STACY: 28-CM-THICK SLABS OF 10%-ENRICHED URANYL NITRATE SOLUTIONS, UNREFLECTED

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IDENTIFICATION NUMBER: LEU-SOL-THERM-017 SPECTRA

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1.0 DETAILED DESCRIPTION

1.1 Overview of Experiments

The six critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1997 at the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) at the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI). Employing the 28-cm-thick, 69-cm-wide slab core tank, a 10%-enriched uranyl nitrate solution was used in these unreflected experiments. The uranium concentration was adjusted, in stages, to values in the range of approximately 464 gU/l to 315 gU/l. The free nitric acid concentration ranged from 0.8 mol/l to 1.0 mol/l, approximately.

Other STACY experiments with 10%-enriched uranyl nitrate solution are evaluated in LEU-SOL-THERM-004 (water reflector), LEU-SOL-THERM-007 (unreflected), LEU-SOL-THERM-008 (concrete reflector), LEU-SOL-THERM-009 (borated-concrete reflector), LEU-SOL-THERM-010 (polyethylene reflector), and LEU-SOL-THERM-016 (water reflector).

All six critical configurations are accepted as benchmark experiments.

1.2 Description of Experimental Configuration

The schematic view of the 280T core tank is shown in Figure 1. The dimensions shown in mm units are the design values. The 280T core tank was made of stainless steel, S.S.304L (or SUS304L), and the inner-thickness, inner-width, and inner-height design values were, respectively, 280 mm, 690 mm, and 1500 mm. The side walls, lower plate, and upper plate thicknesses were respectively 25 mm, 20 mm, and 29 mm. The inspected dimensions of the 280T core tank compared with design values are listed in Table 1. The standard deviation (1σ) is due to many measurements during the inspection process. The accuracy means the precision of the measurement instrument.

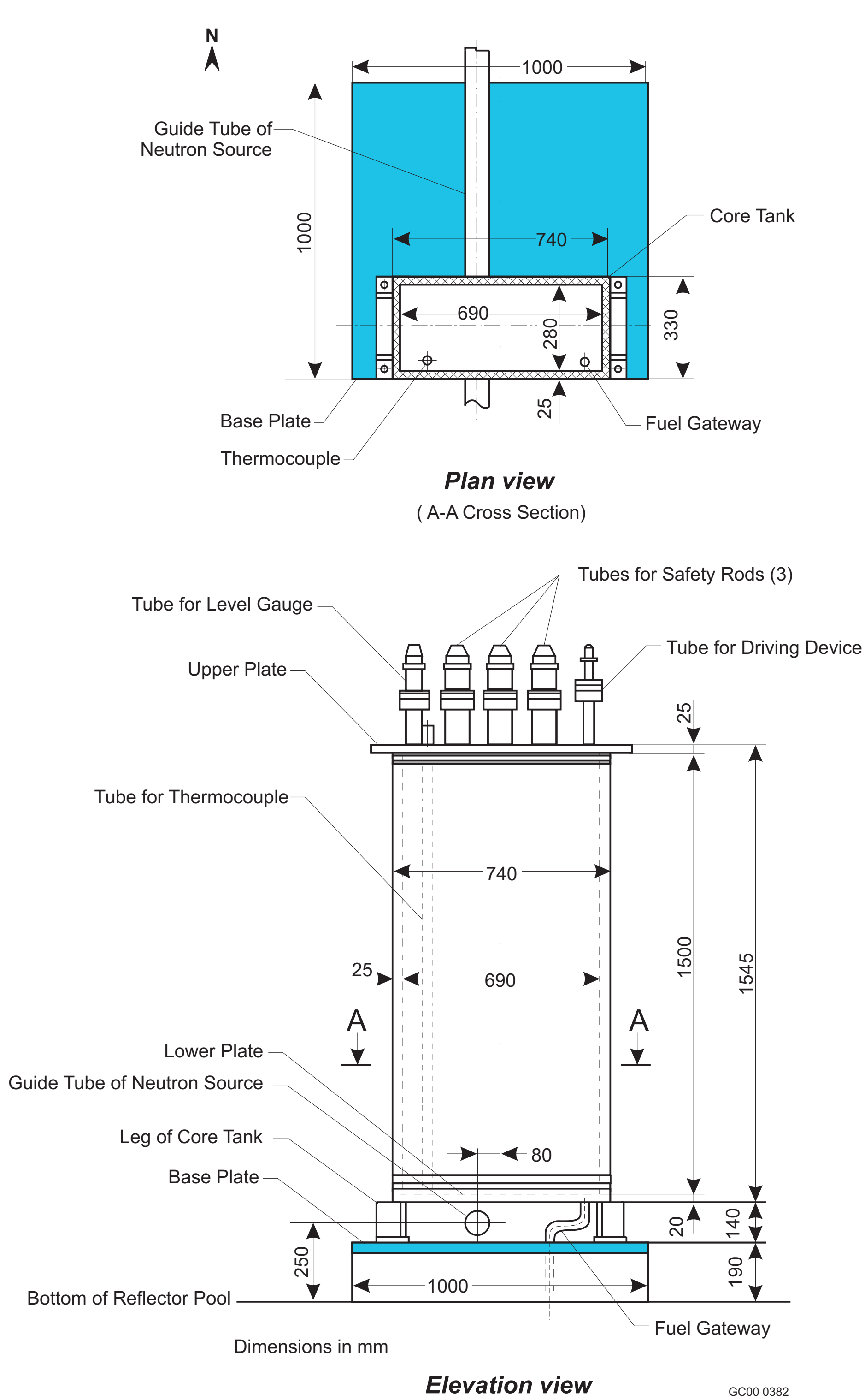


Figure 1. Schematic View of STACY Core Tank.
(design dimensions)

Table 1.a. Dimensions of 280T Core tank (Unit: mm).

Items of Dimension		Inspection Result[(a)]	Design Value
(inner size)	thickness	280.8±0.5	280.0
	width	690.3±0.5	690.0
	height	1497.5±0.6	1500.0
(thickness)	side wall	25.3±0.1	25.0
	lower plate	20.4±0.1	20.0
	upper plate	28.8±0.1	25.0

(a) Uncertainties are from adding quadratically the uncertainties of standard deviation and accuracy.

Table 1.b. Detailed Measurements[(a)] of the Core Tank (Unit: mm).

Measured Item	Number of Measured Points	Average	Standard Deviation	Accuracy	Uncertainty
Thickness of upper plate	4	28.75	0.03	0.10	0.10
Thickness of lower plate	14	20.41	0.02	0.10	0.10
Thickness of side wall	90	25.32	0.03	0.10	0.10
Outer height of tank	4	1546.61	0.24	0.50	0.55
Outer thickness of tank	45	331.39	0.13	0.50	0.52
Outer width of tank	30	740.95	0.11	0.50	0.51

(a) The outer size of the tank is measured by the usual methods, and the others are measured by the supersonic wave-measure method.

The inner thickness of the tank was estimated using the tank outer thickness and double the side-wall thickness. In the same way, the inner width of the tank was estimated using the tank outer width and double the side-wall thickness. The inner height of the tank was estimated using the tank outer height and the upper and lower plate thicknesses.

The core tank was vertically penetrated by a tube (the outer diameter was 17.3 mm, and its wall thickness was 3.2 mm) for thermocouples; this tube extended to the bottom of the core tank. A level gauge and three cylindrical safety rods containing B_4C pellets were held at the upper part of the core tank. In their withdrawn position, the bottom of the safety rods was at 1850 mm above the bottom of the core tank. In their fully inserted position, the bottom of the safety rods was at 50 mm above the bottom of the core tank. The cladding tube of the safety rod, which was made of stainless steel, had an outer diameter of 61.9 mm, an inner diameter of 54.9 mm, a bottom cover thickness of 3.5 mm, and total length of 2277 mm. The diameter of the B_4C pellets was 54.6 mm, and their active length in the cladding tube was 1550 mm.

The fuel solution was fed into the tank from the bottom through the fuel feed/drain line, which had an outer diameter of 27.2 mm and a thickness of 2.9 mm. In the operating condition, the fuel feed/drain line was filled with fuel solution.

In this paper, all measurements are given with an uncertainty corresponding to one standard deviation.

The core tank was supported by four stainless steel legs. These legs were 140 mm high, and stood on the core tank support. The top of the core tank support was a stainless steel base plate, which was 1000 mm wide, 1000 mm long, and 30 mm thick. The base plate was centered under the tank in the east-west direction, but was not centered in the north-south direction, as shown in Figure 1. The base plate was supported by 160-mm-high stainless steel beams located on the bottom of the empty water-reflector pool tank. A guide tube, which had an outer diameter of 89.1 mm and a thickness of 5.5 mm, for inserting an Am-Be neutron source lay horizontally between the lower plate of the core tank and the base plate in the north-south direction. The centerline of this tube was 100 mm below the bottom of the active region in the core tank, and 80 mm west of the centerline of the core tank.

The scale drawing and side views of the large empty tank in which the core tank was set are shown in Figures 2.a and 2.b. The outer dimensions of the pool tank, which was made of stainless steel, were 2020 mm width (east-west direction), 4020 mm length (north-south direction), and 2400 mm height. The thicknesses of the side walls and of the bottom plate were 10 mm and 15 mm, respectively. The bottom of the core tank was 330 mm above the bottom of the pool tank. The shortest distance between the side wall of the core tank and the inner surface of the pool tank is approximately 630 mm.

The pool tank was surrounded by a hood. The hood had a cubic shape and its internal dimensions were 9 x 10 meters horizontally and 9.8 meters high. This hood was installed in the reactor room, which was 12.6 meters wide, 13.1 meters long, and 12.1 meters high (Figure 3). All walls of the reactor room were made of concrete. The thickness of the concrete wall was more than 1 meter.

The STACY facility consisted of the core tank containing fuel solution, a solution transfer system, a fuel treatment system, and a fuel storage system. Reactivity was controlled by adjusting the fuel solution level in the core tank. Initially, a fast-feed pump was used to feed the fuel solution to just below half of the predicted critical height. After that, a slow-feed pump was used to feed the fuel solution to the near-critical state. The maximum excess reactivity and maximum reactivity addition rate were adjusted by limiting the position of the contact-type level gauge and the feed speed of the slow-feed pump. The level gauge consisted of a needle to detect the surface of solution, an electric motor for changing the vertical position of the needle, and an encoder indicating the vertical position. The accuracy of this level gauge was 0.2 mm.

The accuracy of the level gauge (0.2 mm) was determined during the inspection at manufacture, using a highly accurate gauge as reference. The reproductive performance of this gauge, which is confirmed every annual inspection by using a higher-accuracy gauge, is almost within 0.02 mm (1/10 of the accuracy). After every annual inspection or change to the core tank, the adjustment of the zero level is performed by directly detecting the bottom of the core tank and resetting the indication of level gauge.

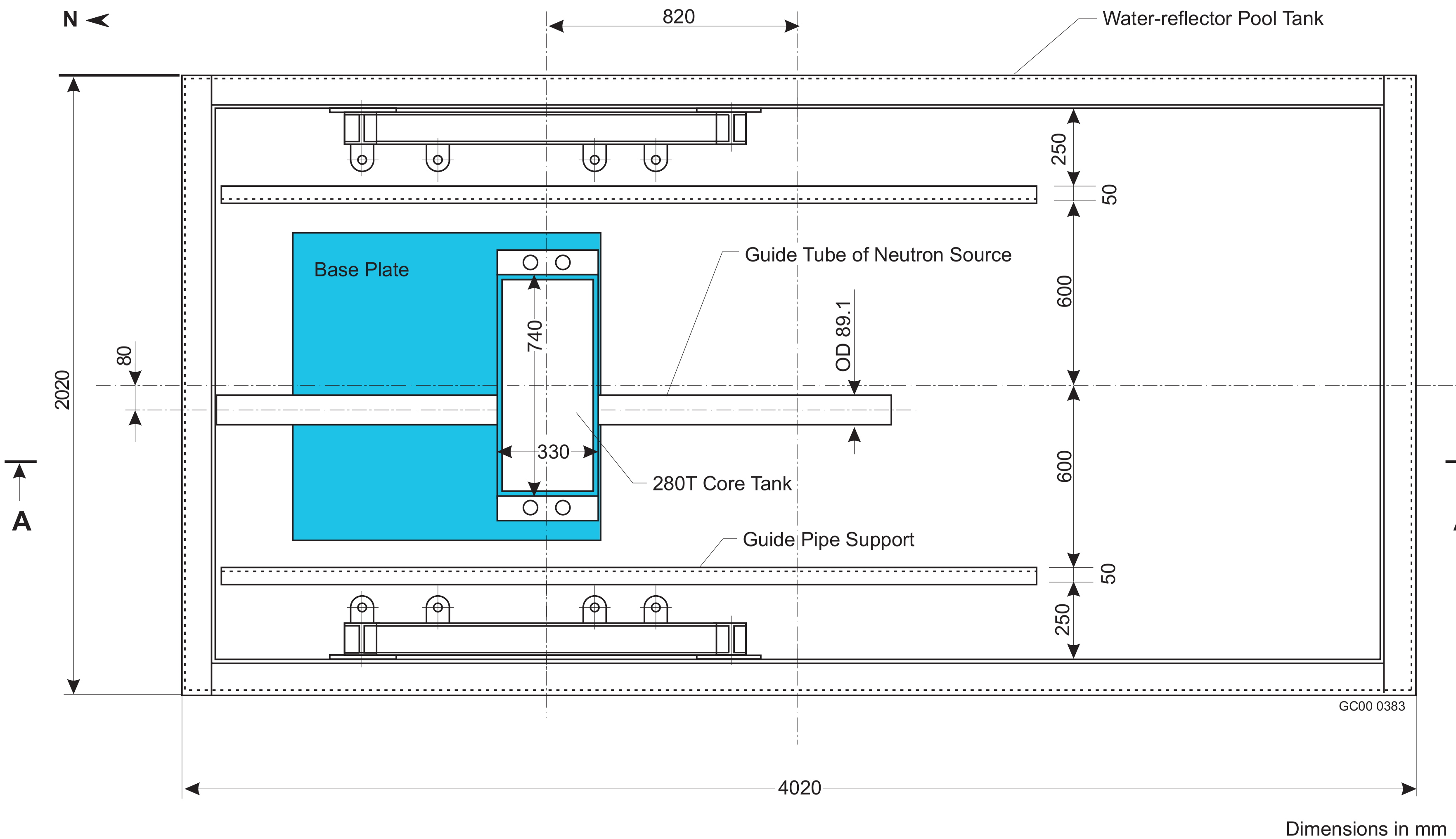


Figure 2.a. View from Above of the Empty Water-Reflector Pool Tank.

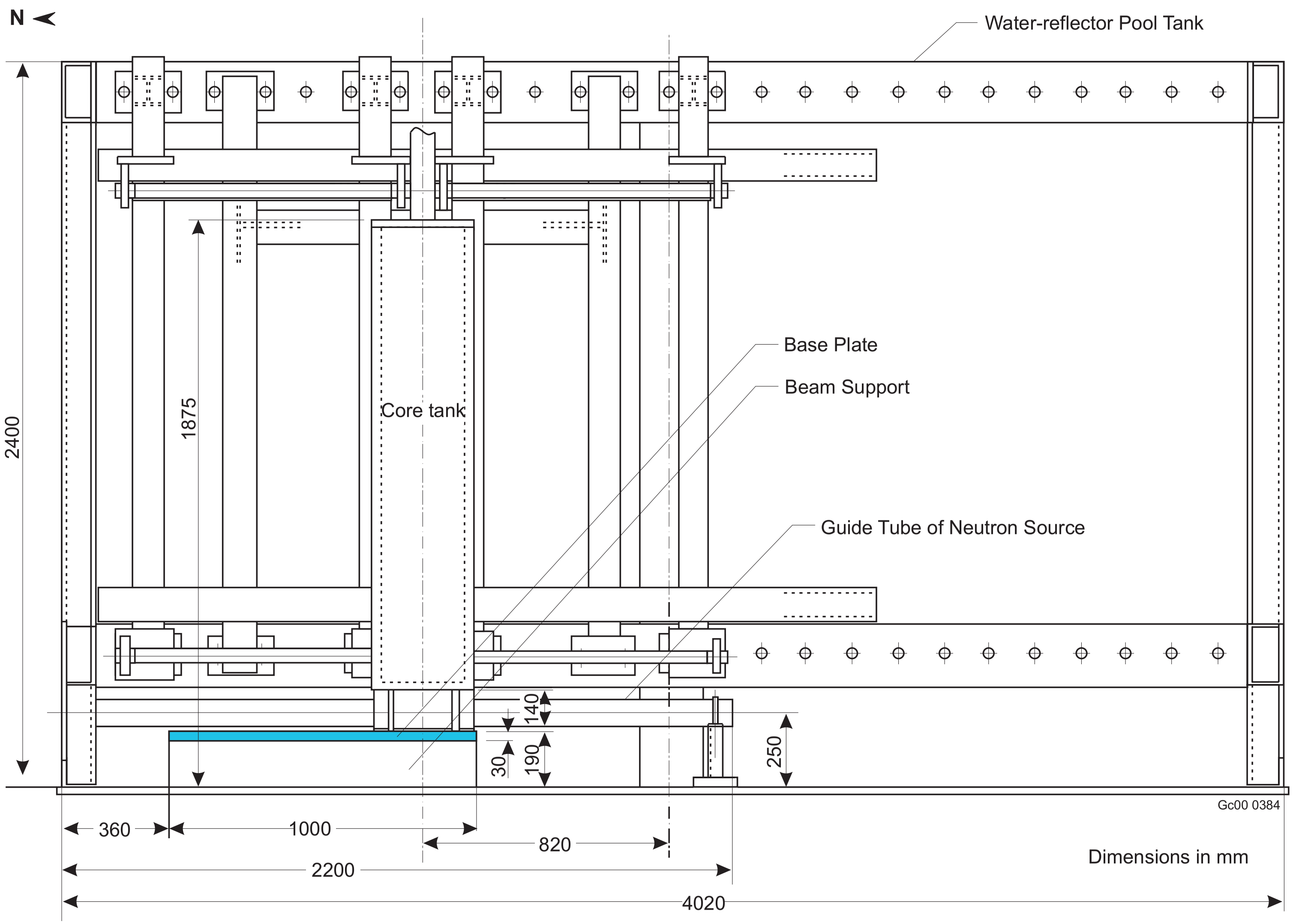


Figure 2.b. Elevation View of the Empty Water-Reflector Pool Tank (A-A Cross Section).

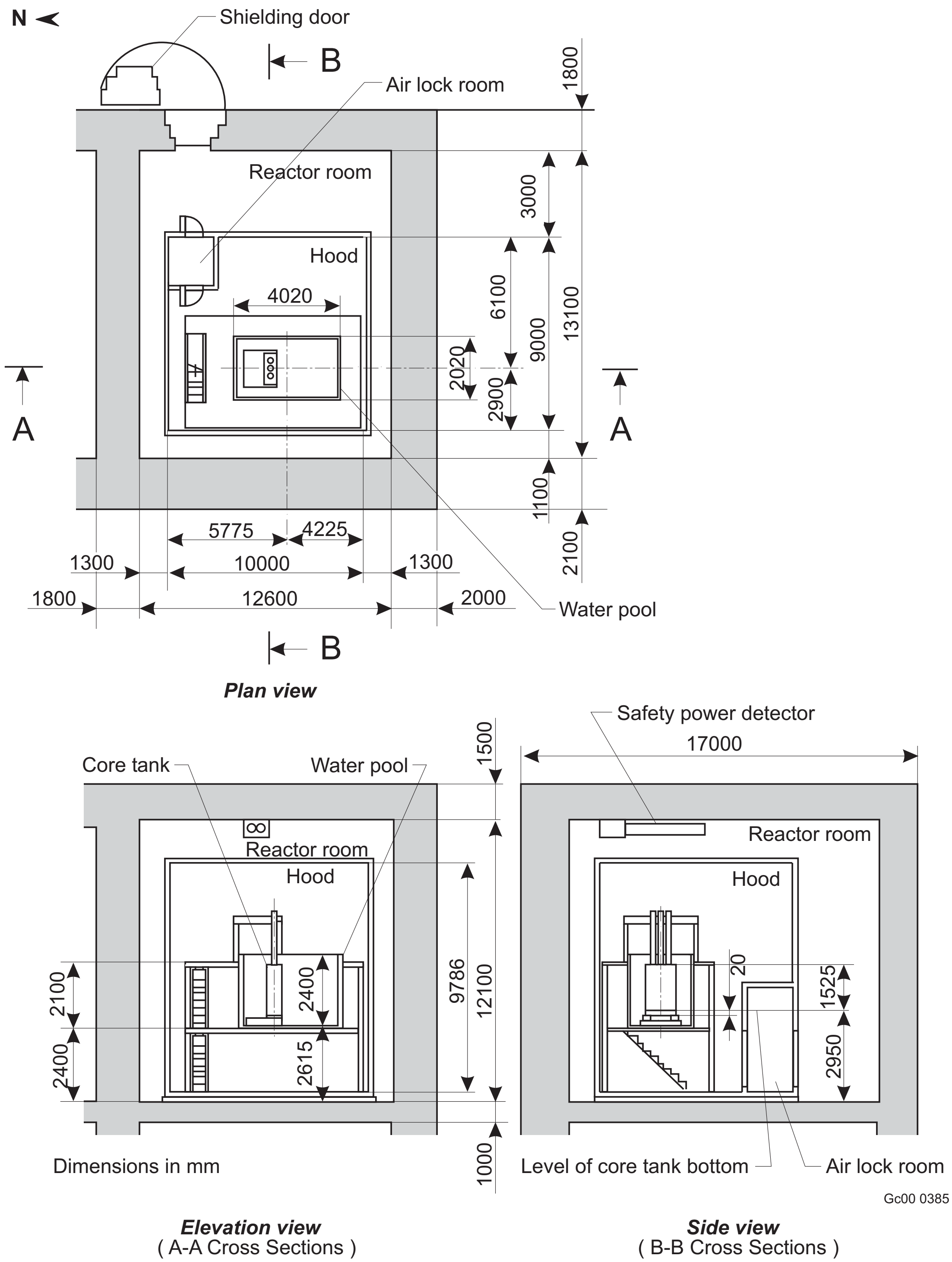


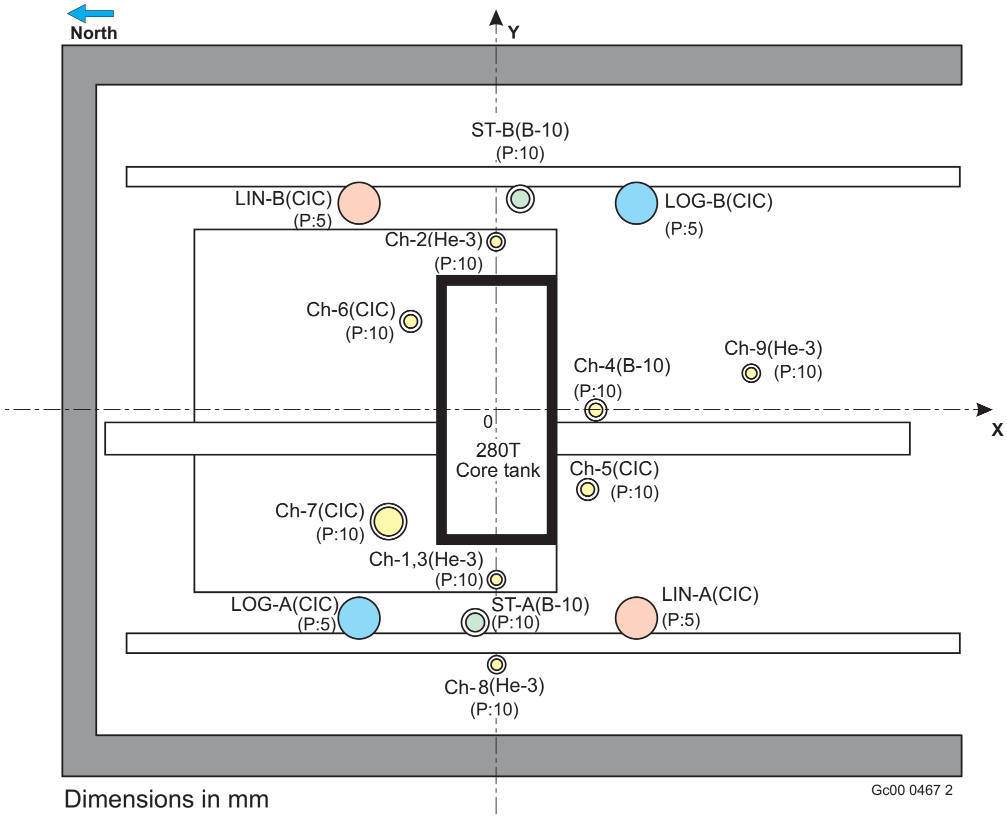
Figure 3. Schematic View Inside the Reactor Room.

The bottom of the tank was exactly flat and horizontal. After manufacturing the tank, the inclination of the bottom plate was measured and found to be within 0.6 mm (maximum height minus minimum height at edge). Also, when setting the core tank into the pool tank, the verticality of the side walls was checked by measuring the inclination and found to be within 1/1500 mm per mm.

To obtain the critical height, first a critical solution height was confirmed by observing the steady-state neutron-flux level. Then the final critical height was determined by a series of reactivity measurements for which the fuel solution was repeatedly drained and fed near the critical state. In the measurements, subcritical and supercritical conditions were repeated. For example, measured reactivities might have been –3 cents, +3 cents, -6 cents, +6 cents, -9 cents, and +9 cents. The reactivities were measured by employing a digital reactivity meter. A digital reactivity meter calculates reactivities by solving the reactor kinetics equation in real time, using an analog signal from a neutron detector. Near the critical state, the variation of reactivity versus solution height is approximately linear.

The arrangement of the neutron detectors is shown in Figure 4. The positions of the neutron detectors were variable depending on the experimental requirements. Figure 4 shows the arrangement of Run No. 104 as an example. Two ^{10}B-lined proportional counters (ST-A and B) and four gamma-ray compensated ionization chambers (LIN-A, B, LOG-A and B) were located around the core tank to measure the neutron flux level for the start-up power range and the operational power range, respectively. Maximum power was limited to 200W. Nine additional experimental neutron detectors were also located around the core tank: two ^{3}He proportional counters (Ch-1 and 3) on the west side, one ^{3}He proportional counter (Ch-8) on the west side, one ^{3}He proportional counter (Ch-2) on the east side, two gamma-ray compensated ionization chambers (Ch-6 and Ch-7), used as input to a digital reactivity meter in the north side, one ^{3}He proportional counter (Ch-9), one ^{10}B-lined proportional counter (Ch-4), and one gamma-ray compensated ionization chamber (Ch-5) in the south side. Further, a pulsed neutron source (Pulsatron) was located in the north side for Run No. 122, 123, and 126. For improving the neutron efficiency, the detectors were covered with polyethylene (except Ch-1 to 3). The thicknesses of polyethylene are given in Figure 4.

The six critical conditions are summarized in Table 2.



Experimental Channels

ID	TYPE	X,Y	HC	OD1	L1	OD2	A	U,L (A)	P	U, L (P)
CH-1	HE-3(H)	0, -470	100	6.0	82.5	22.0	1.0	-160, 2240	10.0	5, 195
CH-2	HE-3(H)	0, 470	200	6.0	82.5	22.0	1.0	-160, 2240	10.0	205, 395
CH-3	HE-3(H)	0, -470	300	6.0	82.5	22.0	1.0	-160, 2240	10.0.	305, 495
CH-4	B-10	250, 0	200	25.4	295.1	37.0	3.0	11, 485	10.0	26, 406
CH-5	CIC	245, -225	200	38.1	235.0	47.0	3.0	42, 466	10.0	54, 258
CH-6	CIC	-245, 250	200	38.1	235.0	47.0	3.0	42, 466	10.0	54, 258
CH-7	CIC	-285, -300	200	77.0	241.0	90.0	4.0	53, 564	10.0	83, 443
CH-8	HE-3(L)	0, -705	200	6.3	10.0	22.0	1.0	-350, 2050	10.0	175, 225.
CH-9	HE-3(L)	705, 100	200	6.3	10.0	22.0	1.0	-350, 2050	10.0	175, 225.

Nuclear Instruments

ID	TYPE	X,Y	HC	OD1	L1	OD2	A	U,L (A)	P	U, L (P)
ST-A	B-10	64, -591	200	25.4	266.7	45.0	3.0	-350, 2150	10.0	-25, 425
ST-B	B-10	64, 591	200	25.4	266.7	45.0	3.0	-350, 2150	10.0	-25, 425
LIN-A	CIC	384, -573	200	79.5	355.6	100.0	3.0	-350, 2150	5.0	-80, 480
LIN-B	CIC	-384, 573	200	79.5	355.6	100.0	3.0	-350, 2150	5.0	-80, 480
LOG-A	CIC	-384, -573	200	79.5	355.6	100.0	3.0	-350, 2150	5.0	-80, 480
LOG-B	CIC	384, 573	200	79.5]	355.6	100.0	3.0	-350, 2150	5.0	-80, 480

X,Y: Horizontal position
HC : Height of the central position of neutron counter
OD1: Counter diameter
L1: Counter length
OD2: outer diameter of aluminum guide tube and Inner diameter of polyethylene sheet
A, P: Thicknesses of aluminum guide tube and polyethylene sheet, respectively
U,L (A): Height of upper and lower end of aluminum guide tube, respectively
U,L (P): Height of upper and lower end of polyethylene sheet, respectively

Origin of vertical position is the bottom of solution.

He Gas Pressure: He-3(H); 102Pa, He-3(L); 39Pa Polyethylene Density: 0.97 g/cm^3

Figure 4.a. Neutron-Detector Locations, from Above (Run No. 104, unreflected).

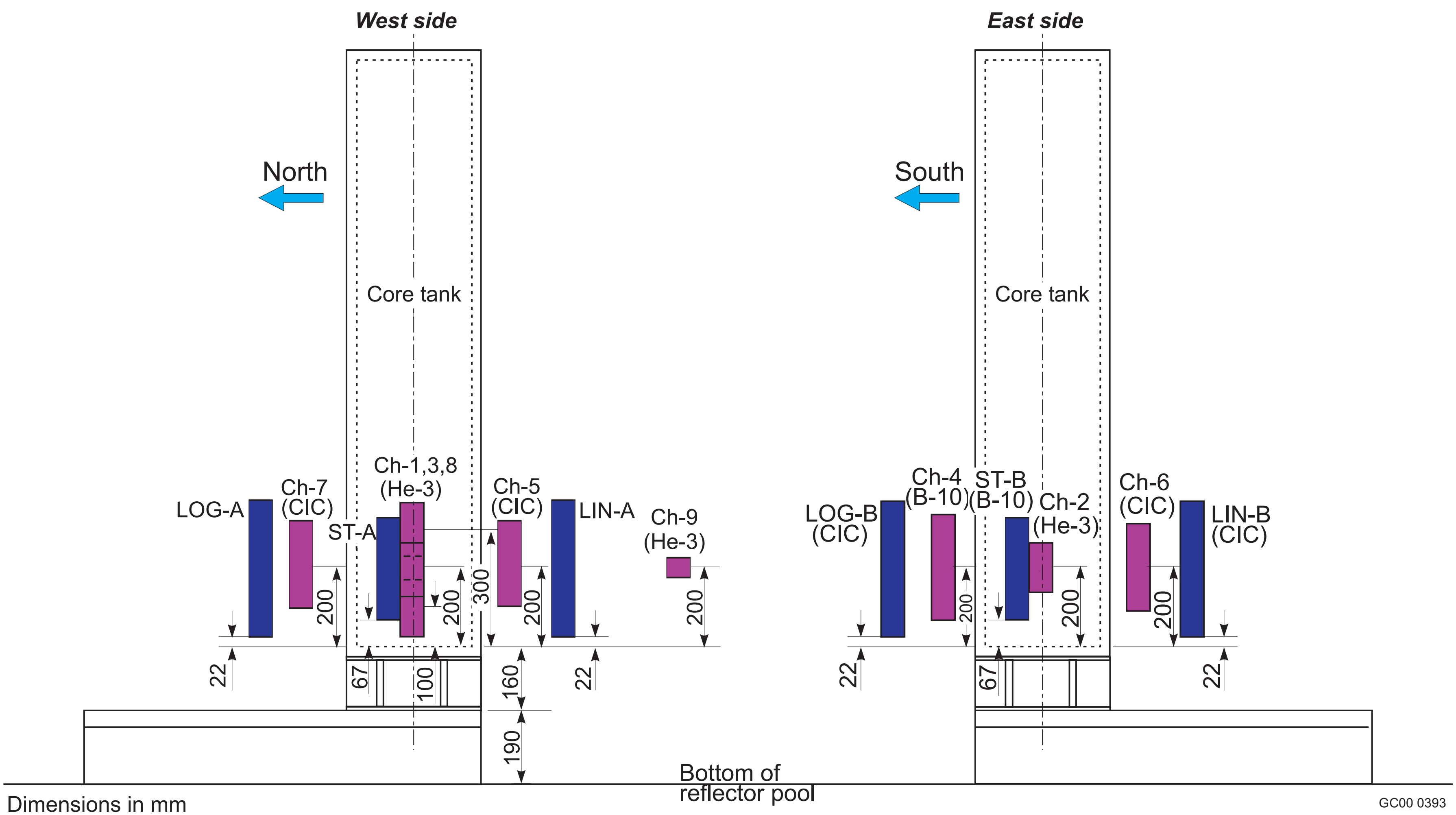


Figure 4.b. Counter Locations from West.

Figure 4.c. Counter Locations from East.

1.3 Description of Material Data

The isotopic composition of uranium, which was measured by mass spectrometry before the series of experiments, is given in Table 3. The enrichment of the uranium was 9.97±0.013 wt.%. The chemical analyses (uranium concentration, free nitric acid concentration, and solution density) of the uranyl nitrate solution were carried out approximately every week during a series of experiments. The uranium concentration was adjusted to decrease approximately from 464 gU/l to 315 gU/l by successive steps. The free nitric acid concentration was approximately in the range from 0.8 mol/l to 1.0 mol/l.

The fuel solution characteristics at the time of each experiment were determined by the interpolation of the chemical analyses and are given in Table 2. The uncertainties of the measured values in Table 2 include uncertainties for interpolation.

Table 2. Critical Conditions of STACY Unreflected Cores.

Run No.	Date yy/mm/dd	Characteristics of Fuel Solution (25.0 °C)			Critical Height (cm)	Temperature (°C)
		U conc. (gU/l)	H^+ conc. (mol/l)	Density (g/cm^3)		
104	97/04/16	464.2±0.8	0.852±0.018	1.6462±0.0005	44.92±0.02	25.5
122	97/06/09	432.4±0.9	0.800±0.020	1.6033±0.0005	47.88±0.02	25.0
123	97/06/13	369.7±1.1	0.800±0.018	1.5185±0.0005	60.25±0.02	25.2
126	97/06/23	350.6±0.7	0.800±0.018	1.4947±0.0005	68.57±0.02	25.0
130	97/07/09	328.9±0.6	0.800±0.018	1.4666±0.0005	84.49±0.02	25.1
147	97/11/12	315.3±0.6	0.955±0.015	1.4520±0.0005	111.91±0.04	25.1

Table 3. Isotopic Composition of Uranium.

Isotope	Weight %
^{234}U	0.08
^{235}U	9.97±0.013
^{236}U	0.01
^{238}U	89.94

Uranyl nitrate solution consists of uranyl nitrate [$UO_2(NO_3)_2$], free nitric acid [HNO_3], and water [H_2O]. A sample of uranyl nitrate solution was taken from the dump tank, which was located in the basement under the reactor room. The results of the chemical analysis were obtained at a fixed solution temperature of 25 °C. The uranium concentration was measured by Davies and Gray's method.[a] The uncertainty of the uranium concentration was determined to be 1.0 gU/l. The measurement of free nitric acid concentration was as follows: Initially, the uranium was precipitated by adding $(NH_4)_2SO_4$ and H_2O_2 to a sample solution. After that, the total acidity was determined by titration with sodium hydroxide. The free nitric acid concentration was estimated by subtracting the radical of uranyl nitrate from the total acidity. The uncertainty of free nitric acid concentration was determined to be 0.02 mol/l. The solution density was measured by employing a digital density meter. The accuracy of this meter was ±0.0001 g/cm^3. The uncertainty including the error of the sampling process was estimated to be ±0.0005 g/cm^3.

The temperature of the fuel solution was measured during an operation by the thermocouple inserted in the guide tube within the core tank.

Three elements, Fe, Cr, and Ni, were considered as the main impurities contained in the fuel solution; their concentrations were measured by chemical analysis. The measured concentrations of Fe, Cr and Ni were, respectively, lower than 252 mg/l, 67 mg/l, and 45 mg/l.

The main body of the core tank (the side wall, the lower plate, and the upper plate) was made of stainless steel S.S.304L (or SUS304L). Its measured chemical composition is given in Table 4. The density of the stainless steel is 7.93 g/cm^3 according to the Japanese Industrial Standard (JIS). Other structural materials (legs of core tank, tube for thermocouple, guide tube of safety rod, guide tube for the Am-Be source, base plate, walls of water-reflector pool tank, fuel feed/drain line, and sheath of B_4C pellets) were also made of stainless steel S.S.304.

Table 4. Chemical Composition of Stainless Steel S.S.304 (Unit: wt.%).

C	Si	Mn	P	S	Ni	Cr	Fe
0.018	0.42	1.14	0.033	0.007	10.52	18.21	69.652

The containers of the neutron detectors were made of aluminum. The structural materials for fixing the detectors were also made of aluminum.

1.4 Supplemental Experimental Measurements

As mentioned in Section 1.2, the final critical height was determined by the reactivity measurement, employing a digital reactivity meter. The differential reactivity worth with respect to solution height was also estimated from this measurement.

For a typical core configuration, kinetic parameters, such as β/l, were measured by a pulsed-neutron method and/or a frequency noise analysis.

[a] W. Davies, W. Gray: *Talanta,* **11**, 1203 (1964).

The results of these measurements are written in the logbook or other unpublished internal documents.

At the present time, the β/l measurement for the slab core tank is written in the unpublished internal report, while the measurement for the 60-cm-diameter core tank is written in the published report.[a]

[a] K.Tonoike et al., Proc. ICNC 99, 1215 Versailles, France (1999).

2.0 EVALUATION OF EXPERIMENTAL DATA

2.1 General Notes

Six critical configurations were collected from the logbook and other unpublished internal documents. The effects on k_{eff} of uncertainties in measured data were estimated by sensitivity studies. The sensitivity studies were performed with a two-dimensional transport code, TWOTRAN, and a 16-energy-group cross section set collapsed from the 107-energy-group SRAC public library based on the evaluated nuclear data library, JENDL-3.2. The k_{eff}'s were calculated with convergence criteria of 1×10^{-5}.

For the sensitivity studies, a density formula for uranyl nitrate solution developed at JAERI was used. This formula gives the density of uranyl nitrate solution as a function of uranium concentration, free nitric acid concentration, and solution temperature. The details of this formula are described in Appendix B.

Horizontal XY calculations (X: north-south; Y: east-west) with 6.9-cm extrapolation length in the Z (vertical) direction were performed for the horizontal-dimension sensitivity studies. The XZ calculations with 8.7-cm extrapolation length in the Y direction were done for the vertical-dimension sensitivity studies.

2.2 Fuel Solution Uncertainties

As mentioned in Section 1.3, the uncertainties of uranium enrichment, uranium concentration, free nitric acid concentration, and solution density were determined to be 0.013 wt.%, 1.0 gU/l, 0.02 mol/l and 0.0005 g/cm^3, respectively. The solution height was measured with a contact-type level gauge, of which the accuracy was 0.2 mm. The solution temperature was measured with a thermocouple. The temperature change during the operation was estimated to be within 0.3 °C. The concentration of the main impurities Fe, Cr, and Ni were less than 252 mg/l, 67 mg/l, and 45 mg/l, respectively. The effects on k_{eff} of uncertainties pertaining to the fuel solution are given in Table 5.

Table 5. Effects on k_{eff} of Uncertainties Pertaining to the Fuel Solution (Δk_{eff}, %).

Parameter	Variation	Run No.					
		104	122	123	126	130	147
U enrichment	±0.013 wt.%	±0.038	±0.039	±0.042	±0.043	±0.045	±0.046
U concentration	±1.0 gU/l	±0.030	±0.038	±0.056	±0.063	±0.073	±0.080
H^+ concentration	±0.02 mol/l	-/+0.032	-/+0.031	-/+0.030	-/+0.030	-/+0.030	-/+0.029
Solution density	±0.0005 g/cm^3	±0.020	±0.018	±0.014	±0.013	±0.011	±0.009
Solution height	±0.2 mm	±0.008	±0.006	±0.003	±0.002	±0.001	±0.001
Temperature	±0.3 °C	-/+0.013	-/+0.012	-/+0.011	-/+0.011	-/+0.010	-/+0.010
Impurity (Fe)	+252 mg/l	-/+0.005	-/+0.006	-/+0.007	-/+0.007	-/+0.007	-/+0.008
Impurity (Cr)	+67 mg/l	-/+0.002	-/+0.002	-/+0.002	-/+0.002	-/+0.003	-/+0.003
Impurity (Ni)	+45 mg/l	-/+0.002	-/+0.002	-/+0.002	-/+0.002	-/+0.002	-/+0.002
Total		±0.060	±0.066	±0.079	±0.084	±0.092	±0.098

There are two uncertainties on the temperature:

(1) The change of temperature during the experiment (0.3 °C).
(2) The fact that atom densities are known at 25 °C and the experiments are conducted at other temperatures, a maximum difference of 0.5 °C (25-25.5 °C).

The temperature uncertainty has two effects:

(1) The change in density, which is calculated with the density formula, gives the change in solution density.
(2) The change in uranium concentration C(U).

The following relationships hold for volume, density, and concentration:

Volume × Density = Constant,
Volume × Concentration = Constant.

Therefore, the following relationships are derived:

$$\Delta V/V = -\Delta\rho/\rho = -\Delta C(U)/C(U) .$$

ΔC may be calculated, since $\Delta\rho$ is calculated with the density formula. All these effects are included in the Δk_{eff}'s in Table 5.

2.3 Core Tank Uncertainties

As to the effects on k_{eff} of uncertainties pertaining to the core tank, the effects caused by the dimensional uncertainties were evaluated: core thickness, core width, thicknesses of side wall and lower plate. As shown in Table 1, the uncertainties of those were less than 0.05 cm, 0.05 cm, 0.01 cm and 0.01 cm, respectively. The effects on k_{eff} of uncertainties pertaining to the core tank were calculated using these uncertainties as variations, and the results are given in Table 6. The calculated effect on k_{eff} was divided by the square root of the number of measurements to obtain the standard deviation of the mean.

Table 6. Effects on k_{eff} of Uncertainties Pertaining to the Core Tank (Δk_{eff}, %).

Parameter	Variation	Run No.					
		104	122	123	126	130	147
Solution thickness	±0.05cm	±0.052	±0.052	±0.052	±0.053	±0.053	±0.053
Solution width	±0.05cm	±0.011	±0.011	±0.012	±0.012	±0.012	±0.012
Side-wall thickness, X[(a)]	±0.01cm	±0.011	±0.011	±0.011	±0.011	±0.011	±0.011
Side-wall thickness, Y[(b)]	±0.01cm	±0.001	±0.001	±0.001	±0.001	±0.001	±0.001
Lower-plate thickness	±0.01cm	±0.002	±0.002	±0.001	<±0.001	<±0.001	<±0.001
Total		±0.054	±0.054	±0.054	±0.055	±0.055	±0.056

(a) X: north-south direction, (b) Y: east-west direction

2.4 Conclusions

Because the experimental conditions are obviously known and the uncertainties of those have been sufficiently quantified, the six critical configurations included in this evaluation are acceptable benchmark experiments.

3.0 BENCHMARK SPECIFICATION

3.1 Description of Benchmark Model

3.1.1 Detailed Model - The detailed model consists of the fuel solution, the core tank, the structure and devices. Most of the structures and devices act as neutron reflectors (model simplification effect). To estimate the model simplification effect for each core configuration, a detailed model that includes the following structures was constructed:

(1) Tube for the thermocouple within the core tank.
(2) Contact-type level gauge. This is above the surface of the fuel solution.
(3) Four legs supporting the core tank.
(4) Fuel feed/drain line containing fuel solution. The outer diameter of the tube is 27.2 mm, and its thickness is 2.9 mm.
(5) Guide tube for the neutron source. This tube lies horizontally below the core tank.
(6) Base plate supporting the four legs. The upper surface of this plate is 14 cm below the bottom of the core tank. The thickness of this plate is 30 mm.
(7) Beams supporting the base plate. These beams lie on the bottom of the pool tank. The height of these beams is 16 cm.
(8) Six neutron detectors for reactor operation; two ^{10}B-lined proportional counters, and four gamma-ray compensated ionization chambers. These were covered with polyethylene to improve the neutron efficiency and were located on the side of reflector
(9) Nine neutron detectors and pulsed neutron source (for Run No. 122, 123, and 126) for the experimental measurements; five ^{3}He proportional counters, one ^{10}B-lined proportional counter and three gamma-ray compensated ionization chambers. The arrangement of neutron detectors for Run No.104 was shown in Figure 4.
(10) Structures and devices on the top of the core tank: guide tubes of the safety rods, level-gauge device, safety rods, and so on.
(11) Side walls and bottom plate of the pool tank. The thicknesses of the side walls and the bottom plate are 10 mm and 15 mm, respectively. The bottom plate is 33 cm below the core tank.
(12) Hood and concrete walls of the reactor room.
(13) Other structure outside the core tank.

3.1.2 Benchmark Model - The benchmark model is shown in Figure 5. The model consists of the fuel solution, the core tank and the two additional structures which, according to results from MCNP's "cell-flagging" option, have dominant room-return effect. The following structures were included so as to reduce excessive bias in the benchmark-model k_{eff}:

(1) Base plate supporting four legs. The upper surface of this plate is 14 cm below the bottom of the core tank. The thickness of this plate is 30 mm.
(2) Side walls and bottom plate of the pool tank. The thicknesses of the side walls and the bottom plate are 10 mm and 15 mm, respectively. The bottom plate is 33 cm below the core tank.

3.1.3 Results of Calculations of Simplifications - The model simplification effect is defined as the difference of k_{eff}'s between the benchmark model and the detailed model. The calculations of k_{eff}'s were carried out by MCNP 4B with JENDL-3.2 (10^7 neutron histories). The estimated results of the model simplification effects are given in Table 7.

Table 7. Estimated Result of Model Simplification Effect.

Run No.	Calculated k_{eff} ($\pm 1\sigma$)		Model Simplification Effect, Δk_{eff} (%)
	Benchmark Model	Detailed Model	
104	1.00907±0.00024	1.01122±0.00018	-0.215±0.030
122	1.00891±0.00024	1.01037±0.00018	-0.146±0.030
123	1.00700±0.00023	1.00822±0.00018	-0.122±0.029
126	1.00788±0.00022	1.00871±0.00018	-0.083±0.028
130	1.00715±0.00022	1.00848±0.00018	-0.133±0.028
147	1.00673±0.00022	1.00715±0.00018	-0.042±0.028

The model simplification effects are included as biases in the benchmark-model k_{eff}'s.

The maximum bias in calculated k_{eff} of the benchmark model is estimated to be 0.2%. In the evaluation, half of the bias (0.1%) was uniformly considered as the uncertainty for all the benchmark models.

In the benchmark model, impurities such as Fe, Cr, and Ni are omitted. The reactivity effects of these impurities were obtained in Section 2.2. Because the reactivity effects were estimated with the maximum concentrations during the experiments and the estimated effects were very small, they are not included as biases in the benchmark-model k_{eff}'s. But they are included as uncertainties in the benchmark-model k_{eff}'s.

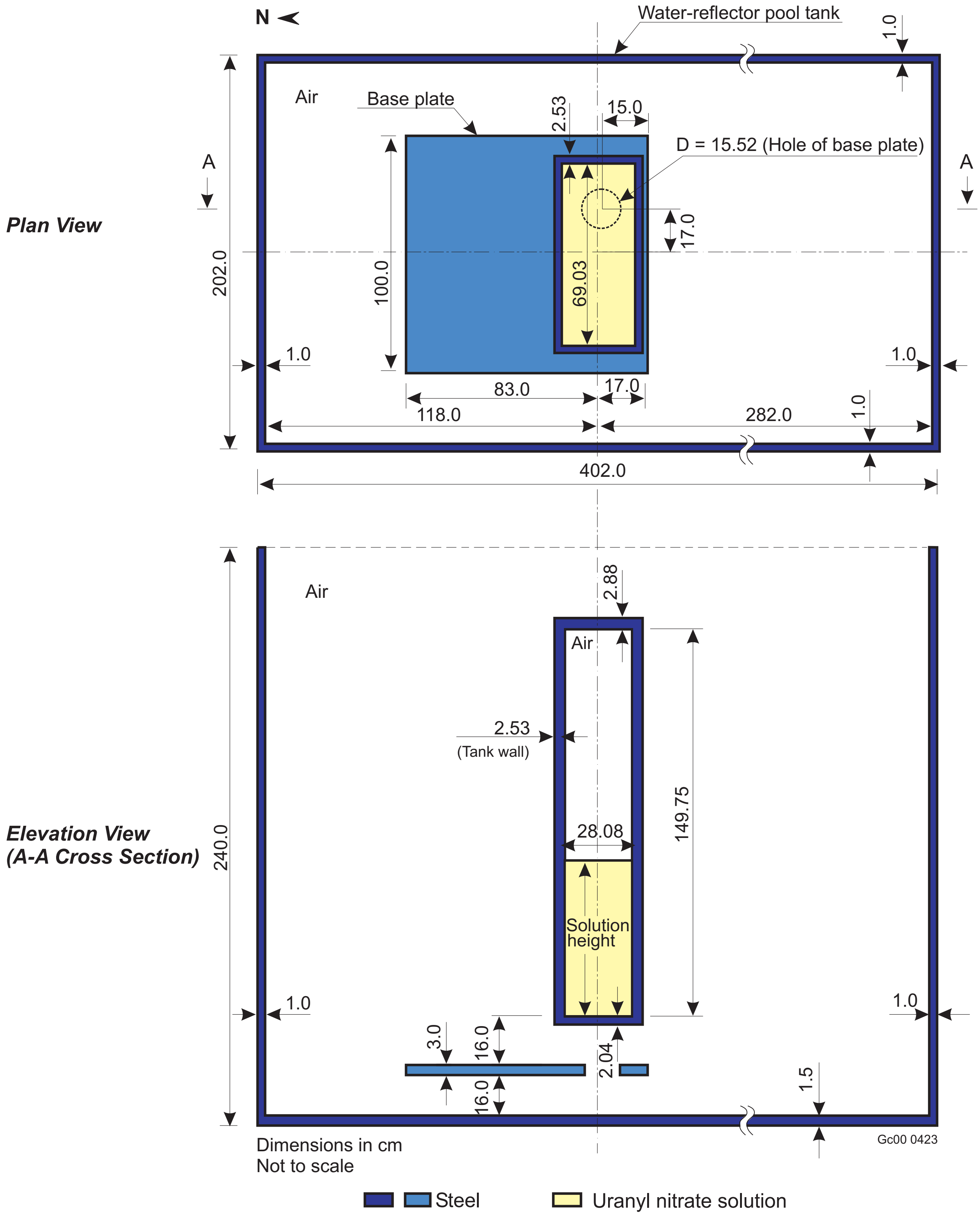


Figure 5. Benchmark Model of the STACY Experiments.

3.2 Dimensions

The dimensions of the benchmark model are shown in Figure 5.

The core is uranyl nitrate solution in a rectangular stainless steel tank. The tank's inner dimensions are 28.08 cm x 69.03 cm x 149.75 cm high. The four side walls are 2.53 cm thick. The tank bottom is 2.04 cm thick, and the top is 2.88 cm thick.

The following surrounding structures are included:
- Base plate - The upper surface of this plate is 16 cm below the bottom of the core solution. This plate is 100 cm wide, and 100 cm long and is made of 3-cm-thick stainless steel. The long edges of the plate are parallel to the sides of the core tank. The center of the base plate is 33 cm north of the vertical centerline of the core tank. The plate has a 15.52-cm-diameter hole at an off-center position. (The center of the hole is 2 cm south and 17 cm east of the core-tank vertical centerline.)
- Open-top pool tank - The thickness of the side walls and the bottom plate are 1.0 cm and 1.5 cm, respectively. This tank is made of stainless steel. The inner dimensions of the pool tank are 400 cm wide, 200 cm long, and 238.5 cm high. The bottom inner surface of the pool tank is 16 cm below the base plate. The vertical centerline of the core is 82 cm north of the center of the pool tank, and the wider sides of the core tank are parallel to the 200-cm sides of the pool tank.

The critical solution heights for each case are summarized in Table 8.

Table 8. Critical Solution Heights.

Run No.	Critical Solution Height (cm)
104	44.92
122	47.88
123	60.25
126	68.57
130	84.49
147	111.91

3.3 Material Data

The uranium concentration, the free nitric acid concentration, and the solution density at 25 °C are known for each core configuration. The atom densities of the fuel solution are given in Table 9. Their derivation is described in Appendix C.

Table 9. Atom Densities of Fuel Solution at 25 °C (Unit: atoms/barn-cm).

Run No.	^{234}U	^{235}U	^{236}U	^{238}U	H	N	O
104	9.5555E-07	1.1858E-04	1.1843E-07	1.0562E-03	5.5582E-02	2.8647E-03	3.8481E-02
122	8.9009E-07	1.1045E-04	1.1032E-07	9.8382E-04	5.6423E-02	2.6723E-03	3.8178E-02
123	7.6102E-07	9.4437E-05	9.4320E-08	8.4116E-04	5.7696E-02	2.3547E-03	3.7544E-02
126	7.2170E-07	8.9558E-05	8.9447E-08	7.9771E-04	5.8220E-02	2.2579E-03	3.7419E-02
130	6.7703E-07	8.4015E-05	8.3910E-08	7.4833E-04	5.8744E-02	2.1480E-03	3.7241E-02
147	6.4904E-07	8.0541E-05	8.0441E-08	7.1739E-04	5.8714E-02	2.1724E-03	3.7184E-02

The density of the stainless steel S.S.304L is 7.93 g/cm^3. The atom densities of the stainless steel used for the core tank, the base plate, and the water-reflector pool tank is given in Table 10.

Table 10. Atom Densities of Stainless Steel (Unit: atoms/barn-cm).

C	Si	Mn	P	S	Ni	Cr	Fe
7.1567E-05	7.1415E-04	9.9095E-04	5.0879E-05	1.0424E-05	8.5600E-03	1.6725E-02	5.9560E-02

It is assumed that the void region above the surface of the fuel solution is occupied by air of density 0.001184 g/cm^3. The air is composed of 76.64 wt.% nitrogen and 23.36 wt.% oxygen[a]. The atom densities (atoms/barn-cm) of the air are:

N: 3.9016E-05, and
O: 1.0409E-05.

3.4 Temperature Data

The solution temperature for each core configuration varies from 25.0 °C to 25.5 °C. However, the solution temperature adopted in the benchmark models is fixed at 25 °C because the chemical analyses were performed at this temperature. The effects of the temperature differences were estimated by TWOTRAN calculations with convergence criteria of 1×10^{-5}. The k_{eff}'s at the experimental temperature and at the adopted temperature were calculated. To obtain the atom densities at each temperature, both the density formula from Appendix B and the formula in Section 2.2 were used to derive the temperature effect data. The cross section modification due to the differences of temperature were included in the TWOTRAN calculations. The estimated results of the temperature effects are given in Table 11.

Table 11. Evaluated Results of Temperature Effects.

Run No.	Experimental Temperature	k_{eff} at 25.0 °C	k_{eff} at Experimental Temperature	Temperature Effect Δk_{eff} (%)
104	25.5 °C	1.00609	1.00588	+0.021
122	25.0 °C	1.00637	1.00637	±0.000
123	25.2 °C	1.00566	1.00559	+0.007
126	25.0 °C	1.00669	1.00669	±0.000
130	25.1 °C	1.00660	1.00657	+0.003
147	25.1 °C	1.00636	1.00633	+0.003

Each temperature effect is regarded as a bias in the benchmark-model k_{eff}.

[a] B. TAMAMUSHI et al., Rikagaku Jiten (Science Encyclopedia), Iwanami Shoten (1975) (in Japanese). Other elements were neglected. The wt.% of N and O were adjusted such that the ratio of these were conserved.

3.5 Experimental and Benchmark-Model k_{eff}

The experimental k_{eff}'s are unity. The following sources were considered as possible biases in the benchmark models:

(1) model simplification effect – neglecting structures and devices in or around the tank,
(2) impurity effect – excluding the impurities (Fe, Cr, and Ni) from the fuel solution,
(3) temperature effect – difference between the experimental temperature and the adopted temperature (25 °C).

Both the model simplification effect and the temperature effect are considered to be biases in the benchmark models. They are estimated in Section 3.1 and 3.4.

As discussed in Section 3.1, the impurity effects are not included in the biases, but are included in the uncertainties (part of those pertaining to the fuel solution). In Section 2.0, the uncertainties are estimated as originating from (1) fuel solution properties and (2) core tank geometry.

The uncertainties of k_{eff}'s included in the benchmark model are obtained by the square root of the sum of individual uncertainties' squares, and correspond to one standard deviation. Consequently, the benchmark-model k_{eff}'s are:

Run 104	0.9981±0.0013,
Run 122	0.9986±0.0013,
Run 123	0.9989±0.0014,
Run 126	0.9992±0.0014.
Run 130	0.9987±0.0015, and
Run 147	0.9996±0.0015.

.

4.0 RESULTS OF SAMPLE CALCULATIONS

The results of the sample calculations using MCNP 4B with the JENDL-3.2 library are given in Table 12.a. These high values are known to be caused by the capture cross section of ^{235}U in the resonance energy range of the library, which is smaller than that of the other libraries. In addition, the CRISTAL code system of IPSN (APOLLO-2 cell code with the CEA93 172-group library based on JEF2.2 evaluation, and MORET-4 Monte Carlo code with $\sigma = 0.033$ %) were used for sample calculations. The results are given in Table 12.b. The results of KENO and MCNP calculations with ENDF/B-IV, V, and VI libraries are given in Table 12.c.

Table 12.a. Results of Sample Calculations (Japan).

Code (Cross Section Set) → Run No. ↓	MCNP (Continuous Energy JENDL-3.2)
104	1.0091 ± 0.0002
122	1.0089 ± 0.0002
123	1.0070 ± 0.0002
126	1.0079 ± 0.0002
130	1.0072 ± 0.0002
147	1.0067 ± 0.0002

Table 12.b. Results of Sample Calculations (France).[a]

Code (Cross Section Set) → Run No. ↓	APOLLO-2 / MORET-4 (CEA93 Library-172 group)
104	1.0074 ± 0.0003
122	1.0072 ± 0.0003
123	1.0057 ± 0.0003
126	1.0061 ± 0.0003
130	1.0060 ± 0.0003
147	1.0045 ± 0.0003

(a) Results provided by IPSN/DPEA/SEC.

Table 12.c. Results of Sample Calculations (United States).[(a)]

Code (Cross Section Set) → Run No. ↓	KENO[(b)]			MCNP	
	Hansen-Roach	27-Group (ENDF/B-IV)	238-Group (ENDF/B-V)	Continuous Energy ENDF/B-V	Continuous Energy ENDF/B-VI
104	1.0000 ± 0.0010	1.0061 ± 0.0009	1.0032 ± 0.0009	1.0065 ± 0.0008	0.9998 ± 0.0008
122	1.0020 ± 0.0009	1.0062 ± 0.0009	1.0048 ± 0.0010	1.0050 ± 0.0008	1.0003 ± 0.0008
123	1.0011 ± 0.0009	1.0032 ± 0.0009	1.0045 ± 0.0009	1.0027 ± 0.0007	1.0006 ± 0.0007
126	1.0046 ± 0.0008	1.0033 ± 0.0008	1.0027 ± 0.0008	1.0046 ± 0.0007	0.9980 ± 0.0007
130	1.0049 ± 0.0009	1.0034 ± 0.0008	1.0019 ± 0.0008	1.0041 ± 0.0007	0.9982 ± 0.0007
147	1.0066 ± 0.0008	1.0039 ± 0.0008	1.0023 ± 0.0008	1.0031 ± 0.0007	0.9980 ± 0.0007

(a) Results provided by Richard Taylor, Oak Ridge Y-12.
(b) calculated with an earlier model with base plate 16 cm rather than 14 cm below the core tank; input listings have been corrected.

5.0 REFFERENCES

1. T. Kikuchi, Y. Miyoshi, Y. Torii, Y. Yamane, K. Tonoike, “Critical Configurations of Basical Slab Cores with 10% Enriched Uranyl Nitrate Solution,” (in Japanese) *JAERI-Tech 99-038* (1999).

2. S. Onodera, H. Sono, H. Hirose, Y. Takatsuki, M. Nakagawa, K. Murakami, T. Takahashi, K. Sakuraba, M. Miyauchi, T. Kikuchi, "Annual Report of STACY Operation in F.Y. 1997 - 280 mm Thickness Slab Core -- 10% Enriched Uranyl Nitrate Solution - " (in Japanese) *JAERI-Tech 98-023*(1998).

APPENDIX A: TYPICAL INPUT LISTING

A.1 MCNP Input Listing

Japanese MCNP 4B with the continuous-energy cross sections based on the JENDL-3.2 library was run with 2,000 active generations of 5,000 neutrons each (10 million neutron histories), after skipping 50 generations (100,000 neutron histories).

a) MCNP4B Benchmark-Model Input Listing for Run No.104, Table 12.a and Table 7.

```
STACY 280t Core tank critical analysis.
c    R104(bare)    ;Hc= 44.92cm U=315.5(g/lit) A=0.96(mol/lit)
c
c    cellcard
c
1    1   9.81034711E-02   1  -2   3  -4   5  -7    imp:n=1 u=1
2    4   4.94250000E-05   1  -2   3  -4   7  -6    imp:n=1 u=1
3    2   8.66829700E-02  #1  #2                    imp:n=1 u=1
4    0                  11 -12  13 -14  15 -16    imp:n=1 u=2 fill=1
5    2   8.66829700E-02  (-43 44 -46 47 -48 49) 45 imp:n=1 u=2
6    4   4.94250000E-05  #4  #5                    imp:n=1 u=2
7    0                  21 -22  23 -24  25 -26    imp:n=1 u=3 fill=2
8    2   8.66829700E-02  #7                       imp:n=1 u=3
9    0                  31 -32  33 -34  35 -26    imp:n=1 fill=3
10   0                   #9                       imp:n=0

c
c    surface cards (origin x=0.0 y=0.0 z=0.0)
c    fuel
1    px    -34.515
2    px     34.515
3    py    -14.04
4    py     14.04
5    pz      0.0
6    pz    149.75
c   Critical level
7    pz     44.92
c    sus304
c
11   px    -37.045
12   px     37.045
13   py    -16.57
14   py     16.57
15   pz     -2.04
16   pz    152.63
c    water
c
21   px    -100.0
22   px     100.0
23   py   -118.0
24   py    282.0
25   pz    -35.0
26   pz    205.4
c
31   px    -101.0
32   px     101.0
33   py   -119.0
34   py    283.0
35   pz    -36.5
c
c    Base Plate
43   pz    -16.0
44   pz    -19.0
45   c/z    17.0 2.0 7.76
46   py     17.0
47   py    -83.0
48   px     50.0
49   px    -50.0
c

c
c    data cards
c
mode  n                    $ transfort neutrons only
c
c    material cards
```

a) MCNP4B Benchmark-Model Input Listing for Run No.104, Table 12.a and Table 7 (cont'd).

```
c
c    R104(bare);U=464.2/A=0.852/D=1.6462
c    atomic density =  9.81034711E-02
m1    1001.37c     5.5582E-02
      7014.37c     2.8647E-03
      8016.37c     3.8481E-02
     92234.37c     9.5555E-07
     92235.37c     1.1858E-04
     92236.37c     1.1843E-07
     92238.37c     1.0562E-03
mt1   lwtr.01t    $  300k
c
c    sus304L(tank) 7.93g/cm3
c    atomic density  8.668297E-2
m2    6012.37c 7.1567E-05  $ C
     14000.37c 7.1415E-04  $ Si
     25055.37c 9.9095E-04  $ Mn
     15031.37c 5.0879E-05  $ P
     16000.37c 1.0424E-05  $ S
     28000.37c 8.5600E-03  $ Ni
     24000.37c 1.6725E-02  $ Cr
     26000.37c 5.9560E-02  $ Fe
c
c    water (STACY)  298.15 K
c    atomic density  9.9987E-02
m3    1001.37c    6.6658E-02
      8016.37c    3.3329E-02
mt3   lwtr.01t    $  300k
c
c     air (0.001184 g/cm3)
c    atomic density  4.9425E-05
m4    7014.37c 3.9016E-05
      8016.37c 1.0409E-05
c
c    tallies
f14:n   1                $ ave flux in cell 1
fm14  (-1 1 -6 -7)        $ ave flux in cell 1
sd14    1
cf14    5 8
c
c    criticality cards
c
kcode  5000  1.0  50  2050
c    kcode  1000  1.0 20  820
sdef  cel=d1 x=d2 y=d3 z=d4  erg=d5
c
si1  1  9:7:4:1
sp1       1
c  *** x-coodinate
si2    h   -34.5  34.5
sp2     0  1
c  *** y-coodinate
si3    h   -14.0  14.0
sp3     0  1
c  *** z-coodinate
si4    h   0.0    44.92
sp4     0  1
c
sp5    -3
c
prdmp  j -100 1 3
c
print -175
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7.

```
STACY 280t Core tank critical analysis.
c    R104(bare)    ;Hc= 44.92cm U=315.5(g/lit) A=0.96(mol/lit)
c    FUEL UO2(NO3)2
c     Bare refrector
c    Tank is all considered.
c
c    cellcard
c
221  2  8.66829700E-02   #(-226 227 -231) -226 1 -230 imp:n=1 u=2
222  2  8.66829700E-02   227 -2 -228 229     imp:n=1 u=2
223  4  4.94250000E-05   227 -2 -229         imp:n=1 u=2
224  4  4.94250000E-05  -229  2 -3          imp:n=1 u=2
225  2  8.66829700E-02   229 -228 2 -3       imp:n=1 u=2
226  1  9.81034711E-02   -500 501 -233       imp:n=1 u=2
1    1  9.81034711E-02   1  -2  11 -12 13 -14  228 #221  imp:n=1 u=2
2    4  4.94250000E-05   228 2  -3  11 -12 13 -14        imp:n=1 u=2
3    2  8.66829700E-02  -4 #(11 -12 13 -14 1 -3) #226
       #(3 -229) #(3 -221) #(3 -222) #(3 -223)           imp:n=1 u=2
70   2  8.66829700E-02  #(4 -221 -225) -171 4
                  #(330 -331)          imp:n=1 u=2
261  19 1.37809E-01       330 -331           imp:n=1 u=2
71   2  8.66829700E-02  #(4 -222 -225) -172 4
                  #(330 -332)          imp:n=1 u=2
262  19 1.37809E-01       330 -332           imp:n=1 u=2
72   2  8.66829700E-02  #(4 -223 -225) -173 4
                  #(330 -333)          imp:n=1 u=2
263  19 1.37809E-01       330 -333           imp:n=1 u=2
74   2  8.66829700E-02  4  -176 -175        imp:n=1 u=2
75   2  8.66829700E-02  4  -177             imp:n=1 u=2
76   2  8.66829700E-02  4  -178             imp:n=1 u=2
77   2  8.66829700E-02  4  -179             imp:n=1 u=2
210  2  8.66829700E-02  4  -220             imp:n=1 u=2
170  4  4.94250000E-05  3 -221 -225         imp:n=1 u=2
171  4  4.94250000E-05  3 -222 -225         imp:n=1 u=2
172  4  4.94250000E-05  3 -223 -225         imp:n=1 u=2
174  4  4.94250000E-05  3 -4 -229           imp:n=1 u=2
78   4  4.94250000E-05  #(11 -12 13 -14 1 -3)  #3 #70 #71 #72
                  #210 #74 #75 #76 #77
                  #170 #171 #172      #174 #226
                  #261 #262 #263
                                  imp:n=1 u=2
79   0  5  15 -16 17 -18                     imp:n=1 u=3 fill=2
c    NS guide pipe
c   250  4  4.94250000E-05   -531              imp:n=1 u=3
c   251  2  8.66829700E-02    531 -532          imp:n=1 u=3
c   252  4  4.94250000E-05    532 -533          imp:n=1 u=3
c   253  2  8.66829700E-02    533 -534          imp:n=1 u=3
c   12   2  8.66829700E-02    41 -42            imp:n=1 u=3
c   163  4  4.94250000E-05    534 -41           imp:n=1 u=3
c
c    Foot of tank
 4   2  8.66829700E-02  (15 -16 51 -52  -5 43):
                     (15 -16 52 -53 -57 43) imp:n=1 u=3
 5   2  8.66829700E-02  (15 -16 -54 55  -5 43):
                     (15 -16 -55 56 -57 43) imp:n=1 u=3
c
c fuel feed pipe 1
c
227  1  9.81034711E-02  -233 234  -5    imp:n=1 u=3
228  2  8.66829700E-02   233 -232 234 -5 imp:n=1 u=3
c
c fuel feed pipe 2
c
230  1  9.81034711E-02  -236  237 -238  imp:n=1 u=3
231  2  8.66829700E-02   236 -235 237 -238  imp:n=1 u=3
c
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
c fuel feed pipe 3
c
233  1  9.81034711E-02 -241 -242  43    imp:n=1 u=3
234  2  8.66829700E-02  241 -240 -242 43 imp:n=1 u=3
c
c   8    4  4.94250000E-05  #12 #163 #4 #5 #6 #7 #250 #251 #252 #253
c      #(-232 234) #(237 -238 -235) #(-242 -240) imp:n=1 u=5
c
c   85   0  -5 43 -51                    imp:n=1 u=3 fill=5
c
c    base plate
13   2  8.66829700E-02 (-43 44 -45 46 -47 48) 410 imp:n=1 u=3
310  2  8.66829700E-02  -44  412 (-45 46 -47 48)  411
                        (414:-415:416:-417) imp:n=1 u=3
311  2  8.66829700E-02   82 -413 (-45 46 -47 48)  411
                        (414:-415:416:-417) imp:n=1 u=3
312  2  8.66829700E-02 -412  413 (-418 419 -420 421)  411
                        (422:-423:424:-425) imp:n=1 u=3
313  2  8.66829700E-02 -412  413  410 -411        imp:n=1 u=3
c    neutron source guide tube
254  4  4.94250000E-05  -531  -530 84          imp:n=1 u=3
255  2  8.66829700E-02  531 -532  -530 84       imp:n=1 u=3
256  4  4.94250000E-05  532 -533  -530 84       imp:n=1 u=3
257  2  8.66829700E-02  533 -534  -530 84       imp:n=1 u=3
86   2  8.66829700E-02  41 -42  -530 84         imp:n=1 u=3
164  4  4.94250000E-05  534 -41  -530 84       imp:n=1 u=3
c
c    ch-4
21  13  5.02274000E-02   -101 -102  103            imp:n=1 u=3
401  6  1.24933300E-01   -105 106 101 -104          imp:n=1 u=3
c    ch-5
24  14  1.07067000E-01   -107 -108  109         imp:n=1 u=3
410  6  1.24933300E-01    107 -110 -111  112     imp:n=1 u=3
c    ch-6
27  15  8.80834000E-02   -113 -114  115         imp:n=1 u=3
420  6  1.24933300E-01    113 -116 -117  118     imp:n=1 u=3
c    ch-7
30  16  3.46630000E-02   -122  123 -119         imp:n=1 u=3
31  16  3.46630000E-02   -122  123  119 -120     imp:n=1 u=3
430  6  1.24933300E-01   -121  120  125 -124     imp:n=1 u=3
c   66   4  4.94250000E-05   -121 -136 137 #30 #31 #32 imp:n=1 u=3
c    ch-1 3
90   4  4.94250000E-05   -136  163 -180         imp:n=1 u=3
91   7 -2.69900000E+00   -136  163  180 -161     imp:n=1 u=3
440  6  1.24933300E-01   -162  161  164 -165     imp:n=1 u=3
c   92   3  9.99870000E-02   -162  161  163 -164     imp:n=1 u=3
c   93   4  4.94250000E-05   -162 -136 137 #90 #91 #92 imp:n=1 u=3
c    ch-2
94   4  4.94250000E-05   -136  163 -190         imp:n=1 u=3
95   7 -2.69900000E+00   -136  163  190 -181     imp:n=1 u=3
450  6  1.24933300E-01    166 -167  181 -182     imp:n=1 u=3
c   96   3  9.99870000E-02   -182  181  183 -184     imp:n=1 u=3
c   97   4  4.94250000E-05   -182 -136 137 #94 #95 #96 imp:n=1 u=3
c    pulsartron
c   33  17  2.726620E-02     -325 -126 127          imp:n=1 u=3
c   460  4  4.942500E-05      325 -128 -129 130      imp:n=1 u=3
c   35   3  9.99870000E-02   -128 -126 127 #33 #34   imp:n=1 u=3
c    st-a
36  11  1.25762000E-02   -131 -134  135         imp:n=1 u=3
37   4  4.94250000E-05   -131 -136  137 #36      imp:n=1 u=3
38   7 -2.69900000E+00    131 -132 -136  137     imp:n=1 u=3
470  6  1.24933300E-01   -133  132 -138  139     imp:n=1 u=3
c   40   4  4.94250000E-05    132 -133 -136  137 #39 imp:n=1 u=3
c    st-b
41  11  1.25762000E-02   -140 -134  135         imp:n=1 u=3
42   4  4.94250000E-05   -140 -136  137 #41      imp:n=1 u=3
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
43   7 -2.69900000E+00    140 -141 -136  137     imp:n=1 u=3
480  6  1.24933300E-01    141 -142 -138  139     imp:n=1 u=3
c   45   4  4.94250000E-05    141 -142 -136  137 #44 imp:n=1 u=3
c    lin-a
46  12  1.86958000E-02   -143 -146  147          imp:n=1 u=3
47   4  4.94250000E-05   -143 -136  149 #46      imp:n=1 u=3
48   7 -2.69900000E+00    143 -144 -136  149     imp:n=1 u=3
49   6  1.24933300E-01    144 -145 -150  151     imp:n=1 u=3
c  50   4  4.94250000E-05    144 -145 -148  137 #49 imp:n=1 u=3
c    lin-b
51  12  1.86958000E-02   -152 -146  147          imp:n=1 u=3
52   4  4.94250000E-05   -152 -136  137 #51      imp:n=1 u=3
53   7 -2.69900000E+00    152 -153 -136  137     imp:n=1 u=3
54   6  1.24933300E-01    153 -154 -350  351     imp:n=1 u=3
c   55   4  4.94250000E-05    153 -154 -148  149 #54 imp:n=1 u=3
c    log-a
56  12  1.86958000E-02   -155 -146  147          imp:n=1 u=3
57   4  4.94250000E-05   -155 -136  137 #56      imp:n=1 u=3
58   7 -2.69900000E+00    155 -156 -136  137     imp:n=1 u=3
59   6  1.24933300E-01    156 -157 -150  151     imp:n=1 u=3
c   60   4  4.94250000E-05    156 -157 -148  149 #59 imp:n=1 u=3
c    log-b
61  12  1.86958000E-02   -158 -146  147          imp:n=1 u=3
62   4  4.94250000E-05   -158 -136  149 #61      imp:n=1 u=3
63   7 -2.69900000E+00    158 -159 -136  149     imp:n=1 u=3
64   6  1.24933300E-01    159 -160 -350  351     imp:n=1 u=3
c   65   4  4.94250000E-05    159 -160 -148  137 #64 imp:n=1 u=3
c
270  2  8.66829700E-02  3 -4  15 -16 502 -503 #(17 -18) imp:n=1 u=3
c
c    bare-reflector (data ommited)
c
199  4  4.94250000E-05   #79 #(-42 84 -530) #13
         #270
         #21  #401   #24  #410    #27  #420
         #(-120 -122 123) #430 #(-136 163 -161) #440 #(-136 163 -181) #450
         #(-132 -136 137) #470 #(-141 -136 137) #480 #(-144 -136 149) #49
         #(-153 -136 137) #54
         #(-156 -136 137) #59
         #(-159 -136 149) #64
         #4  #5
         #(-232 234 -5) #(237 -238 -235) #(-242 -240 43)
         #310 #311 #312 #313
         imp:n=1 u=3
200  0              -81  82  -83  84  -85  86 imp:n=1 u=4 fill=3
201  2  8.66829700E-02      #200              imp:n=1 u=4
202  0              -91  92  -93  94  -95  96 imp:n=1 u=6 fill=4
281  19 1.37809E-01    91 -331 -335            imp:n=1 u=6
282  2  8.66829700E-02 91  331 -171 -335        imp:n=1 u=6
283  19 1.37809E-01    91 -332 -335            imp:n=1 u=6
284  2  8.66829700E-02 91  332 -172 -335        imp:n=1 u=6
285  19 1.37809E-01    91 -333 -335            imp:n=1 u=6
286  2  8.66829700E-02 91  333 -173 -335        imp:n=1 u=6
203  0 #281 #282 #283 #284 #285 #286          #202  imp:n=1 u=6
204  0  300 -301 302 -303 304 -305             imp:n=1 u=7 fill=6
205  2  8.66829700E-02  #204                  imp:n=1 u=7
206  0  306 -307 308 -309 310 -311             imp:n=1 u=8 fill=7
207  0  #206                          imp:n=1 u=8
208  0  312 -313 314 -315 316 -317             imp:n=1 u=9 fill=8
209  18  8.153E-2   #208                  imp:n=1 u=9
212  0  318 -319 320 -321 322 -323             imp:n=1 fill=9
211  0                   #212              imp:n=0

c
c    surface cards (origin x=0.0 y=0.0 z=0.0)
c    cylinder
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
500  pz   -0.0001
501  pz   -1.9999
502  py   -44.0
503  py    44.0
 1   pz     0.0
 2   pz    44.92
 3   pz   149.75
 4   pz   152.63
 5   pz    -2.04
11   px   -14.04
12   px    14.04
13   py   -34.515
14   py    34.515
15   px   -16.57
16   px    16.57
17   py   -37.045
18   py    37.045
c
41   c/x   -8.0  -10.0  3.905
42   c/x   -8.0  -10.0  4.455
531  c/x   -8.0  -10.0  1.3
532  c/x   -8.0  -10.0  1.5
533  c/x   -8.0  -10.0  2.65
534  c/x   -8.0  -10.0  3.0
530  px    220.0
c    41   gq    0.5 0.5 1. -1. 0. 0. 11.31371 -11.31371 20. 148.750975
c    42   gq    0.5 0.5 1. -1. 0. 0. 11.31371 -11.31371 20. 144.152975
43   pz   -16.0
44   pz   -19.0
45   py    50.0
46   py   -50.0
47   px    17.0
48   px   -83.0
c    49   py     78.48
c    50   px    -71.42
c   base plate lower pipe and hari
410  c/z     2.0  17.0  7.76
411  c/z     2.0  17.0  8.26
412  pz    -20.0
413  pz    -34.0
414  px      2.0
415  px    -68.0
416  py     35.0
417  py    -35.0
418  px      9.85
419  px    -75.85
420  py     42.85
421  py    -42.85
422  px      9.15
423  px    -75.15
424  py     42.15
425  py    -42.15
c
c   foot of tank
51   py    33.5
52   py    34.5
53   py    42.5
54   py   -33.5
55   py   -34.5
56   py   -42.5
57   pz   -15.0
c
c   pool wall
 81  pz    205.4
 82  pz    -35.0
 83  px    283.0
```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b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
 84  px   -119.0
 85  py    100.0
 86  py   -100.0
 91  pz    205.401
 92  pz    -36.5
 93  px    284.0
 94  px   -120.0
 95  py    101.0
 96  py   -101.0
c
c   neutron counter
c  ch-4
101  c/z    25.0     0.0  1.85
102  pz     50.281
103  pz      2.881
104  c/z    25.0     0.0  2.85
105  pz     42.081
106  pz      4.081
c  ch-5
107  c/z    24.5   -22.5   2.35
108  pz     46.91
109  pz      4.51
110  c/z    24.5   -22.5   3.35
111  pz     40.71
112  pz      5.71
c  ch-6
113  c/z   -24.5    25.0   2.35
114  pz     57.91
115  pz      4.51
116  c/z   -24.5    25.0   3.35
117  pz     50.71
118  pz      5.71
c  ch-7
119  c/z   -28.5 -30.0    4.499
120  c/z   -28.5 -30.0    4.5
121  c/z   -28.5 -30.0    5.5
122  pz     56.25
123  pz      5.15
124  pz     44.15
125  pz      8.15
c  ch-1 and 3
180  c/z    0.0  -47.0  1.0
161  c/z    0.0  -47.0  1.1
162  c/z    0.0  -47.0  2.1
163  pz    -15.999
164  pz      0.5
165  pz     39.5
166  pz     10.5
167  pz     29.5
c  ch-2
190  c/z    0.0   47.0  1.0
181  c/z    0.0   47.0  1.1
182  c/z    0.0   47.0  2.1
c
c pulsertron
325  c/z   -61.5   0.0  5.5
126  pz     83.23
127  pz     10.33
128  c/z   -61.5   0.0 10.5
129  pz     41.53
130  pz     11.53
c  st-a
131  c/z    -6.4   -59.1   1.95
132  c/z    -6.4   -59.1   2.25
133  c/z    -6.4   -59.1   3.25
134  pz    36.393
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
135  pz     2.103
136  pz    205.5
137  pz    -15.999
138  pz    42.535
139  pz    -2.465
c  st-b
140  c/z     6.4   59.1   1.95
141  c/z     6.4   59.1   2.25
142  c/z     6.4   59.1   3.25
c  lin-a
143  c/z    38.4   -57.3  4.7
144  c/z    38.4   -57.3  5.0
145  c/z    38.4   -57.3  5.5
146  pz     43.145
147  pz     -1.61
148  pz    205.5
149  pz     -34.999
150  pz     46.98
151  pz     -9.02
c  lin-b
152  c/z   -38.4   57.3    4.7
153  c/z   -38.4   57.3    5.0
154  c/z   -38.4   57.3    5.5
350  pz     46.98
351  pz     -9.02
c  log-a
155  c/z   -38.4  -57.3   4.7
156  c/z   -38.4  -57.3   5.0
157  c/z   -38.4  -57.3   5.5
c  log-b
158  c/z    38.4   57.3    4.7
159  c/z    38.4   57.3    5.0
160  c/z    38.4   57.3    5.5
c
330  pz     185.35
335  pz     340.35
c  crd-1
171  c/z    0.00    15.0  3.815
221  c/z    0.00    15.0  3.095
331  c/z    0.00    15.0  2.73
c  crd-2
172  c/z    0.00   -15.0  3.815
222  c/z    0.00   -15.0  3.095
332  c/z    0.00   -15.0  2.73
c  crd-3
173  c/z    0.0      0.0  3.815
223  c/z    0.0      0.0  3.095
333  c/z    0.0      0.0  2.73
c  spare
175  c/z    10.0    30.0  3.815
176  pz     184.5
c  n-4(level guage)
177  c/z   -10.5   -30.0   2.4
c  n-2(gas-outlet)
178  c/z   -25.0     7.5   1.7
c  n-5(driving device)
179  c/z    -9.0    30.0   2.13
c  n-7(thermocouple guide)
220  c/z    11.5   -25.0    1.6
225  pz     185.0
226  pz     5.5
227  pz     2.5
228  c/z    11.5   -25.0    0.865
229  c/z    11.5   -25.0    0.545
230  c/z    11.5   -25.0    1.475
231  c/z    11.5   -25.0    0.975
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
c
c   fuel feed pipe
232  c/z    12.5    29.0     1.36
233  c/z    12.5    29.0     1.07
234  pz    -9.6
235  gq    0.5 0.5 1. -1. 0. 0.  16.5     -16.5      22. 255.275
236  gq    0.5 0.5 1. -1. 0. 0.  16.5     -16.5      22. 255.98
c    235   c/x    29.0  -11.0 1.36
c    236   c/x    29.0  -11.0 1.07
238  p     1.  1. 0.  41.5
237  p     1.  1. 0.  19.0
c    238  px     12.5
c    237  px    -12.5
c    239  px      6.2
240  c/z     2.0      17.0     1.36
241  c/z     2.0      17.0     1.07
242  pz    -12.3601
c
c  Reflector support plate
c
c   Kirikaki
c
378  p   1. -1. 0. -51.33595
379  p   1. -1. 0.  51.33595
380  p   1.  1. 0.  51.33595
381  p   1.  1. 0. -51.33595
382  p   1. -1. 0. -12.02082
383  p   1. -1. 0.  12.02082
384  p   1.  1. 0.  12.02082
385  p   1.  1. 0. -12.02082
c
c  Hood and Concrete
c
300  px    -487.5
301  px     512.5
302  py    -290.0
303  py     610.0
304  pz    -290.0
305  pz     738.0
306  px    -488.2
307  px     513.2
308  py    -290.7
309  py     610.7
310  pz    -290.7
311  pz     738.7
312  px     -617.0
313  px      642.0
314  py     -400.0
315  py      910.0
316  pz     -295.0
317  pz      915.0
318  px     -797.0
319  px      842.0
320  py     -610.0
321  py     1090.0
322  pz     -395.0
323  pz     1065.0

c
c    data cards
c
mode  n                    $ transport neutrons only
c
c    material cards
c
c    R104(bare);U=464.2/A=0.852/D=1.6462
c    atomic density =  9.81034711E-02
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
m1    1001.37c     5.5582E-02
      7014.37c     2.8647E-03
      8016.37c     3.8481E-02
     92234.37c     9.5555E-07
     92235.37c     1.1858E-04
     92236.37c     1.1843E-07
     92238.37c     1.0562E-03
mt1   lwtr.01t    $  300k
c
c    sus304L(tank) 7.93g/cm3
c    atomic density  8.668297E-2
m2    6012.37c 7.1567E-05  $ C
     14000.37c 7.1415E-04  $ Si
     25055.37c 9.9095E-04  $ Mn
     15031.37c 5.0879E-05  $ P
     16000.37c 1.0424E-05  $ S
     28000.37c 8.5600E-03  $ Ni
     24000.37c 1.6725E-02  $ Cr
     26000.37c 5.9560E-02  $ Fe
c
c     water 25 deg.c
c
m3    1001.37c   6.6658E-02    $ H
      8016.37c   3.3329E-02    $ O
mt3   lwtr.01t                $ 300K
c
c     air
c
m4    7014.37c  3.9016E-05
      8016.37c  1.0409E-05
c
c    polyethylene 0.97g/cm3
m6    1001.37c   8.32889E-02
      6012.37c   4.16444E-02
mt6   poly.01t    $  300k
c
c    alminum 2.699g/cm3
m7   13027.37c  -100.0     $ Al
c
c    sus304 7.93g/cm3  (d)daiza,annaikan etc.
m9    6012.37c  -0.05      $ C
     14000.37c  -0.41      $ Si
     25055.37c  -0.93      $ Mn
     15031.37c  -0.030     $ P
     16000.37c  -0.004     $ S
     28000.37c  -8.29      $ Ni
     24000.37c -18.36      $ Cr
     26000.37c -71.930     $ Fe
c
c    st-a,b  (1.25762e-2)
m11   6012.37c  1.51491E-7   $ C
      8016.37c  3.02982E-7   $ O
     13027.37c  1.25729E-2   $ Al
     18040.37c  2.85066E-6   $ Ar
c
c    lin-a,b,log-a,b (1.86958e-2)
m12   7014.37c  3.82159E-5   $ N
     13027.37c  1.86576E-2   $ Al
c
c    ch-4(wl)   (5.02274e-2)
m13   6012.37c  8.92716E-8   $ C
      8016.37c  1.78543E-7   $ O
     13027.37c  5.02254E-2   $ Al
     18040.37c  1.70771E-6   $ Ar
c
c    ch-5      (1.07067e-1)
m14   7014.37c  3.11542E-5   $ N
```

b) MCNP4B Detailed-Model Input Listing for Run No.104, Table 7 (cont'd).

```
    13027.37c  1.07036E-1   $ Al
c
c    ch-6      (8.80834e-2)
m15   7014.37c  2.47374E-5   $ N
    13027.37c  8.80587E-2   $ Al
c    ch-7      (3.46630e-2)
m16   7014.37c  2.27114E-5   $ N
    13027.37c  3.46403E-2   $ Al
c     pulsartron
m17   6012.37c  3.54473E-5   $ C
    13027.37c  1.29223E-2   $ Al
    14000.37c  1.14537E-4   $ Si
    25055.37c  1.33181E-4   $ Mn
    15031.37c  7.73834E-6   $ P
    16000.37c  8.85058E-7   $ S
    28000.37c  1.11341E-3   $ Ni
    24000.37c  2.78370E-3   $ Cr
    26000.37c  1.01550E-2   $ Fe
c    HANDBOOK Concrete
m18   1001.37c  1.3742e-2          $ H
      8016.37c  4.5919e-2          $ O
      6012.37c  1.1532e-4          $ C
    11023.37c  9.6395e-4           $ Na
    12000.37c  1.2388e-4           $ Mg
    13027.37c  1.7409e-3           $ Al
    14000.37c  1.6617e-2           $ Si
    19000.37c  4.6052e-4           $ K
    20000.37c  1.5025e-3           $ Ca
    26000.37c  3.4492e-4           $ Fe
mt18   lwtr.01t
c
c      B4C (2.51g/cm3)
c     1.37809e-1
m19   5010.37c   2.18289e-2
      5011.37c   8.84185e-2
      6012.37c   2.75619e-2
c
c    criticality cards
c
kcode  5000 1.0  50  2050
sdef  cel=d1 x=d2 y=d3 z=d4  erg=d5
c
si1  1  212:208:206:204:202:200:79:1
sp1       1
c  *** x-coodinate
si2    h   -14.0  14.0
sp2     0  1
c  *** y-coodinate
si3    h   -34.5  34.5
sp3     0  1
c  *** z-coodinate
si4    h   0.0    44.92
sp4     0  1
c
sp5    -3
c
c     ctme   25
prdmp  j -100 1 3
c
print -175
```

A.2 <u>CRISTAL: APOLLO-2 / MORET-4 Input Listing</u> (Case 1, number 104)

The k eff calculation is run in two steps using two codes of the code system CRISTAL.

1. APOLLO 2 is a one-dimensional multigroup cell code. It is used to determine material buckling B m 2 , k infinite , and homogeneous macroscopic-medium cross sections. The APOLLO 2 Library usedis 172 groups CEA93 (cross sections coming from JEF2.2).

2. MORET IV is a three-dimensional multigroup Monte Carlo code. It uses macroscopic cross sections coming from APOLLO 2. Each calculation employed 1000 neutron histories.MORET 4 uses the P5 anisotropic treatment and 172-group library.

A pre-processor called CIGALES-PREAPOL is used to prepare the APOLLO 2 input code data.

Input code data of APOLLO 2 and MORET IV are provided, and also CIGALE input data as comments.

For the zinc, only 64 Zn is taken into account (48.6 at.% natural Zn) since no other cross-section data are available in the library for the natural Zn. Materials of low reactivity effect are homogenized according to their volume percentage.

In the following input example (Case 4) are provided:
· APOLLO2 input,
· PREAPOL-CIGALES input,
· MORET4 input.

In the Moret description the wall tank and the support plate 100x100x3.0 cm with its hole (7.76 cm dia.) are described

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 104 of Table 12.b.

```
*********************************************************
*            C.E.A / I.P.S.N. SYSTEM CODES              *
* CRISTAL :  APOLLO2 ( CEA93 172 gr library) - MORET 4    *
*.......................................................*
*            I.C.S.B.E.P : LEU-SOL-THERM-017            *
*                                                       *
*  STACY T280   UNREFLECTED EXPERIMENT U(9.97%)O2(NO3)2   *
*         CASE  01 NUMBER 104 :::  C(U)=464.2 g/l         *
*********************************************************
DEBUT_APOLLO2
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*      CIGALES version 1.0   en date du 06/01/2000
*                Creation du Fichier le 08/06/00 14:22:50
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*                   -=- INITIALISATION - CALCUL 1 -=-
CALCUL_CRISTAL = 1                                                ;
REPPROC            = OUVRIR: 22 'VARIABLE' 1024 10000
                               'ADRESSE' 'aprocristal'            ;
CHARGE_APROCRISTAL = LIRE: REPPROC 'APROC' 'CHARGE_APROCRISTAL'   ;
FERMER: REPPROC                                                   ;
EXECUTER CHARGE_APROCRISTAL                                       ;
TSTR TOPT = INITIALISER_CRISTAL 1                                 ;
*            -=- OPTIONS -=-
*
TOPT.'STCRI'.'NGROUP_FINAL' = 172                                 ;
TOPT.'STCRI'.'ANISOTROPIE'  = 'P5'                                ;
*
*==============================================================
* APOLLO PIJ CALCUL  1
*
ANISO = CONCAT: '&' TOPT.'STCRI'.'ANISOTROPIE'                    ;
*==============================================================
*
TITRE: ' air                                                      ' ;
* air
WRITE: TOPT.'RESU' '*air                                        ' ' ' ;
*
*            -=- Description des milieux -=-
*air
nom_calc =  'MILHOM1'                                             ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                          ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                 ;
TSTR.nom_calc = TABLE:                                            ;
*
nom_mil = 'air'                                                   ;
TOPT.'STMIL'.nom_mil = TABLE:                                     ;
TOPT.'STMIL'.nom_mil.'N14      '  =    4.19850E-05                ;
TOPT.'STMIL'.nom_mil.'O16      '  =    1.12630E-05                ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE'  =  21.                        ;
*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT                     ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM: &CYLI &MAIL 1 &EQD 1.
                            &MILI TSTR.'MILREF'.nom_mil 1         ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'IDB' TSTR.nom_calc.'GEO'
                                ( TEXTE TOPT.'REPBIB' )           ;
*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
                      TSTR.'MILREF'.nom_mil
                      &TOTA &SELF &ABSO &ENER &FISS &ENER
                      &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO   ;
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 104 of Table 12.b (cont'd).

```
*
*            -=- Creation de la Macrolib pour le milieu MILHOM1  -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO
         &FICH 47 &NOMMIL TSTR.'MILREF'.nom_mil nom_mil            ;
*==============================================================
* APOLLO PIJ CALCUL  2
*==============================================================
*
TITRE: ' stainless steel SUS304L                                    ' ;
* stainless steel SUS304L
WRITE: TOPT.'RESU' '*stainless steel SUS304L                    ' ' ' ;
*
*            -=- Description des milieux -=-
************************************************************
TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT                         ;
*stainless steel SUS304L
nom_calc =  'MILHOM2'                                               ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                            ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                   ;
TSTR.nom_calc = TABLE:                                              ;
*
nom_mil = 'stainless steel SUS304'                                  ;
TOPT.'STMIL'.nom_mil = TABLE:                                       ;
TOPT.'STMIL'.nom_mil.'FENAT    '  =    5.95600E-02                  ;
TOPT.'STMIL'.nom_mil.'CRNAT    '  =    1.67248E-02                  ;
TOPT.'STMIL'.nom_mil.'NINAT    '  =    8.55998E-03                  ;
TOPT.'STMIL'.nom_mil.'MN55     '  =    9.90953E-04                  ;
TOPT.'STMIL'.nom_mil.'CNAT     '  =    7.15673E-05                  ;
TOPT.'STMIL'.nom_mil.'SINAT    '  =    7.14148E-04                  ;
TOPT.'STMIL'.nom_mil.'P31      '  =    5.08793E-05                  ;
TOPT.'STMIL'.nom_mil.'S32      '  =    1.04556E-05                  ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE'  =  25.                          ;
*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT                       ;
*
*                         -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM: &CYLI &MAIL 1 &EQD 1.
                            &MILI TSTR.'MILREF'.nom_mil 1           ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'APOLIB'
                                TSTR.'IDB' TSTR.nom_calc.'GEO'
                                ( TEXTE TOPT.'REPBIB' )             ;
*
TSTR.nom_calc.'MAC' = MACROLIB: &EDIT TOPT.'STIMP'.'MACROLIB'
                      TSTR.'MILREF'.nom_mil
                      &TOTA &SELF &ABSO &ENER &FISS &ENER
                      &SNNN &TRAC &P0   &DIFF ANISO &TRAN ANISO      ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM2  -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
         &FICH 47 &NOMMIL TSTR.'MILREF'.nom_mil nom_mil            ;
*==============================================================
* APOLLO PIJ CALCUL  3
*==============================================================
*
TITRE: 'STACY T280 ** exp. N° 104  C(U)=464.2 g/l              CAS 3 ' ;
*STACY T280 ** exp. N° 104  C(U)=464.2 g/l              CAS 3
WRITE: TOPT.'RESU' 'NITR ANALY C(U)=464.200 C(PU)=0.000 '
' CAS 3'                                                              ;
*
*            -=- Description des milieux -=-
************************************************************
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 104 of Table 12.b (cont'd).

```
TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT                                ;
*NITR ANALY C(U)=464.200 C(PU)=0.000 H+=0.85 GD=0.00
nom_calc =  'MILHOM3'                                                      ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                                   ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                          ;
TSTR.nom_calc = TABLE:                                                     ;
*
nom_mil = 'NITR ANALY C(U)=464,20'                                         ;
TOPT.'STMIL'.nom_mil = TABLE:                                              ;
TOPT.'STMIL'.nom_mil.'U234     '  =    9.55545E-07                         ;
TOPT.'STMIL'.nom_mil.'U235     '  =    1.18577E-04                         ;
TOPT.'STMIL'.nom_mil.'U236     '  =    1.18429E-07                         ;
TOPT.'STMIL'.nom_mil.'U238     '  =    1.05618E-03                         ;
TOPT.'STMIL'.nom_mil.'H2O      '  =    2.77912E-02                         ;
TOPT.'STMIL'.nom_mil.'O16      '  =    1.06893E-02                         ;
TOPT.'STMIL'.nom_mil.'N14      '  =    2.86474E-03                         ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE'  =  25.                                 ;
*
TRES TSTR TOPT = GENERE_MILIEUX_S 2 TSTR TOPT                              ;
*
*                          -=- Creation de la geometrie -=-
*
TSTR.nom_calc.'GEO' = GEOM: &CYLI &MAIL 1 &EQD 1.
                            &MILI TSTR.'MILREF'.nom_mil  1                 ;
*
*            -=- Creation de la bibliotheque interne -=-
*
TSTR.'APOLIB' = BIBINT: &EDIT 1 TSTR.'APOLIB'
                                TSTR.'IDB' TSTR.nom_calc.'GEO'
                                ( TEXTE TOPT.'REPBIB' )                    ;
*
*            -=-  autoprotection -=-
*
TSTR.'GEOAU' = TSTR.nom_calc.'GEO'                                         ;
*
TRES TSTR TOPT = AUTOPROTECTION_CRI_S 1 TSTR TOPT                          ;
*
*            -=- Flux a B2 nul -=-
*
TOPT.'TYPE_B2' = 'NUL'                                                     ;
TRES TSTR TOPT = CALFLUX_PIJ_CRI_S 1 TSTR TOPT                             ;
*
*            -=- Flux a B2 critique -=-
*
SI ( TRES.'KINF' GT 1. )                                                   ;
TOPT.'TYPE_B2' = 'CRITIQUE'                                                ;
TRES TSTR TOPT = CALFLUX_PIJ_CRI_S 1 TSTR TOPT                             ;
FINSI                                                                      ;
*
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc.'B2' = TRES.'B2'                  ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc.'KINF' = TRES.'KINF'              ;
*
*            -=- Condensation homogeneisation  -=-
*
TRES TSTR TOPT = HOMOGE_COND_S  1 TSTR TOPT                                ;
*
*            -=- Creation de la Macrolib pour le milieu MILHOM3  -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
         &FICH 47 &NOMMIL TSTR.nom_calc.'MILEQ' nom_mil                    ;
*
EDTIME: ;
ARRET: ;
FIN_APOLLO2
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 104 of Table 12.b (cont'd).

```
***********************************************************
*             C.E.A / I.P.S.N. SYSTEM CODES               *
* CRISTAL :  APOLLO2 ( CEA93 172 gr library) - MORET 4    *
*.........................................................*
*            I.C.S.B.E.P : LEU-SOL-THERM-017              *
*                                                         *
*  STACY T280   UNREFLECTED EXPERIMENT U(9.97%)O2(NO3)2   *
*         CASE  01 NUMBER 104 :::  C(U)=464.2 g/l         *
***********************************************************
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
*      CIGALES version 1.0   en date du 06/01/2000
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
(
 air
*air
*------- Données milieu de structure-------
* ---  Milieu  1 CONC. ATOMIQUES- %volumique  100
*             N14           4.1985E-05
*             O16           1.1263E-05
)
OPTION  V4 GROUP 172 P5 FINOPTION
MORET
 GEOM HOMO
CHIMIE
*air
 MICRO 1 2
          N14         O16
   CONC   4.1985E-05  1.1263E-05
FINC
SECTION TOUT
FIN
(
 stainless steel SUS304L
*stainless steel SUS304L
*------- Données milieu de structure-------
* ---  Milieu  1 %-prop MASSIQUES- Dens= 7.93- %volumique  100
*             FENAT         69.652          CRNAT         18.21
*             NINAT         10.52           MN55          1.14
*             CNAT          0.018           SINAT         0.42
*             P31           0.033           S32           0.007
)
OPTION  V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
 GEOM HOMO
CHIMIE
*stainless steel SUS304L
 MICRO 1 8
          FENAT         CRNAT         NINAT         MN55
          CNAT          SINAT         P31           S32
   CONC   5.956003E-02  1.672481E-02  8.559981E-03  9.909532E-04
          7.156727E-05  7.14148E-04   5.087931E-05  1.045559E-05
FINC
SECTION TOUT
FIN
*                   RAPPEL GEOMETRIE
*_____________________________________________________________________
* GEOMETRIE HOMOGENE    BIBLIO CEA93.V4  172 groupes ANISOTROPIE P5
*=====================================================================
* MILIEU FISSILE 1:
* LOI DE DILUTION : Nitrate analyse
*     Densité :1.6462
*_____________________________________________________________________
*     VECTEUR ISOTOPIQUE    MASSE
*_____________________________________________________________________
*     Uranium:
*     U234:  0.08
*     U235:  9.97
*     U236:  0.01
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 104 of Table 12.b (cont'd).

```
*      U238: 89.94
*________________________________________________________________________
*  Delta Date (Analyse chimique - Analyse isotopique) :
*  Delta Date (Expérience - Analyse chimique) :
*  Impuretés (g/l) :
*   Fe=0.000  Cr=0.000  Ni=0.000  Mn=0.000  Ca=0.000  Cu=0.000
*   Al=0.000  Mg=0.000  Zn=0.000  Na=0.000  Co=0.000
*________________________________________________________________________
* MASSES ATOMIQUES MOYENNES
* Uranium: 237.74411 - Plutonium:  - Uranium+Plutonium:
*________________________________________________________________________
*      POISON (g/l) :  Gd=.    Cd=.   Bnat=.
*      ACIDITE : 0.852 N
*========================================================================
(
STACY T280 ** exp. N° 104  C(U)=464.2 g/l             CAS 3
*NITR ANALY    C(U)=464.200    C(PU)=0.000      H+=0.85    GD=0.00
SORTIE SECTIONS TOUTE LA CELLULE
)
OPTION V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
GEOMETRIE HOMOGENE
CHIMIE
*NITR ANALY    C(U)=464.200    C(PU)=0.000      H+=0.85    GD=0.00
 MICRO 1 7
                U234         U235         U236         U238
                H2O          O16          N14
   VERIF 1.6462 9.555454E-07 1.185767E-04 1.184288E-07 1.056176E-03
                0.0277912    1.068932E-02 2.864736E-03
FINC
SECTION TOUT
FIND
DEBUT_MORET4
EXPERIMENT STACY T280 UNREFLECTED c(U) = 464.2 g/l
* with pool tank wall and support plate 100x100x3 cm  (+ hole 7.76 cm dia.)
* LEU-COMP-THERM-017 case 01
*
* milieux : (1) air      (2) st.st. SS304     (3) nitrate solution
 MINIMUM 40 SIGE 0.000330 SIGI 0.000330 PAS 20
NOBILAN
CHIMIE   SEALINK 3   APO2 3   1  2  3    FINC
GEOMETRIE
* pool tank wall
     TYPE 1 BOITE 201 101 120
       VOLUME 1 0 1 2 201 0.0 120
       RBOITE 0 0  0 0  0 0
     TYPE 2 BOITE 200 100 119.25
       VOLUME 2 1 2 1 201 0.0 120.75
* support plate
     TYPE 3 BOITE 50 50 1.5
       VOLUME 3 2 3 2 85.57 0.0 19.0
*   hole 7.76 cm diameter
     TYPE 10 CYLZ 3.88 1.5
     VOLUME 10 3 10 1 121.0 17.0 19.0
*  stainless steel tank
     TYPE 4 BOITE 16.57 37.045  77.335
        VOLUME 4 2 4 2 119.0 0.0 111.835
*  inner air
     TYPE 5 BOITE 14.04 34.515  74.875
        VOLUME 5 4 5 1 119.0 0.0 111.415
*  fissile solution  Hc = 44.92
     TYPE 6  BOITE 14.04 34.515  22.46
        VOLUME  6 5  6 3 119.0 0.0  59.00
FING
*   sources de neutron
* ---------------------
SOURCE NRES
    POINT  300  6  119.0 0.0  49.0
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 104 of Table 12.b (cont'd).

```
    POINT  400  6  119.0 0.0  59.0
    POINT  300  6  119.0 0.0  69.0
FINS
SORTIE
MAIL 1 5 21 48 95 135 172
GLOBAL
CARA
FSORTIE
GRAPHIQUE Z 40  FGRAPH
GRAPHIQUE X 0.0 FGRAPH
FINDONNEES
FIN_MORET4
```

A.3 KENO Input Listing

SCALE4.3 KENO V.a cases with Hansen-Roach 16-group, CSAS 27-group ENDF/B-IV, and CSAS 238-group ENDF/B-V cross sections were run with 1000 generations of 1000 neutrons each, after skipping 50 generations, for a total of 1 million neutron histories.

KENO-V.a Input Listing for Run 104 of Table 12.c (SCALE4.3 27-group ENDF/B-IV cross sections)

```
=csas25   parm=size=200000
LEU-SOL-THERM-017 Run no. 104  27 group
27groupndf4 infhommedium
'FUEL
u-234   1 0 9.5555-7 end
u-235   1 0 1.1858-4 end
u-236   1 0 1.1843-7 end
u-238   1 0 1.0562-3 end
h       1 0 5.5582-2 end
n       1 0 2.8647-3 end
o       1 0 3.8481-2 end
'AIR
n       2 0 3.9016-5 end
o       2 0 1.0409-5 end
'STAINLESS STEEL
c       3 0 7.1567-5 end
si      3 0 7.1415-4 end
mn      3 0 9.9095-4 end
p       3 0 5.0879-5 end
s       3 0 1.0424-5 end
ni      3 0 8.5600-3 end
cr      3 0 1.6725-2 end
fe      3 0 5.9560-2 end
end comp
LEU-SOL-THERM-017 Run no. 104  27 group
read parm  gen=1050 npg=1000 nsk=50  end parm
read geom
unit  1
com="unit 1 is fissile unit (in upper part)"
cuboid  1 1 14.04 -14.04 34.515 -34.515 44.92 0
cuboid  2 1 14.04 -14.04 34.515 -34.515 149.75 0
cuboid  3 1 16.57 -16.57 37.045 -37.045 152.63 -2.04
cuboid  2 1 16.57 -16.57 100 -100 203.5 -2.04
cuboid  3 1 16.57 -16.57 101 -101 203.5 -2.04
unit  2
com="unit 2 is north end in upper part"
cuboid  2 1 50.715 -50.715 100 -100 203.5 -2.04
cuboid  3 1 50.715 -50.715 101 -101 203.5 -2.04
unit  3
com="unit 3 is south end in upper part"
cuboid  2 1 132.715 -132.715 100 -100 203.5 -2.04
cuboid  3 1 133.715 -133.715 101 -101 203.5 -2.04
unit  4
com="unit 4 is 3 unit (units 2 1 3) array"
array  1 0 0 0
unit  5
com="unit 5 is lower part"
cylinder  2 1 7.76 3 0
cuboid  3 1 15 -85 33 -67 3 0
cuboid  2 1 280 -120 83 -117 16.96 -16
cuboid  3 1 281 -121 84 -118 16.96 -17.5
end geom
read array
ara=1 nux=3  fill 2 1 3 end fill
ara=2 nuz=2  fill 5 4 end fill
end array
read start
nst=1
xsm=106  xsp=134
ysm=67   ysp=135
zsm=39   zsp=83
end start
end data
end
```

APPENDIX B: DENSITY FORMULA[a]

The density formula usable for U(VI)-nitrate aqueous solution, Pu(IV)-nitrate aqueous solution and U(VI)-Pu(IV)-nitrate aqueous solution was used for sensitivity calculations in Section 2 and for calculating the bias in the benchmark-model k_{eff} due to temperature. The equation is as follows:

$$\begin{aligned}
\rho = {} & 0.99833 + 1.6903\times10^{-3}\cdot C_{Pu25} + 1.4276\times10^{-3}\cdot C_{U25} \\
& + 3.9956\times10^{-2}\cdot C_{HN25} - 8.696\times10^{-8}\cdot (C_{Pu25})^2 \\
& - 1.087\times10^{-7}\cdot (C_{U25})^2 - 8.513\times10^{-4}\cdot (C_{HN25})^2 \\
& - 5.442\times10^{-6}\cdot T^2 - 4.4889\times10^{-5}\cdot C_{Pu25}\cdot C_{HN25} \\
& - 1.310\times10^{-6}\cdot C_{Pu25}\cdot T - 1.564\times10^{-5}\cdot C_{U25}\cdot C_{HN25} \\
& - 9.487\times10^{-7}\cdot C_{U25}\cdot T - 8.684\times10^{-5}\cdot C_{HN25}\cdot T,
\end{aligned}$$

where

ρ : density of solution at T (g/cm^3),
C_{Pu25} : concentration of plutonium at 25 °C (g/liter),
C_{U25} : concentration of uranium at 25 °C (g/liter),
C_{HN25} : concentration of free nitric acid at 25 °C (mol/liter),
T : temperature (°C).

The equation is valid under the following conditions:

C_{U25}<530 g/liter,
C_{Pu25}<480 g/liter,
$C_{Pu25}+C_{U25}$<350 g/liter (valid for mixed fuel solution),
C_{HN25}<7 mol/liter,
10<T<60 °C.

The accuracy of this equation is 0.0032 g/cm^3.

[a] S. Sakurai and S. Tachimori, "Modified density equation for aqueous solutions with plutonium (IV), uranium (IV) and nitric acid," JAERI-M 88-127 (1988) (in Japanese).

APPENDIX C DERIVATION OF ATOM DENSITIES OF FUEL SOLUTION

Run 104 (No Reflector)

Atomic weight of H=	A1=	1.0079
Atomic weight of N=	A7=	14.0067
Atomic weight of O=	A8=	15.9994
Atomic weight of U234=	A24=	234.0409
Atomic weight of U235=	A25=	235.0439
Atomic weight of U236=	A26=	236.0456
Atomic weight of U238=	A28=	238.0508
Wt.% of U234=	W24=	0.08
Wt.% of U235=	W25=	9.97
Wt.% of U236=	W26=	0.01
Wt.% of U238=	W28=	89.94
Uranium concentration (g/l)=	UD=	464.2
Free nitric acid concentration (mol/l)=	AC=	0.852
Solution density (g/cc)=	D=	1.6462
Avogadro's number=	AV=	0.60221
Atom density of U234=N24=	UD/1000*W24/100/A24*AV=	9.5555E-07
Atom density of U235=N25=	UD/1000*W25/100/A25*AV=	1.1858E-04
Atom density of U236=N26=	UD/1000*W26/100/A26*AV=	1.1843E-07
Atom density of U238=N28=	UD/1000*W28/100/A28*AV=	1.0562E-03
Total uranium atom density=	UN=	1.1758E-03
	HNO3	
NH(HNO3)=	AC/1000*AV=	5.1308E-04
NN(HNO3)=	AC/1000*AV=	5.1308E-04
NO(HNO3)=	AC/1000*AV*3=	1.5392E-03
Density of HNO3 (g/cc)=DN=	AC*(A1+A7+3*A8)/1000=	0.053686906
	UO2(NO3)2	
Molecular weight of UO2(NO3)2=MWU=	(N24*A24+N25*A25+N26*A26 +N28*A28)/UN+2*A7+8*A8=	393.7527074
Density of UO2(NO3)2=DU=	MWU*UN/AV=	0.76880983
Density of H2O=DH=	D-DU-DN=	0.823703265
NH(H2O)=	DH/(2*A1+A8)*AV*2=	5.5069E-02
NO(H2O)=	DH/(2*A1+A8)*AV=	2.7535E-02
Atom density of H=	NH(HNO3)+NH(H2O)=	5.5582E-02
Atom density of O=	NO(H2O)+NO(HNO3)+8*UN=	3.8481E-02
Atom density of N=	NN(HNO3)+2*UN=	2.8647E-03