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

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IDENTIFICATION NUMBER: LEU-SOL-THERM-016 SPECTRA

KEY WORDS: acceptable, critical experiment, homogeneous, low-enriched uranium, moderated, slab, solution, STACY, thermal, uranyl nitrate, water-reflected

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiments

The seven critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed from 1997 to the summer of 1998 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 experiments. The uranium concentration was adjusted, in stages, to values in the range of approximately 464 gU/l to 300 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-017 (unreflected).

All seven 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). 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.

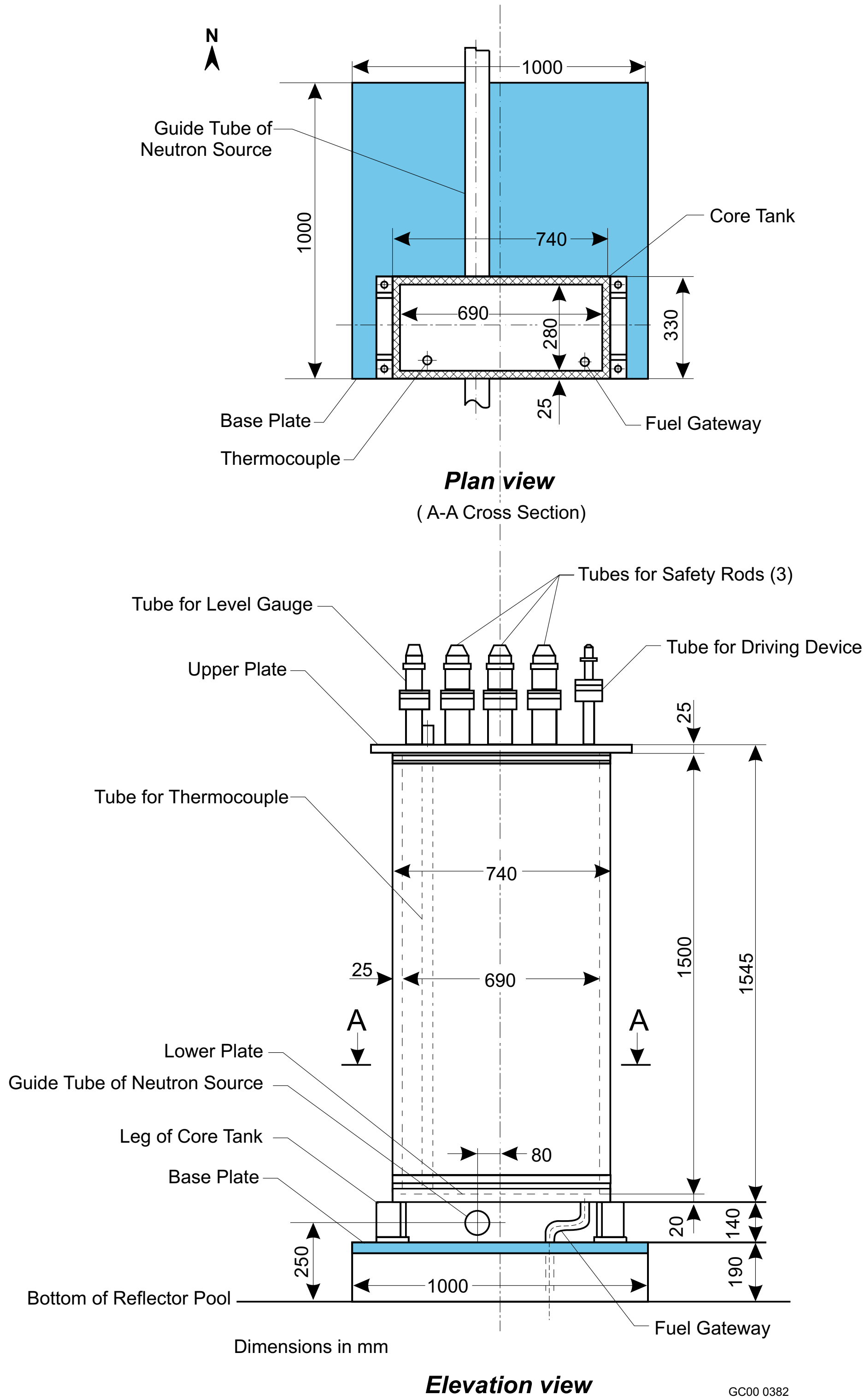


Figure 1. Schematic View of STACY Core Tank.
(design dimensions)

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 (1σ).

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 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 water-reflector 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), 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. For the experiments in the water-reflected condition, the water-reflector pool was filled with water to approximately 20 cm above the top of the core tank.

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.

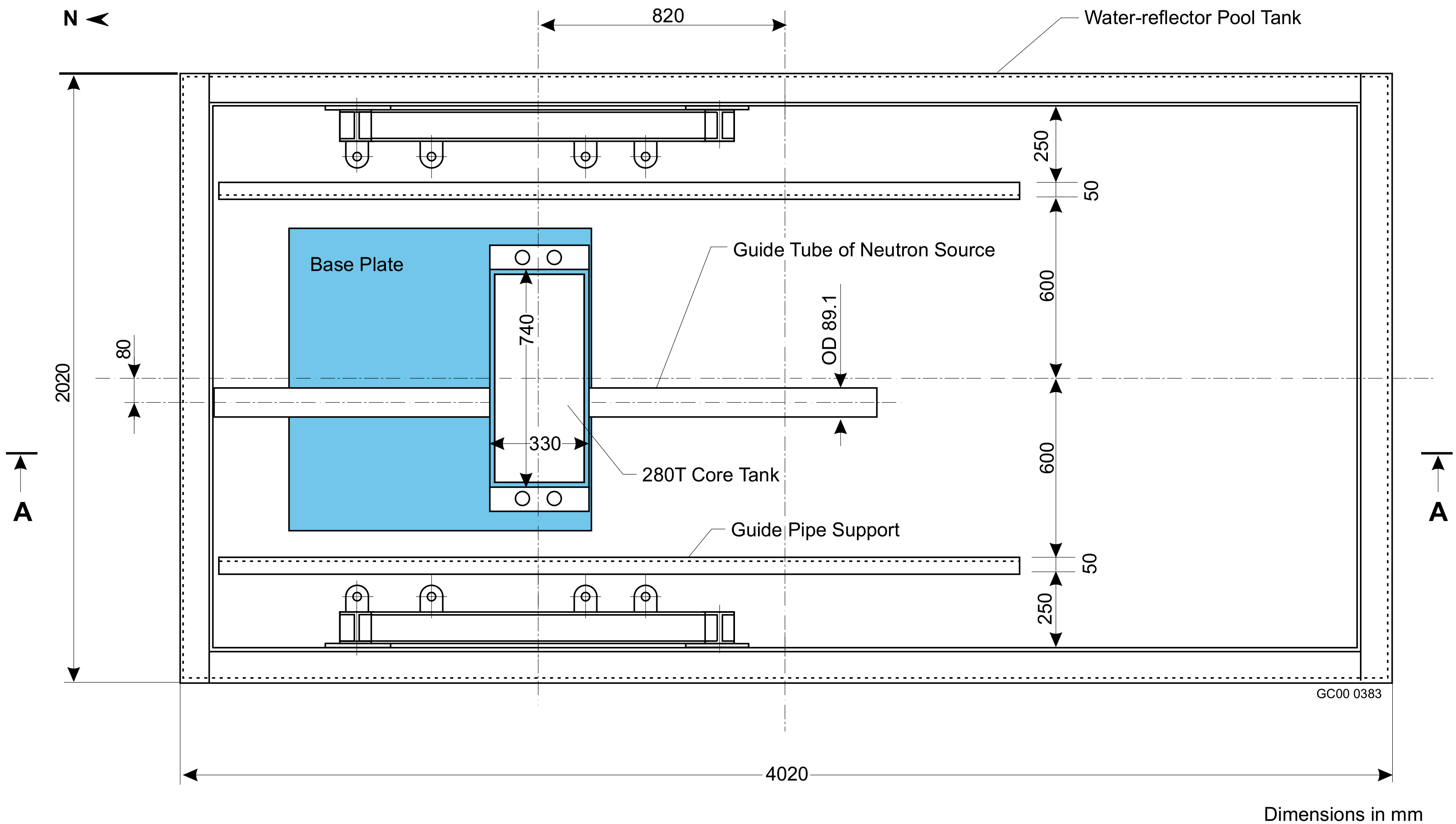


Figure 2.a. View from Above of the Water-Reflector Pool Tank.

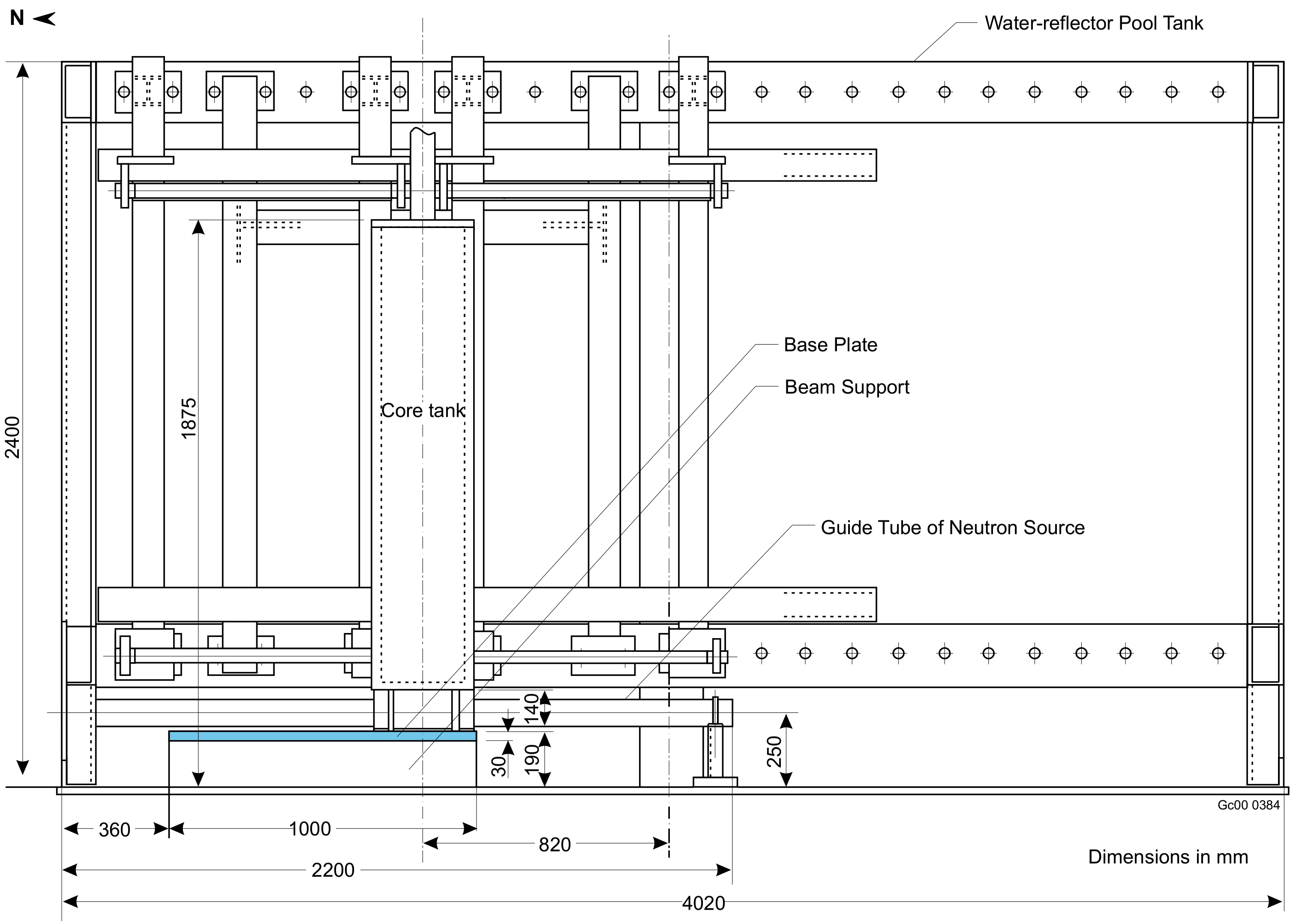


Figure 2.b. Elevation View of the Water-Reflector Pool Tank (A-A Cross Section).

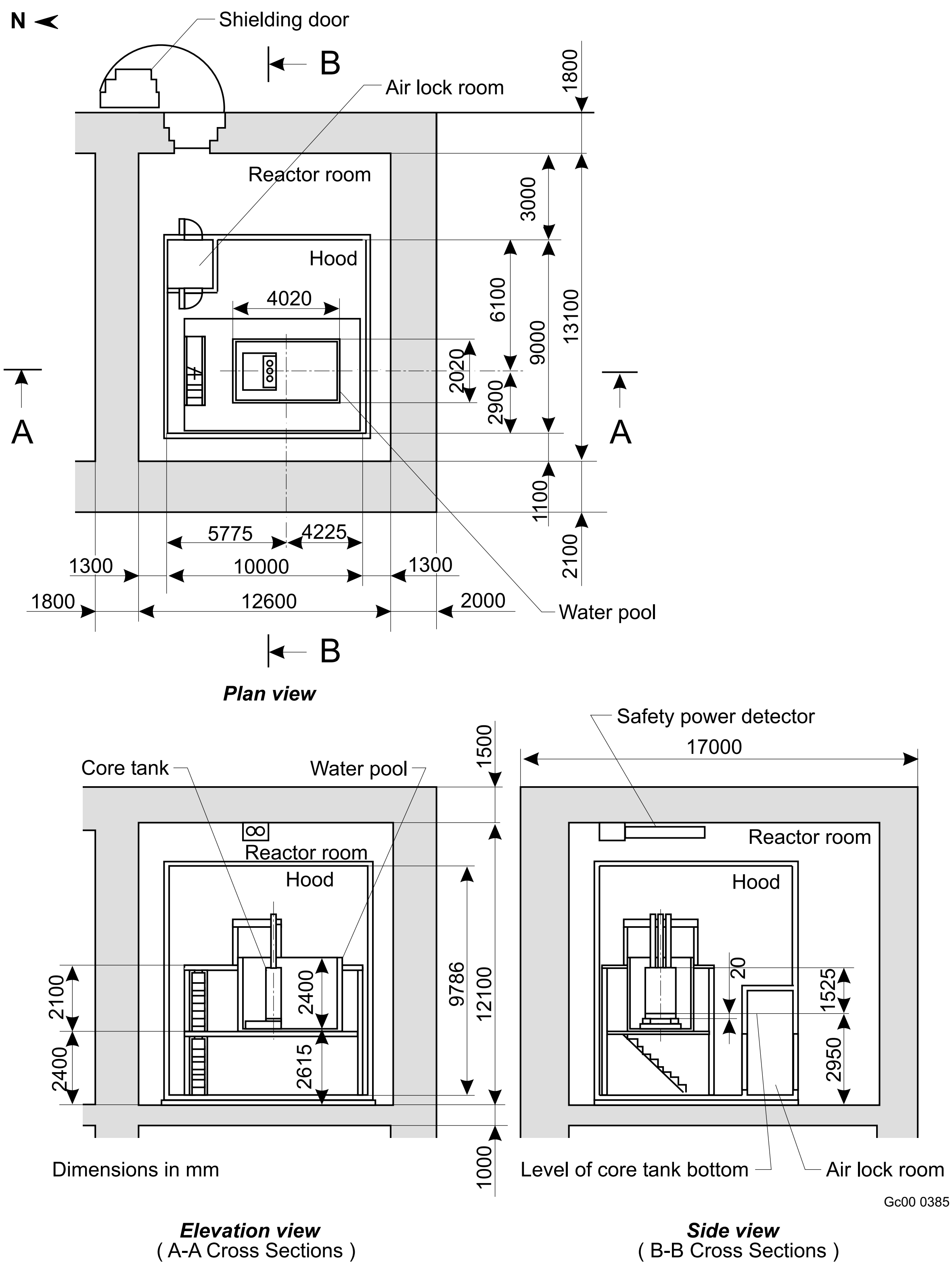


Figure 3. Schematic View Inside the Reactor Room.

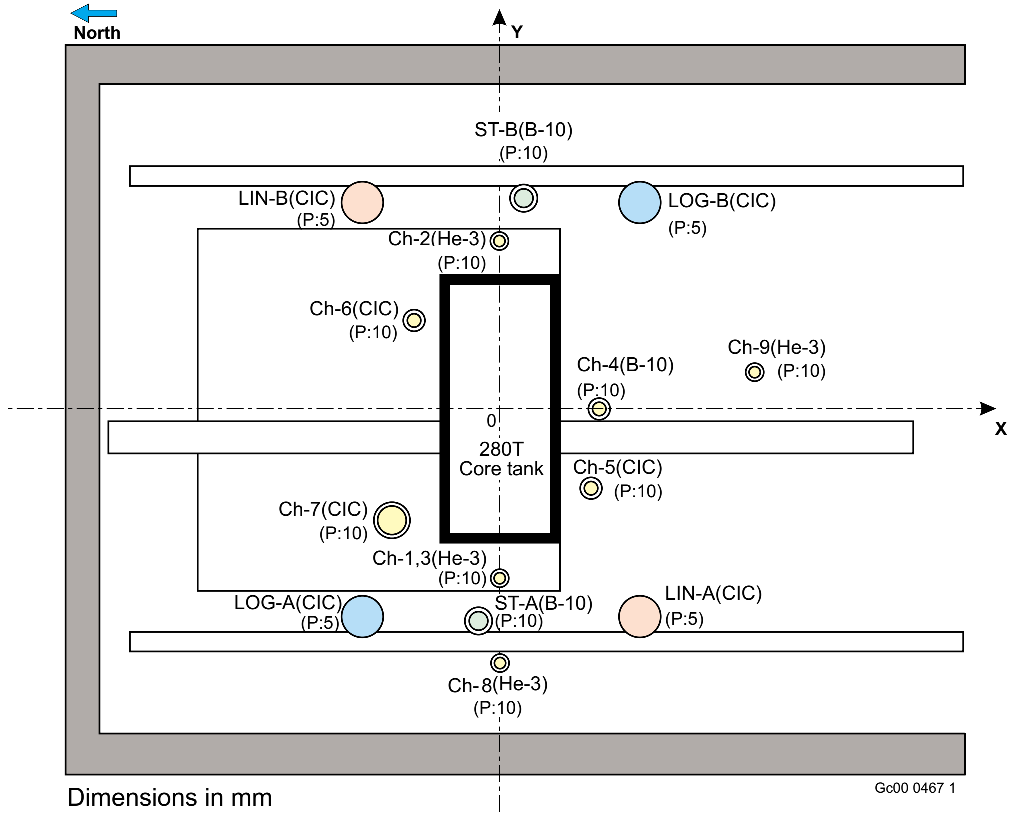
The accuracy of the level gauge (0.2 mm) was determined during the inspection at manufacture, using a highly accurate gauge as reference. The reproductive performance of this gauge, which is confirmed every annual inspection by using a higher-accuracy gauge, is almost within 0.02 mm (1/10 of the accuracy). 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 the level gauge.

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.105 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 on 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) on the south side. Further, a pulsed neutron source (Pulsatron) was located outside the core for Runs No. 125, 129, 131, and 140. 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 seven 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, respective
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. 105, Water-Reflected).

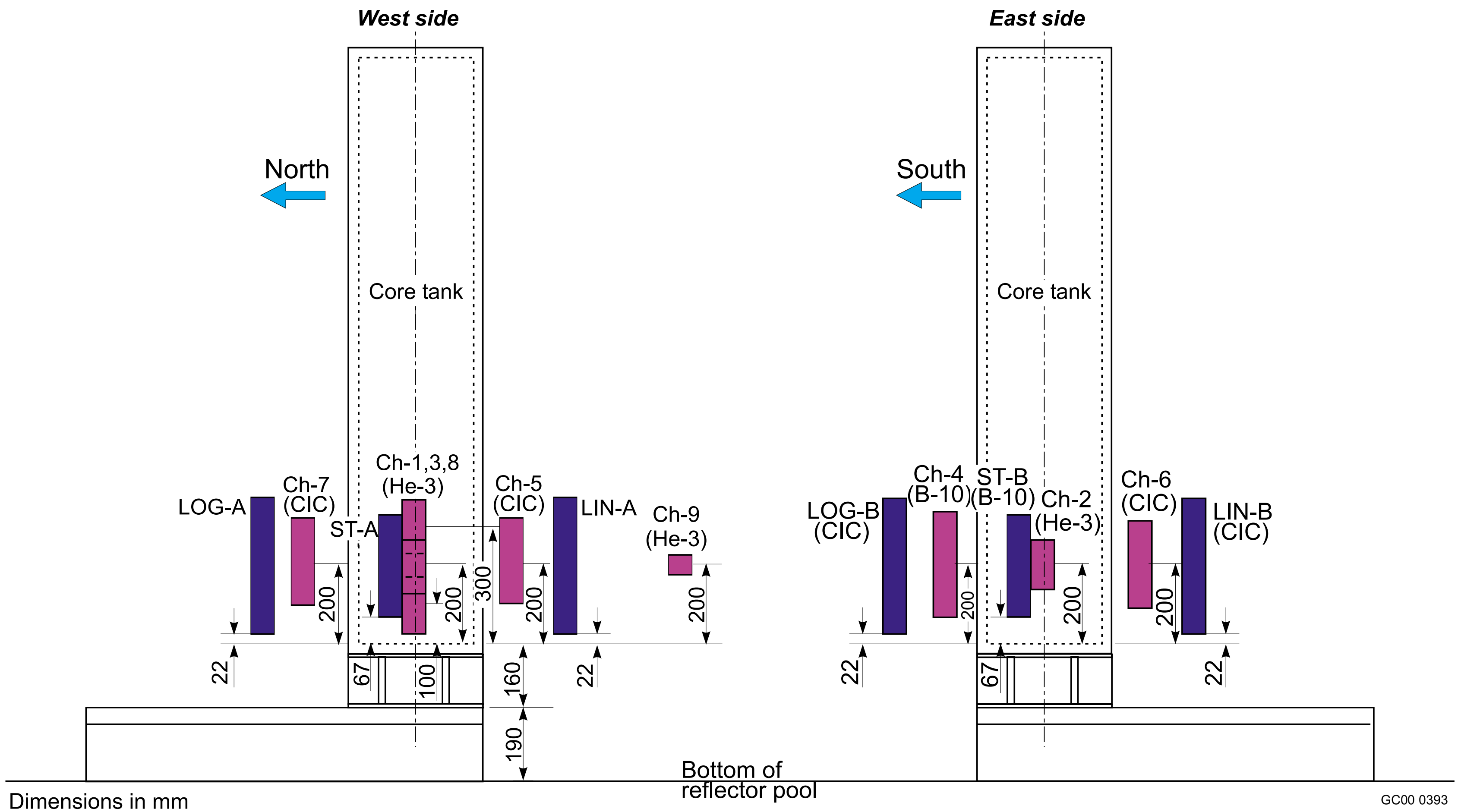


Figure 4.b. Counter Locations from West.

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 300 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 Water-Reflected Cores.

Run No	Date yy/mm/dd	Reflector	Fuel Solution Characteristics (25.0 °C)			Critical Height (cm)	Temp. (°C)
			U conc. (gU/l)	H^+ conc. (mol/l)	Density (g/cm^3)		
105	97/04/16	Water	464.2±0.8	0.852±0.018	1.6462±0.0005	40.09±0.02	23.8
113	97/05/07	Water	429.9±0.8	0.800±0.020	1.5997±0.0005	42.77±0.02	24.8
125	97/06/18	Water	371.9±1.1	0.800±0.020	1.5237±0.0005	51.37±0.02	23.1
129	97/07/04	Water	350.8±0.7	0.800±0.020	1.4957±0.0005	56.96±0.02	23.7
131	97/07/10	Water	328.9±0.6	0.800±0.020	1.4665±0.0005	66.39±0.02	23.4
140	97/10/08	Water	311.4±0.7	0.955±0.015	1.4465±0.0005	81.47±0.02	21.7
196	98/08/26	Water	299.6±0.6	0.965±0.015	1.4318±0.0004	102.34±0.02	22.8

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 on the uranium concentration was determined to be 1.0 gU/l. The

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

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.304L (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 <u>Supplemental Experimental Measurements</u>

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.

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.

2.0 EVALUATION OF EXPERIMENTAL DATA

2.1 General Notes

Seven 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 a 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 7.9-cm extrapolation length in the Z (vertical) direction were performed for the horizontal-dimension sensitivity studies. The XZ calculations with 10.1-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.						
		105	113	125	129	131	140	196
U enrichment	±0.013 wt.%	±0.038	±0.040	±0.042	±0.044	±0.045	±0.046	±0.047
U concentration	±1.0 gU/l	±0.031	±0.039	±0.056	±0.064	±0.073	±0.082	±0.089
H^+ concentration	±0.02 mol/l	-/+0.032	-/+0.031	-/+0.030	-/+0.029	-/+0.029	-/+0.029	-/+0.029
Solution density	±0.0005 g/cm^3	±0.020	±0.018	±0.014	±0.012	±0.010	±0.009	±0.007
Solution height	±0.2 mm	±0.010	±0.008	±0.005	±0.004	±0.003	±0.001	±0.001
Temperature	±0.3 °C	-/+0.011	-/+0.012	-/+0.010	-/+0.010	-/+0.009	-/+0.007	-/+0.008
Impurity (Fe)	+252 mg/l	-/+0.005	-/+0.006	-/+0.007	-/+0.007	-/+0.007	-/+0.008	-/+0.008
Impurity (Cr)	+67 mg/l	-/+0.002	-/+0.002	-/+0.002	-/+0.003	-/+0.003	-/+0.003	-/+0.003
Impurity (Ni)	+45 mg/l	-/+0.002	-/+0.002	-/+0.002	-/+0.002	-/+0.002	-/+0.002	-/+0.002
Total		±0.064	±0.068	±0.079	±0.085	±0.092	±0.099	±0.106

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 3.3 °C (25-21.7 °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.						
		105	113	125	129	131	140	196
Solution thickness	±0.05cm	±0.046	±0.046	±0.047	±0.047	±0.047	±0.048	±0.048
Solution width	±0.05cm	±0.011	±0.011	±0.011	±0.011	±0.011	±0.011	±0.011
Side-wall thickness (X)[(a)]	±0.01cm	±0.004	±0.004	±0.004	±0.004	±0.004	±0.004	±0.004
Side-wall thickness (Y)[(b)]	±0.01cm	<±0.001	<±0.001	<±0.001	<±0.001	<±0.001	<±0.001	<±0.001
Lower-plate thickness	±0.01cm	<±0.001	<±0.001	<±0.001	<±0.001	<±0.001	<±0.001	<±0.001
Total		±0.047	±0.047	±0.048	±0.048	±0.048	±0.050	±0.050

(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 seven critical configurations included in this evaluation are acceptable benchmark experiments.

3.0 BENCHMARK SPECIFICATION

3.1 Description of Benchmark Model

The benchmark model is shown in Figure 5. The model consists of the fuel solution, the core tank, and the water reflector. The following structure and devices are not included in the benchmark model, for simplification:

(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. 125, 129, 131 and 140) 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.105 was shown in Figure 4.
(10) Structures and devices on the top of the core tank: guide tubes of the safety rods, the 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.

To estimate the model simplification effect for each core configuration, a detailed model that includes the structures (1)-(13) was constructed. 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.

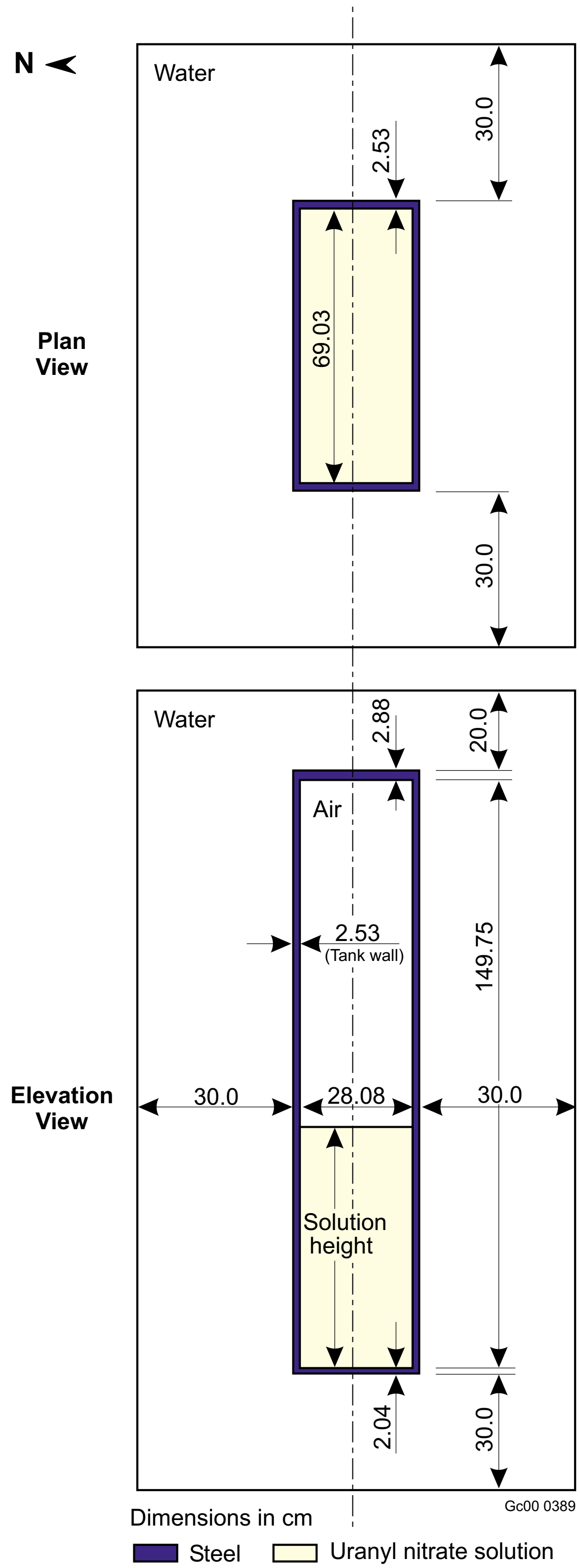


Figure 5. Benchmark Model of the STACY Experiments.

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	
105	1.01106±0.00025	1.01100±0.00025	0.006±0.035
113	1.01122±0.00023	1.01069±0.00024	0.053±0.033
125	1.01031±0.00023	1.00998±0.00023	0.033±0.033
129	1.00930±0.00022	1.00900±0.00023	0.030±0.032
131	1.00886±0.00021	1.00874±0.00022	0.012±0.030
140	1.00779±0.00021	1.00686±0.00021	0.093±0.030
196	1.00916±0.00021	1.00860±0.00021	0.056±0.030

The model simplification effects are not definitely known. Thus, the biases in calculated k_{eff} of the benchmark model are estimated to be none, but uniformly considered as the uncertainty of 0.1% 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.

3.2 Dimensions

The dimensions of the benchmark model are given 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 tank is centered horizontally in a rectangular water reflector. The thickness of the water reflector is 30 cm on the sides and bottom, and 20 cm on the top.

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

Table 8. Critical Solution Heights.

Run No.	Critical Solution Height (cm)
105	40.09
113	42.77
125	51.37
129	56.96
131	66.39
140	81.47
196	102.34

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.	Reflector	^{234}U	^{235}U	^{236}U	^{238}U	H	N	O
105	Water	9.5555E-07	1.1858E-04	1.1843E-07	1.0562E-03	5.5582E-02	2.8647E-03	3.8481E-02
113	Water	8.8494E-07	1.0981E-04	1.0968E-07	9.7813E-04	5.6459E-02	2.6597E-03	3.8146E-02
125	Water	7.6555E-07	9.4999E-05	9.4881E-08	8.4617E-04	5.7800E-02	2.3658E-03	3.7641E-02
129	Water	7.2211E-07	8.9609E-05	8.9498E-08	7.9816E-04	5.8265E-02	2.2589E-03	3.7445E-02
131	Water	6.7703E-07	8.4015E-05	8.3910E-08	7.4833E-04	5.8738E-02	2.1480E-03	3.7238E-02
140	Water	6.4101E-07	7.9545E-05	7.9446E-08	7.0852E-04	5.8778E-02	2.1527E-03	3.7137E-02
196	Water	6.1672E-07	7.6531E-05	7.6435E-08	6.8167E-04	5.9066E-02	2.0989E-03	3.7057E-02

The temperature of water of the benchmark model is 25 °C. The density of water at 25 °C is 0.99704 (g/cm^3). The atom densities (atom/barn-cm) of the water reflector derived from this density are as follows:

H: $6.6658\text{x}10^{-2}$ and
O: $3.3329\text{x}10^{-2}$.

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 are 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 temperatures for the core configurations vary from 21.7 °C to 24.8 °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 formulas in Section 2.2 were used to derive the temperature-effect data. The cross section modifications 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} (%)
105	23.8 °C	1.00448	1.00493	-0.045
113	24.8 °C	1.00512	1.00520	-0.008
125	23.1 °C	1.00583	1.00644	-0.061
129	23.7 °C	1.00565	1.00607	-0.043
131	23.4 °C	1.00562	1.00610	-0.049
140	21.7 °C	1.00435	1.00516	-0.081
196	22.8 °C	1.00540	1.00601	-0.061

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).

In fact, only the temperature effects are considered to be biases in the benchmark models. They are estimated in Section 3.4.

As discussed in Section 3.1, the model simplification effects are not definitely known and are uniformly considered as uncertainties of 0.1% in all the benchmark models. Also, 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 105	0.9996±0.0013,
Run 113	0.9999±0.0013,
Run 125	0.9994±0.0014,
Run 129	0.9996±0.0014,
Run 131	0.9995±0.0014,
Run 140	0.9992±0.0015, and
Run 196	0.9994±0.0015.

4.0 RESULTS OF SAMPLE CALCULATIONS

The results of the sample calculations using MCNP 4B and THREEDANT[a] 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 σ=0.033 %) were used for sample calculations. The results are given in Table 12.b. The results of KENO V.a and MCNP 4B 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)	THREEDANT (16-Energy-Group JENDL-3.2)
105	1.0111 ± 0.0003	1.0112
113	1.0112 ± 0.0002	1.0117
125	1.0103 ± 0.0002	1.0118
129	1.0093 ± 0.0002	1.0113
131	1.0089 ± 0.0002	1.0110
140	1.0078 ± 0.0002	1.0096
196	1.0092 ± 0.0002	1.0107

[a] Alcouffe, R. E., et al.: DANTSYS: A Diffusion Accelerated Neutral Particle Transport Code System, LA-12969-M, (1995).

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

Code (Cross Section Set) → Run No. ↓	APOLLO-2 / MORET-4 (172-group CEA93 Library)
105	1.0091 ± 0.00033
113	1.0092 ± 0.00033
125	1.0083 ± 0.00033
129	1.0079 ± 0.00033
131	1.0061 ± 0.00033
140	1.0055 ± 0.00033
196	1.0066 ± 0.00033

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

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

Code (Cross Section Set) → Run No. ↓	KENO			MCNP	
	Hansen-Roach	27-Group (ENDF/B-IV)	238-Group (ENDF/B-V)	Continuous Energy ENDF/B-V	Continuous Energy ENDF/B-VI
105	1.0034 ± 0.0009	1.0070 ± 0.0009	1.0057 ± 0.0009	1.0074 ± 0.0008	1.0023 ± 0.0008
113	1.0047 ± 0.0008	1.0083 ± 0.0010	1.0068 ± 0.0008	1.0093 ± 0.0007	1.0011 ± 0.0008
125	1.0086 ± 0.0008	1.0056 ± 0.0009	1.0056 ± 0.0008	1.0056 ± 0.0007	1.0016 ± 0.0007
129	1.0106 ± 0.0009	1.0115 ± 0.0009	1.0119 ± 0.0008	1.0064 ± 0.0007	1.0013 ± 0.0007
131	1.0064 ± 0.0008	1.0043 ± 0.0008	1.0052 ± 0.0008	1.0058 ± 0.0007	0.9999 ± 0.0007
140	1.0083 ± 0.0008	1.0013 ± 0.0008	1.0046 ± 0.0008	1.0029 ± 0.0007	0.9988 ± 0.0007
196	1.0101 ± 0.0008	1.0039 ± 0.0008	1.0045 ± 0.0008	1.0043 ± 0.0006	1.0000 ± 0.0006

(a) Results provided by Richard Taylor, Oak Ridge Y-12.

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.105, Table 12.a and Table 7.

```
STACY 280t Core tank critical analysis.
c   R105(water)   ;Hc=40.09cm U=311.2(g/lit) A=0.94(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   3   9.99870000E-02  #4                       imp:n=1 u=2
6   0                21 -22  23 -24  25 -26   imp:n=1     fill=2
7   0                #6                     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    40.09
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   -67.045
22   px    67.045
23   py   -46.57
24   py    46.57
25   pz   -35.0
26   pz   172.5

c
c   data cards
c
mode  n                  $ transfort neutrons only
c
c   material cards
c
c   R105(watr);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
```

a) MCNP4B Benchmark-Model Input Listing for Run No.105, Table 12.a and Table 7 (cont'd).

```
    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    criticality cards
c
kcode  5000  1.0  50   2050
sdef  cel=d1 x=d2 y=d3 z=d4  erg=d5
c
si1  l  6:4:1
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    40.09
sp4     0  1
sp5    -3
prdmp  j -100 1 3
print -175
c    ctme   10
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7.

```
file name=run105; STACY ( model 5 )
c    FUEL UO2(NO3)2
c    Hc = 40.09 cm
c     Water 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   3  9.99870000E-02  -80 #(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
80   4  4.94250000E-05  80 #(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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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
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  3  9.998700E-02      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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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
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
198  3  9.99870000E-02  -80 #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
199  4  4.94250000E-05   80 #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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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
500  pz   -0.0001
501  pz   -1.9999
502  py   -44.0
503  py    44.0
 1   pz      0.0
 2   pz     40.09
 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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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  water hight
 80  pz    172.5
c   pool wall
 81  pz    205.4
 82  pz    -35.0
 83  px    283.0
 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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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   -31.5   0.0  5.5
126  pz    108.23
127  pz     35.33
128  c/z   -31.5   0.0  5.51
129  pz     66.53
130  pz     36.53
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    46.393
135  pz    12.103
136  pz    205.5
137  pz    -34.999
138  pz    52.535
139  pz     7.535
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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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
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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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    R105(watr);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 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
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
    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
    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  l  212:208:206:204:202:200:79:1
sp1        1
c  *** x-coodinate
```

b) MCNP4B Detailed-Model Input Listing for Run No.105, Table 7 (cont'd).

```
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    40.09
sp4     0  1
c
sp5    -3
c
c     ctme   25
prdmp  j -100 1 3
c
print -175
```

A.2 THREEDANT Input Listing

THREEDANT was run with the 16-energy-group cross sections based on the JENDL-3.2 library, S_8 angular quadrature, and P_1 scattering order. The 16-energy-group constants were calculated by using the SRAC code system. The k_{eff}'s were calculated with a convergence criterion of 1×10^{-5}.

a) SRAC Input Listing for Run No.105, Table 12.a

```
MATR
STCY(280T)Hc=40.09cm 9.97wt% 464.2g/l 0.85mol/l wt-ref 16G
 0 0 0 1 0   0 0 0  0 0   0 -2 1 0 1   3 1 0 0 0 / SRAC CONTROL
0.00345838 /  CRITICAL BUCKLING ( no use )
/dg02/g0435/j9347/SRAC98/SRACLIB-JDL32/pds/pfast       Old      File
/dg02/g0435/j9347/SRAC98/SRACLIB-JDL32/pds/pthml       O        F
/dg02/g0435/j9347/SRAC98/SRACLIB-JDL32/pds/pmcrs       O        F
$PDS_DIR/UFAST           Scratch  Core
$PDS_DIR/UTHERMAL        S        C
$PDS_DIR/UMCROSS         S        C
$PDS_DIR/MACROWRK        S        C
$PDS_DIR/MACRO           New      C
$PDS_DIR/FLUX            S        C
$PDS_DIR/MICREF          S        C
  70  37  10  6 / NEF NET NERF NERT (JAERI-1302 18P)
 70(1)       /  NEGF  (THERMAL CUT ENERGY = 0.6825 EV)
 37(1)       /  NEGT
   5  5  5  5  8  8  9  8  9  8 /
            4  6  6  6  6  9 /

15&
   1 0 1  8 1    1 0  4  39 1    107 0 0 0 0    0  0  0  0  0
   0 0 0 35 0    0 0  0 100 0     0 0 0 0 1    0
16*
1.00  0.00 0.0001 1.420892   69.00 40.09  0.0  0.0 0.0 0.5 0.0002 0.05
   0.0001 0.75
00T
 4*
    0.0   5*2.00   4*1.00   5*0.50   5*5.00  10*1.0  10*2.0
 8&
   9(1)   5(2)   5(3)   20(4)
 9&
    1   2   3   4
19&
  4(1)
27&
    1   2   3   4
00T
 4 / NMAT
FU1LX01X  0 7 298.15 0.67  1.0      /  MAT 1 : FUEL u=464.2 g/l
XH01H001  0 0 5.55820E-02
XN040001  0 0 2.86470E-03
XO060001  0 0 3.84810E-02
XU040001  2 0 9.55550E-07
XU050001  2 0 1.18580E-04
XU060001  2 0 1.18430E-07
XU080001  2 0 1.05620E-03
SU10X02X  0 8 298.15 0.1   0.0      /  MAT  2 : SUS-304L(side)
XC02000A  0 0 7.15670E-05
XSIN0001  0 0 7.14150E-04
XMN50001  0 0 9.90950E-04
XP010001  0 0 5.08790E-05
XS0N0001  0 0 1.04240E-05
XNIN0001  0 0 8.56000E-03
XCRN0001  0 0 1.67250E-02
XFEN000A  0 0 5.95600E-02
AIR0X03X  0 2 298.15 0.1   0.0      /  MAT  3 : AIR
XN040001  0 0 3.90160E-05
XO060001  0 0 1.04090E-05
WATRX04X  0 2 298.15 0.1   0.0      /  MAT  4 : H2O
XH01H001  0 0 6.66580E-02
XO060001  0 0 3.33290E-02
CORE
STCY(D=59.cm)H=46.83cm
 0 0 0 1 0   0 0 0  0 1   0  3 0 0 1   3 1 0 0 0 / SRAC CONTROL
 1.E-15
```

a) SRAC Input Listing for Run No.105, Table 12.a (cont'd)

```
   1  /
STCY(D=59.cm)H=46.83cm UO2(NO3)2 9.97% 253.6g/l HNO3 2.24N WR40 RF TW16G
   0    1    8   16    3    3    1    0    0    0    1    0
    4  4  0    0    0    0    0    0    0 0 0 0    0    30    0
    0  1    2    0    0 1 1 1 1 3 0    0    0    0    0 /42I
       1.00        0.0         0.0         0.0         0.0         0.0
      1.0E-6       1.0         0.0         0.0  /10 FLOAT
 16   5  2       / FINE R MESH 47
  4   10 35      / FINE Z MESH 90
 0.0  24.5  1*5.0 1*0.30      &    COARSE R MESH
 0.0  2.0 7.0  48.83    &  Z MESH
& CROSS SECTION ID
  -2 -2 -2                            &    COARSE Z MESH
  -1 -3 -2
  -1 -1 -2
 9(0)/ X-REG
 4 / NMAT
MATRA010  0 0 298.15 0.0   1.0      /  MAT  1 : FUEL UO2(NO3)2 253.6g
MATRA020  0 0 298.15 0.0   1.0      /  MAT  2 : SUS-304
MATRA030  0 0 298.15 0.0   1.0      /  MAT  3 : AIR
MATRA040  0 0 298.15 0.0   1.0      /  MAT  4 : H2O

END_DATA
```

b) THREEDANT Input Listing for Run No.105, Table 12.a

```
    2     0     0
 R105 (HC=40.09cm) model 2 STACY 280T
Cross sections from file
/
/ block 1
/
  igeom=x-y-z ngroup=16 isn=8
  niso=4 mt=4 nzone=4
  im=5 it=20 jm=5 jt=26 km=8 kt=50
  maxscm=1200000 maxlcm=1700000
  T
/
/ block 2
/
 xmesh=0.0 10.0  14.04 16.57 21.57 46.57
 xints=  4  3  2  3  8
 ymesh=0.0 29.5  34.515  37.045  42.045  67.045
 yints= 10  3  2  3  8
 zmesh=0.0 25.0 30.0 32.04  37.04  72.13  181.79 184.67  204.67
 zints=  8  3  2  3 11  18  1  4
 zones= 4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       2 2 2 4 4;
       2 2 2 4 4;
       2 2 2 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       1 1 2 4 4;
       1 1 2 4 4;
       2 2 2 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       1 1 2 4 4;
       1 1 2 4 4;
       2 2 2 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       3 3 2 4 4;
       3 3 2 4 4;
       2 2 2 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       2 2 2 4 4;
       2 2 2 4 4;
       2 2 2 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
/
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
       4 4 4 4 4;
```

b) THREEDANT Input Listing for Run No.105, Table 12.a (cont'd)

```
       4 4 4 4 4;
  T
/
/ block 3
/
 lib=xr105
 ihm=20 iht=5 ihs=12          / 1 activity position in slot 1
 maxord=1
 ititl=1 ifido=0 i2lp1=0
 names=fuel sus air watr
 T
/
/
/ block 4
/
matls=isos
assign=matls
  T
/
/ block 5
/
ievt=1 ith=0 ibl=1 ibb=1 ibt=0 ibback=0 ibfrnt=0
norm=1 iitl=2 iitm=3000 oitm=300 itlim=86400 xsectp=2
epsi=1.0e-6 chi=
 2.26086E-01 5.31932E-01 1.97972E-01 3.70126E-02 6.64707E-03 3.34428E-04
 1.48252E-05 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
kcalc=1 isct=1 fissrp=0 rmflux=0
 T
/
/ block 6
/
  pted=1 zned=0 edoutf=0
  resdnt=0
 T
```

A.3 CRISTAL: APOLLO-2 / MORET-4 Input Listing

The k_{eff} calculation is run in two steps using two codes:

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.

2. MORET IV is a three-dimensional multigroup Monte Carlo code. It uses macroscopic cross sections coming from APOLLO 2. Each calculation employed between 700 and 800 neutron histories, and between 1000 and 1200 batches.

The APOLLO 2 Library used is JEF2.2.

A pre-processor called CIGALES is also used to compute atom densities and all necessary input data for the APOLLO 2 code. Input code data of APOLLO 2 and MORET IV are provided, as well as CIGALE input with comments.

MORET IV uses P5 anisotropic treatment and 172-group library.

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 105 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-016             *
*                                                      *
*  STACY T280 WATER REFLECTED EXPERIMENT U(9.97%)O2(NO3)2 *
*        CASE  01 NUMBER 105 :::  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
(
 eau
*eau
*------- Données milieu de structure-------
* ---  Milieu  1 CONC. ATOMIQUES- %volumique  100
*           H2O          0.033329
)
OPTION  V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
 GEOM HOMO
CHIMIE
*eau
 MICRO 1 1
                                   H2O
  CONC       0.033329
FINC
SECTION TOUT
FIN
(
 stainless steel SS304
*stainless steel SS304
*------- 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 SS304
 MICRO 1 8
              FENAT                     CRNAT                    NINAT       MN55
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 105 of Table 12.b (cont'd)

```
              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
*     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 : N° 1 * C(U) = 464.2 g/l              CAS 4
*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 WATER REFLECTED c(U) = 464.2 g/l
* LEU-COMP-THERM-016 case 01
*
* milieux : (1) air    (2) water    (3) st.st. SS304    (4) nitrate solution
 MINIMUM 40 SIGE 0.000330 SIGI 0.000330 PAS 20
NOBILAN
CHIMIE   SEALINK 4   APO2 4   1  2  3  4    FINC
GEOMETRIE
*  water
    TYPE 1 BOITE 46.57 67.045  102.335
      VOLUME 1 0 1 2 0.0 0.0 102.335
      RBOITE 0 0  0 0  0 0
*  stainless steel tank
```

CRISTAL: APOLLO-2 / MORET-4 Input Listing for Run No. 105 of Table 12.b (cont'd)

```
    TYPE 2 BOITE 16.57 37.045  77.335
      VOLUME 2 1 2 3 0.0 0.0 107.335
*  inner air
    TYPE 3 BOITE 14.04 34.515  74.875
      VOLUME 3 2 3 1 0.0 0.0 106.915
*  fissile solution  Hc = 40.09
    TYPE 4  BOITE 14.04 34.515  20.045
      VOLUME  4 3  4 4 0.0 0.0  52.085
FING
*   sources de neutron
* ---------------------
SOURCE NRES
   POINT  300  4  0.0 0.0  42.0
   POINT  400  4  0.0 0.0  52.0
   POINT  300  4  0.0 0.0  62.0
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.4 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 2000 generations of 5000 neutrons each, after skipping 50 generations, for a total of 1 million neutron histories.

KENO-V.a Input Listing for Run 105 of Table 12.c (SCALE4.3 27-group ENDF/B-IV cross sections)

KENO Input Listing for Run No. 105 of Table 12.c

```
=csas25   parm=size=200000
LEU-SOL-THERM-016 Run no. 105  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
'WATER
h       4 0 6.6658-2 end
o       4 0 3.3329-2 end
end comp
LEU-SOL-THERM-016 Run no. 105  27 group
read parm  tba=5 tme=240 gen=2050 npg=5000 nsk=50  end parm
read geom
cuboid    1 1 34.515 -34.515 14.04 -14.04 40.09 0
cuboid    2 1 34.515 -34.515 14.04 -14.04 149.75 0
cuboid    3 1 37.045 -37.045 16.57 -16.57 152.63 -2.04
cuboid    4 1 67.045 -67.045 46.57 -46.57 172.63 -32.04
end geom
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 105 (Water 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