density of UO_2 is 10.96 g/cm^3). This method is useful for tertiary mixtures such as $\text{UO}_2 + \text{ThO}_2 + \text{H}_2\text{O}$ where analytical details of such mixtures are difficult to find. Using this method, significant errors in atom densities may occur in the denser solutions (i.e., where the density of individual compounds in the solution is near theoretical density) as a result of changes in chemical bonding in the solution under these conditions. Compound densities assumed for atom density calculations are shown in Table I.

An example of the method used in this work to calculate atom densities is given in Appendix A. For nitrate mixtures, it is assumed that the solution contains no excess nitrates (i.e., 0.0 molar excess HNO_3).

TABLE I. Theoretical Densities for Compounds of Interest

<u>Compound</u>	<u>Chemical Formula</u>	<u>Theoretical Density (g/cm³)</u>	<u>Reference</u>
Uranium Oxide	UO ₂	10.96	2
Plutonium Oxide	PuO ₂	11.46	3
Thorium Oxide	ThO ₂	9.86	2
Uranyl Nitrate	UO ₂ (NO ₃) ₂	5.1657	3
Plutonium Nitrate	Pu(NO ₃) ₄	5.629	3
Thorium Nitrate	Th(NO ₃) ₄	5.203	4, 5(a)
Water	H ₂ O	1.000	3

(a) Derived from data given in these references.

CROSS SECTIONS AND COMPUTER CODES

For this work, ENDF/B-IV cross section data were used for all nuclides except Thorium-232. Thorium cross section data updated by B. R. Leonard and used in analyzing ^{233}U -Thorium High Temperature Gas Cooled Reactor lattices⁽⁶⁾ were used in place of the ENDF/B-IV data.

The EGGNIT code⁽⁷⁾ was used to generate multigroup data from the cross section libraries. The cross section libraries had been processed by the FLANGE⁽⁸⁾ (thermal data); and ETOG⁽⁹⁾ (epithermal data) codes prior to use in EGGNIT.

Critical parameters (sphere, cylinder radius, and slab thickness) were calculated using the one-dimensional multigroup diffusion code HFN⁽¹⁰⁾.

K-infinity and material buckling data were taken from the EGGNIT code output. The parameters are both derived from a two group critical equation discussed in the GAMTEC-II code literature⁽¹¹⁾.

VALIDATIONS

Validation calculations have been performed using the codes and cross section data previously described. The results of these calculations are shown in Table II. Calculations 1-4 (Table II notation) were done on bare and water reflected spheres of plutonium nitrate. Hydrogen-to- ^{239}Pu atom ratios ranged from 56 to 1159. The calculated values of k_{eff} for these systems ranged from about 2% to 5% above criticality ($k_{\text{eff}} = 1.0$). The average value of k_{eff} for the plutonium solution was 1.036.

Calculations 5-9 were performed on bare and water reflected spheres and cylinders of uranyl (^{235}U) nitrate and uranyl (^{235}U) fluoride. Enrichment for these systems ranged from 93.2 to 4.89 wt% and the hydrogen-to- ^{235}U atom ratios ranged from 43.2 to 1835. The calculated values of k_{eff} ranged from about 1/2% below criticality to about 3% above. The average value of k_{eff} for the ^{235}U solutions was 1.011.

Calculations 10-12 were performed on bare and water reflected spheres of uranyl (^{233}U) nitrate. The calculated k_{eff} for these solutions ranged from about 1% to 1 1/2% above criticality. The average value of k_{eff} for the ^{233}U solutions was 1.011.

DTF-IV calculations were performed on one of each of the different nuclide systems to assure congruence with the corresponding HFN calculations.⁽¹⁷⁾

As noted in Table II, the computed values of k_{eff} are close to, or above, unity and none is significantly below unity. The average values are above unity which implies these particular calculations to be conservative (critical system expected to be calculated as super critical). No check calculations were made, however, on aqueous homogeneous solutions containing thorium due to lack of appropriate critical experiment data.

TABLE II. Results of Some Validation Checks

Description of Experiment	Enrichment or ⁽¹⁾ ²⁴⁰ Pu Content (w/o)	H/fissile Atom Ratio	Sphere	Cylinder		K _{eff}		Reference
			Diameter (cm)	Diameter (cm)	Height (cm)	HFN	DTF-IV	
<u>Pu-239</u>								
1. Full Water Reflected (FWR) SS Sphere, Pu(NO ₃) ₄	4.6	56	29.21	--	--	1.049	--	12
2. FWR SS Sphere, Pu(NO ₃) ₄	4.6	370	29.21	--	--	1.030	--	12
3. Bare SS Sphere, Pu(NO ₃) ₄	4.6	664	38.61	--	--	1.044	--	12
4. FWR SS Sphere, Pu(NO ₃) ₄	4.6	1159	38.61	--	--	1.021	1.022	12
<u>U-235</u>								
5. FWR Al Cylinder, UO ₂ F ₂	93.2	43.2	--	15.24	70.10	1.018	--	13
6. Bare Al Cylinder, UO ₂ F ₂	93.2	331	--	25.40	170.10	1.028	--	13
7. Bare Al Sphere, UO ₂ (NO ₃) ₂ ⁽²⁾	93.2	1378	69.19	--	--	1.001	0.999	14
8. Bare Al Sphere, UO ₂ (NO ₃) ₂ ⁽²⁾	93.2	1835	122.02	--	--	0.995	--	14
9. FWR SS Cylinder, UO ₂ F ₂	4.89	735	--	38.10	153.01	1.014	--	15
<u>U-233</u>								
10. FWR Al Sphere, UO ₂ (NO ₃) ₂ ⁽³⁾	98.70	405	26.6	--	--	1.015	--	16
11. Bare Al Sphere, UO ₂ (NO ₃) ₂	97.70	1533	69.19	--	--	1.013		14
12. Bare Al Sphere, UO ₂ (NO ₃) ₂	97.67	1986	122.02	--	--	1.006	1.009	14

(1) ²³³U or ²³⁵U enrichment (wt%).(2) These solutions contained small amounts of ²³²Th.

(3) Vessel thickness not specified, 1/16 inch wall thickness assumed.

RESULTS AND CONCLUSIONS

The calculated critical parameters are shown in Appendix B in Figures 1-144. Each calculated point indicates a critical system ($K_{\text{eff}} = 1.0$) with no calculational bias correction applied. There are six sections - U-235 enriched uranyl nitrates (Figures 1-32), U-233 enriched uranyl nitrates (Figures 33-64), Pu-239 nitrates (Figures 65-72), U-235 enriched uranium oxides (Figures 73-104), U-233 enriched uranium oxides (Figures 105-136) and Pu-239 oxides (Figures 137-144). Each section contains critical parameters for spheres, cylinders and slabs with bare and full water reflection conditions. For the uranium systems, calculations were made with enrichments of 100%, 20%, 10% and 5%. For plutonium systems, no Pu-240 is included. Th to U or Pu (Th/X) ratios of 0, 1, 4 and 8 were used in the calculations with Th. K-infinity and material buckling curves are also presented in each section. The calculated values on the figures presented in Appendix B were plotted by computer and eye-guide smooth curves were drawn between the calculated points. Where the data were so sparse that an eye-guide curve might be misleading only the data points are shown.

Using the calculated data, a comparison can be made of the effect of replacing U-238 in enriched uranium with Th-232. Data in Table III compares 20% U-235 enriched uranium with a similar system in which Th-232 replaces U-238 by weight. Bare slab thickness is shown over a range of 0.08 to 8.0 grams heavy metal (HM)/cm³. The data are essentially identical up to about 2 g HM/cm³ where the Th mixture becomes slightly less reactive than the U-238 mixture. Comparisons at 10% enrichments and with nitrates show similar results.

TABLE III. Criticality (Bare Slab Critical Thickness) of ^{235}U -Th Mixtures Compared to that of Enriched Uranium Mixtures

Heavy Metal Concentration (g HM/cm ³)	Bare Slab Thickness (cm)	
	20% U-235 in U (no Thorium)	20% U-235 in Th (no U-238)
0.08	47.60	---
0.10	32.30	32.58
0.15	---	22.86
0.20	19.72	---
0.25	---	18.18
0.30	17.26	---
0.40	---	16.20
0.50	15.70	15.68
0.80	15.16	---
1.0	15.10	15.06
1.5	---	15.36
2.0	15.84	---
2.5	---	16.54
3.0	17.02	---
4.0	---	19.08
5.0	19.74	21.28
8.0	24.38	---

REFERENCES

1. B. F. Gore, "Compilation of Criticality Data Involving Thorium or ^{233}U and Light Water Moderation," PNL 2080-12, Pacific Northwest Laboratory, Richland, WA 99352, 1978.
2. _____, Handbook of Chemistry and Physics, 60th Edition, Edited by R. C. Weast, The Chemical Rubber Co., Cleveland, OH, 1979.
3. R. D. Carter et al., Criticality Handbook, ARH-600, Atlantic Richfield Hanford Co., Richland, WA 99352, 1968.
4. K. H. McCorkle, "Surface Chemistry and Viscosity of Thoria Sols," ORNL-TM-1536, Oak Ridge National Laboratory, Oak Ridge, TN 37830, 1966.
5. A. Apelblat, D. Azoulay and A. Sahar, "Properties of Aqueous Thorium Nitrate Solutions - Part 1: Densities, Viscosities, Conductivities, pH, Solubility, and Activities at Freezing Point," J. Chem. Soc., Faraday Trans., I-69, No. 9, p.1618, 1973.
6. D. F. Newman, et al., "Evaluation of Temperature Coefficients of Reactivity for ^{233}U - Thorium Fueled HTGR Lattices," EPRI-NP-222, Electric Power Research Institute, Palo Alto, CA, 94303, 1977.

7. C. R. Richey, "EGGNIT: A Multigroup Cross-Section Code." BNWL-1203, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, 1969.
8. H. C. Honeck and D. R. Finch, "FLANGE II (Version 71-1), A Code to Process Thermal Neutron Data from an ENDF/B Tape," DP-1278 (ENDF-152) 1971.
9. K. E. Kusner, R. A. Dannels and S. Kellman, "ETOG-1: A FORTRAN IV Program to Process Data from the ENDF/B File to the MUFT, GAM and ANISN Formats," WCAP-3845-1 (ENDF-114), 1969.
10. J. R. Lilley, "Computer Code HFN - Multigroup Multiregion Neutron Diffusion Theory in One Space Dimension," HW-71545, General Electric Co., 1961.
11. C. R. Richey, et al., "GAMTEC II, A Code for Generating Consistent Multigroup Constants Utilized in Diffusion and Transport Theory Calculations," BNWL-35, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, 1965.
12. R. C. Lloyd, et al., "Criticality Studies of Plutonium Solutions," Nuc. Sci. Eng., 25:105, 1966.
13. J. K. Fox and L. W. Gilley, "Critical Parameters of Aqueous Solutions of Uranium-235," ORNL-2389, Oak Ridge National Laboratory, Oak Ridge, TN 37830, 1958.

14. R. Gwin and D. W. Magnuson, "The Measurement of Eta and Other Nuclear Properties of ^{233}U and ^{235}U in Critical Aqueous Solutions," Nuc. Sci. Eng., 12:374, 1972.
15. D. F. Cronin, "Critical Mass Studies, Part X. - Uranium of Intermediate Enrichment," ORNL-2968, Oak Ridge National Laboratory, Oak Ridge, TN 37830, September 20, 1960.
16. J. K. Fox, L. W. Gilley and E. R. Roher, "Critical Mass Studies, Part VIII. - Aqueous Solutions of U^{233} ," ORNL-2143, Oak Ridge National Laboratory, Oak Ridge, TN 37830, September 23, 1959.
17. D. K. Lathrop, "DTF-IV, A FORTRAN IV Program for Solving the Multi-group Transport Equation with Anisotropic Scattering," LA-3373, Los Alamos Scientific Laboratory, Los Alamos, NM 87545, 1965.

APPENDIX A - ATOM DENSITY SAMPLE CALCULATION

The following is an example of the method used to calculate atom densities for this report. The system described is:

Let

$$E = \text{fissile isotopic content (weight \%)} = \frac{\text{grams fissile isotope in U}}{\text{grams U}}$$

$$R = \text{thorium to uranium weight ration} = \frac{\text{grams Th}}{\text{grams U}}$$

$$\rho = \text{assumed uranium density} = \frac{\text{grams U}}{\text{cm}^3}$$

$$D^X = \text{atom density of fissile isotope X}$$

$$D^{28} = \text{atom density of U-238}$$

$$A^X = \text{atomic weight of fissile isotope X}$$

$$A^{28} = \text{atomic weight of U-238}$$

$$D^H = \text{atom density of hydrogen in the mixture}$$

$$D^O = \text{atom density of oxygen in the mixture}$$

Then

$$D^X = \frac{E\rho}{A^X} \cdot 0.6022 \left\{ \frac{\text{atom x}}{\text{b-cm}} \right\}^*$$

* Atoms of isotope x per barn-centimeter (b-cm).

and

$$D^{28} = \frac{(1-E)_p}{A^{28}} \cdot 0.6022 \quad \left\{ \text{atom } ^{238}\text{U} / \text{b-cm} \right\}$$

If the oxygen and nitrogen atom density in $\text{UO}_2(\text{NO}_3)_2$ is O^U and N^U , respectively, then

$$O^U = 8 \cdot (D^{28} + D^X) \quad \left\{ \text{atom O} / \text{b-cm} \right\}$$

and

$$N^U = 2 \cdot (D^{28} + D^X) \quad \left\{ \text{atom N} / \text{b-cm} \right\} .$$

Let

$$D^{\text{Th}} = \text{thorium atom density}$$

$$N^{\text{Th}} = \text{nitrogen atom density in } \text{Th}(\text{NO}_3)_4$$

$$O^{\text{Th}} = \text{oxygen atom density in } \text{Th}(\text{NO}_3)_4$$

$$A^{\text{Th}} = \text{thorium atomic weight}$$

then

$$D^{\text{Th}} = \frac{R_p}{A^{\text{Th}}} \cdot 0.6022 \quad \left\{ \text{atom Th} / \text{b-cm} \right\}$$

and

$$N^{\text{Th}} = 4 \cdot D^{\text{Th}} \quad \left\{ \text{atom N} / \text{b-cm} \right\}$$

$$O^{\text{Th}} = 12 \cdot D^{\text{Th}} \quad \left\{ \text{atom O} / \text{b-cm} \right\} .$$

Now let

f = fraction of each cm^3 of mixture that contains water

$\bar{U}$ = uranium molecular weight = $EA^X + (1 - E)A^{28}$

ρ_U = theoretical density of $\text{UO}_2(\text{NO}_3)_2$ in solution

ρ_{Th} = theoretical density of $\text{Th}(\text{NO}_3)_4$ in solution

$$C_1 = \frac{\text{grams } \text{UO}_2(\text{NO}_3)_2}{\text{grams U}} = \frac{\bar{U} + \text{molecular weight } \text{N}_2\text{O}_8}{\bar{U}}$$

and

$$C_2 = \frac{\text{grams } \text{Th}(\text{NO}_3)_4}{\text{grams Th}}$$

Then

$$f = 1 - \left[\frac{\rho_U C_1}{\rho_U} + \frac{R C_2}{\rho_{\text{Th}}} \right]$$

Let

D_W^H = hydrogen atom density in water

D_W^O = oxygen atom density in water

Then

$$D_W^H = 0.06689 \cdot f \quad \left\{ \text{atom H} / \text{b-cm} \right\}$$

$$D_W^O = 0.03345 \cdot f \quad \left\{ \text{atom O} / \text{b-cm} \right\}$$

Summarizing

$$D^X = \frac{E_p}{A^X} \cdot 0.6022$$

$$D^{28} = \frac{(1-E)p}{A^{28}} \cdot 0.6022$$

$$D^H = D_W^H = 0.06689 \cdot f$$

$$D^O = D_W^O + O^{Th} + O^U = 0.03345f + (12 \cdot D^{Th}) + 8 \cdot (D^{28} + D^X)$$

$$D^N = N^{Th} + N^U = 4 \cdot O^{Th} + 2(D^{28} + D^X)$$

APPENDIX B - RESULTS OF CALCULATIONS

The following figures graphically show the results of calculations on nitrate and oxide homogeneous water mixtures of U-233, U-235 and Pu-239:

FIGURES

		<u>Page</u>
1. Bare Sphere Radius U Nitrate U-235 Enrichment	= 1.00	22
2. FWR ^(a) Sphere Radius U Nitrate U-235 Enrichment	= 1.00	23
3. Bare Sphere Radius U Nitrate U-235 Enrichment	= 0.20	24
4. FWR Sphere Radius U Nitrate U-235 Enrichment	= 0.20	25
5. Bare Sphere Radius U Nitrate U-235 Enrichment	= 0.10	26
6. FWR Sphere Radius U Nitrate U-235 Enrichment	= 0.10	27
7. Bare Sphere Radius U Nitrate U-235 Enrichment	= 0.05	28
8. FWR Sphere Radius U Nitrate U-235 Enrichment	= 0.05	29
9. Bare Cylinder Radius U Nitrate U-235 Enrichment	= 1.00	30
10. FWR Cylinder Radius U Nitrate U-235 Enrichment	= 1.00	31
11. Bare Cylinder Radius U Nitrate U-235 Enrichment	= 0.20	32
12. FWR Cylinder Radius U Nitrate U-235 Enrichment	= 0.20	33
13. Bare Cylinder Radius U Nitrate U-235 Enrichment	= 0.10	34
14. FWR Cylinder Radius U Nitrate U-235 Enrichment	= 0.10	35
15. Bare Cylinder Radius U Nitrate U-235 Enrichment	= 0.05	36
16. FWR Cylinder Radius U Nitrate U-235 Enrichment	= 0.05	37
17. Bare Slab Thickness U Nitrate U-235 Enrichment	= 1.00	38
18. FWR Slab Thickness U Nitrate U-235 Enrichment	= 1.00	39

^(a) Full Water Reflected (25.4 cm)

19.	Bare Slab Thickness U Nitrate U-235 Enrichment	= 0.20	40
20.	FWR Slab Thickness U Nitrate U-235 Enrichment	= 0.20	41
21.	Bare Slab Thickness U Nitrate U-235 Enrichment	= 0.10	42
22.	FWR Slab Thickness U Nitrate U-235 Enrichment	= 0.10	43
23.	Bare Slab Thickness U Nitrate U-235 Enrichment	= 0.05	44
24.	FWR Slab Thickness U Nitrate U-235 Enrichment	= 0.05	45
25.	K-Infinity U Nitrate U-235 Enrichment	= 1.00	46
26.	K-Infinity U Nitrate U-235 Enrichment	= 0.20	47
27.	K-Infinity U Nitrate U-235 Enrichment	= 0.10	48
28.	K-Infinity U Nitrate U-235 Enrichment	= 0.05	49
29.	Material Buckling U Nitrate U-235 Enrichment	= 1.00	50
30.	Material Buckling U Nitrate U-235 Enrichment	= 0.20	51
31.	Material Buckling U Nitrate U-235 Enrichment	= 0.10	52
32.	Material Buckling U Nitrate U-235 Enrichment	= 0.05	53
33.	Bare Sphere Radius U Nitrate U-233 Enrichment	= 1.00	54
34.	FWR Sphere Radius U Nitrate U-233 Enrichment	= 1.00	55
35.	Bare Sphere Radius U Nitrate U-233 Enrichment	= 0.20	56
36.	FWR Sphere Radius U Nitrate U-233 Enrichment	= 0.20	57
37.	Bare Sphere Radius U Nitrate U-233 Enrichment	= 0.10	58
38.	FWR Sphere Radius U Nitrate U-233 Enrichment	= 0.10	59
39.	Bare Sphere Radius U Nitrate U-233 Enrichment	= 0.05	60
40.	FWR Sphere Radius U Nitrate U-233 Enrichment	= 0.05	61
41.	Bare Cylinder Radius U Nitrate U-233 Enrichment	= 1.00	62
42.	FWR Cylinder Radius U Nitrate U-233 Enrichment	= 1.00	63
43.	Bare Cylinder Radius U Nitrate U-233 Enrichment	= 0.20	64
44.	FWR Cylinder Radius U Nitrate U-233 Enrichment	= 0.20	65

45.	Bare Cylinder Radius U Nitrate U-233 Enrichment	- 0.10	66
46.	FWR Cylinder Radius U Nitrate U-233 Enrichment	= 0.10	67
47.	Bare Cylinder Radius U Nitrate U-233 Enrichment	= 0.05	68
48.	FWR Cylinder Radius U Nitrate U-233 Enrichment	= 0.05	69
49.	Bare Slab Thickness U Nitrate U-233 Enrichment	= 1.00	70
50.	FWR Slab Thickness U Nitrate U-233 Enrichment	= 1.00	71
51.	Bare Slab Thickness U Nitrate U-233 Enrichment	= 0.20	72
52.	FWR Slab Thickness U Nitrate U-233 Enrichment	= 0.20	73
53.	Bare Slab Thickness U Nitrate U-233 Enrichment	= 0.10	74
54.	FWR Slab Thickness U Nitrate U-233 Enrichment	= 0.10	75
55.	Bare Slab Thickness U Nitrate U-233 Enrichment	= 0.05	76
56.	FWR Slab Thickness U Nitrate U-233 Enrichment	= 0.05	77
57.	K-Infinity U Nitrate U-233 Enrichment	= 1.00	78
58.	K-Infinity U Nitrate U-233 Enrichment	= 0.20	79
59.	K-Infinity U Nitrate U-233 Enrichment	= 0.10	80
60.	K-Infinity U Nitrate U-233 Enrichment	= 0.05	81
61.	Material Buckling U Nitrate U-233 Enrichment	= 1.00	82
62.	Material Buckling U Nitrate U-233 Enrichment	= 0.20	83
63.	Material Buckling U Nitrate U-233 Enrichment	= 0.10	84
64.	Material Buckling U Nitrate U-233 Enrichment	= 0.05	85
65.	Bare Sphere Radius Pu Nitrate 100% Pu-239		86
66.	FWR Sphere Radius Pu Nitrate 100% Pu-239		87
67.	Bare Cylinder Radius Pu Nitrate 100% Pu-239		88
68.	FWR Cylinder Radius Pu Nitrate 100% Pu-239		89
69.	Bare Slab Thickness Pu Nitrate 100% Pu-239		90
70.	FWR Slab Thickness Pu Nitrate 100% Pu-239		91
71.	K-Infinity Pu Nitrate 100% Pu-239		92

72.	Material Buckling Pu Nitrate 100% Pu-239		93
73.	Bare Sphere Radius U Oxide U-235 Enrichment	= 1.00	94
74.	FWR Sphere Radius U Oxide U-235 Enrichment	= 1.00	95
75.	Bare Sphere Radius U Oxide U-235 Enrichment	= 0.20	96
76.	FWR Sphere Radius U Oxide U-235 Enrichment	= 0.20	97
77.	Bare Sphere Radius U Oxide U-235 Enrichment	= 0.10	98
78.	FWR Sphere Radius U Oxide U-235 Enrichment	= 0.10	99
79.	Bare Sphere Radius U Oxide U-235 Enrichment	= 0.05	100
80.	FWR Sphere Radius U Oxide U-235 Enrichment	= 0.05	101
81.	Bare Cylinder Radius U Oxide U-235 Enrichment	= 1.00	102
82.	FWR Cylinder Radius U Oxide U-235 Enrichment	= 1.00	103
83.	Bare Cylinder Radius U Oxide U-235 Enrichment	= 0.20	104
84.	FWR Cylinder Radius U Oxide U-235 Enrichment	= 0.20	105
85.	Bare Cylinder Radius U Oxide U-235 Enrichment	= 0.10	106
86.	FWR Cylinder Radius U Oxide U-235 Enrichment	= 0.10	107
87.	Bare Cylinder Radius U Oxide U-235 Enrichment	= 0.05	108
88.	FWR Cylinder Radius U Oxide U-235 Enrichment	= 0.05	109
89.	Bare Slab Thickness U Oxide U-235 Enrichment	= 1.00	110
90.	FWR Slab Thickness U Oxide U-235 Enrichment	= 1.00	111
91.	Bare Slab Thickness U Oxide U-235 Enrichment	= 0.20	112
92.	FWR Slab Thickness U Oxide U-235 Enrichment	= 0.20	113
93.	Bare Slab Thickness U Oxide U-235 Enrichment	= 0.10	114
94.	FWR Slab Thickness U Oxide U-235 Enrichment	= 0.10	115
95.	Bare Slab Thickness U Oxide U-235 Enrichment	= 0.05	116
96.	FWR Slab Thickness U Oxide U-235 Enrichment	= 0.05	117

97.	K-Infinity U Oxide U-235 Enrichment	= 1.00	118
98.	K-Infinity U Oxide U-235 Enrichment	= 0.20	119
99.	K-Infinity U Oxide U-235 Enrichment	= 0.10	120
100.	K-Infinity U Oxide U-235 Enrichment	= 0.05	121
101.	Material Buckling U Oxide U-235 Enrichment	= 1.00	122
102.	Material Buckling U Oxide U-235 Enrichment	= 0.20	123
103.	Material Buckling U Oxide U-235 Enrichment	= 0.10	124
104.	Material Buckling U Oxide U-235 Enrichment	= 0.05	125
105.	Bare Sphere Radius U Oxide U-233 Enrichment	= 1.00	126
106.	FWR Sphere Radius U Oxide U-233 Enrichment	= 1.00	127
107.	Bare Sphere Radius U Oxide U-233 Enrichment	= 0.20	128
108.	FWR Sphere Radius U Oxide U-233 Enrichment	= 0.20	129
109.	Bare Sphere Radius U Oxide U-233 Enrichment	= 0.10	130
110.	FWR Sphere Radius U Oxide U-233 Enrichment	= 0.10	131
111.	Bare Sphere Radius U Oxide U-233 Enrichment	= 0.05	132
112.	FWR Sphere Radius U Oxide U-233 Enrichment	= 0.05	133
113.	Bare Cylinder Radius U Oxide U-233 Enrichment	= 1.00	134
114.	FWR Cylinder Radius U Oxide U-233 Enrichment	= 1.00	135
115.	Bare Cylinder Radius U Oxide U-233 Enrichment	= 0.20	136
116.	FWR Cylinder Radius U Oxide U-233 Enrichment	= 0.20	137
117.	Bare Cylinder Radius U Oxide U-233 Enrichment	= 0.10	138
118.	FWR Cylinder Radius U Oxide U-233 Enrichment	= 0.10	139
119.	Bare Cylinder Radius U Oxide U-233 Enrichment	= 0.05	140
120.	FWR Cylinder Radius U Oxide U-233 Enrichment	= 0.05	141
121.	Bare Slab Thickness U Oxide U-233 Enrichment	= 1.00	142
122.	FWR Slab Thickness U Oxide U-233 Enrichment	= 1.00	143
123.	Bare Slab Thickness U Oxide U-233 Enrichment	= 0.20	144

124.	FWR Slab Thickness U Oxide U-233 Enrichment	= 0.20	145
125.	Bare Slab Thickness U Oxide U-233 Enrichment	= 0.10	146
126.	FWR Slab Thickness U Oxide U-233 Enrichment	= 0.10	147
127.	Bare Slab Thickness U Oxide U-233 Enrichment	= 0.05	148
128.	FWR Slab Thickness U Oxide U-233 Enrichment	= 0.05	149
129.	K-Infinity U Oxide U-233 Enrichment	= 1.00	150
130.	K-Infinity U Oxide U-233 Enrichment	= 0.20	151
131.	K-Infinity U Oxide U-233 Enrichment	= 0.10	152
132.	K-Infinity U Oxide U-233 Enrichment	= 0.05	153
133.	Material Buckling U Oxide U-233 Enrichment	= 1.00	154
134.	Material Buckling U Oxide U-233 Enrichment	= 0.20	155
135.	Material Buckling U Oxide U-233 Enrichment	= 0.10	156
136.	Material Buckling U Oxide U-233 Enrichment	= 0.05	157
137.	Bare Sphere Radius Pu Oxide 100% Pu-239		158
138.	FWR Sphere Radius Pu Oxide 100% Pu-239		159
139.	Bare Cylinder Radius Pu Oxide 100% Pu-239		160
140.	FWR Cylinder Radius Pu Oxide 100% Pu-239		161
141.	Bare Slab Thickness Pu Oxide 100% Pu-239		162
142.	FWR Slab Thickness Pu Oxide 100% Pu-239		163
143.	K-Infinity Pu Oxide 100% Pu-239		164
144.	Material Buckling Pu Oxide 100% Pu-239		165

FIGURE 1. BARE SPHERE RADIUS U NITRATE U-235 ENRICHMENT=1.00

FIGURE 2. FWR SPHERE RADIUS U NITRATE U-235 ENRICHMENT=1.00

FIGURE 3. BARE SPHERE RADIUS U NITRATE U-235 ENRICHMENT=0.20

FIGURE 4. FWR SPHERE RADIUS U NITRATE U-235 ENRICHMENT=0.20

FIGURE 5. BARE SPHERE RADIUS U NITRATE U-235 ENRICHMENT=0.10

FIGURE 6. FWR SPHERE RADIUS U NITRATE U-235 ENRICHMENT=0.10

FIGURE 7. BARE SPHERE RADIUS U NITRATE U-235 ENRICHMENT=0.05

FIGURE 8. FWA SPHERE RADIUS U NITRATE U-235 ENRICHMENT=0.05

FIGURE 9. BARE CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=1.00

FIGURE 10. FWA CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=1.00

FIGURE 11. BARE CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=0.20

FIGURE 12. FWR CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=0.20

FIGURE 13. BARE CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=0.10

FIGURE 14. FWR CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=0.10

FIGURE 15. BARE CYLINDER RADIUS U NITRATE U-235 ENRICHMENT:0.05

FIGURE 16. FWR CYLINDER RADIUS U NITRATE U-235 ENRICHMENT=0.05

FIGURE 17. BARE SLAB THICKNESS U NITRATE U-235 ENRICHMENT=1.00

FIGURE 18. FWR SLAB THICKNESS U NITRATE U-235 ENRICHMENT=1.00

FIGURE 19. BARE SLAB THICKNESS U NITRATE U-235 ENRICHMENT=0.20

FIGURE 20. FWR SLAB THICKNESS U NITRATE U-235 ENRICHMENT=0.20

FIGURE 21. BARE SLAB THICKNESS U NITRATE U-235 ENRICHMENT=0.10

FIGURE 22. FWR SLAB THICKNESS U NITRATE U-235 ENRICHMENT=0.10

FIGURE 23. BARE SLAB THICKNESS U NITRATE U-235 ENRICHMENT=0.05

FIGURE 24. FWR SLAB THICKNESS U NITRATE U-235 ENRICHMENT=0.05

FIGURE 25. K-INFINITY U NITRATE U-235 ENRICHMENT=1.00

FIGURE 26. K-INFINITY U NITRATE U-235 ENRICHMENT=0.20

FIGURE 27. K-INFINITY U NITRATE U-235 ENRICHMENT=0.10

FIGURE 28. $K\text{-INFINITY}$ U NITRATE U-235 ENRICHMENT=0.05

FIGURE 29. MATERIAL BUCKLING U NITRATE U-235 ENRICHMENT:1.00

FIGURE 30. MATERIAL BUCKLING U NITRATE U-235 ENRICHMENT=0.20

FIGURE 31. MATERIAL BUCKLING U NITRATE U-235 ENRICHMENT=0.10

FIGURE 32. MATERIAL BUCKLING U NITRATE U-235 ENRICHMENT:0.05

FIGURE 33. BARE SPHERE RADIUS U NITRATE U-233 ENRICHMENT=1.00

FIGURE 34. FWA SPHERE RADIUS U NITRATE U-233 ENRICHMENT=1.00

FIGURE 35. BARE SPHERE RADIUS U NITRATE U-233 ENRICHMENT = 0.20

FIGURE 36. FWR SPHERE RADIUS U NITRATE U-233 ENRICHMENT:0.20

FIGURE 37. BARE SPHERE RADIUS U NITRATE U-233 ENRICHMENT=0.10

FIGURE 38. FVR SPHERE RADIUS U NITRATE U-233 ENRICHMENT=0.10

FIGURE 39. BARE SPHERE RADIUS U NITRATE U-233 ENRICHMENT=0.05

SPHERE CRITICAL RADIUS (CM)

FIGURE 40. FWR SPHERE RADIUS U NITRATE U-233 ENRICHMENT=0.05

FIGURE 41. BARE CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=1.00

FIGURE 42. FWR CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=1.00

FIGURE 43. BARE CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=0.20

FIGURE 44. FWR CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=0.20

FIGURE 45. BARE CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=0.10

FIGURE 46. FWR CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=0.10

FIGURE 47. BARE CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=0.05

CYLINDER CRITICAL RADIUS (CM)

FIGURE 48. FWA CYLINDER RADIUS U NITRATE U-233 ENRICHMENT=0.05

FIGURE 49. BARE SLAB THICKNESS U NITRATE U-233 ENRICHMENT=1.00

FIGURE 58. FWA SLAB THICKNESS U NITRATE U-233 ENRICHMENT=1.00

FIGURE 51. BARE SLAB THICKNESS U NITRATE U-233 ENRICHMENT=0.20

FIGURE 52. FWR SLAB THICKNESS U NITRATE U-233 ENRICHMENT=0.20

FIGURE 53. BARE SLAB THICKNESS U NITRATE U-233 ENRICHMENT=0.10

FIGURE 54. FWR SLAB THICKNESS U NITRATE U-233 ENRICHMENT=0.10

SLAB CRITICAL THICKNESS (CM)

FIGURE 55. BARE SLAB THICKNESS U NITRATE U-233 ENRICHMENT=0.05

SLAB CRITICAL THICKNESS (CM)

FIGURE 56. FWR SLAB THICKNESS U NITRATE U-233 ENRICHMENT=0.05

FIGURE 58. K-INFINITY U NITRATE U-233 ENRICHMENT=0.20

FIGURE 59. K-INFINITY U NITRATE U-233 ENRICHMENT=0.10

FIGURE 60. $K\text{-INFINITY}$ U NITRATE U-233 ENRICHMENT=0.05

FIGURE 61. MATERIAL BUCKLING U NITRATE U-233 ENRICHMENT 1.00

FIGURE 62. MATERIAL BUCKLING U NITRATE U-233 ENRICHMENT:0.20

FIGURE 63. MATERIAL BUCKLING U NITRATE U-233 ENRICHMENT=0.10

FIGURE 64. MATERIAL BUCKLING U NITRATE U-233 ENRICHMENT=0.05

FIGURE 65. BARE SPHERE RADIUS PU NITRATE 100% PU-239

FIGURE 66. FWR SPHERE RADIUS PU NITRATE 100% PU-239

FIGURE 67. BARE CYLINDER RADIUS PU NITRATE 100% PU-239

FIGURE 68. FWR CYLINDER RADIUS PU NITRATE 100% PU-239

FIGURE 69. BARE SLAB THICKNESS PU NITRATE 100% PU-239

FIGURE 70. FWA SLAB THICKNESS PU NITRATE 100% PU-239

FIGURE 71. K-INFINITY PU NITRATE 100% PU-239

FIGURE 72. MATERIAL BUCKLING PU NITRATE 100% PU-239

FIGURE 73. BARE SPHERE RADIUS U OXIDE U-235 ENRICHMENT=1.00

FIGURE 74. FWR SPHERE RADIUS U OXIDE U-235 ENRICHMENT=1.00

FIGURE 75. BARE SPHERE RADIUS U OXIDE U-235 ENRICHMENT=0.20

FIGURE 76. FVR SPHERE RADIUS U OXIDE U-235 ENRICHMENT=0.20

FIGURE 77. BARE SPHERE RADIUS U OXIDE U-235 ENRICHMENT=0.10

FIGURE 78. FWR SPHERE RADIUS U OXIDE U-235 ENRICHMENT=0.10

FIGURE 79. BARE SPHERE RADIUS U OXIDE U-235 ENRICHMENT=0.05

FIGURE 80. FWR SPHERE RADIUS U OXIDE U-235 ENRICHMENT=0.05

FIGURE 81. BARE CYLINDER RADIUS U OXIDE U-235 ENRICHMENT=1.00

FIGURE 82. FWR CYLINDER RADIUS U OXIDE U-235 ENRICHMENT=1.00

FIGURE 83. BARE CYLINDER RADIUS U OXIDE U-235 ENRICHMENT=0.20

FIGURE 84. FWR CYLINDER RADIUS U OXIDE U-235 ENRICHMENT:0.20

FIGURE 85. BARE CYLINDER RADIUS U OXIDE U-235 ENRICHMENT=0.10

FIGURE 86. FWR CYLINDER RADIUS U OXIDE U-235 ENRICHMENT=0.10

FIGURE 87. BARE CYLINDER RADIUS U OXIDE U-235 ENRICHMENT=0.05

FIGURE 88. FWR CYLINDER RADIUS U OXIDE U-235 ENRICHMENT 0.05

FIGURE 89. BARE SLAB THICKNESS U OXIDE U-235 ENRICHMENT=1.00

FIGURE 90. FWR SLAB THICKNESS U OXIDE U-235 ENRICHMENT=1.00

FIGURE 91. BARE SLAB THICKNESS U OXIDE U-235 ENRICHMENT=0.20

FIGURE 92. FWR SLAB THICKNESS U OXIDE U-235 ENRICHMENT=0.20

FIGURE 93. BARE SLAB THICKNESS U OXIDE U-235 ENRICHMENT=0.10

FIGURE 94. FWR SLAB THICKNESS U OXIDE U-235 ENRICHMENT=0.10

FIGURE 95. BARE SLAB THICKNESS U OXIDE U-235 ENRICHMENT:0.05

FIGURE 96. FWR SLAB THICKNESS U OXIDE U-235 ENRICHMENT=0.05

FIGURE 97. K-INFINITY U OXIDE U-235 ENRICHMENT=1.00

FIGURE 98. K-INFINITY U OXIDE U-235 ENRICHMENT=0.20

FIGURE 99. K-INFINITY U OXIDE U-235 ENRICHMENT=0.10

FIGURE 100. K-INFINITY U OXIDE U-235 ENRICHMENT=0.05

FIGURE 101. MATERIAL BUCKLING U OXIDE U-235 ENRICHMENT=1.00

FIGURE 102. MATERIAL BUCKLING U OXIDE U-235 ENRICHMENT:0.20

FIGURE 103. MATERIAL BUCKLING U OXIDE U-235 ENRICHMENT=0.10

FIGURE 104. MATERIAL BUCKLING U OXIDE U-235 ENRICHMENT 0.05

FIGURE 185. BARE SPHERE RADIUS U OXIDE U-233 ENRICHMENT=1.00

FIGURE 106. FWR SPHERE RADIUS U OXIDE U-233 ENRICHMENT=1.00

FIGURE 187. BARE SPHERE RADIUS U OXIDE U-233 ENRICHMENT=0.20

FIGURE 108. FWR SPHERE RADIUS U OXIDE U-233 ENRICHMENT=0.20

FIGURE 129. BARE SPHERE RADIUS U OXIDE U-233 ENRICHMENT=0.10

FIGURE 110. FVR SPHERE RADIUS U OXIDE U-233 ENRICHMENT=0.10

FIGURE III. BARE SPHERE RADIUS U OXIDE U-233 ENRICHMENT=0.05

FIGURE 112. FVR SPHERE RADIUS U OXIDE U-233 ENRICHMENT=0.05

FIGURE 113. BARE CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=1.00

FIGURE 114. FWR CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=1.00

FIGURE 115. BARE CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=0.20

FIGURE 116. FWR CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=0.20

FIGURE 117. BARE CYLINDER RADIUS U OXIDE U-233 ENRICHMENT: 0.10

FIGURE 118. FWR CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=0.18

FIGURE 119. BARE CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=0.05

FIGURE 120. FVR CYLINDER RADIUS U OXIDE U-233 ENRICHMENT=0.05

FIGURE 121. BARE SLAB THICKNESS U OXIDE U-233 ENRICHMENT=1.00

FIGURE 122. FVR SLAB THICKNESS U OXIDE U-233 ENRICHMENT=1.00

FIGURE 123. BARE SLAB THICKNESS U OXIDE U-233 ENRICHMENT:0.20

FIGURE 124. FWR SLAB THICKNESS U OXIDE U-233 ENRICHMENT=0.20

FIGURE 125. BARE SLAB THICKNESS U OXIDE U-233 ENRICHMENT: 0.10

FIGURE 126. FWR SLAB THICKNESS U OXIDE U-233 ENRICHMENT=0.10

FIGURE 127. BARE SLAB THICKNESS U OXIDE U-233 ENRICHMENT:0.05

FIGURE 128. FWR SLAB THICKNESS U OXIDE U-233 ENRICHMENT=0.05

FIGURE 129. K-INFINITY U OXIDE U-233 ENRICHMENT=1.00

FIGURE 130. K-INFINITY U OXIDE U-233 ENRICHMENT=0.20

FIGURE 131. K-INFINITY U OXIDE U-233 ENRICHMENT=0.10

FIGURE 132. K-INFINITY U OXIDE U-233 ENRICHMENT=0.05

FIGURE 134. MATERIAL BUCKLING U OXIDE U-233 ENRICHMENT:0.20

FIGURE 135. MATERIAL BUCKLING U OXIDE U-233 ENRICHMENT=0.10

FIGURE 136. MATERIAL BUCKLING U OXIDE U-233 ENRICHMENT=0.05

FIGURE 137. BARE SPHERE RADIUS PU OXIDE 100% PU-239

FIGURE 138. FWA SPHERE RADIUS PU OXIDE 100% PU-239

FIGURE 139. BARE CYLINDER RADIUS PU OXIDE 100% PU-239

FIGURE 140. FWR CYLINDER RADIUS PU OXIDE 100% PU-239

FIGURE 141. BARE SLAB THICKNESS PU OXIDE 100% PU-239

FIGURE 142. FWA SLAB THICKNESS PU OXIDE 100% PU-239

FIGURE 143. K-INFINITY PU OXIDE 100% PU-239

FIGURE 144. MATERIAL BUCKLING PU OXIDE 100% PU-239

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