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STACY: 80-CM-DIAMETER CYLINDRICAL TANK OF 10%-ENRICHED URANYL NITRATE SOLUTIONS, WATER-REFLECTED

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

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiments

The four critical configurations included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed from autumn of 1998 to the winter of 1999 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 80-cm-diameter cylindrical 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 243 gU/l to 194 gU/l. The free nitric-acid concentration was kept at 1.0 mol/l, approximately.

Other STACY experiments with 10%-enriched uranyl nitrate solution are evaluated in
LEU-SOL-THERM-007, LEU-SOL-THERM-017, and LEU-SOL-THERM-021 (unreflected);
LEU-SOL-THERM-004 and LEU-SOL-THERM-016 (water reflector);
LEU-SOL-THERM-010 and LEU-SOL-THERM-019 (polyethylene reflector);
LEU-SOL-THERM-008 and LEU-SOL-THERM-018 (concrete reflector); and
LEU-SOL-THERM-009 (borated-concrete reflector).

All four critical configurations are accepted as benchmark experiments.

1.2 Description of Experimental Configuration

The schematic view of the core tank is shown in Figure 1. The dimensions shown in mm unit are the design values. The core tank was made of stainless steel, S.S.304L (or SUS304L), and the inner diameter and the inner height were designed to be 790 mm and 1500 mm, respectively. The side walls, lower plate, and upper plate thicknesses were respectively 3 mm, 20 mm, and 25 mm. The inspected dimensions of the 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.

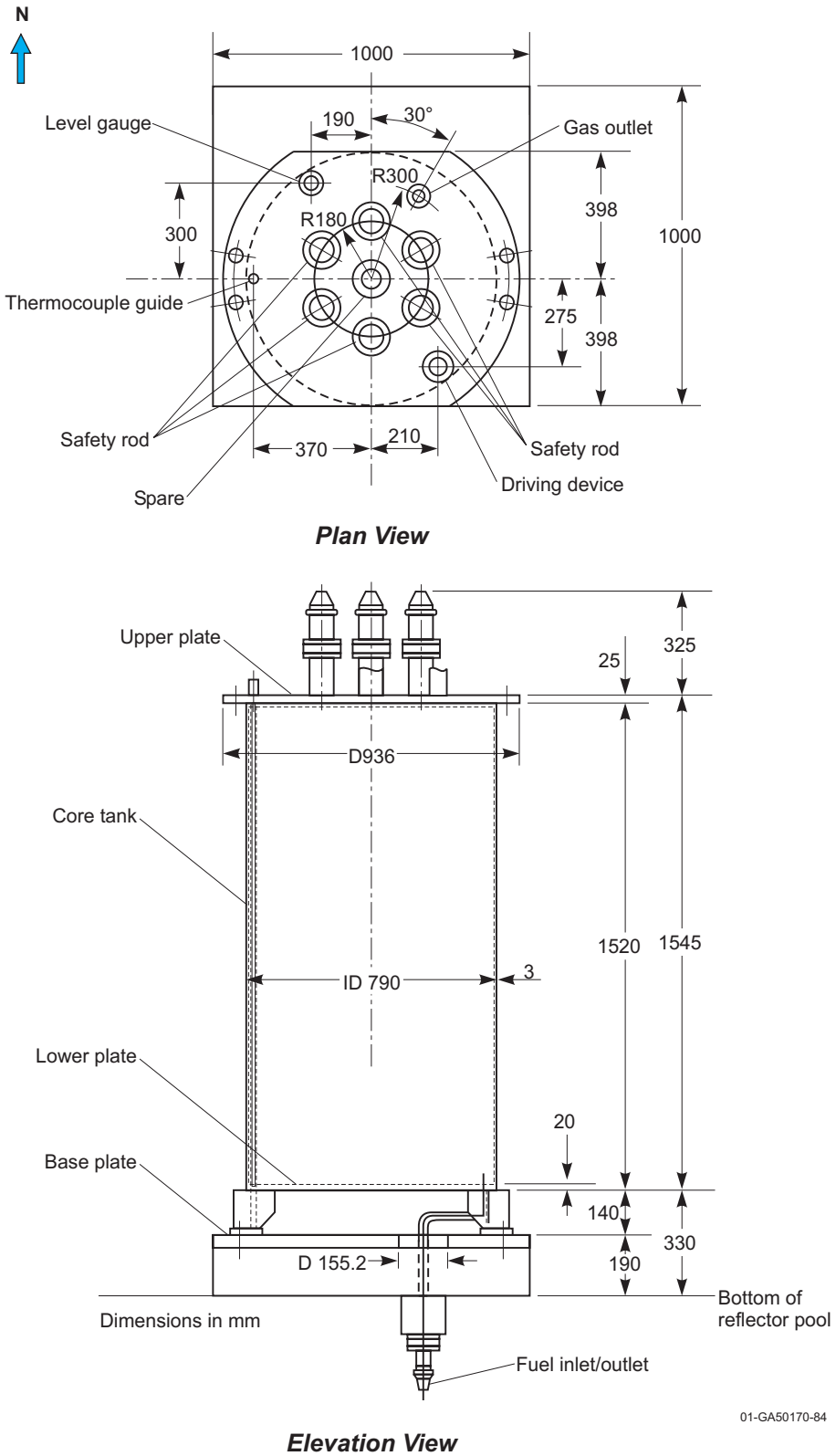


Figure 1. Schematic View of STACY Core Tank.
(design dimensions)

Table 1. Dimensions of the Cylindrical Core Tank (Unit: mm).

Tank	Dimension	Inspected Result [(a)]	Design Value
(inner size)	diameter	790.1±0.3	790
	height	1497.1±0.5	1500
(thickness)	side wall	3.1±0.1	0.3
	lower plate	20.6±0.1	20
	upper plate	29.3±0.1	25

(a) Uncertainties are from the standard deviation and accuracy, added quadratically.

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

Measured Item	Number of Measured Points	Average	Standard Deviation	Accuracy	Uncertainty
Thickness of upper plate	4 in θ	29.25	0.03	0.10	0.10
Thickness of lower plate	24 (3 in radial direction, 8 in θ)	20.58	0.03	0.10	0.10
Outer height of tank	5 in θ	1546.88	0.11	0.50	0.51
Thickness of side wall	120 (15 in height) x (8 in θ)	3.10	0.01	0.10	0.10
Circumference of tank	15 in height	2501.78	0.20	0.50	0.54

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

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

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 six 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. When used, the driving device controlled the axial

position of a moveable detector for various axial distribution measurements (temperature, neutron flux, and so on).

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.

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, 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. There was a 155.2-mm-diameter hole (centered at 170 mm east and 248 mm south of the axis of the core tank) in the base plate for the fuel feed/drain line. 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 is 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 600 mm. For these water-reflected experiments, 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.

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.

The bottom of the tank was horizontal and exactly flat. 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, 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.216 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 ^{10}B-lined proportional counter (Ch-4) 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 gamma-ray compensated ionization chamber (Ch-5) on the north side, and two ^{3}He proportional counters (Ch-8, 9) on the south side. The detectors were kept dry inside the aluminum guide tubes. The detectors were covered with polyethylene (except Ch-1 to 3, 8 and 9). The thicknesses of polyethylene are given in Figure 4.

The four critical conditions are summarized in Table 2.

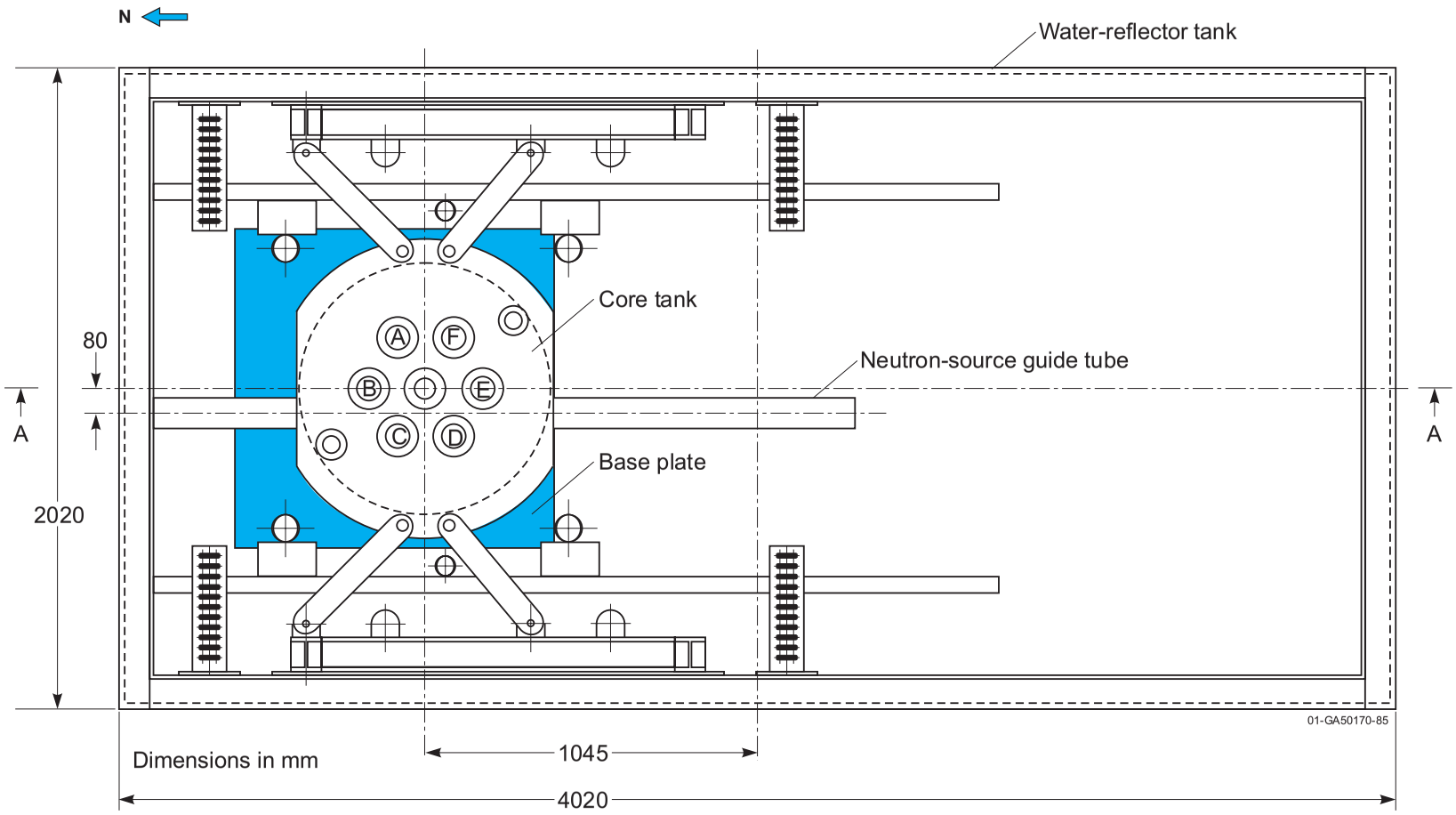


Figure 2.a. View from Above of the Water-Reflector Pool Tank.

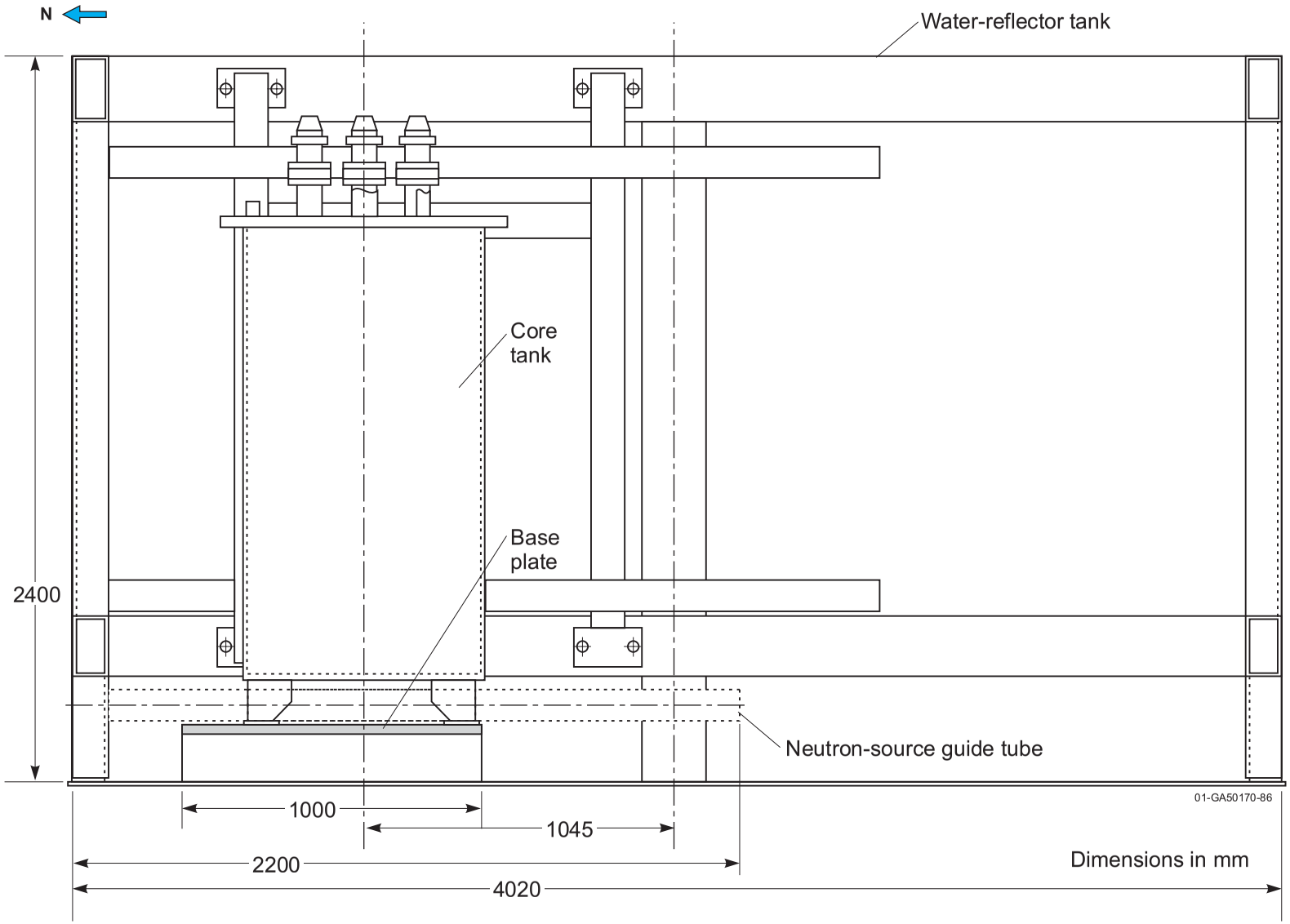


Figure 2.b. Elevation View of the Water-Reflector Pool Tank (A-A Cross Section).

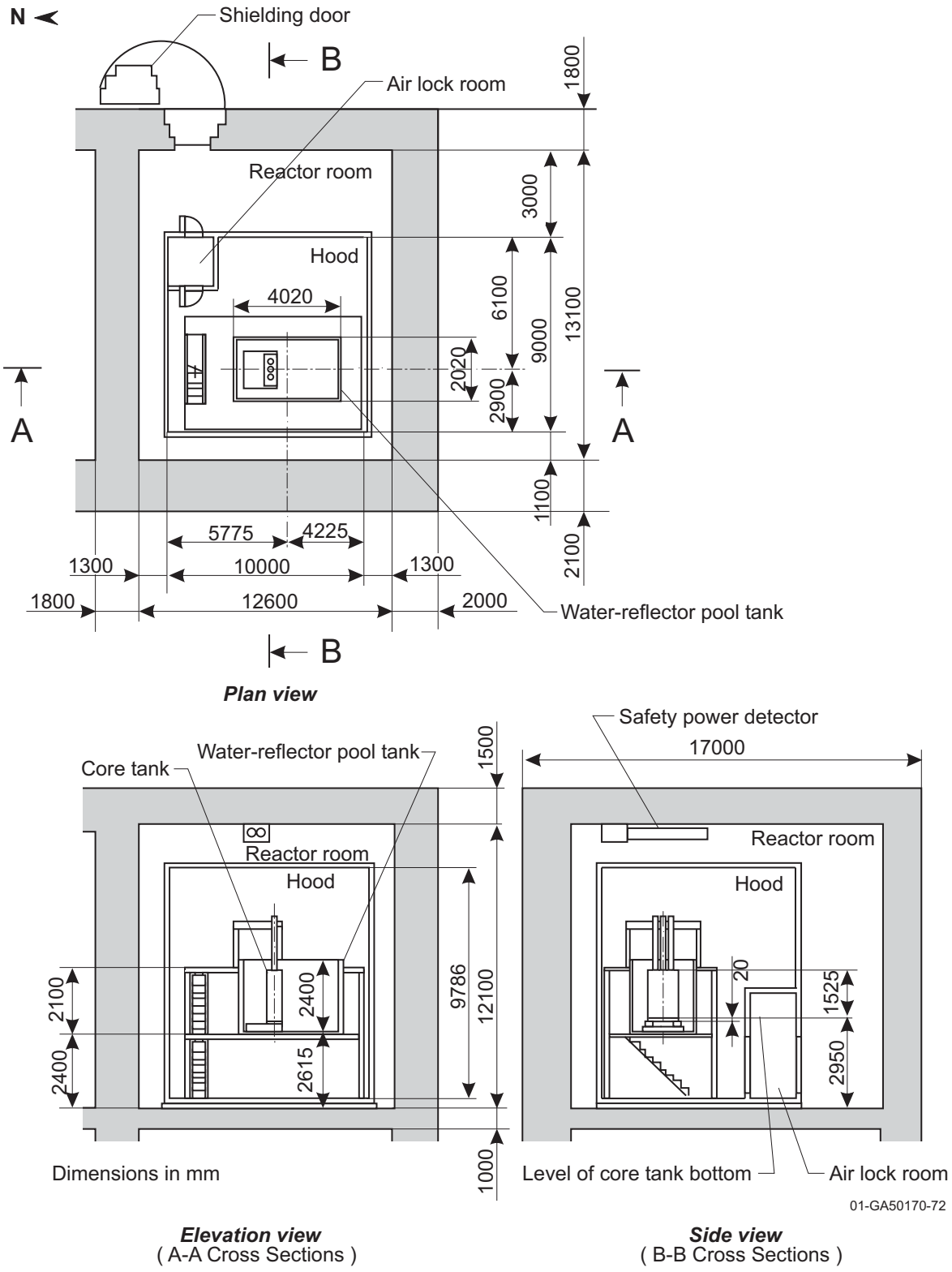
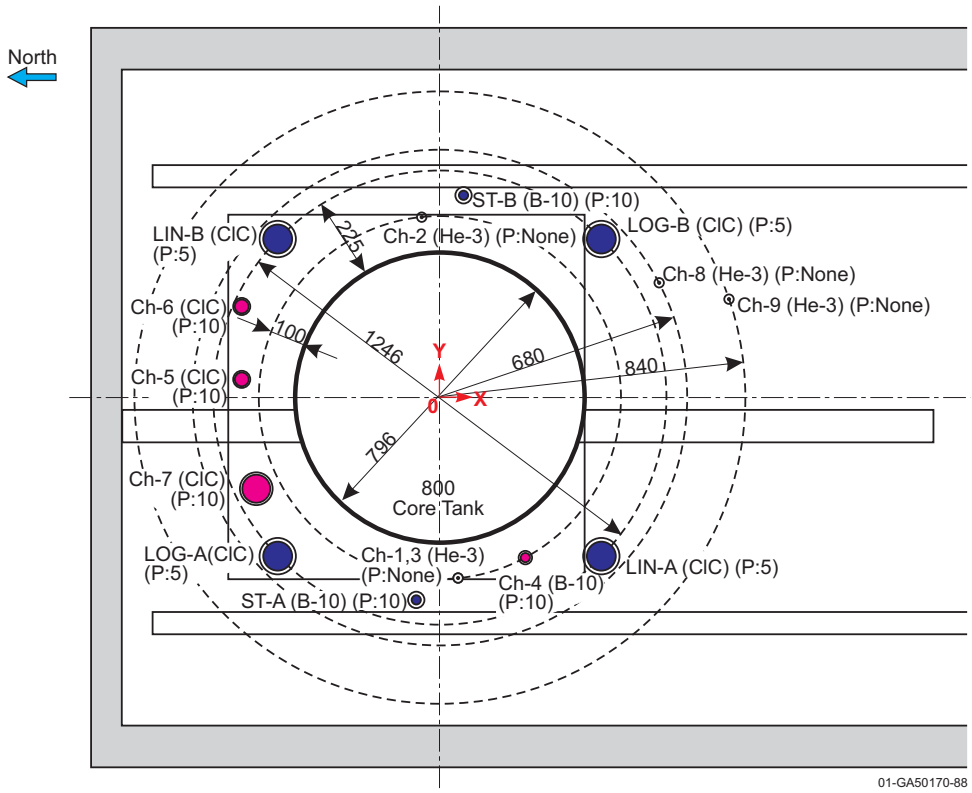


Figure 3. Schematic View Inside the Reactor Room.



Experimental Channels

(Unit: mm)

ID	Type	X , Y	Hc	OD1	L1	OD2	A	L , U (A)	P	L , U (P)
Ch-1	He-3(H)	50 , -495	105	6.0	82.5	22.0	1.0	-160 , 2240	-	- , -
Ch-2	He-3(H)	-50 , 495	210	6.0	82.5	22.0	1.0	-160 , 2240	-	- , -
Ch-3	He-3(H)	50 , -495	315	6.0	82.5	22.0	1.0	-160 , 2240	-	- , -
Ch-4	B-10	235 , -439	210	25.4	295.1	37.0	3.0	24 , 498	10.0	36 , 415.6
Ch-5	CIC	-545 , 50	210	38.1	235.0	47.0	3.0	52 , 476	10.0	64 , 414.1
Ch-6	CIC	-545 , 250	210	38.1	235.0	47.0	3.0	52 , 476	10.0	64 , 414.1
Ch-7	CIC	-505 , -250	210	77.0	241.0	90.0	4.0	63 , 574	10.0	93 , 452.5
Ch-8	He-3(L)	603 , 315	210	6.3	10.0	22.0	1.0	-350 , 2050	-	- , -
Ch-9	He-3(L)	795 , 270	210	6.3	10.0	22.0	1.0	-350 , 2050	-	- , -

Nuclear Instruments

ID	Type	X , Y	Hc	OD1	L1	OD2	A	L , U (A)	P	L , U (P)
ST-A	B-10	-65 , -555	200	25.4	266.7	45.0	3.0	-350 , 2150	10.0	-25 , 425
ST-B	B-10	65 , 555	200	25.4	266.7	45.0	3.0	-350 , 2150	10.0	-25 , 425
LIN-A	CIC	445 , -435	225	79.5	355.6	100.0	3.0	-350 , 2150	5.0	-55 , 505
LIN-B	CIC	-445 , 435	225	79.5	355.6	100.0	3.0	-350 , 2150	5.0	-55 , 505
LOG-A	CIC	-445 , -435	225	79.5	355.6	100.0	3.0	-350 , 2150	5.0	-55 , 505
LOG-B	CIC	445 , 435	225	79.5	355.6	100.0	3.0	-350 , 2150	5.0	-55 , 505

X,Y: Horizontal position
Hc : Height of the center 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
L,U (A): Height of lower and upper end of aluminum guide tube, respectively
L,U (P): Height of lower and upper end of polyethylene sheet, respectively

Zero level of height 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. 216, Water-Reflected).

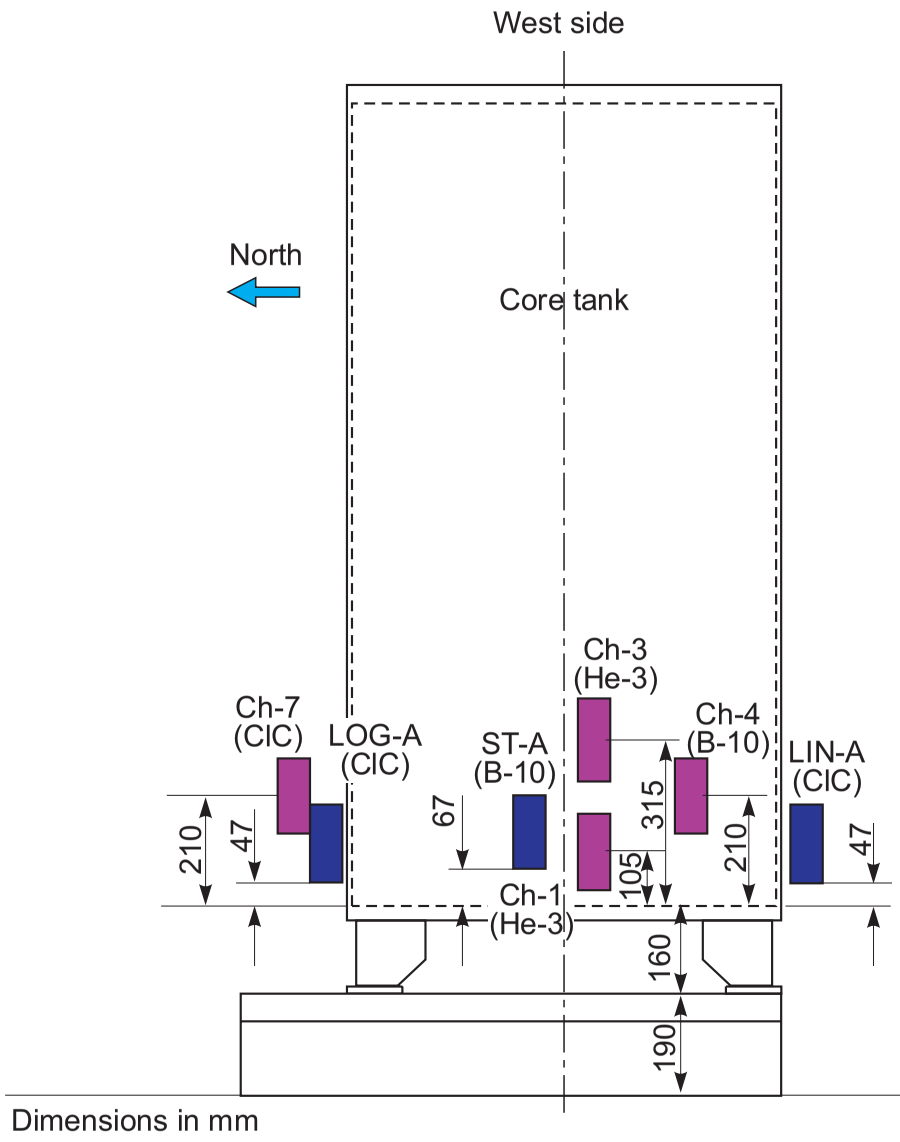


Figure 4b. Counter Location from West.

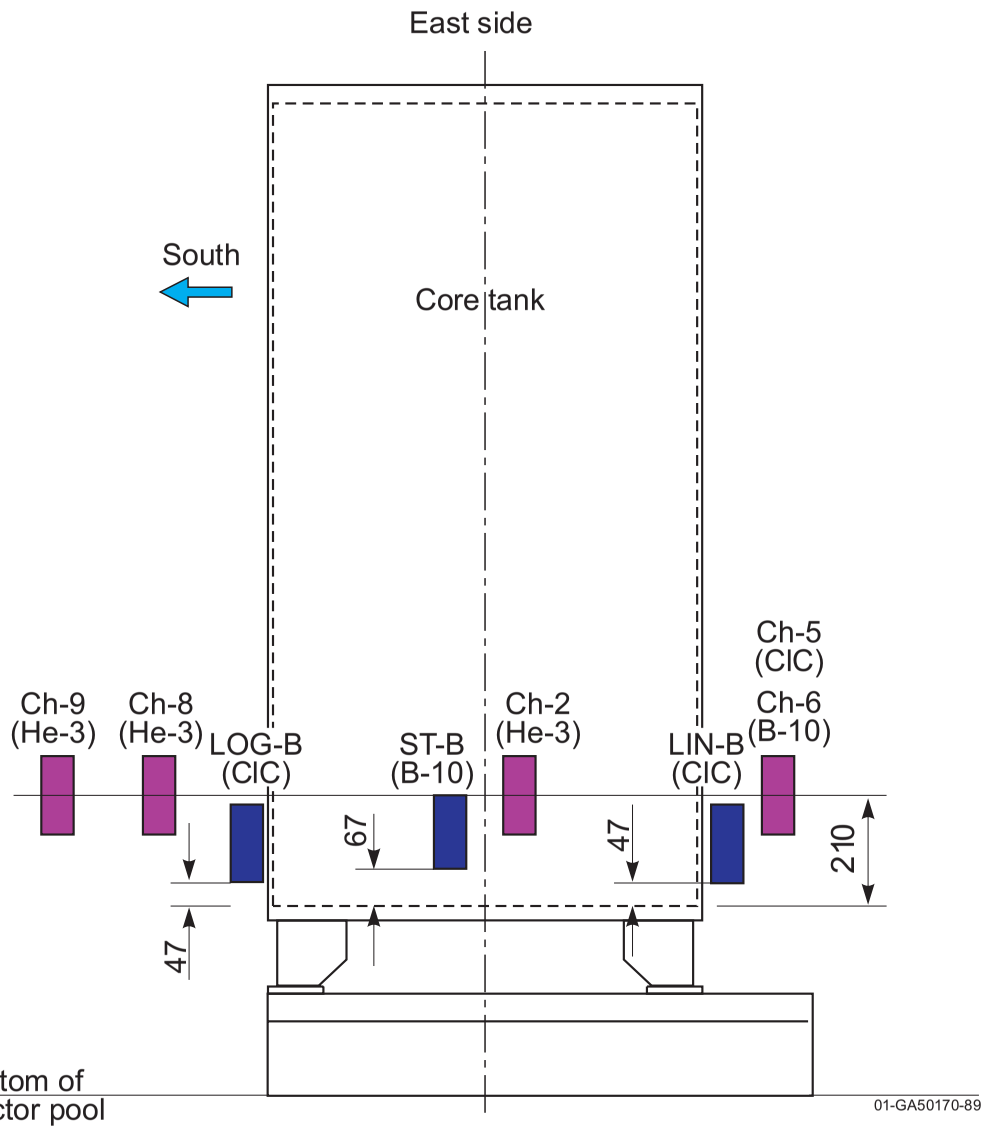


Figure 4c. Counter Location from East.

1.3 Description of Material Data

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 decreased from approximately 243 gU/l to 194 gU/l by successive steps. The free nitric-acid concentration was kept at 1.0 mol/l, approximately.

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. As for Run 220, the fuel solution data were not interpolated because of the single chemical analysis. So, the uncertainty was evaluated based on the maximum error values of other interpolated cases.

Table 2. Critical Conditions of STACY in Water-reflected Cores.

Run No.	Date yy/mm/dd	Fuel Solution Characteristics (25.0°C)			Critical Height (cm)	Temperature (°C)
		U Conc. (gU/l)	H^+ Conc. (mol/l)	Density (g/cm^3)		
216	1998/11/27	243.1±0.5	0.97±0.02	1.3569±0.0004	41.46±0.02	22.9
217	1998/12/02	225.5±0.4	0.97±0.02	1.3339±0.0004	47.87±0.02	23.3
220	1998/12/09	204.7±0.5	0.99±0.02	1.3060±0.0004	62.56±0.02	23.6
226	1998/12/21	193.7±0.5	0.98±0.02	1.2909±0.0004	81.09±0.02	23.7

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.%.

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 0.5 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 ±0.0004 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 60 mg/l, 14 mg/l, and 12 mg/l; no analysis of other impurities was made.

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 material (legs of core tank, tube for thermocouple, guide tube of safety rod, 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 (Unit: wt.%).

C	Si	Mn	P	S	Ni	Cr	Fe
0.011	0.625	1.33	0.028	0.002	10.25	18.265	69.489

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. 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 80-

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

cm-diameter core tank is written in the unpublished internal report, while the measurement for the 60-cm-diameter core tank was 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

Four 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}.

RZ calculations (R: radial; Z: axial) were performed for all sensitivity studies, including both the radial and the vertical dimension sensitivity studies.

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. This formula was not used to determine the benchmark solution densities. The measured densities at 25°C were used for the benchmark model.

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.%, 0.5 gU/l, 0.02 mol/l and 0.0004 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 60 mg/l, 14 mg/l and 12 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.			
		216	217	220	226
U enrichment	±0.013 wt.%	±0.051	±0.054	±0.056	±0.058
U concentration	±0.5 gU/l	±0.065	±0.074	±0.088	±0.096
H^+ concentration	±0.02 mol/l	-/+0.029	-/+0.029	-/+0.029	-/+0.030
Solution density	±0.0004 g/cm^3	±0.001	-/+0.001	-/+0.004	-/+0.006
Solution height	±0.2 mm	±0.009	±0.009	±0.006	±0.002
Temperature	±0.3 °C	-/+0.007	-/+0.007	-/+0.006	-/+0.005
Impurity (Fe)	+60mg/l	-/+0.003	-/+0.003	-/+0.003	-/+0.004
Impurity (Cr)	+14mg/l	-/+0.001	-/+0.001	-/+0.001	-/+0.001
Impurity (Ni)	+12 mg/l	-/+0.001	-/+0.001	-/+0.001	-/+0.002
Total		±0.088	±0.097	±0.109	±0.116

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 2.1°C (25-22.9).

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.

In the sensitivity studies of the impurities, each impurity was added without changing the other constituents of the fuel solution.

2.3 Core Tank Uncertainties

The inner diameter of the tank for the benchmark model was estimated from the measurements, using the tank outer diameter, derived from the circumference, 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.

As to the effects on k_{eff} of uncertainties pertaining to the core tank, the effects caused by the dimensional uncertainties were evaluated: core inner diameter, thickness of side wall and lower plate. As shown in Table 1, the uncertainties of those were 0.03 cm, 0.01 cm and 0.01 cm, respectively. The effect caused by the stainless steel density was also evaluated. The uncertainty of the density is assumed to be in the least significant digit, 0.01 g/cm^3. 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 (Table 1.b) 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.			
		216	217	220	226
Inner diameter	±0.03cm	±0.005	±0.005	±0.005	±0.005
Side-wall thickness	±0.01cm	±0.006	±0.006	±0.006	±0.006
Lower-plate thickness	±0.01cm	±0.001	±0.001	<±0.001	<±0.001
Stainless steel density	±0.01 g/cm^3	<±0.001	<±0.001	<±0.001	<±0.001
Total		±0.008	±0.008	±0.008	±0.008

2.4 Conclusions

The calculated effects of material and geometrical uncertainties are summarized in Table 7.

Table 7. Summary of Effects on k_{eff} for Materials and Geometrical Uncertainties (Δk_{eff}, %).

Parameter	Run No.			
	216	217	220	226
Fuel Solution	±0.088	±0.097	±0.109	±0.116
Core Tank Dimension and Density	±0.008	±0.008	±0.008	±0.008
Total	±0.088	±0.097	±0.109	±0.116

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

3.0 BENCHMARK SPECIFICATION

3.1 Description of 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 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 and were located in the water reflector.
(9) Nine neutron detectors; 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.216 was shown in Figure 4.
(10) Structures and devices on the top of the core tank: guide tubes of the safety rods, device of the level gauge, 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.

Most of the above 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 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 8. The input listing for the detailed model is given in Appendix C.

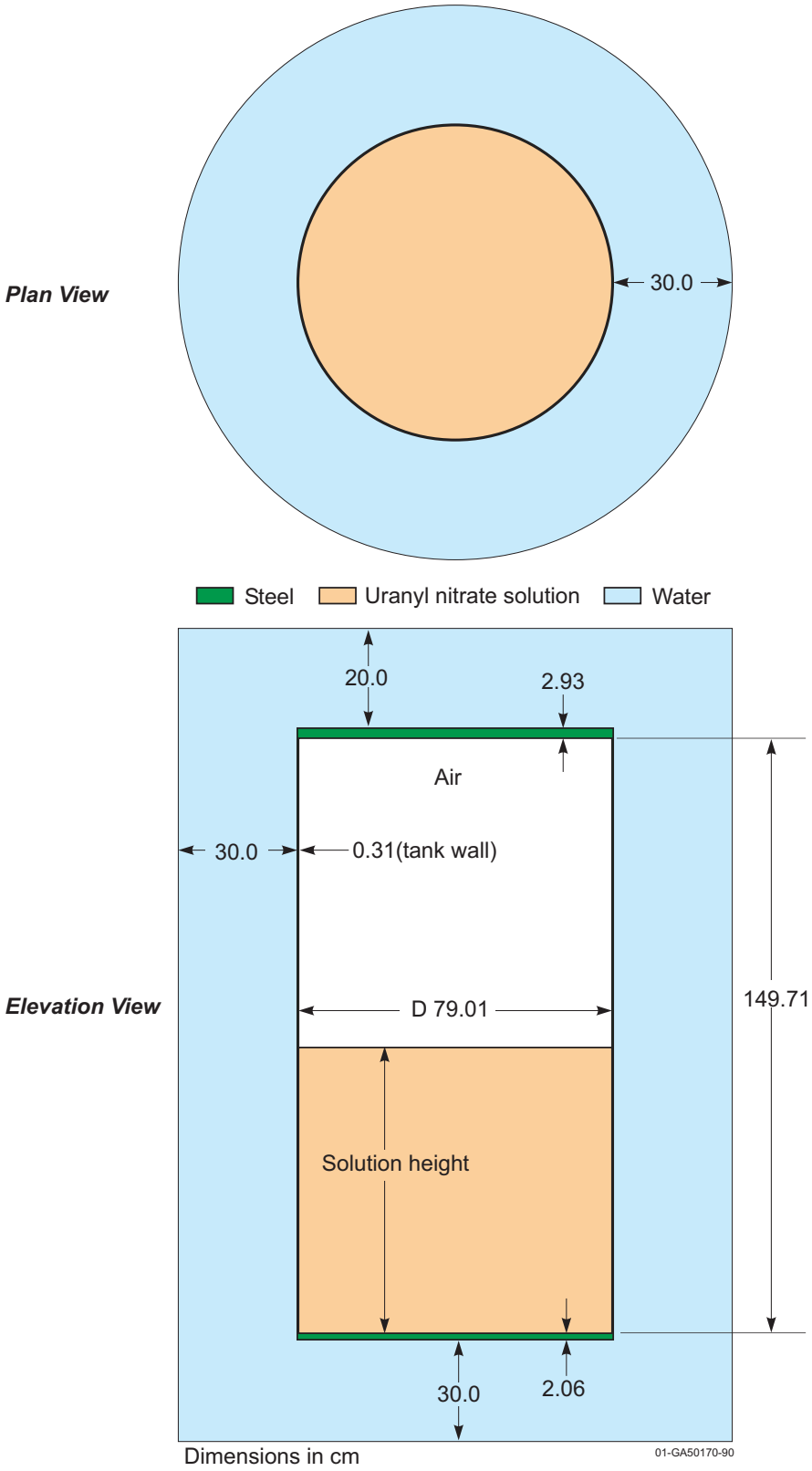


Figure 5. Benchmark Model of the STACY Experiments.

Table 8. Estimated Results of Model Simplification Effect.

Run No.	Calculated k_{eff} ($\pm 1\sigma$)		Model Simplification Effect, Δk_{eff} (%)
	Benchmark Model	Detailed Model	
216	1.0052±0.0002	1.0050±0.0002	+0.02±0.03
217	1.0042±0.0002	1.0044±0.0002	-0.02±0.03
220	1.0035±0.0002	1.0038±0.0002	-0.03±0.03
226	1.0040±0.0002	1.0040±0.0002	0.00±0.03

Results in Table 7 show that, if there are model simplification effects, they are small, i.e., of the order of the standard deviation of the Monte Carlo calculation (≤0.03%). Because of the full water reflection of this configuration, effects of items outside the core tank are expected to be insignificant.[a] Therefore, the bias in calculated k_{eff} of the benchmark model is estimated to be none. It is determined that the model simplification effects should be considered as uncertainties for all the benchmark models, and the combined standard deviations (1σ) of the Monte Carlo calculations should also be included as uncertainties.

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 critical solution heights for each case are summarized in Table 9.

Table 9. Critical Solution Heights.

Run No.	Critical Solution Height (cm)
216	41.46
217	47.87
220	62.56
226	81.09

[a] The large contributor to the model-simplification effect is expected to be the base plate beneath the core tank. Its effect, calculated by TWOTRAN, is ≤0.001% for all four cases.

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 10. Their derivation is described in Appendix D.

Table 10. 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
216	5.0042E-07	6.2098E-05	6.2021E-08	5.5312E-04	6.0297E-02	1.8157E-03	3.6535E-02
217	4.6419E-07	5.7602E-05	5.7531E-08	5.1307E-04	6.0708E-02	1.7265E-03	3.6384E-02
220	4.2137E-07	5.2289E-05	5.2224E-08	4.6575E-04	6.1073E-02	1.6332E-03	3.6175E-02
226	3.9873E-07	4.9479E-05	4.9418E-08	4.4072E-04	6.1318E-02	1.5715E-03	3.6060E-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: 6.6658×10^{-2},
O: 3.3329×10^{-2}.

The density of the stainless steel S.S.304L (or SUS304L) is 7.93 g/cm^3. The atom densities of the stainless steel used for the core tank are given in Table 11.

Table 11. Atom Densities of Stainless Steel (Unit: atoms/barn-cm).

C	Si	Mn	P	S	Ni	Cr	Fe
4.3736E-05	1.0627E-03	1.1561E-03	4.3170E-05	2.9782E-06	8.3403E-03	1.6775E-02	5.9421E-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: 3.9014E-05, and
O: 1.0410E-05.

[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.

3.4 Temperature Data

The solution temperature for each core configuration varies from 22.9°C to 23.7°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 a 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 12.

Table 12. Evaluated Results of Temperature Effects.

Run No.	Experimental Temperature	k_{eff} at 25.0 °C	k_{eff} at Experimental Temperature	Temperature Effect Δk_{eff} (%)
216	22.9	1.00829	1.00875	-0.046
217	23.3	1.00781	1.00817	-0.036
220	23.6	1.00670	1.00697	-0.027
226	23.7	1.00728	1.00751	-0.023

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

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, if any, are very small and are considered as uncertainties in all the benchmark models; the combined standard deviations (1σ) of the Monte Carlo calculations are also included as uncertainties. 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 216	: 0.9995±0.0010,
Run 217	: 0.9996±0.0010,
Run 220	: 0.9997±0.0012, and
Run 226	: 0.9998±0.0012.

4.0 RESULTS OF SAMPLE CALCULATIONS

The results of the sample calculations using MCNP 4B and TWOTRAN with the JENDL-3.2 library are given in Table 13.a. These high values are known to be caused by the library's capture cross section of ^{235}U in the resonance energy range, 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=0.03 %) were used for sample calculations. The results are given in Table 13.b. The results of KENO V.a with ENDF/B-IV and V libraries MCNP4C calculations with ENDF/B-V and VI libraries are given in Table 13.c.

Table 13.a. Sample Calculation Results (Japan).

Case No.	Code (Cross Section Set) → Run No. ↓	MCNP 4B (Continuous Energy JENDL-3.2)	TWOTRAN (16-Group Energy JENDL-3.2)
1	216	1.0052±0.0002	1.00765
2	217	1.0042±0.0002	1.00754
3	220	1.0035±0.0002	1.00691
4	226	1.0040±0.0002	1.00775

Table 13.b. Sample Calculation Results (France). (a)

Case No.	Code (Cross Section Set) → Run No. ↓	APOLLO-2 / MORET-4 (CEA93 Library-172-Group)
1	216	1.0011±0.0003
2	217	1.0002±0.0003
3	220	0.9992±0.0003
4	226	0.9997±0.0003

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

Table 13.c. Sample Calculation Results (United States). [a]

Case No.	Code (Cross Section Set)→ Run No. ↓	KENO			MCNP [b]	
		27-Group (ENDF/B-IV)	44-Group (ENDF/B-V)	238-Group (ENDF/B-V)	ENDF/B-V (.50c)	ENDF/B-VI (.60c)
1	216	0.9995±0.0002	1.0006±0.0002	1.0012±0.0002	1.0010±0.0002	0.9975±0.0002
2	217	0.9982±0.0002	0.9998±0.0002	1.0001±0.0002	1.0008±0.0002	0.9976±0.0002
3	220	0.9970±0.0002	0.9988±0.0002	0.9992±0.0002	0.9997±0.0002	0.9970±0.0002
4	226	0.9979±0.0002	0.9996±0.0002	1.0005±0.0002	1.0006±0.0002	0.9979±0.0002

(a) Results provided by Virginia Dean.
(b) Input listings provided by the authors; for ENDF/B-VI calculations, ^{235}U and ^{238}U cross sections were Release 4 (.49c).

5.0 REFFERENCES

1. S. Onodera, H. Sono, H. Hirose, S. Tanino, M. Nagasawa, K. Murakami, K. Sakuraba, M. Miyauchi, Y. Yamane and A. Ohno, "Annual Report of STACY Operation in F.Y. 1998(2) - 800 mm-Diameter Cylindrical Core -- 10% Enriched Uranyl Nitrate Solution - ," (in Japanese) *JAERI-Tech 2000-013*(2000).

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).

United States MCNP4C calculations used the same inputs files except that cross sections were changed to .50c (sulphur to 16032.50c) for ENDF/B-V and were changed to .60c for ENDF/B-VI.4 (except ^{235}U and ^{238}U which were .49c), and 80 generations were run before the 2,000 active generations.

MCNP4B Benchmark-Model Input Listing for Run No.216, Table 13.a and Table 8.

```
file name=r216benm2; STACY ( model 2 )
c   FUEL UO2(NO3)2  235U 9.97wt%
c   Hc = 41.46 cm
c   Water Reflector Thickness 30.0(cm)
c   Tank is all considered.
c
c   cell card
c
1   1  9.92630348E-02         1  -2 -10       imp:n=1 u=1
2   4  4.94510000E-05         2  -3 -10       imp:n=1 u=1
3   2  8.68450000E-02   #1 #2                 imp:n=1 u=1
4   0                    -4   5 -20       imp:n=1 u=2 fill=1
6   3  9.99870000E-02   #4                   imp:n=1 u=2
7   0                    -6   7 -30       imp:n=1     fill=2
8   0                  #7                 imp:n=0

c
c   surface cards (origin x=0.0 y=0.0 z=0.0)
c   cylinder
 1   pz      0.0
 2   pz     41.46
 3   pz    149.71
 4   pz    152.64
 5   pz     -2.06
 6   pz    172.64
 7   pz    -34.5
10   cz     39.505
20   cz     39.815
30   cz     69.8

c
c   data cards
c
mode  n                  $ transport neutrons only
c
c   material cards
c
c   R216(watr);U=243.1/A=0.97/D=1.3569
c   atomic density =  9.92630348E-02
m1    1001.37c     6.0297E-02
      7014.37c     1.8157E-03
      8016.37c     3.6535E-02
     92234.37c     5.0042E-07
     92235.37c     6.2098E-05
     92236.37c     6.2021E-08
     92238.37c     5.5312E-04
mt1   lwtr.01t    $  300k
c
c   sus304L(tank) 7.93g/cm3
c   atomic density  8.6845E-02
m2    6012.37c 4.3736E-05  $ C
     14000.37c 1.0627E-03  $ Si
     25055.37c 1.1561E-03  $ Mn
     15031.37c 4.3170E-05  $ P
     16000.37c 2.9782E-06  $ S
     28000.37c 8.3403E-03  $ Ni
     24000.37c 1.6775E-02  $ Cr
     26000.37c 5.9421E-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)
```

MCNP4B Benchmark-Model Input Listing for Run No.216, Table 13.a and Table 8 (cont'd).

```
c    atomic density  4.9451E-05
m4    7014.37c 3.9016E-05
      8016.37c 1.0409E-05
c
c
kcode  5000 1.0  50  2050
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 7:4:1
sp1        1
c
si2    h   0.0   39.500
sp2   -21  1
c
si3    h   0.0   41.46
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print –175
```

MCNP4B ENDF/B-VI.4 Benchmark-Model Input Listing for Run No. 220, Table.13.c.

STACY 280t Core tank critical analysis.

```
file name=r220benm2; STACY ( model 2 )
c    FUEL UO2(NO3)2  235U 9.97wt%
c    Hc = 62.56 cm
c    Water Reflector Thickness 30.0(cm)
c    Tank is all considered.
c
c    cellcard
c
1    1  9.9400362E-02          1  -2 -10        imp:n=1 u=1
2    4  4.94240000E-05          2  -3 -10        imp:n=1 u=1
3    2  8.68450000E-02   #1 #2                  imp:n=1 u=1
4    0                       -4   5 -20        imp:n=1 u=2 fill=1
6    3  9.99868000E-02   #4                              imp:n=1 u=2
7    0                       -6   7 -30        imp:n=1     fill=2
8    0                    #7                  imp:n=0

c
c    surface cards (origin x=0.0 y=0.0 z=0.0)
c    cylinder
 1   pz      0.0
 2   pz     62.56
 3   pz    149.71
 4   pz    152.64
 5   pz     -2.06
 6   pz    172.64
 7   pz    -32.06
10   cz     39.505
20   cz     39.815
30   cz     69.815

c
c    data cards
c
mode  n                    $ transport neutrons only
c
c    material cards
c
c    atomic density =  9.9400362E-02
m1     1001.60c     6.1073E-02
       7014.60c   1.6272E-03
       7015.60c   6.0429E-06
        8016.60c     3.6175E-02
       92234.49c     4.2137E-07
       92235.49c     5.2289E-05
       92236.49c     5.2224E-08
       92238.49c     4.6575E-04
mt1   lwtr.01t    $  300k
c
c    sus304L(tank) 7.93g/cm3
c    atomic density  8.6845E-02
m2     6000.60c 4.3736E-05  $ C
       14000.60c 1.0627E-03  $ Si
       25055.60c 1.1561E-03  $ Mn
       15031.60c 4.3170E-05  $ P
       16000.60c 2.9782E-06  $ S
         28058.60c       0.005693913 $ Ni
         28060.60c       0.002176814
         28061.60c       9.42452E-05
         28062.60c       0.000299416
         28064.60c       7.58966E-05
         24050.60c       0.000728888 $ Cr
         24052.60c       0.014056043
         24053.60c       0.001593656
         24054.60c       0.000396736
```

MCNP4B ENDF/B-VI.4 Benchmark-Model Input Listing for Run No. 220, Table.13.c (cont'd).

```
      26054.60c      0.003505818 $ Fe
      26056.60c      0.054500616
      26057.60c      0.001247834
      26058.60c      0.000166378
c
c    water (STACY)  298.15 K
c    atomic density  9.9400362E-02
m3    1001.60c    6.6658E-02
      8016.60c    3.3329E-02
mt3   lwtr.01t    $  300k
c
c     air (0.001184 g/cm3)
c    atomic density  4.9424E-05
m4    7014.60c  3.8870E-05
      7015.60c  1.4435E-07
      8016.60c 1.0410E-05
c
c
kcode  5000 1.0  80  2080
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 7:4:1
sp1        1
c
si2    h   0.0   39.500
sp2   -21  1
c
si3    h   0.0   41.46
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```

A.2 TWOTRAN Input Listing

TWOTRAN 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 SRAC code system. The k_{eff}'s were calculated with a convergence criteria of 1×10^{-5}.

SRAC and TWOTRAN Input Listing for Run No.216, Table 13.a.

```
ANS1
STCY(D=79.cm)H=41.46 UO2(NO3)2 9.97%  WR40 RF T16G
 0 0 0 1 0   0 0 0  0 0   0 -2 1 0 1   3 1 0 0 0 / SRAC CONTROL
0.00200420 /  CRITICAL BUCKLING (R=29.8+40 H=75.41+34.5)
/s8000/home/g7/j9347/SRAC2K/SRACLIB-JDL32/pds/pfast       Old      File
/s8000/home/g7/j9347/SRAC2K/SRACLIB-JDL32/pds/pthml       O        F
/s8000/home/g7/j9347/SRAC2K/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           S        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 2    1 0  4  55 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   75.96 0.0     0.0  0.0 0.0 0.5 0.0002 0.05
  0.0001 0.75
00T
 4*
   0.0  24*1.4375   5*1.0  1*0.30  5*5.0    10*1.0  10*2.0
 8&
  29(1)  2  5(4)  20(3)
 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 : R216(water)
XH01H001  0 0 6.02970E-02
XN040001  0 0 1.81570E-03
XO060001  0 0 3.65350E-02
XU040001  2 0 5.00420E-07
XU050001  2 0 6.20980E-05
XU060001  2 0 6.20210E-08
XU080001  2 0 5.53120E-04
SU10X02X  0 8 298.15 0.1   0.0      /  MAT  2 : SUS-304(TANK)
XC02000A  0 0 4.37360E-05
XSIN0001  0 0 1.06270E-03
XMN50001  0 0 1.15610E-03
XP010001  0 0 4.31700E-05
XS0N0001  0 0 2.97820E-06
XNIN0001  0 0 8.34030E-03
XCRN0001  0 0 1.67750E-02
XFEN000A  0 0 5.94210E-02
WATRX03X  0 2 298.15 0.1   0.0      /  MAT  3 : H2O
XH01H001  0 0 6.66580E-02
XO060001  0 0 3.33290E-02
AIR0X04X  0 2 298.15 0.1   0.0      /  MAT  4 : AIR
XN040001  0 0 3.90160E-05
XO060001  0 0 1.04090E-05
CORE
STCY(D=79.cm)H=41.46 UO2(NO3)2 9.97%  WR40 RF TW16G
 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
```

SRAC and TWOTRAN Input Listing for Run No.216, Table 13.a (cont'd).

```
   1  /
STCY(D=79.cm)H=41.46 UO2(NO3)2 9.97%  WR40 RF TW16G
   0    1    8   16    5    8    1    0    0    0    1    0
   4  4  0    0    0    0    0    0    0 0 0 0    0   30    0
   0  7000    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-5      1.0       0.0       0.0  /10 FLOAT
 24   5  1  10 10     / FINE R MESH 50
 10  10  2   5 26  22  2  10   / FINE Z MESH 87
 0.0  34.5  1*5.005 1*0.31 1*10.0 1*20.0             &    COARSE R MESH
 0.0  22.5 1*10.0  1*2.06 1*5.0  1*36.46
      1*108.25 1*2.93  1*20.0   &  Z MESH
& CROSS SECTION ID
  -3 -3 -3 -3 -3                          &    COARSE R MESH
  -3 -3 -3 -3 -3                          &    COARSE R MESH
  -2 -2 -2 -3 -3                          &    COARSE Z MESH
  -1 -1 -2 -3 -3
  -1 -1 -2 -3 -3
  -4 -4 -2 -3 -3
  -2 -2 -2 -3 -3                          &    COARSE Z MESH
  -3 -3 -3 -3 -3                          &    COARSE R MESH
 40(0)/ X-REG
 4 / NMAT
ANS1A010  0 0 300.0  0.0   1.0     /  MAT  1 : FUEL UO2(NO3)2 241.9g
ANS1A020  0 0 300.0  0.0   1.0     /  MAT  2 : SUS-304
ANS1A030  0 0 300.0  0.0   1.0     /  MAT  3 : H2O
ANS1A040  0 0 300.0  0.0   1.0     /  MAT  4 : AIR

END_DATA
```

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

The calculations of k_{eff}'s were run in two steps, using the CRISTAL code system.

1) APOLLO-2 is a one-dimensional multigroup cell code. It is used to determine material buckling B_m^2, infinite multiplication factor (k_{inf}), and homogeneous macroscopic medium cross sections.
2) MORET-4 is a three-dimensional multigroup Monte Carlo code. It uses macroscopic cross sections coming from APOLLO-2. It uses P5 anisotropic treatment and 172-group library. Each calculation employed 1,000 neutrons per batch and was run to achieve precision of 0.0010.

APOLLO-2 used the CEA93 172-group library based on JEF2.2 evaluation. A pre-processor called CIGALES-PREAPOL is used to prepare the APOLLO-2 input data.

CRISTAL Input Listing for Run No.216, Table 13.b.

```
DEBUT_APOLLO2
**************************************************
*      C.E.A / I.P.S.N. SYSTEM CODES            *
* CRISTAL : APOLLO2 (CEA93 172gr library)- MORET4 *
*................................................*
*      I.C.S.B.E.P : LEU-SOL-THERM-020          *
*................................................*
*              water reflected                  *
*  STACY 80-cm-dia. EXPERIMENT U(9.97%)O2(NO3)2   *
*         RUN N□216    C(U)=243.1 g/l           *
**************************************************
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*     CIGALES version 2.0   en date du 18/05/2001
*             Creation du Fichier le 28/05/01 17:46:49
*=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
*                -=- 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'             ;
*==============================================================
*
* STACY water 25□c
TITRE: ' STACY water 25□c                          ' ;
WRITE: TOPT.'RESU' '*STACY water 25□c                  ' ' ' ;
*
*          -=- Description des milieux -=-
*STACY water 25□c
nom_calc =  'MILHOM1'                                      ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                   ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:          ;
TSTR.nom_calc = TABLE:                                     ;
*
nom_mil = 'STACY water 25□c'                               ;
TOPT.'STMIL'.nom_mil = TABLE:                              ;
TOPT.'STMIL'.nom_mil.'H2O      ' =    3.33290E-02          ;
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.'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 Input Listing for Run No.216, Table 13.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
*=============================================================
*
* stacy cylindrical 80 cm dia. core tank stainless steel
TITRE: ' stacy cylindrical 80 cm dia. core tank stainless steel      ' ;
WRITE: TOPT.'RESU' '*stacy cylindrical 80 cm dia. core tank stain' ' ' ;
*
*          -=- Description des milieux -=-
*************************************************************
TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT                        ;
*stacy cylindrical 80 cm dia. core tank stainless steel
nom_calc =  'MILHOM2'                                              ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                           ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:                  ;
TSTR.nom_calc = TABLE:                                             ;
*
nom_mil = 'stacy cylindrical 80 c'                                 ;
TOPT.'STMIL'.nom_mil = TABLE:                                      ;
TOPT.'STMIL'.nom_mil.'FENAT    ' =    5.94207E-02                  ;
TOPT.'STMIL'.nom_mil.'CRNAT    ' =    1.67753E-02                  ;
TOPT.'STMIL'.nom_mil.'NINAT    ' =    8.34029E-03                  ;
TOPT.'STMIL'.nom_mil.'MN55     ' =    1.15611E-03                  ;
TOPT.'STMIL'.nom_mil.'SINAT    ' =    1.06272E-03                  ;
TOPT.'STMIL'.nom_mil.'CNAT     ' =    4.37356E-05                  ;
TOPT.'STMIL'.nom_mil.'P31      ' =    4.31703E-05                  ;
TOPT.'STMIL'.nom_mil.'S32      ' =    2.98731E-06                  ;
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
*=============================================================
*
* air
TITRE: ' air                                          ' ;
WRITE: TOPT.'RESU' '*air                                  ' ' ' ;
*
*          -=- Description des milieux -=-
```

CRISTAL Input Listing for Run No.216, Table 13.b (cont'd).

```
************************************************************
TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT                    ;
*air
nom_calc =  'MILHOM3'                                  ;
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     ' =   4.18048E-05            ;
TOPT.'STMIL'.nom_mil.'O16     ' =   1.12633E-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 MILHOM3  -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
       &FICH 47 &NOMMIL TSTR.'MILREF'.nom_mil nom_mil          ;
*============================================================
* APOLLO PIJ CALCUL  4
*============================================================
*
*stacy * run 216                          CAS 4
TITRE: 'stacy * run 216                          CAS 4 ' ;
WRITE: TOPT.'RESU' 'NITR ANALY C(U)=243.100 C(PU)=0.000 '
' CAS 4'                                               ;
*
*          -=- Description des milieux -=-
************************************************************
TSTR TOPT = INITIALISER_CRISTAL 1 TSTR TOPT                    ;
*NITR ANALY C(U)=243.100 C(PU)=0.000 H+=0.97 =0.00
nom_calc =  'MILHOM4'                                  ;
TOPT.'STCRI'.'CALCUL_INITIAL' = nom_calc                   ;
TOPT.'STCRI'.'CALCULS_INITIAUX'.nom_calc = TABLE:              ;
TSTR.nom_calc = TABLE:                                 ;
*
nom_mil = 'NITR ANALY C(U)=243,10'                         ;
TOPT.'STMIL'.nom_mil = TABLE:                          ;
TOPT.'STMIL'.nom_mil.'U234    ' =   5.00416E-07            ;
TOPT.'STMIL'.nom_mil.'U235    ' =   6.20982E-05            ;
TOPT.'STMIL'.nom_mil.'U236    ' =   6.20207E-08            ;
TOPT.'STMIL'.nom_mil.'U238    ' =   5.53116E-04            ;
TOPT.'STMIL'.nom_mil.'H2O     ' =   3.01483E-02            ;
TOPT.'STMIL'.nom_mil.'O16     ' =  6.38657E-03             ;
TOPT.'STMIL'.nom_mil.'N14     ' =   1.81570E-03            ;
TOPT.'STMIL'.nom_mil.'TEMPERATURE'  =  25.                   ;
```

CRISTAL Input Listing for Run No.216, Table 13.b (cont'd).

```
*
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 MILHOM4  -=-
*
APOTRIM: &EDIT 1 TSTR.nom_calc.'MAC' ANISO &NOMA
        &FICH 47 &NOMMIL TSTR.nom_calc.'MILEQ' nom_mil           ;
*
EDTIME: ;
ARRET: ;
FIN_APOLLO2
*****************************************************
*       C.E.A / I.P.S.N. SYSTEM CODES               *
* CRISTAL : APOLLO2 (CEA93 172gr library)- MORET4 *
*.....................................................*
*       I.C.S.B.E.P : LEU-SOL-THERM-020              *
*.....................................................*
*                 water reflected                   *
*  STACY 80-cm-dia. EXPERIMENT U(9.97%)O2(NO3)2   *
*          RUN N□216    C(U)=243.1 g/l              *
*****************************************************
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
*      CIGALES version 2.0   en date du 18/05/2001
*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
(
 STACY water 25□¢
*STACY water 25□¢
*****  Milieu  1 CONC. ATOMIQUES- %volumique  100
*H2O          0.033329
```

CRISTAL Input Listing for Run No.216, Table 13.b (cont'd).

```
)
OPTION  V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
 GEOM HOMO
CHIMIE
*STACY water 25□t
 MICRO 1 1     H2O
CONC           3.33290E-02
FINC
SECTION TOUT
FIN
(
 stacy cylindrical 80 cm dia. core tank stainless steel
*stacy cylindrical 80 cm dia. core tank stainless steel
*****  Milieu  1 %-prop MASSIQUES- Dens= 7.93- %volumique  100
*FENAT         69.489
*CRNAT         18.265
*NINAT         10.25
*MN55          1.33
*SINAT         0.625
*CNAT          0.011
*P31           0.028
*S32           0.002
)
OPTION  V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
 GEOM HOMO
CHIMIE
*stacy cylindrical 80 cm dia. core tank stainless steel
 MICRO 1 8     FENAT       CRNAT       NINAT       MN55        SINAT
             CNAT        P31         S32
CONC           5.94207E-02 1.67753E-02 8.34029E-03 1.15611E-03 1.06272E-03
             4.37356E-05 4.31703E-05 2.98731E-06
FINC
SECTION TOUT
FIN
(
 air
*air
*****  Milieu  1 CONC. ATOMIQUES- %volumique  100
*N14           4.18048E-05
*O16           1.12633E-05
)
OPTION  V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
 GEOM HOMO
CHIMIE
*air
 MICRO 1 2     N14         O16
CONC           4.18048E-05 1.12633E-05
FINC
SECTION TOUT
FIN
*                RAPPEL DONNEES  MORET Pij
*=====================================================================
* BIBLIO CEA93.V4  172 groupes   ANISOTROPIE P5
*_____________________________________________________________________
*<*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*><*>
*                RAPPEL GEOMETRIE du MILIEU FISSILE
*_____________________________________________________________________
* GEOMETRIE HOMOGENE
*_____________________________________________________________________
* MILIEU FISSILE 1:
* NOUVELLE LOI DE DILUTION 2001 : Nitrate analyse
*     Densit□1.3569
```

CRISTAL Input Listing for Run No.216, Table 13.b (cont'd).

```
*_____________________________________________________________________
*     VECTEUR ISOTOPIQUE    MASSE
*_____________________________________________________________________
*     Uranium:
*     U233:
*     U234: 0.08
*     U235: 9.97
*     U236: 0.01
*     U238: 89.94
*_____________________________________________________________________
*  Delta Date (Analyse chimique - Analyse isotopique) :
*  Delta Date (Expeience - Analyse chimique) :
*  C(U)=2.431e02  C(Pu)=
*  Impuretes (g/l) :
*  Fe=0.000e00  Cr=0.000e00  Ni=0.000e00
*  Mn=0.000e00  Ca=0.000e00  Cu=0.000e00
*  Al=0.000e00  Mg=0.000e00  Zn=0.000e00
*  Na=0.000e00  Co=0.000e00
*_____________________________________________________________________
* MASSES ATOMIQUES MOYENNES
* Uranium: 237.74411 - Plutonium:  - Uranium+Plutonium:
*     ACIDITE : 9.700e-01 N
*=====================================================================
*=====================================================================
(
stacy * run 216                                CAS 4
NITR ANALY    C(U)=243.100    C(PU)=0.000   □CAS  4
*NITR ANALY    C(U)=243.100    C(PU)=0.000      H+=0.97    =0.00
SORTIE SECTIONS TOUTE LA CELLULE
)
OPTION V4 GROUP 172 P5 TEMPER  25  FINOPTION
MORET
GEOMETRIE HOMOGENE
CHIMIE
*NITR ANALY    C(U)=243.100    C(PU)=0.000      H+=0.97    =0.00
 MICRO 1 7     U234        U235        U236        U238        H2O
             O16         N14
VERIF 1.35690  5.00416E-07 6.20982E-05 6.20207E-08 5.53116E-04 3.01483E-02
             6.38657E-03 1.81570E-03
FINC
SECTION TOUT
FIND
DEBUT_MORET4
    ICSBEP        LEU-SOL-THERM-018      RUN 216
*                                       *
* U(9.97%)O2(NO3)2     C(U)=243.1 g/l  H+=0.97     *
*                                       *
* CRITICAL HEIGHT 41.46 water reflected  80-cm-DIA.*
*.....................................................*
*                                       *
*    benchmark Keff = 0.9995 +/- 0.0013           *
*                                       *
*****************************************************
* precision
  SIGI 0.00033 SIGE 0.00033 MINI 100 PAS 50   NOBIL
* SIGI 0.015 SIGE 0.015  MINI 10 NOBIL
* medium
* 1   *-  water
* 2   *-  tank wall stainless steel
* 3   *-  air
* 4   *-  U(10)O2(NO3)2 solution
CHIMIE
 SEALINK 4  APO2      4    1 2 3 4
FINCHIMIE
*
GEOMETRY
```

CRISTAL Input Listing for Run No.216, Table 13.b (cont'd).

```
** water reflector 30-cm-dia
  TYPE 1 CYLZ 69.815  102.35
  VOLUME 1 0 1 1   0.0 0.0 102.35
*..... tank : st.st. SUS 304 L .....
  TYPE 2 CYLZ  39.815 77.35
  VOLUME 2 1 2 2   0.0 0.0 107.35
*.................  air .....................................
  TYPE 3 CYLZ 39.505 74.855
  VOLUME 3 2 3 3   0.0 0.0 106.915
* .....fissile solution Hc = 41.46 cm  altitude = Hc + 32.06
  TYPE 4 PLAZ INF 73.52
  VOLUME 4 3 4 4   0.0 0.0 52.0  ETSUP 1 3
FINGEOMETRY

*.....      sources    ..................................
  SOURCE NRES POINT  1000  4 0.0 0.0 60
  FINSOURCE
* GRAPH Z 100 FGRAPH
SORTIE
MAIL 1 5 21 48 95 135 172
GLOBAL
FSORTIE
FINDATA
FIN_MORET4
```

A.4 KENO Input Listings

SCALE4.3 KENO V.a cases with CSAS 27-group ENDF/B-IV, and CSAS 44-group and 238-group ENDF/B-V cross sections were run with 2000 generations of 5000 neutrons each, after skipping 80 generations, for a total of 10 million neutron histories.

KENO-V.a Input Listing for Run 216 of Table 13.c (SCALE4.4 238-group ENDF/B-V cross sections).

```
=CSAS25     PARM=SIZE=4500000
LST20-1, STACY RUN 216, 80-CM-DIAM TANK OF U(10)O2(NO3)2 SOLN, WATER REFL
238GROUPNDF5 MULTIREGION
' U(9.97)02(NO3)2 SOLUTION
U-234  1 0  5.0042E-07  END
U-235  1 0  6.2098E-05  END
U-236  1 0  6.2021E-08 END
U-238  1 0  5.5312E-04  END
H  1 0  6.0297E-02 END
N  1 0  1.8157E-03 END
O  1 0  3.6535E-02 END
' SS Tank
C   2 0  4.3736E-05 END
Si  2 0  1.0627E-03 END
Mn  2 0  1.1561E-03 END
P   2 0  4.3170E-05 END
S   2 0  2.9782E-06 END
Ni  2 0  8.3403E-03 END
Cr  2 0  1.6775E-02 END
Fe  2 0  5.9421E-02 END
' Water
H  3 0 6.6658E-02  END
O  3 0 3.3329E-02  END
' Air
N  4 0  3.9016E-05 END
O  4 0  1.0409E-05 END
END COMP
BUCKLEDCYL VAC REFL 0.0 41.46 END  1 39.505 2 39.815 3 69.815  END ZONE
LST20-1, STACY RUN 216, 80-CM-DIAM TANK OF U(10)O2(NO3)2 SOLN, WATER REFL
READ PARA TME=200 GEN=2080 NPG=5001 NSK=80 NUB=YES XS1=YES RUN=YES
END PARA
READ GEOM
UNIT 1
 COM=* SOLUTION IN TANK *
 CYLINDER  1 1  39.505 41.46 0.0
 CYLINDER  4 1  39.505 149.71 0.0
 REPLICATE 2 1  0.31 2.93 2.06 1
 REPLICATE 3 1  30 20 30 1
END GEOM
READ PLOT
 TTL="HORIZONTAL CROSS SECTION"
 LPI=10 XUL=-74 YUL=74 ZUL=10 XLR=74 YLR=-74
 ZLR=10  UAX=1  VDN=-1 NAX=1200  NCH=' S23*ca' END
 TTL="VERTICAL CROSS SECTION"
 XUL=-74 YUL=0 ZUL=174 XLR=74 YLR=0
 ZLR=-34  UAX=1  WDN=-1 NAX=1200  NCH=' S23*ca' END  END PLOT
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: INPUT LISTING FOR DETAILED MODEL

The MCNP4B detailed-model input listing for Run No.216, Table 8, is provided below. The continuous-energy cross sections based on the JENDL-3.2 library were used. MCNP4B was run with 2,000 active generations of 5,000 neutrons each (10 million neutron histories), after skipping 50 generations (100,000 neutron histories).

```
file name=r216  ; STACY ( model 5 )
c   FUEL UO2(NO3)2
c   Hc = 41.46 cm
c   water reflector
c   Tank is all considered.
c
c   cell card
c
221  2  8.68449842E-02   #(-226 227 -231) -226 1 -230 imp:n=1 u=2
222  2  8.68449842E-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  8.68449842E-02   229 -228 2 -3       imp:n=1 u=2
226  1  9.92630348E-02   -500 501 -233       imp:n=1 u=2
1    1  9.92630348E-02   1  -2 -33 228 #221  imp:n=1 u=2
2    4  4.94250000E-05   228 2  -3 -33       imp:n=1 u=2
3    2  8.68449842E-02  -4 #(-33 1 -3) #226
      #(3 -229) #(3 -221) #(3 -222) #(3 -223) #(3 -224)
      #(3 -342) #(3 -345)                imp:n=1 u=2
70   2  8.68449842E-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  8.68449842E-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  8.68449842E-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
73   2  8.68449842E-02  #(4 -224 -225) -174 4
                  #(330 -334)          imp:n=1 u=2
264  19 1.37809E-01       330 -334          imp:n=1 u=2
80   2  8.68449842E-02  #(4 -342 -225) -341 4
                  #(330 -343)          imp:n=1 u=2
265  19 1.37809E-01       330 -343          imp:n=1 u=2
81   2  8.68449842E-02  #(4 -345 -225) -344 4
                  #(330 -346)          imp:n=1 u=2
266  19 1.37809E-01       330 -346          imp:n=1 u=2
c   74   2  8.68449842E-02  4  -176 -175        imp:n=1 u=2
75   2  8.68449842E-02  4  -177 -176         imp:n=1 u=2
76   2  8.68449842E-02  4  -178 -176         imp:n=1 u=2
77   2  8.68449842E-02  4  -179 -176         imp:n=1 u=2
210  2  8.68449842E-02  4  -220 -336         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
173  4  4.94250000E-05  3 -224 -225          imp:n=1 u=2
175  4  4.94250000E-05  3 -342 -225          imp:n=1 u=2
176  4  4.94250000E-05  3 -345 -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 #(-33 1 -3)  #3 #70 #71 #72
                  #210 #73     #75 #76 #77 #80 #81
                  #170 #171 #172 #173 #174 #175 #176 #226
                  #261 #262 #263 #264 #265 #266
                              imp:n=1 u=2
83   4  4.94250000E-05   80 #(-33 1 -3)  #3 #70 #71 #72
                  #210 #73     #75 #76 #77 #80 #81
                  #170 #171 #172 #173 #174 #175 #176 #226
                  #261 #262 #263 #264 #265 #266
                              imp:n=1 u=2
```

```
79   0  5 -34                          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  8.68449842E-02    531 -532           imp:n=1 u=3
c   252  4  4.94250000E-05    532 -533           imp:n=1 u=3
c   253  2  8.68449842E-02    533 -534           imp:n=1 u=3
c   12   2  8.68449842E-02    41 -42             imp:n=1 u=3
c   163  4  4.94250000E-05    534 -41            imp:n=1 u=3
c    Foot of tank
4    2  8.68449842E-02  (72 -73 58 -51 -5 43):
            (75 -74 52 -51 -5 43):
            (64 -65 74 -72 -5 43) imp:n=1 u=3
5    2  8.68449842E-02  (68 -69 56 -51 -5 43):
            (71 -70 77 -51 -5 43):
            (-68 70 60 -61 -5 43) imp:n=1 u=3
6    2  8.68449842E-02  (-54 72 -73 -51 -5 43):
            (-55 75 -74 -51 -5 43):
            (67 -66 -72 74 -5 43) imp:n=1 u=3
7    2  8.68449842E-02  (68 -69 -79 -51 -5 43):
            (71 -70 -57 -51 -5 43):
            (-68 70 63 -62 -5 43) imp:n=1 u=3
c
c fuel feed pipe 1
c
227  1  9.92630348E-02  -233 234  -5    imp:n=1 u=3
228  2  8.68449842E-02   233 -232 234 -5 imp:n=1 u=3
c
c fuel feed pipe 2
c
230  1  9.92630348E-02  -236  237 -238  imp:n=1 u=3
231  2  8.68449842E-02   236 -235 237 -238  imp:n=1 u=3
c
c fuel feed pipe 3
c
233  1  9.92630348E-02 -241 -242  43    imp:n=1 u=3
234  2  8.68449842E-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  8.68449842E-02 (-43 44 -45 46 -47 48) 410 imp:n=1 u=3
310  2  8.68449842E-02  -44  412 (-45 46 -47 48)  411
                        (414:-415:416:-417) imp:n=1 u=3
311  2  8.68449842E-02   82 -413 (-45 46 -47 48)  411
                        (414:-415:416:-417) imp:n=1 u=3
312  2  8.68449842E-02 -412  413 (-418 419 -420 421)  411
                        (422:-423:424:-425) imp:n=1 u=3
313  2  8.68449842E-02 -412  413  410 -411        imp:n=1 u=3
c
c    neutron source guide tube
254  4  4.94250000E-05  -531  -530 84          imp:n=1 u=3
255  2  8.68449842E-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  8.68449842E-02  533 -534  -530 84       imp:n=1 u=3
86   2  8.68449842E-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
22   3  9.99870000E-02   -101  137 #21             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
26   3  9.99870000E-02   -107  137 #24             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
```

```
29   3  9.99870000E-02   -113  #27  137             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  6  1.249333E-01      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  149 #36      imp:n=1 u=3
38   7 -2.69900000E+00    131 -132 -136  149     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  149 #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  149 #41      imp:n=1 u=3
43   7 -2.69900000E+00    140 -141 -136  149     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  149 #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  137 #46      imp:n=1 u=3
48   7 -2.69900000E+00    143 -144 -136  137     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  149 #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  137 #61      imp:n=1 u=3
63   7 -2.69900000E+00    158 -159 -136  137     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  149 #64 imp:n=1 u=3
c
270  2  8.68449842E-02  3 -4 -504 -502 503 34    imp:n=1 u=3
c
198  3  9.99870000E-02  -80  #79 #(-42 84 -530) #13
          #270
          #(-101 137) #401 #(-107 137) #410 #(-113 137) #420
          #(-120 -122 123) #430 #(-136 163 -161) #440 #(-136 163 -181) #450
                #(-132 -136 149) #470
          #(-141 -136 149) #480 #(-144 -136 137) #49
          #(-153 -136 137) #54
          #(-156 -136 137) #59
          #(-159 -136 137) #64
          #4 #5 #6 #7
```

```
        #(-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
        #(-101 137) #401 #(-107 137) #410 #(-113 137) #420
        #(-120 -122 123) #430 #(-136 163 -161) #440 #(-136 163 -181) #450
              #(-132 -136 149) #470
        #(-141 -136 149) #480 #(-144 -136 137) #49
        #(-153 -136 137) #54
        #(-156 -136 137) #59
        #(-159 -136 137) #64
        #4 #5 #6 #7
        #(-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  8.68449842E-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  8.68449842E-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  8.68449842E-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  8.68449842E-02 91  333 -173 -335        imp:n=1 u=6
287  19 1.37809E-01    91 -334 -335             imp:n=1 u=6
288  2  8.68449842E-02 91  334 -174 -335        imp:n=1 u=6
289  19 1.37809E-01    91 -343 -335             imp:n=1 u=6
290  2  8.68449842E-02 91  343 -341 -335        imp:n=1 u=6
291  19 1.37809E-01    91 -346 -335             imp:n=1 u=6
292  2  8.68449842E-02 91  346 -344 -335        imp:n=1 u=6
203  0 #281 #282 #283 #284 #285 #286 #287 #288 #289 #290 #291 #292
                              #202  imp:n=1 u=6
204  0  300 -301 302 -303 304 -305             imp:n=1 u=7 fill=6
205  2  8.68449842E-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    39.801
503  py    -39.801
504  cz     46.8
 1   pz      0.0
 2   pz     41.46
 3   pz    149.71
 4   pz    152.64
 5   pz     -2.06
33   cz     39.505
34   cz     39.815
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     39.8
48   px    -60.2
c   base plate lower pipe and hari
410  c/z    24.8  17.0  7.76
411  c/z    24.8  17.0  8.26
412  pz    -20.0
413  pz    -34.0
414  px     24.8
415  px    -45.2
416  py     35.0
417  py    -35.0
418  px     32.65
419  px    -53.05
420  py     42.85
421  py    -42.85
422  px     31.95
423  px    -52.35
424  py     42.15
425  py    -42.15
c   foot of tank
60   p     1.  1. 0.  47.6180816
61   p     1.  1. 0.  49.0322943
62   p     1.  1. 0. -27.6180816
63   p     1.  1. 0. -29.0322943
64   p     1. -1. 0.  47.6180816
65   p     1. -1. 0.  49.0322943
66   p     1. -1. 0. -27.6180816
67   p     1. -1. 0. -29.0322943
68   p     1. -1. 0.  17.07106781
69   p     1. -1. 0.  18.48528137
70   p     1. -1. 0.   2.92893219
71   p     1. -1. 0.   1.51471863
72   p     1.  1. 0.  17.07106781
73   p     1.  1. 0.  18.48528137
74   p     1.  1. 0.   2.92893219
75   p     1.  1. 0.   1.51471863
76   py     33.6
77   p     1.  1. 0.  43.5671140
79   p     1.  1. 0. -18.5671140
c    51   px     33.6
51   c/z    10.0  0.0 33.7315
52   p     1. -1. 0.  38.56711
53   px    -33.6
54   p     1. -1. 0. -18.56711
55   p     1. -1. 0. -18.94113
56   p     1.  1. 0.  38.94113
57   p     1.  1. 0. -23.94113
58   p     1. -1. 0.  43.94113
c
c
c  water height
 80  pz    172.64
c   pool wall
 81  pz    205.4
 82  pz    -35.0
c    83  px    100.0
 83  px    291.0
c    84  px   -100.0
 84  px   -111.0
c    85  py    291.0
 85  py    100.0
c    86  py   -111.0
 86  py   -100.0
 91  pz    205.401
 92  pz    -36.5
c    93  px    101.0
 93  px    292.0
c    94  px   -101.0
 94  px   -112.0
c    95  py    292.0
 95  py    101.0
```

```
c   96  py   -112.0
 96  py   -101.0
c  neutron counter
c  ch-4
101  c/z    23.5  -43.9   1.85
102  pz     51.281
103  pz      3.881
104  c/z    23.5  -43.9   2.85
105  pz     43.081
106  pz      5.081
c  ch-5
107  c/z   -54.5     5.0   2.35
108  pz     47.91
109  pz      5.51
110  c/z   -54.5     5.0   3.35
111  pz     41.71
112  pz      6.71
c  ch-6
113  c/z   -54.5    25.0   2.35
114  pz     58.91
115  pz      5.51
116  c/z   -54.5    25.0   3.35
117  pz     51.71
118  pz      6.71
c  ch-7
119  c/z   -50.5  -25.0   4.499
120  c/z   -50.5  -25.0   4.5
121  c/z   -50.5  -25.0   5.5
122  pz     57.25
123  pz      6.15
124  pz     45.15
125  pz      9.15
c  ch-1 and 3
180  c/z     5.0 -49.5  1.0
161  c/z     5.0 -49.5  1.1
162  c/z     5.0 -49.5  2.1
163  pz    -15.999
164  pz      1.0
165  pz     41.0
166  pz     11.5
167  pz     30.5
c  ch-2
190  c/z    -5.0  49.5  1.0
181  c/z    -5.0  49.5  1.1
182  c/z    -5.0  49.5  2.1
c
c pulsertron
325  c/z    53.8   0.0  5.5
126  pz     82.23
127  pz      9.33
128  c/z    53.8   0.0 10.5
129  pz     40.53
130  pz     10.53
c  st-a
131  c/z    -6.5   -55.5   1.95
132  c/z    -6.5   -55.5   2.25
133  c/z    -6.5   -55.5   3.25
134  pz    36.393
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     6.5   55.5   1.95
141  c/z     6.5   55.5   2.25
142  c/z     6.5   55.5   3.25
c  lin-a
143  c/z    44.5   -43.5  4.7
144  c/z    44.5   -43.5  5.0
145  c/z    44.5   -43.5  5.5
```

```
146  pz     45.645
147  pz      0.89
148  pz    205.5
149  pz    -34.999
150  pz     49.48
151  pz     -6.52
c  lin-b
152  c/z   -44.5   43.5    4.7
153  c/z   -44.5   43.5    5.0
154  c/z   -44.5   43.5    5.5
350  pz     49.48
351  pz     -6.52
c  log-a
155  c/z   -44.5  -43.5   4.7
156  c/z   -44.5  -43.5   5.0
157  c/z   -44.5  -43.5   5.5
c  log-b
158  c/z    44.5   43.5    4.7
159  c/z    44.5   43.5    5.0
160  c/z    44.6   43.5    5.5
c
330  pz     190.47
335  pz     345.47
336  pz     162.62
c  crd-1
171  c/z    9.0     15.59 3.815
221  c/z    9.0     15.59 3.095
331  c/z    9.0     15.59 2.73
c  crd-2
172  c/z   -9.0     15.59 3.815
222  c/z   -9.0     15.59 3.095
332  c/z   -9.0     15.59 2.73
c  crd-3
173  c/z  -18.00     0.0  3.815
223  c/z  -18.00     0.0  3.095
333  c/z  -18.00     0.0  2.73
c  crd-4
174  c/z   18.00     0.0  3.815
224  c/z   18.00     0.0  3.095
334  c/z   18.00     0.0  2.73
c  crd-5
341  c/z    9.0    -15.59 3.815
342  c/z    9.0    -15.59 3.095
343  c/z    9.0    -15.59 2.73
c  crd-6
344  c/z   -9.0    -15.59 3.815
345  c/z   -9.0    -15.59 3.095
346  c/z   -9.0    -15.59 2.73
c  center(spare)
175  c/z    0.0     0.0  3.815
176  pz     189.47
c  n-4(level guide)
177  c/z   -30.0    19.0   2.4
c  n-2(gas-outlet)
178  c/z   -25.98  -15.0   1.7
c  n-5(driving device)
179  c/z    27.5    21.0   2.13
c  n-7(thermocouple guide)
220  c/z     0.0    37.0    1.6
225  pz     190.12
226  pz     5.5
227  pz     2.5
228  c/z     0.0    37.0    0.865
229  c/z     0.0    37.0    0.545
230  c/z     0.0    37.0    1.475
231  c/z     0.0    37.0    0.975
c  fuel feed pipe
c    232  c/z    17.0   -14.5    1.36
232  c/z     0.0      36.5  1.36
233  c/z     0.0      36.5  1.02
234  pz    -9.6
```

```
235  gq    0.38781 0.6122 1. 0.9745 0. 0. -35.57  -44.69  22.0  935.774
236  gq    0.38781 0.6122 1. 0.9745 0. 0. -35.57  -44.69  22.0  936.4786
c   235   c/x   -23.49 -11.0 1.36
c   236   c/x   -23.49 -11.0 1.02
238  p    -1.2564  1. 0.  36.5
237  p    -1.2564  1. 0. -13.78
c   238  px     12.257695
c   237  px    -12.257695
c    239  px      6.2
240  c/z    24.5        17.0   1.36
241  c/z    24.5        17.0   1.02
242  pz    -12.3601
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  Aluminum cover
c
260  cz   30.17
261  cz   61.43
262  p   0.8390996 -1. 0. -0.6527036
263  p   0.8390996 -1. 0.  0.6527036
264  p   0.8390996  1. 0. -0.6527036
265  p   0.8390996  1. 0.  0.6527036
266  pz   142.0
c
c  SUS Futa
c
267  pz   142.6
c
c  Concrete reflector
c
268  cz  30.48
269  cz  60.62
c
c  A-hole
c
270  c/y  0. 28.0  0.25
271  c/y  0. 58.0  0.25
272  c/y  0. 88.0  0.25
c
c  B-hole
c
273  c/x  0. 28.0  0.8
274  c/x  0. 58.0  0.8
275  c/x  0. 88.0  0.8
c
c  D-hole
c
276  c/z  -27.22  27.22 0.8
277  c/z  -35.57  14.73 0.8
278  c/z  -27.22 -27.22 0.8
279  c/z  -14.73 -35.57 0.8
280  c/z   27.22 -27.22 0.8
281  c/z   35.57 -14.73 0.8
282  c/z   27.22  27.22 0.8
283  c/z   14.73  35.57 0.8
c
c  C-hole
c
284  c/z   35.57  14.73 0.25
285  c/z  -35.57 -14.73 0.25
286  c/z  -14.73  35.57 0.25
```

```
287  c/z   14.73 -35.57 0.25
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    R216(watr);U=243.1/A=0.97/D=1.3569
c    atomic density =  9.92630348E-02
m1    1001.37c     6.0297E-02
      7014.37c     1.8157E-03
      8016.37c     3.6535E-02
     92234.37c     5.0042E-07
     92235.37c     6.2098E-05
     92236.37c     6.2021E-08
     92238.37c     5.5312E-04
mt1   lwtr.01t    $  300k
c
c    sus304 7.93g/cm3 core tank
m2    6012.37c  4.7336E-05    $ C
     14000.37c  1.0627E-03    $ Si
     25055.37c  1.1561E-03    $ Mn
     15031.37c  4.3170E-05    $ P
     16000.37c  2.9782E-06    $ S
     28000.37c  8.3403E-03    $ Ni
     24000.37c  1.6775E-02    $ Cr
     26000.37c  5.9421E-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    aluminum 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
     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     Alminum for reflector
```

```
m20  13027.37c  5.9523e-2
     14000.37c  5.7679e-5
     22000.37c  6.7667e-6
     25055.37c  2.9487e-6
     26000.37c  1.7114e-4
     29000.37c  3.5689e-5
c
c    Concrete for reflector
m21   1001.37c  1.6900e-2
      8016.37c  4.5702e-2
     11023.37c  8.4532e-4
     12000.37c  4.9061e-4
     13027.37c  1.5871e-3
     14000.37c  1.5302e-2
     16000.37c  9.0952e-5
     17000.37c  1.5691e-6
     19000.37c  5.4869e-4
     20000.37c  2.2122e-3
     26000.37c  3.9649e-4
mt21  lwtr.01t
c
c    sus304 Futa
m22   6012.37c  1.9880E-04    $ C
     14000.37c  9.1819E-04    $ Si
     25055.37c  1.0518E-03    $ Mn
     15031.37c  4.0087E-05    $ P
     16000.37c  5.9564E-06    $ S
     28000.37c  6.7699E-03    $ Ni
     24000.37c  1.6716E-02    $ Cr
     26000.37c  6.1269E-02    $ Fe
c
c    sus304 Kadai
m23   6012.37c  1.5904E-04    $ C
     14000.37c  9.3519E-04    $ Si
     25055.37c  1.1213E-03    $ Mn
     15031.37c  4.4712E-05    $ P
     16000.37c  2.9782E-06    $ S
     28000.37c  6.8512E-03    $ Ni
     24000.37c  1.6890E-02    $ Cr
     26000.37c  6.0951E-02    $ Fe
c
c    criticality cards
c
kcode  5000 1.0  50  2050
c     kcode  1000 1.0  20  1020
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l  212:208:206:204:202:200:79:1
sp1        1
c
si2    h   0.0   39.500
sp2   -21  1
c
si3    h   0.0   41.46
sp3   -21  0
c
sp4    -3
c
c     ctme   25
prdmp  j -100 1 3
c
print -175
```

APPENDIX D: DERIVATION OF ATOM DENSITIES OF FUEL SOLUTION

Run No.216 (Water-Reflected)

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= 243.1	
Free nitric acid concentration (mol/l)=	AC= 0.97	
Solution density (g/cc)=	D= 1.3569	
Avogadro's number=	AV= 0.60221	
Atom density of U234=N24=	UD/1000*W24/100/A24*AV=	5.0042E-07
Atom density of U235=N25=	UD/1000*W25/100/A25*AV=	6.2098E-05
Atom density of U236=N26=	UD/1000*W26/100/A26*AV=	6.2021E-08
Atom density of U238=N28=	UD/1000*W28/100/A28*AV=	5.5312E-04
Total uranium atom density=	UN=	6.1578E-04
HNO3		
NH(HNO3)=	AC/1000*AV=	5.8414E-04
NN(HNO3)=	AC/1000*AV=	5.8414E-04
NO(HNO3)=	AC/1000*AV*3=	1.7524E-03
Density of HNO3 (g/cc)=DN=	AC*(A1+A7+3*A8)/1000=	0.061122416
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=	0.402623157
Density of H2O=DH=	D-DU-DN=	0.893154427
NH(H2O)=	DH/(2*A1+A8)*AV*2=	5.9713E-02
NO(H2O)=	DH/(2*A1+A8)*AV=	2.9856E-02
Atom density of H=	NH(HNO3)+NH(H2O)=	6.0297E-02
Atom density of O=	NO(H2O)+NO(HNO3)+8*UN=	3.6535E-02
Atom density of N=	NN(HNO3)+2*UN=	1.8157E-03