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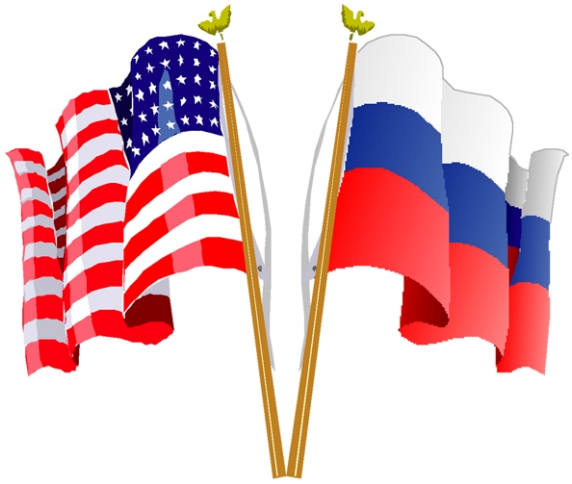
Neutronics Benchmarks for the Utilization of Mixed-Oxide Fuel: Joint U.S./Russian Progress Report for Fiscal Year 1997

Volume 4, Part 7—Homogeneous Mixtures of Polystyrene-Moderated Plutonium and Uranium Oxides



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HOMOGENEOUS MIXTURES OF POLYSTYRENE-MODERATED PLUTONIUM AND URANIUM OXIDES

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HOMOGENEOUS MIXTURES OF POLYSTYRENE-MODERATED PLUTONIUM AND URANIUM OXIDES[1]

1. Detailed Description

1.1 Overview of Experiment

In the 1970s at the Battelle Pacific Northwest Laboratory (PNL), a series of critical experiments using a remotely operated Split-Table Machine was performed with homogeneous mixtures of (Pu-U)O_2-polystyrene fuels in the form of square compacts having different heights. With respect to Pu enrichments and moderation [H/(Pu+U) atomic] ratios (MR), four-different homogeneous (Pu-U)O_2-polystyrene mixtures were considered: Mixture 1) 7.6 wt% Pu with 19.5 MR, Mixture 2) 7.89 wt% Pu with 51.8 MR, Mixture 3) 14.62 wt% Pu with 30.6 MR, and Mixture 4) 30.0 wt% Pu with 47.4 MR. The Pu^{240} isotopic contents in Pu were 23 wt% for Mixture 1 and 8 wt% for Mixtures 2-4. In all mixtures, the uranium was depleted to about 0.151 wt% U^{235}. The critical geometric dimensions for both fully Plexiglas^{TM} reflected and unreflected configurations were reported for Mixture 3 and 4 experiments. The dimensions for Mixture 1 and 2 experiments were given for fully-reflected assemblies.

This evaluation contains a total of 39 critical (fully reflected and bare) experimental configurations as well as 3 slab geometry critical dimensions.

1.2 Description of Experimental Configuration

A large glove box within a heavily shielded cell located at the PNL Critical Mass Laboratory (CML) was used for the experiments. The floor surface of CML was 1067 cm square, with 152-cm-thick side walls (except for a 91-cm-thick south wall) and a 61-cm-thick roof and floor [Smolen 1994]. A remotely operated Split-Table Machine (STM) shown in Fig. 1 was used for performing the experiments. Each half of the split table, one stationary and the other movable, had a steel frame. One of the table halves formed a surface of 76-cm wide and 61-cm long, and the other formed a surface of 76-cm wide and 46-cm long. The table surface was 51-cm above the floor level.

A 30-cm thick aluminum honeycomb material (effective Al density of 0.037 g/cm^3) covered both table halves [Richey 1965]. For Mixture 1 [Lloyd 1974], the geometric dimensions of compacts, including the uncertainties in the measurements for fuel, clad and stacking void are given in Table 1. For Mixtures 2–4 [Bierman 1973], the length and width of solid fuel compacts were in the range of 5.08–5.09 cm, and the height having dimensions of 5.08, 5.09, 3.81 and 1.27 cm was variable. Each of the fuel compacts was clad with a 6-mil-thick #471 tape manufactured by Minnesota Mining and Manufacturing (3M) Company.

In Table 2, the experimentally corrected critical dimensions of the fuel assemblies are given for Mixture 1. For this mixture, Table 3 contains the number of compacts used in the experiments with the specified length, width, and height. The heights are given in number of compacts plus a compact of smaller size. Smaller size compacts should be treated as full layers of thinner fuel compacts having a thickness equal to the fractional layer "times" the thickness indicated for the compacts. The measured (corrected) critical

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dimensions and masses of fuel for Mixtures 2–4 experiments are given in Tables 4–6. In all experiments, the Plexiglas reflector had a thickness of 15 cm.

Table 1. Fuel compact dimensions for Mixture 1

Compacts	Length (cm)	Width (cm)	Height (cm)
Unclad	5.090± 0.005	5.090± 0.006	5.088± 0.018 1.279± 0.040
Clad	5.120± 0.005	5.120± 0.005	5.148± 0.018 1.339± 0.040
Stacked (clad + void)	5.153± 0.010	5.153± 0.010	5.172± 0.025 1.422± 0.043

Table 2. Critical dimensions for Mixture 1 [843 g (Pu+U)/liter]

	Critical dimensions (cm)		
Case	Length	Width	Height[a]
1	61.08± 0.06	66.17± 0.07	30.49± 0.15
2	61.08± 0.06	61.08± 0.06	31.80± 0.16
3	66.17± 0.07	66.17± 0.07	29.24± 0.16
4	61.08± 0.06	50.90± 0.05	35.61± 0.18
5	61.08± 0.06	55.99± 0.06	33.24± 0.16
6	50.90± 0.05	50.90± 0.05	40.76± 0.20
7[b]	47.27± 0.20	47.27± 0.20	47.27± 0.20

[a] Experimentally determined corrections (12.7% reduction in critical height) accounting for the reactivity of the cladding material and the stacking voids.
[b] Cube dimensions obtained by interpolation between critical assemblies.

Table 3. Critical dimensions in terms of number of compacts for Mixture 1

	Fuel length	Fuel width	Fuel height	
Case	5.09 cm	5.09 cm	5.088 cm	1.279 cm[a]
1	12	13	6	3.434± 0.012
2	12	12	7	0.632± 0.004
3	13	13	6	2.317± 0.020
4	12	10	8	0.068± 0.008
5	12	11	7	1.920± 0.016
6	10	10	9	0.703± 0.028

[a] Fractional layers should be treated as full layers having the fractional indicated thickness.

Table 4. Critical dimensions and masses for Mixture 2 [360 g (Pu+U)/liter]

	Critical dimensions (cm)			Critical mass (kg)	
Case	Length	Width	Height[a]	Pu	U
1	40.72± 0.04	45.72± 0.09	32.89± 0.12	1.74± 0.01	20.29± 0.22
2	50.90± 0.05	50.80± 0.10	26.40± 0.10	1.94± 0.02	22.63± 0.25
3	61.08± 0.06	60.96± 0.12	22.66± 0.08	2.39± 0.02	27.88± 0.31
4	61.08± 0.06	66.04± 0.13	22.09± 0.18	2.53± 0.03	29.53± 0.39
5	61.08± 0.06	55.88± 0.11	23.22± 0.08	2.25± 0.02	26.26± 0.28
6	61.08± 0.06	50.80± 0.10	24.37± 0.09	2.15± 0.02	25.06± 0.28
7	40.72± 0.05	40.64± 0.08	36.42± 0.13	1.71± 0.01	19.97± 0.22
8[b]	39.12± 0.28	39.12± 0.28	39.12± 0.28	1.70± 0.01	19.84± 0.32
9[c]	Infinite	Infinite	14.83± 0.60	—	—

[a]Experimentally determined corrections (~15% reduction in critical height) accounting for the reactivity of the cladding material and the stacking voids.
[b]Cube dimensions obtained by interpolation between critical assemblies.
[c]Infinite slab thickness obtained by extrapolation of data.

Table 5. Critical dimensions and masses for Mixture 3 [580 g (Pu+U)/liter]

	Critical dimensions (cm)			Critical mass (kg)	
Case	Length	Width	Height[a]	Pu	U
1	30.54± 0.03	40.72± 0.04	29.81± 0.15	3.14± 0.04	18.35± 0.35
2	40.72± 0.04	40.72± 0.04	23.84± 0.10	3.35± 0.04	19.57± 0.37
3	45.81± 0.04	50.90± 0.05	19.82± 0.11	3.92± 0.05	22.89± 0.44
4	50.90± 0.04	50.90± 0.05	18.92± 0.09	4.16± 0.05	24.28± 0.46
5	61.08± 0.06	50.90± 0.05	17.72± 0.09	4.67± 0.06	27.28± 0.52
6	61.08± 0.06	61.08± 0.06	16.53± 0.09	5.26± 0.06	30.73± 0.59
7[b]	33.30± 0.17	33.30± 0.17	33.30± 0.17	3.13± 0.05	18.28± 0.40
8[c]	Infinite	Infinite	11.56± 0.09	—	—
9[d]	40.72± 0.04	40.76± 0.17	52.39± 0.07	7.37± 0.05	43.06± 0.82
10[d]	40.72± 0.04	45.86± 0.19	45.10± 0.06	7.14± 0.08	41.70± 0.79
11[d]	50.90± 0.05	45.86± 0.19	36.99± 0.05	7.32± 0.08	42.75± 0.81
12[d]	43.78± 0.07	43.78± 0.07	43.78± 0.07	7.12± 0.08	41.55± 0.80

[a]Experimentally determined corrections (~4% reduction in critical height) accounting for the reactivity of the cladding material and the stacking voids.
[b]Cube dimensions obtained by interpolation between critical assemblies.
[c]Infinite slab thickness obtained by extrapolation of data.
[d]Bare (unreflected) critical dimensions.

Table 6. Critical dimensions and masses for Mixture 4 [373 g (Pu+U)/liter]

	Critical dimensions (cm)			Critical mass (kg)	
Case	Length	Width	Height[a]	Pu	U
1	30.54± 0.03	30.54± 0.03	30.89± 0.02	3.23± 0.05	7.53± 0.12
2	35.63± 0.04	35.63± 0.04	23.95± 0.10	3.40± 0.05	7.94± 012
3	40.72± 0.04	40.72± 0.04	20.22± 0.05	3.75± 0.05	8.76± 0.13
4	50.90± 0.05	45.81± 0.05	17.14± 0.07	4.48± 0.06	10.44± 0.16
5	61.08± 0.06	50.90± 0.05	15.53± 0.11	5.44± 0.08	12.69± 0.20
6	61.08± 0.06	55.99± 0.06	15.16± 0.02	5.80± 0.09	13.51± 0.21
7	66.17± 0.06	61.08± 0.06	14.43± 0.10	6.53± 009	15.24± 0.22
8	50.90± 0.02	50.90± 0.05	16.49± 0.04	4.78± 0.08	11.14± 0.18
9[b]	30.60± 0.02	30.60± 0.02	30.60± 0.02	3.21± 0.05	7.49± 0.12
10[c]	Infinite	Infinite	10.80± 0.11	—	—
11[d]	45.81± 0.05	40.72± 0.04	37.98± 0.06	7.93± 0.12	18.51± 0.78
12[d]	40.72± 0.04	40.72± 0.04	42.24± 0.03	7.84± 0.11	18.30± 0.77
13[d]	45.81± 005	50.90± 0.05	32.49± 0.02	7.84± 0.12	19.80± 0.84
14[d]	41.20± 0.05	41.20± 0.05	41.20± 0.05	7.83± 0.11	18.28± 0.77

[a] Experimentally determined corrections (~2% reduction in critical height) accounting for the reactivity of the cladding material and the stacking voids.
[b] Cube dimensions obtained by interpolation between critical assemblies.
[c] Infinite slab thickness obtained by extrapolation of data.
[d] Bare (unreflected) critical dimensions.

1.3 Description of Material Data

The number densities of nuclides contained in fuel (MOX+polystyrene), clad (#471 3M tape) and reflector (methacrylate plastic or Plexiglas) are given in Table 7 for Mixtures 1–4. The ^{239}Pu content in Pu was 68% for Mixture 1, and 91% for Mixtures 2–4.

Table 7. Composition of fuel, clad and reflector

	Atomic density (E+24 atom/cm^3)[a]					
Nuclide	Mixture 1 [843 g (Pu+U)/liter]	Mixture 2 (408 g Oxide/liter)	Mixture 3 (660 g Oxide/liter)	Mixture 4 (426 g Oxide/liter)	Clad (3M tape)	Reflector (plexiglas)
Am^{241}	3.766E-07	1.741E-07	4.036E-07	3.511E-07		
Pu^{238}	9.535E-07	0.0	0.0	0.0		
Pu^{239}	1.092E-04	6.528E-05	1.954E-04	2.578E-04		
Pu^{240}	3.688E-05	5.941E-06	1.702E-05	2.257E-05		
Pu^{241}	8.945E-06	3.481E-07	1.211E-06	1.756E-06		
Pu^{242}	4.689E-06	0.0	0.0	0.0		
U^{235}	2.897E-06	1.285E-06	1.904E-06	1.008E-06		
U^{238}	1.968E-03	8.376E-04	1.252E-03	6.604E-04		
O	4.348E-03	1.830E-03	3.023E-03	1.974E-03		1.428E-02
H	4.155E-02	4.719E-02	4.489E-02	4.468E-02	4.489E-02	5.712E-02
C	4.287E-02	4.540E-02	4.412E-02	4.537E-02	3.110E-02	3.570E-02
Cl	—	—	—	—	7.24E-03	—

[a] Read E+24 as 10^{24}.

In Table 7, the number density for U^{235} of Mixture 4 is an order of magnitude lower than what was given in [Bierman 1973]. The reason for this is explained in Section 2 (Evaluation of Experimental Data). For Mixture 1, the cladding material per compact was 3.175 g and the cladding density was 1.12 g/cm^3. Uranium density per compact was 0.779± 0.006 g/cm^3, the plutonium density was 0.064± 0.001 g/cm^3 and the total fuel density was 1.884± 0.015 g/cm^3. For Mixtures 2-4, the cladding properties were not given because of the reported critical dimensions that account for the reactivity effect of the cladding and stacking void. The measured critical masses of plutonium and uranium are given in Tables 4–6. Particle size distributions which indicate the homogeneity are presented in Table 8 for Mixtures 1–4.

Table 8. Particle size distributions

	Particle diameter (μm)			
		Mixtures 2–4		
Distribution (%)	Mixture 1 PuO_2-UO_2	PuO_2	UO_2	Polystyrene
95	—	<20	<40	<225
90	<20	—	—	—
50	<5	<5	<9	<150
10	<0.8	—	—	—
5	—	<0.5	<3	<50

1.4 Supplemental Experimental Measurements

Inverse multiplication measurements to determine the critical dimensions were performed for both unreflected and fully Plexiglas-reflected configurations for Mixtures 3 and 4. Measurements for Mixtures 1 and 2 were only considered for fully reflected assemblies because of the large volume requirement for unreflected assemblies.

For Mixtures 2–4, critical dimensions in length, width, and experimentally corrected heights were reported. Also, experimentally corrected critical masses of solid fuel assemblies were presented. The corrections on the critical dimensions and masses were made to account for the reactivity effect of cladding and the presence of voids in the assembly of stacked compacts. These corrections were obtained by observing the change in critical mass due to varying the number of layers of cladding on the fuel compacts. For Mixture 1, the experimental assemblies were provided both in terms of fuel compacts and corrected critical dimensions of fuel only. For bare assemblies, an additional correction was also made to account for the reactivity effect of the structural material. The correction was an increase of 0.05% in the critical mass of each bare assembly.

Buckling measurements were performed for six bare critical assemblies. The extrapolation distances of 2.56 cm for Mixture 4 and 2.49 cm for Mixture 3 were calculated. The critical buckling values together with critical dimensions are shown in Table 9 for Mixtures 3 and 4.

Table 9. Critical buckling for Mixtures 3 and 4

Mixture 4 [373 g/(Pu+U)/liter]			
Critical dimensions (cm), $\lambda = 2.56 \pm 0.08$ cm*			B_g^2 (m^{-2})
Width	Length	Height	
45.81± 0.05	40.72± 0.04	37.98± 0.06	138.16± 1.34
40.72± 0.04	40.72± 0.04	42.24± 0.03	137.94± 1.28
45.81± 0.05	50.90± 0.04	32.49± 0.03	139.27± 1.54
	Average		138.46± 1.39
Mixture 3 [580 g/(Pu+U)/liter]			
Critical dimensions (cm), $\lambda = 2.49 \pm 0.07$ cm*			B_g^2 (m^{-2})
Width	Length	Height	
40.76± 0.17	40.72± 0.04	52.39± 0.07	124.42± 1.47
45.86± 0.19	40.72± 0.04	45.10± 0.06	124.79± 1.36
45.86± 0.19	50.90± 0.05	36.99± 0.05	125.82± 1.43
	Average		125.01± 1.43

*Extrapolation length.

2 Evaluation of Experimental Data

Material densities for fuel compacts (Mixtures 1–4) were documented in detail. However, the MR for Mixture 4 is not 47.4. Also, the U^{235} enrichment in U does not correspond to the reported 0.151 wt%. The number density for U^{235} given in [Bierman 1973] is an order of magnitude high. The corrected number density of $1.008 \leftrightarrow 10^{-6}$ is used in Table 7, rather than $1.008 \leftrightarrow 10^{-5}$. With this correction, the MR becomes 47.35 which is in agreement with the reported 47.4. Also, the enrichment of U^{235} becomes about 0.151 wt%. The rest of the material densities were correctly presented.

The geometric units of compacts were given in inches in [Bierman 1973], but the SI units were used in presenting the critical dimensions. In this evaluation, we use the SI units to be consistent with the critical dimensions.

Although the geometric (fuel-clad-void) compact data for Mixture 1 is well presented, this is not the case for Mixtures 2–4. Cladding compositions for Mixtures 2–4 compacts were not given although it is defined by #471 3M tape. The #471 3M tape composition [Bierman 1996] is the same as the Mixture 1 compacts. The stacking void per compact was not provided for these mixture experiments. Instead, the critical sizes and masses were given for solid assemblies of fuel only. Experimentally determined corrections were applied in each case to account for the reactivity effect of the cladding material and the presence of voids in the assembly of the stacked blocks.

The experimentally corrected dimensions of solid fuels were determined graphically. In these graphs, the critical height was plotted as a function of layers of cladding material. Using the data points in these plots, the critical height was extrapolated to zero cladding to determine the critical height of solid fuels only. These plots indicate that for Mixture 4 experiments, there were 3 data points (1, 2, and 3 layers of clad). However, for Mixtures 1–3, there were 2 data points in the reported figures (1 and 2 layers of clad). The fitted curve for Mixture 4 appears to be linear.

For bare assemblies, it is reported that there was only 0.05% increase in critical masses due to structural supports, but the descriptions of these were not given. Also, the exact location of the split table machine (STM) in the heavily shielded cell was not described. In addition, the critical dimensions were determined for slab by extrapolation of data and cube by interpolation between critical assemblies.

The critical dimensions reported in [Bierman 1973] for (Pu-U)O_2-polystyrene and (Pu^{239}-U)O_2-water mixtures in spherical, cylindrical, and slab geometries are not included in this evaluation. These dimensions were calculated by extrapolating one, two or three experimental data points.

For Mixtures 2–4, the experimentally corrected dimensions of solid fuels were given. However, for Mixture 1, the critical dimensions were provided both in terms of number of compacts and the experimentally corrected dimensions of solid assemblies of fuel only. Thus, for Mixture 1:

(a) the corrected dimensions in Table 2 can be calculated from those in Table 3, and
(b) if the k_{eff} of the experiments both in terms of number of compacts and the experimentally corrected dimensions are within the statistical uncertainty, then the corrected dimensions can directly be used for simplifying the computational modeling.

To check "a", the corrected dimensions in Table 2 are calculated using Table 3 dimensions. (The length and the width dimensions of compacts agree each other as seen in Tables 2 and 3.) The corrected critical height given in Table 2 is a 12.7% reduction (accounting for the reactivity effect of the clad and the stacking voids) of the critical height given in Table 3. To verify this, for example, the total fuel height of Case 1 in Table 3 is $6\leftrightarrow5.088+3\leftrightarrow1.279 + (5.12/5.088)^2\leftrightarrow1.279\leftrightarrow0.434 = 34.927$ cm. Considering a 12.7% experimental reduction, the critical height is $(1.0-0.127)\leftrightarrow34.927 = 30.491$ cm, which agrees with the Case 1 dimension of 30.49 cm given in Table 2. Also, all the other dimensions in Tables 2 and 3 agree each other in this manner.

To verify "b", MCNP calculations were performed. Polyethylene (poly.01t) thermal cross sections both in Fuel and Plexiglas was used. The calculated k_{eff} are 0.98210 ± 0.00154 for the Case 1 of Table 2 and 0.98264 ± 0.00094 for the Case 1 of Table 3. Also, the calculated k_{eff} are 0.98635 ± 0.00125 for the Case 2 of Table 2, and 0.98634 ± 0.00139 for the Case 2 of Table 3. Thus, k_{effs} agree each other within the statistical uncertainty. This suggests that the experimentally corrected critical dimensions can directly be used in modeling the experiments. The input listings for these cases are given in Section 6. (Sample MCNP Input Listings.)

3 Benchmark Specifications

3.1 Description of Model

In the benchmark models, experimentally corrected solid fuel critical dimensions accounting for the reactivity effect of the cladding and the stacking voids are considered in calculating k_{effs}. Plexiglas surrounding the assemblies is used as reflector.

3.2 Dimensions

The corrected critical dimensions given in Tables 2, 4, 5, and 6 are used for Mixtures 1-4 experiments, respectively. In all assemblies, a 15-cm-thick Plexiglas reflector is used.

3.3 Material Data

The number densities of Mixtures 1–4 are given in Table 7.

3.4 Temperature Data

Because temperature data was not reported, a room temperature of 300K is assumed.

4 Results of Sample Calculations

The sample k_{eff} calculations were performed using the MCNP4A continuous cross section library based on the ENDF/B-VI data. Polyethylene thermal cross sections (poly.01t card) are used for both fuel mixtures and Plexiglas. In the calculations, 4000 particle histories, 100 active and 25 skipped generations were used. However, additional particle histories were made if k_{eff} had not attained a constant level after 400000 active particle histories. In Table 10, the calculated k_{eff} are listed for the critical dimensions given in Tables 2, and 4–6 for Mixtures 1–4, respectively.

Table 10. MCNP k_{eff} for cases in Tables 2, 4, 5, and 6

Case	Table 2	Table 4	Table 5	Table 6
1	0.98210± 0.00154	1.02956± 0.00140	1.01503± 0.00155	1.00690± 0.00155
2	0.98635± 0.00125	1.02315± 0.00136	1.01885± 0.00133	1.00819± 0.00134
3	0.98532± 0.00123	1.02144± 0.00124	1.01331± 0.00135	1.00699± 0.00145
4	0.98645± 0.00142	1.02099± 0.00212	1.01105± 0.00139	1.00310± 0.00148
5	0.98858± 0.00134	1.01867± 0.00122	1.01567± 0.00159	1.00470± 0.00148
6	0.99110± 0.00130	1.02351± 0.00137	1.01549± 0.00138	1.00243± 0.00154
7	0.99372± 0.00062	1.02940± 0.00125	1.02286± 0.00143	1.00846± 0.00131
8		1.02813± 0.00130	1.00208± 0.00126	1.00565± 0.00141
9		0.99725± 0.00116	1.01234± 0.00151	1.00539± 0.00137
10			1.01033± 0.00158	1.01431± 0.00122
11			1.00995± 0.00151	0.99572± 0.00177
12			1.01396± 0.00159	0.99302± 0.00183
13				0.99148± 0.00152
14				0.99545± 0.00155

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2.10.6 Sample MCNP Input Listings

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CASE 1 of TABLE 2: 7.6 wt% Pu; H:(U+Pu)=19.5 Moderation Ratio
C Cell Cards -Full Layer Compacts
1     1 0.0908999411 1 -2 3 -4 5 -6  imp:n=1 $ Fuel
2     2 0.1071   7 -8 9 -10 11 -12
                        #1       imp:n=1 $  Plexiglas
3     0     -7:8:-9:10:-11:12    imp:n=0 $ outside of the assembly
C Surface Cards
C Full Size Fuel Compact Dimensions
1     pz -15.245
2     pz  15.245 $ Fuel Height
3     px -30.54
4     px  30.54  $ Fuel Length
5     py -33.085
6     py  33.085 $ Fuel Width
C Plexiglas Reflector (15 cm-thick)
7     pz -30.245
8     pz  30.245
9     px -45.54
10   px  45.54
11   py -48.095
12   py  48.095

kcode 4000 1 25 125
ksrc  0. 0. 0.
print
m1 95241.60c 3.766e-7 94238.60c 9.535e-7 94239.60c 1.092e-4
      94240.60c 3.688e-5 94241.60c 8.945e-6 94242.60c 4.689e-6
      92235.60c 2.897e-6 92238.60c 1.968e-3  8016.60c 4.348e-3
       1001.60c 4.155e-2  6000.60c 4.287e-2  $ Fuel Composition
m2  1001.60c 5.712e-2  6000.60c 3.570e-2  8016.60c 1.428e-2
                                                    $ Plexiglas Reflector
Composition
m1t   poly.01t
m2t   poly.01t
```

```
CASE 1 of Table 3: 7.6 wt% Pu; H:(U+Pu)=19.5 Moderation Ratio
C Cell Cards -Full Compacts (5.09 x 5.09 x 5.088)
1     1 0.0908999411 1 -2 3 -4 5 -6  u=1 imp:n=1
                      $ (Pu+U)O_2-Polystyrene Mixture
2     2 0.08323   7 -8 9 -10 11 -12
            #1                    u=1 imp:n=1 $  3M-Clad
3     0      #1 #2            u=1 imp:n=1 $  Stacking Void
C  12x13x6 Fuel Blocks
4     0    13 -14 15 -16 17 -18      imp:n=1 lat=1 u=2
          fill=-5:0 -11:0 -12:0  1 935R  $12x13x6 Fuel Blocks
5     0  19 -20 21 -22 23 -24 fill=2 imp:n=1
C -Smaller Compacts (5.09 x 5.09 x 1.279)
6     1 0.0908999411 27 -28 3 -4 5 -6  u=3 imp:n=1
                      $ (Pu+U)O_2-Polystyrene Mixture
7     2 0.08323   26 -29 9 -10 11 -12
            #6               u=3 imp:n=1 $  3M-Clad
8     0      #6 #7            u=3 imp:n=1 $  Stacking Void
C 12x13x3 Fuel Blocks
9     0    20 -30 15 -16 17 -18      imp:n=1 lat=1 u=4
           fill=-2:0 -11:0 -12:0  3 467R  $12x13x3 Fuel Blocks
10    0  31 -32 21 -22 23 -24 fill=4 imp:n=1
C  Fractional Layer
11     1 0.0908999411  32 -34 15 -22 17 -24 imp:n=1
                      $ (Pu+U)O2-Polystyrene Mixture
12    3 0.1071 #5 #10 #11  38 -39 40 -41 42 -43
                      imp:n=1 $Plexiglas Reflector
13    0 -38:39:-40:41:-42:43   imp:n=0 $ Outside of Critical Assembly

C Surface Cards
C Full Size Fuel Compacts
1     pz  0.042
2     pz  5.13     $ Fuel Height
3     px  0.0315
4     px  5.1215   $ Fuel Length
5     py  0.0315
6     py  5.1215   $ Fuel Width
C Clad Compacts
7     pz  0.012
8     pz  5.16
9     px  0.0165
10   px  5.1365
11   py  0.0165
12   py  5.1365
C Stacked Compacts (Fuel+Clad+Void)
13   pz  0.0
14   pz  5.172
15   px  0.0
16   px  5.153
17   py  0.0
18   py  5.153
C Window Surfaces
19   pz  0.000001
20   pz 31.031999
21   px  0.000001
22   px 61.835999
23   py  0.000001
24   py 66.988999
```

```
C
C Smaller Fuel Compact having height of 1.279 cm
C
26   pz 31.0735
27   pz 31.1035
28   pz 32.3825
29   pz 32.4125
30   pz 32.454
C Window Surfaces
31   pz  31.032
32   pz  35.297999
C Fractional layer on top
34   pz 35.853086
C Reflector
38   pz -15.
39   pz  50.853086
40   px -15.
41   px  76.836
42   py -15.
43   py  81.989

kcode 4000 1 25 225
ksrc  31. 33.5 18.
c print
m1 95241.60c 3.766e-7 94238.60c 9.535e-7 94239.60c 1.092e-4
      94240.60c 3.688e-5 94241.60c 8.945e-6 94242.60c 4.689e-6
      92235.60c 2.897e-6 92238.60c 1.968e-3  8016.60c 4.348e-3
        1001.60c 4.155e-2  6000.60c 4.287e-2  $ Fuel Composition
m2   1001.60c 4.489e-2  6000.60c 3.110e-2 17000.60c 7.240e-3
      $ Clad Composition
m3   1001.60c 5.712e-2  6000.60c 3.570e-2  8016.60c 1.428e-2
      $ Plexiglas Reflector Composition
m1t   poly.01t
m2t   poly.01t
m3t   poly.01t
```

```
CASE 2 of TABLE 2: 7.6 wt% Pu; H:(U+Pu)=19.5 Moderation Ratio
C Cell Cards -Full Layer Compacts
1     1 0.0908999411 1 -2 3 -4 5 -6  imp:n=1 $ Fuel
2     2 0.1071   7 -8 9 -10 11 -12
            #1                     imp:n=1 $  Plexiglas
3     0     -7:8:-9:10:-11:12       imp:n=0 $ outside of the assembly

C Surface Cards
C Full Size Fuel Compact Dimensions
1     pz -15.9
2     pz  15.9   $ Fuel Height
3     px -30.54
4     px  30.54  $ Fuel Length
5     py -30.54
6     py  30.54 $ Fuel Width
C Plexiglas Reflector (15 cm-thick)
7     pz -30.9
8     pz  30.9
9     px -45.54
10   px  45.54
11   py -45.54
12   py  45.54

kcode 4000 1 25 125
ksrc  0. 0. 0.
print
m1    95241.60c 3.766e-7 94238.60c 9.535e-7 94239.60c 1.092e-4
      94240.60c 3.688e-5 94241.60c 8.945e-6 94242.60c 4.689e-6
      92235.60c 2.897e-6 92238.60c 1.968e-3  8016.60c 4.348e-3
       1001.60c 4.155e-2  6000.60c 4.287e-2  $ Fuel Composition
m2     1001.60c 5.712e-2  6000.60c 3.570e-2  8016.60c 1.428e-2
      $ Plexiglas Reflector Composition
m1t   poly.01t
m2t   poly.01t
```

```
CASE 2 of TABLE 3: 7.6 wt% Pu; H:(U+Pu)=19.5 Moderation Ratio
C Cell Cards -Full Layer Compacts
1     1 0.0908999411 1 -2 3 -4 5 -6  u=1 imp:n=1
                                $ (Pu+U)O_2-Polystyrene Mixture
2     2 0.08323   7 -8 9 -10 11 -12
             #1                    u=1 imp:n=1 $  3M-Clad
3     0      #1 #2            u=1 imp:n=1 $  Stacking Void
C 12x12x7 Fuel Blocks
4     0    13 -14 15 -16 17 -18      imp:n=1 lat=1 u=2
             fill=-6:0 -11:0 -11:0  1 1007R  $12x12x7 Fuel Blocks
5     0  19 -20 21 -22 23 -24 fill=2 imp:n=1
C Corrections
6     1 0.0908999411 20 -25 15 -22 17 -24  imp:n=1
                                     $ (Pu+U)O2-Polystyrene
7     3 0.1071 #5 #6  30 -31 32 -33 34 -35 imp:n=1
                  $ Plexiglas Reflector
8    0 -30:31:-32:33:-34:35      imp:n=0 $ Outside of Critical Assembly

C Surface Cards
C Full Size Fuel Compact Dimensions
1     pz  0.042
2     pz  5.13     $ Fuel Height
3     px  0.0315
4     px  5.1215   $ Fuel Length
5     py  0.0315
6     py  5.1215   $ Fuel Width
C Clad Compacts
7     pz  0.012
8     pz  5.16
9     px  0.0165
10   px  5.1365
11   py  0.0165
12   py  5.1365
C Stacked Compacts (Fuel+Clad+Void)
13   pz  0.0
14   pz  5.172
15   px  0.0
16   px  5.153
17   py  0.0
18   py  5.153
C Window Surfaces
19   pz  0.000001
20   pz 36.203999
21   px  0.000001
22   px 61.835999
23   py  0.000001
24   py 61.835999
C  Corrections
25   pz  37.012328
C Reflector
30   pz -15.0
31   pz  52.012328
32   px -15.0
33   px  76.836
34   py -15.0
35   py  76.836
```

```
kcode 4000 1 25 225
ksrc  31. 31. 18.5
c print
m1  95241.60c 3.766e-7 94238.60c 9.535e-7 94239.60c 1.092e-4
      94240.60c 3.688e-5 94241.60c 8.945e-6 94242.60c 4.689e-6
      92235.60c 2.897e-6 92238.60c 1.968e-3  8016.60c 4.348e-3
       1001.60c 4.155e-2  6000.60c 4.287e-2  $ Fuel Composition
m2  1001.60c 4.489e-2  6000.60c 3.110e-2 17000.60c 7.240e-3
      $ Clad Composition
m3  1001.60c 5.712e-2  6000.60c 3.570e-2  8016.60c 1.428e-2
      $ Plexiglas Reflector Composition
m1t   poly.01t
m2t   poly.01t
m3t   poly.01t
```

Figure 1. Remote split table with faces separated.

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