STACY: UNREFLECTED 10%-ENRICHED URANYL NITRATE SOLUTION IN A 60-CM-DIAMETER CYLINDRICAL TANK

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IDENTIFICATION NUMBER: LEU-SOL-THERM-007 SPECTRA

KEY WORDS: acceptable, critical experiment, cylindrical tank, homogeneous, low enriched, solution, STACY, thermal, unreflected, uranium, uranyl nitrate

1.0 DETAILED DESCRIPTION

1.1 Overview of Experiment

Five critical experiments included in this evaluation are part of a series of experiments with the Static Experiment Critical Facility (STACY) performed in 1995 at the Nuclear Fuel Cycle Safety Engineering Research Facility in the Tokai Research Establishment of the Japan Atomic Energy Research Institute. In the first series of experiments using the unreflected 60-cm-diameter and 150-cm-high cylindrical tank, five sets of critical data were obtained. The uranium concentration of the fuel solution ranged from 242 to 313 gU/liter and the uranium enrichment was 10 wt.%. The core tank was unreflected. The five critical configurations are considered to be acceptable for use as critical benchmark data.

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

1.2 Description of Experimental Configuration

The schematic view of the core tank is shown in Figure 1. The core tank, which is made of stainless steel SUS304, has a cylindrical shape with an inner diameter of 590 mm. The height is approximately 1500 mm. The thickness of the side wall is 3 mm, and the upper and lower flat plates are 25 and 20 mm thick, respectively, as shown in Figure 1. The core tank is vertically penetrated by a tube (the outer diameter is 17.3 mm and its thickness is 3.2 mm) for thermocouples; this tube extends to the bottom of the tank. Four cylindrical safety rods containing B_4C pellets and a level meter are held at the upper part of the core tank. In its withdrawn position, the bottom of the safety rod is 1850 mm above the bottom of the core tank. In its fully inserted position, the bottom of the safety rod is 50 mm above the bottom of the core tank. The stainless steel cladding of the safety rod has a diameter of 61.9 mm, an inner diameter of 54.9 mm, a bottom thickness of 3.5 mm, and total length of 2277 mm. The outer diameter of the B_4C pellet is 54.6 mm. The fuel solution is fed through the fuel feed/drain line (outer diameter: 27.2 mm, thickness: 3.4 mm) from the bottom of the core tank. When the critical height is measured, the fuel solution is in this pipe.

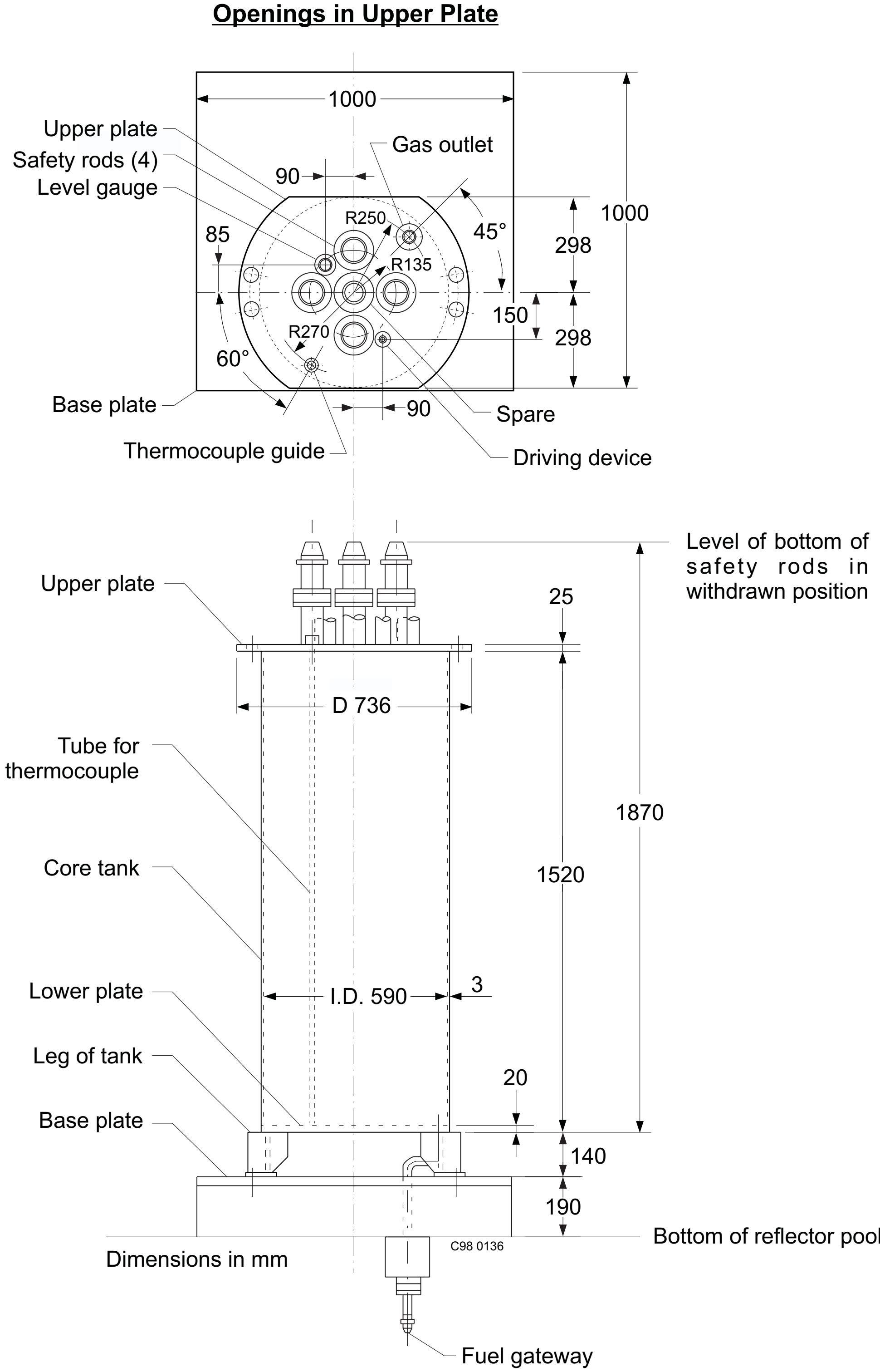


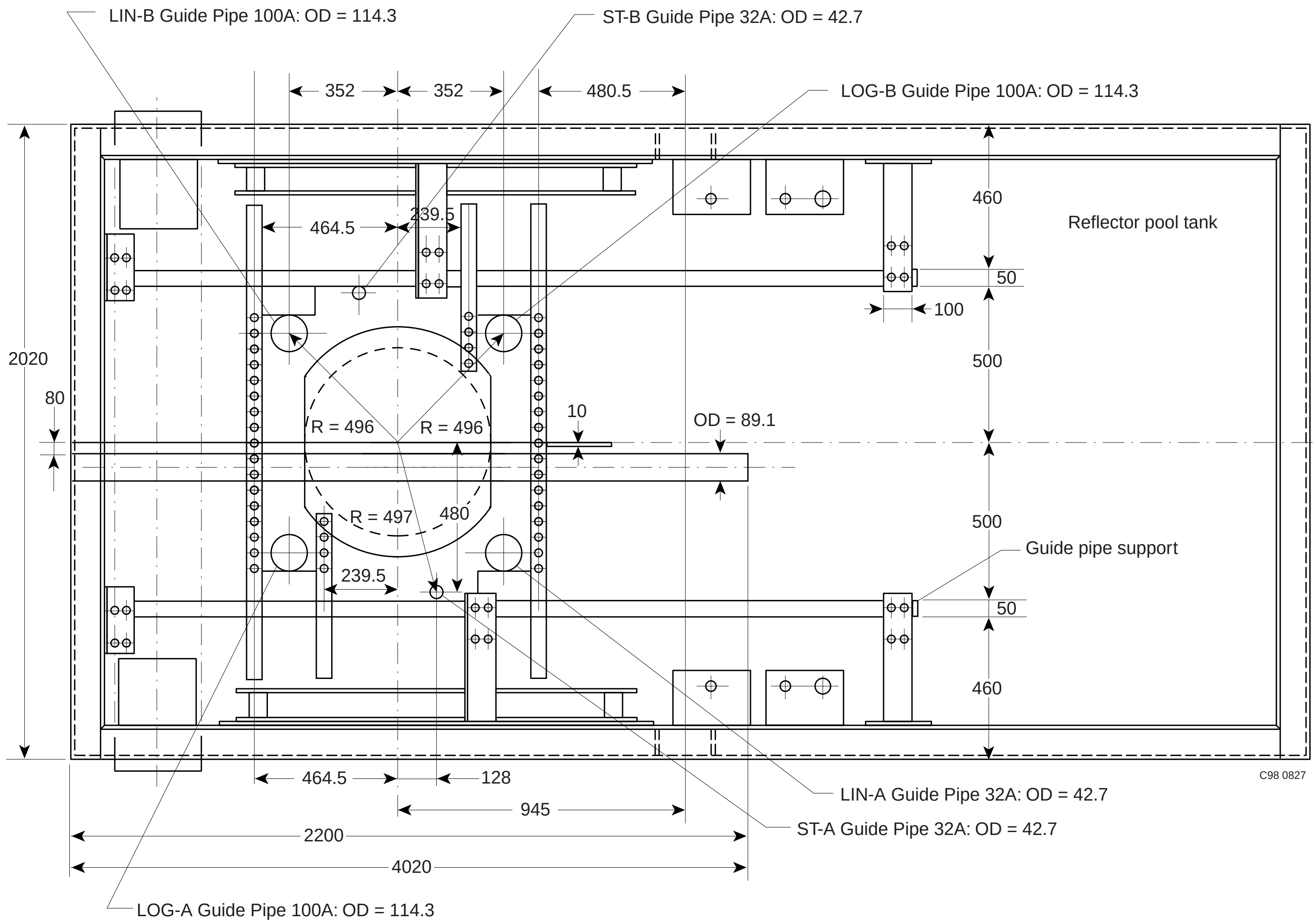
Figure 1. STACY Core Tank.

The core tank is supported by four stainless steel legs. These legs are 140 mm tall and stand on a stainless steel base plate. This plate is 1000 mm wide by 1000 mm long by 30 mm thick. The base plate is centered under the tank in one direction, and is off-center in the other direction, as shown in Figure 1. The base plate is supported by 160-mm-high stainless steel beams located on the bottom of the pool tank. A guide tube (the outer diameter is 89.1 mm and the thickness is 5.5 mm) for inserting an Am-Be neutron source lies horizontally between the bottom plate of the core tank and the base plate. The center line of this tube is 100 mm below the bottom of the solution in the core tank.

The pool tank which is made of stainless steel is 2020 mm wide by 4020 mm long by 2400 mm high (Figure 2.a, b). The side wall thickness of the pool tank is 10 mm and the bottom plate thickness is 15 mm. The bottom of the core tank is 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 700 mm. The pool tank is surrounded by a metal hood which is 9 m wide by 10 m long by 9.8 m high. This hood is installed in a reactor room which is 12.6 m wide by 13.1 m long by 12.1 m high (Figure 3). All walls of the reactor room are made of concrete. The thickness of the concrete walls is more than 1 m.

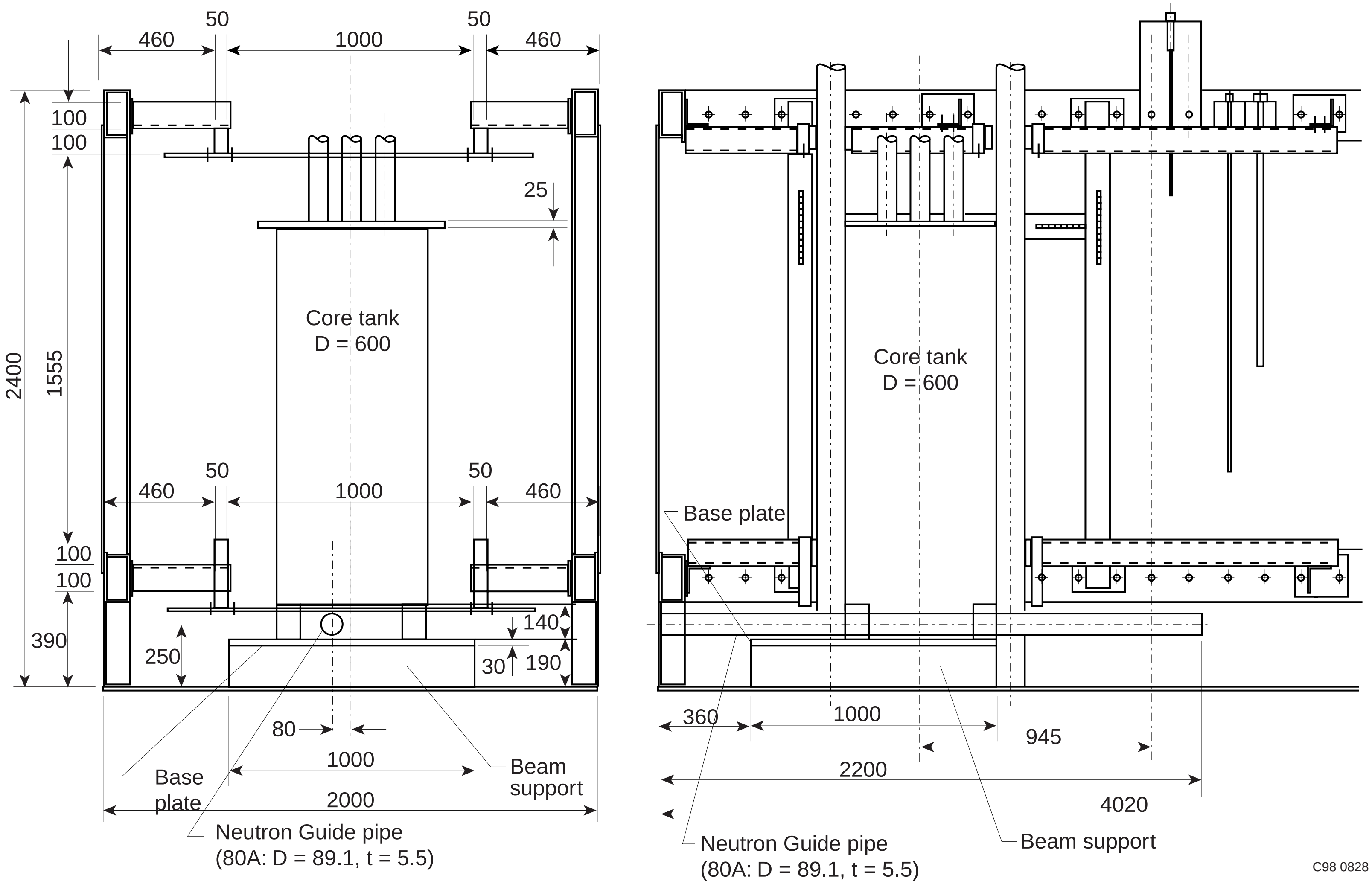
The STACY facility consists of a core tank containing fuel solution, a solution transfer system, a fuel treatment system, and a fuel storage system. Reactivity is controlled by adjusting the fuel solution height in the core tank. Initially, a fast-feed pump is used to feed the fuel solution to just below half of the predicted critical height. After that, a slow-feed pump is used to feed the fuel solution to the near-critical state. The maximum excess reactivity and maximum reactivity addition rate are adjusted by limiting the position of the contact-type height gauge and the feed speed of the slow-feed pump. The height gauge consists 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 critical solution height was determined by observing the steady-state neutron flux level.

The configuration of neutron counters is shown in Figure 4 (a, b, c). The positions of the counters are variable depending on experimental requirements. Figure 4 shows the configuration of Run No. 14 as an example. Two ^{10}B counters and four gamma-ray compensation ionization chambers are positioned around the core tank to measure the neutron flux level for the start-up power range and operation power range, respectively. Maximum power is limited to 200 W. Seven additional experimental neutron monitors (four ^{3}He proportional counters, one ^{10}B counter and two gamma-ray compensation ionization chambers) are also positioned around the core tank. For improving the efficiencies, all counters are covered with polyethylene. The thicknesses of the annuli are given in Figure 4.a. As shown in Figure 4.a, the core tank is equipped with a Pulsatron (pulsed neutron source). The Pulsatron is covered with 5-cm-thick polyethylene sheet.



Dimensions in mm.

Figure 2.a. Horizontal View of Pool Tank.



Dimensions in mm

Figure 2.b. Vertical Views of Pool Tank.

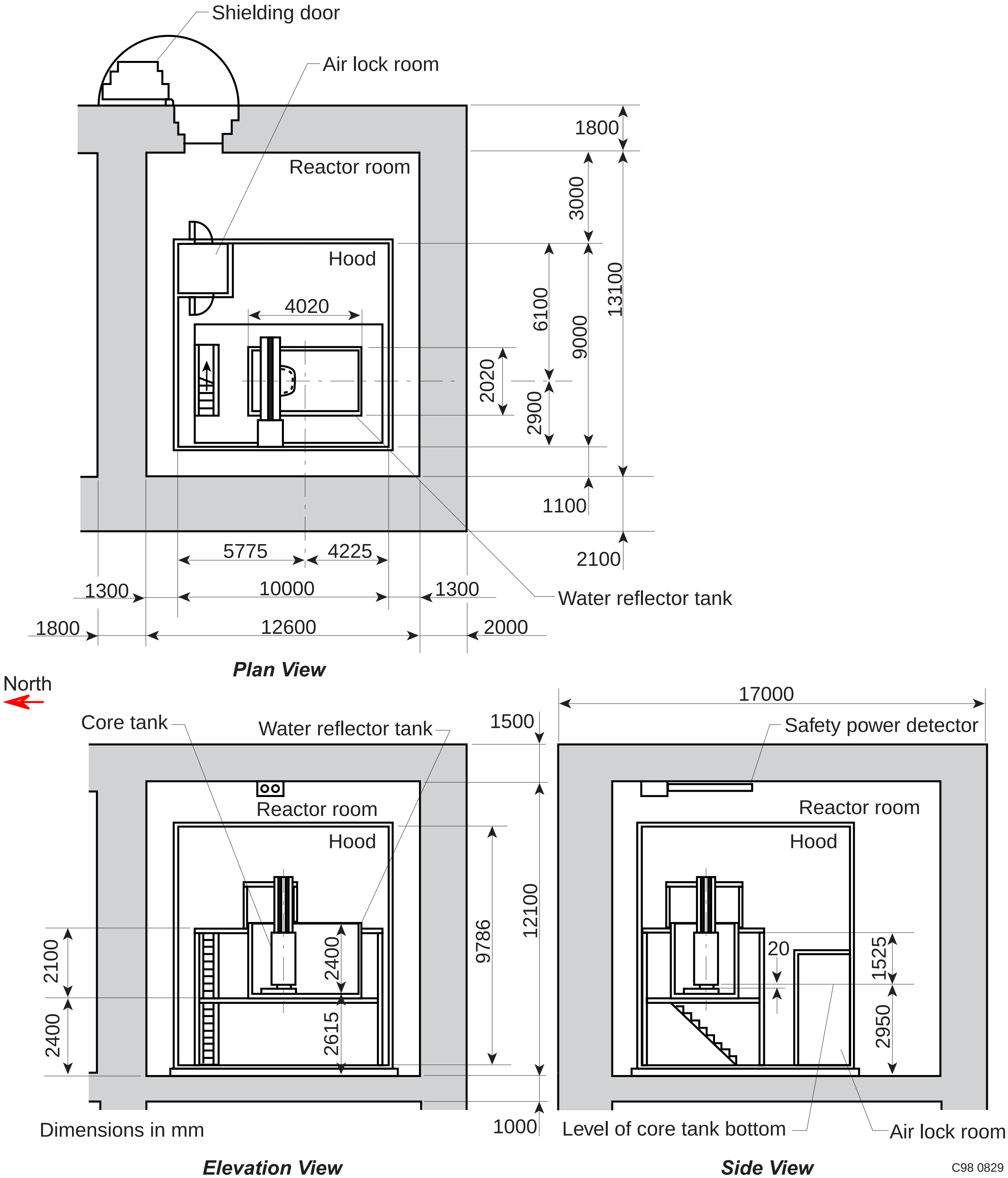
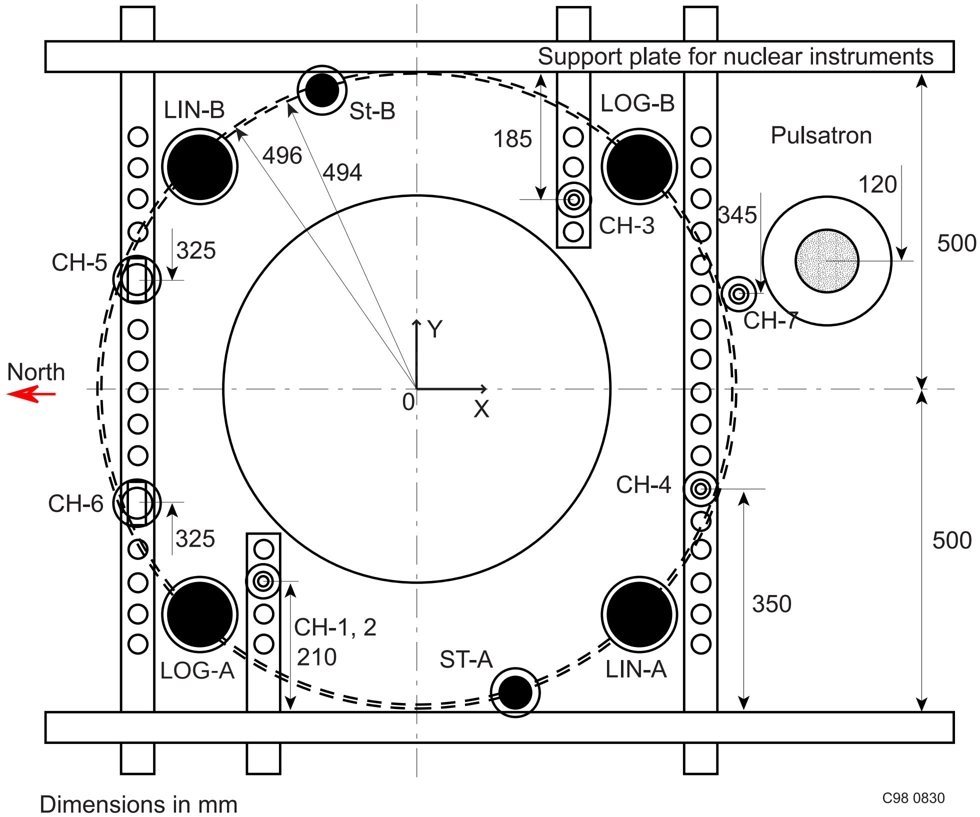


Figure 3. Schematic View inside the Concrete Walls.

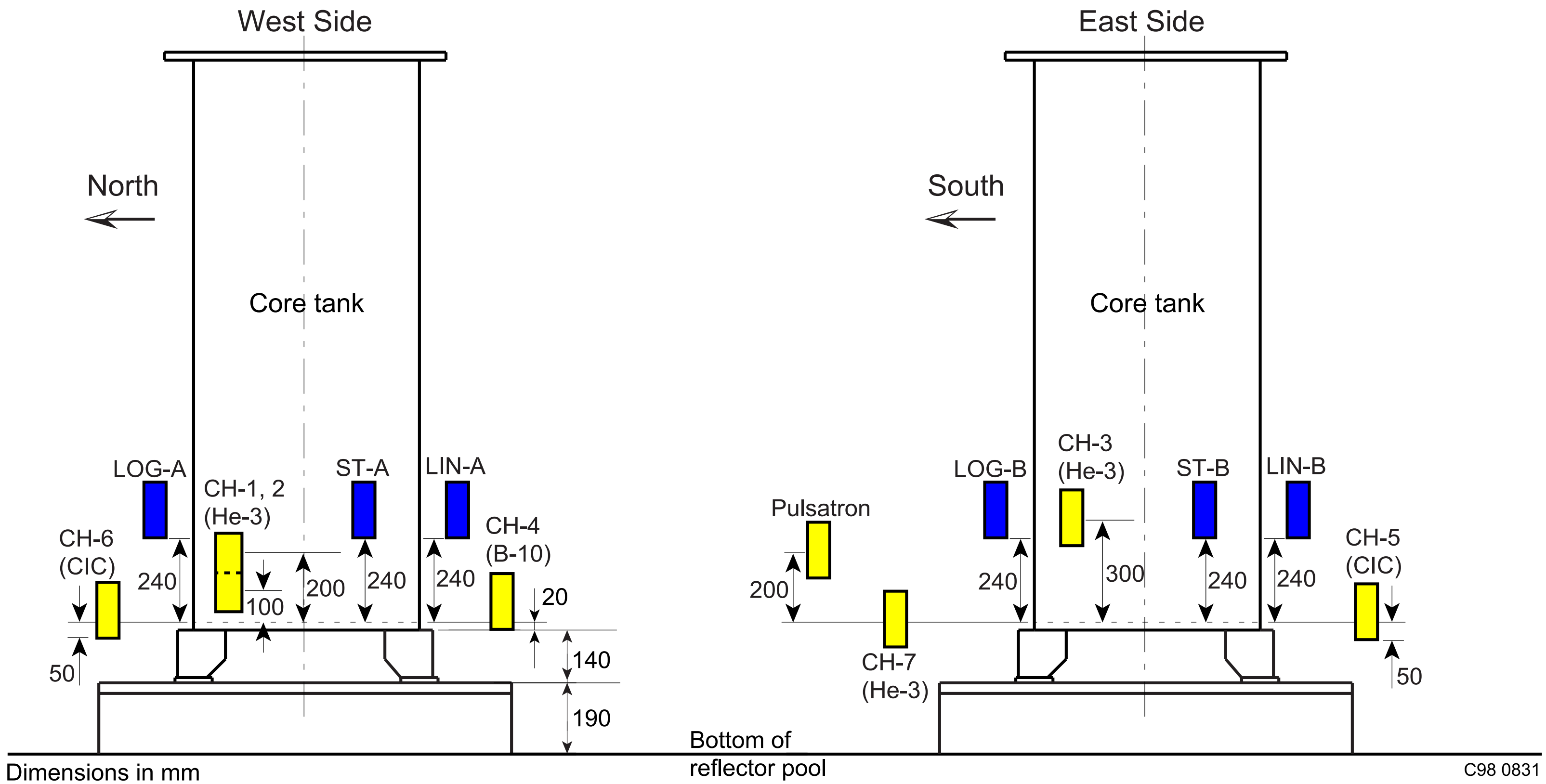


Nuclear Instruments Positions and Dimensions (mm)

Name	X, Y	H	Hb	D	P	U, L
CH-1 He-3	-225, -290	100		24	30	530, -35
CH-2 He-3	-225, -290	200		24	30	530, -35
CH-3 He-3	240, 315	300		24	10	530, -35
CH-4 B-10	460, -150		0	35	10	230, -150
CH-5 CIC	-460, 175		-50	45	10	160, -150
CH-6 CIC	-460, -175		-50	45	10	160, -150
CH-7 He-3	522, 155	0		24	20	60, -20
Pulsatron	652, 380	200		11	50	355, 55
ST-A	128, –490		240	45	10	690, 240
ST-B	-128, 490		240	45	10	690, 240
LIN-A	352, -350		240	10	5	765, 215
LIN-B	-352, 350		240	10	5	780, 220
LOG-A	-352, -350		240	10	5	780, 220
LOG-B	352, 350		240	10	5	765, 215

X, Y – horizontal position
H – vertical position, above core-tank inner bottom
Hb – height of lower end of counter, above core-tank inner bottom
D – diameter of counter without polyethylene (of aluminum tube, if present)
P – thickness of polyethylene
U, L – height of upper, lower end of polyethylene

Figure 4.a. Counter Locations from Top.



Dimensions in mm

Figure 4.b. Counter Locations from West.

Dimensions in mm

Figure 4.c. Counter Locations from East.

The five critical conditions are summarized in Table 1.

Table 1. Critical Conditions of the STACY Experiments.

Run Number	Uranium Concentration[a] (g/liter)	Acidity[a] (mol/liter)	Core Temperature[b] (°C)	Critical Height (mm)	Density[a] (g/cm^3)	Date
14	313.0±0.5	2.25±0.02	23.8	468.3±0.2	1.4881±0.0005	4/11/1995
30	290.7±0.5	2.23±0.02	25.4	542.0±0.2	1.4571±0.0005	6/1/1995
32	270.0±0.5	2.20±0.02	25.8	635.5±0.2	1.4348±0.0005	6/7/1995
36	253.9±0.5	2.23±0.02	25.8	835.5±0.2	1.4102±0.0005	6/21/1995
49	241.9±0.5	2.27±0.02	23.5	1122.7±0.2	1.3941±0.0005	7/13/1995

(a) These values are measured at 25°C.
(b) Temperatures of the experiments.

Table 2. Isotopic Composition of Uranium.

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

1.3 Description of Material Data

The uranium concentration, acidity, temperature, and density of the fuel solutions are listed in Table 1. The isotopic composition is listed in Table 2. The enrichment of the uranium was 9.97 ± 0.013 wt.%. Chemical analyses of the uranium concentration, acid molarity, and density of the fuel solution were made before and after each operation.

A sample of uranyl nitrate solution was taken from the dump tank, which is located in the basement of the reactor room, before and after each reactor operation. The chemical conditions in Table 1 are the latest ones before the experiments. The uranium concentrations were measured with the Davies and Gray method. The uncertainty of uranium concentrations was determined to be 0.5 g/liter. The measurement of acidity is as follows. Uranium was precipitated by adding $(NH_4)_2SO_4$ and H_2O_2 to a sample solution. Then, the total acidity was determined by titration with sodium hydroxide. The uncertainty of the acidity was determined to be 0.02 mol/liter. The density of sample solution was measured with a digital density meter. The accuracy of this meter is 0.0001 g/cm^3. The uncertainty of density was estimated to be 0.0005 g/cm^3.

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

Three elements, Fe, Cr, and Ni, were considered and measured as main impurities contained in the fuel solutions. The concentrations of these elements were found to be independent of the uranium concentration and acid molarity. The concentrations of Fe, Ni, and Cr were less than 28 mg/liter, 11 mg/liter, and 10 mg/liter, respectively.

The core tank is made of stainless steel SUS304. Other structural materials (legs, tube for thermometer, safety rod guide tube, base plate, pool tank, fuel feed/drain pipe, and sheath of B_4C pellets) are also made of stainless steel SUS304. The containers of the neutron counters and the Pulsatron are made of aluminum. The structural material for fixing the counters and Pulsatron are also aluminum. The measured chemical composition of the core tank is given in Table 3. The density of the stainless steel SUS304 is not known. It is assumed that the density of the stainless steel is 7.93 g/cm^3. This value is taken from the Japanese Industrial Standard.

Table 3. Composition of Stainless Steel for Core Tank.

Element	(wt.%)
C	0.011
Si	0.625
Mn	1.33
P	0.028
S	0.002
Ni	10.25
Cr	18.265
Fe	69.489

1.4 <u>Supplemental Experimental Measurements</u>

From the reactor period measured at a slightly supercritical height with two compensated ionization chambers, reactivity was obtained using an inhour equation. The differential reactivity with respect to solution height was measured.

The neutron flux distribution along the vertical direction was measured using the radioactivity distribution of irradiated gold wire. The gold wire was positioned on the outer surface of the core tank and was removed after the high power operation. An extrapolation length along the vertical direction was measured by fitting the flux distribution to the cosine function.

The results of these measurements are given in Reference 1.

To measure the power of a critical core, an Am-Be neutron source was inserted into the critical core. The subsequent power increased linearly with time. The ratio of the initial neutron count rate to its increasing rate was used for estimating the power of the critical state.[a]

Subcritical experiments such as pulsed-neutron method and frequency noise analysis were also carried out and kinetic parameters were measured.[b]

The results of these measurements are written in the logbook or in other classified internal reports.

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[a] Y. Miyoshi et al., Private communications (in Japanese).

[b] K. Tonoike et al., Private communications (in Japanese).

2.0 EVALUATION OF EXPERIMENTAL DATA

2.1 General Notes

The results of five critical experiments are collected from References 1 and 2 and other laboratory reports. The effects on k_{eff} of uncertainties in measured data were calculated and are described in this section. Sensitivity studies were performed with the two-dimensional neutron-transport code TWOTRAN and a 16-group cross section set collapsed from the 107-group SRAC public library based on JENDL-3.2 (with a convergence criteria of 1 x 10^{-6}).

2.2 Fuel Solutions

As shown in Section 1, the uncertainty of uranium concentration, enrichment, acid molarity, and solution density were determined to be 0.5 gU/liter, 0.013 wt.%, 0.02 mol/liter, and 0.0005 g/cm^3, respectively. The effect of these uncertainties on calculated k_{eff} are shown in Table 4. When calculating the effect of enrichment uncertainty, the weight fraction of ^{238}U is also changed such that the total of the weight fractions becomes 100%. Since the uncertainty of the weight fraction of ^{234}U is not given, the same uncertainty as ^{235}Uwas assumed, i.e. 0.013wt.%.

Table 4. Effects of Uncertainties of Fuel on k_{eff} (%).

Parameter	Uncertainty	Run No.				
		14	30	32	36	49
Enrichment	±0.013 wt.%	±0.045	±0.047	±0.049	±0.051	±0.052
U-234 wt.%	±0.013 wt.%	±0.016	±0.016	±0.016	±0.015	±0.015
Concentration	±0.5 gU/l	±0.024	±0.034	±0.046	±0.055	±0.063
Acid molarity	±0.02 mol/l	-+0.044	-+0.042	-+0.037	-+0.034	-+0.031
Density	±0.0005 g/cm^3	±0.011	±0.008	±0.006	-+0.003	-+0.031
Impurity (Fe)	28 mg/l	-0.0023	-0.0030	-0.0027	-0.0032	-0.0029
Impurity (Cr)	10 mg/l	-0.0011	-0.0013	-0.0012	-0.0015	-0.0013
Impurity (Ni)	11 mg/l	-0.0010	-0.0010	-0.0009	-0.0012	-0.0007

2.3 Critical Dimensions

The core tank used for the experiments has tolerances in the diameter, side-wall thickness, and bottom-plate thickness. These tolerances are estimated to be 1.0 mm, 0.2 mm, and 0.4 mm, respectively. The accuracy of the contact-type solution-height gauge is 0.2 mm. These values were adopted as the uncertainties. The effects of these uncertainties were evaluated and are listed in Table 5.

Table 5. Effects on k_{eff} of Tolerances in Critical Dimensions.

Parameter	Uncertainty	Δk_{eff}, %				
		14	30	32	36	54
Diameter	±1.0 mm	±0.045	±0.046	±0.046	±0.045	±0.048
Side-Wall Thickness	±0.2 mm	±0.018	±0.018	±0.018	±0.018	±0.018
Bottom-Plate Thickness	±0.4 mm	±0.009	±0.006	±0.004	±0.002	<0.001
Critical Height	±0.2 mm	±0.007	±0.005	±0.003	±0.002	<0.001

2.4 Temperature

The temperature change during the operations is estimated to be within 0.3 °C. The effect on k_{eff} of this temperature change is calculated and listed in Table 6. To calculate the temperature effects, a density formula[a] for uranyl nitrate solution developed at JAERI was used. This formula gives the density of uranyl nitrate solution as a function of uranium concentration, acid molarity, and temperature. The details of this formula are shown in APPENDIX B.

Table 6. Effects on k_{eff} of Temperature Uncertainty.

Temperature Change	Δk_{eff}, %				
	14	30	32	36	49
±0.3 °C	-+0.010	-+0.010	-+0.010	-+0.008	-+0.009

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 1.5°C (25-23.5).

The temperature uncertainty has two effects.

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

[a] S. Sakurai et al., JAERI-M 88-127 (1988).

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

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

The 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 6.

2.5 Core Tank

The density of the stainless steel SUS304 for the core tank is not known. The value from the Japanese Industrial Standard, 7.93 g/cm^3 was assumed. The sensitivity of k_{eff} to the density was investigated for Run No. 14. The calculated sensitivity, Δk_{eff}, is +0.095% /(g/cm^3). The uncertainty of the density is assumed to be the least significant digit, 0.01g/cm^3. Therefore, the effect of the uncertainty on k_{eff} is estimated to be ±0.001% Δk_{eff}.

Because sufficient data are known and uncertainties have been sufficiently quantified, the five configurations are acceptable benchmark experiments.

3.0 BENCHMARK SPECIFICATION

3.1 Description of Model

The benchmark model is shown in Figure 5. The model is very simple. It consists of the fuel solution and core tank.

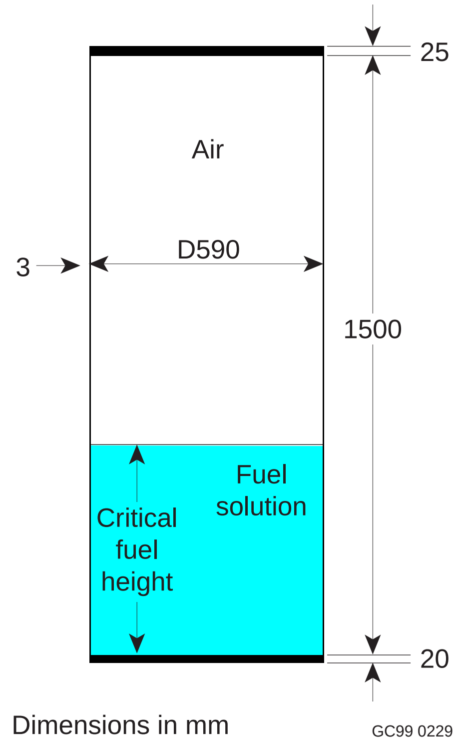

Figure 5. Benchmark Model of the STACY Experiments.

In the benchmark model, nothing exists outside the core tank. The following structures and devices are not included in the benchmark model for simplification of the benchmark model:

(1) Tube for thermocouples within the core tank.
(2) Contact-type level gauge. This is hung above the surface of the fuel solutions.
(3) Four legs supporting the core tank.
(4) Fuel feed/drain pipe containing fuel solution. The outer diameter of this pipe is 27.2 mm and the thickness of the pipe wall is 3.4 mm.
(5) Guide tube for neutron source. This tube lies horizontally below the core tank.
(6) Base plate. This plate is supporting the four legs. The upper surface of this plate is 14 cm below the bottom of the core tank.

(7) Beams below the base plate. These beams are supporting the base plate and lie on the bottom of the pool tank. The thickness of these beams is 16 cm.
(8) Neutron counters with polyethylene sheets. The closest counter is 4 cm away from the side wall of the core tank.
(9) Pulsatron.
(10) Upper structure of the core tank. The guide tubes of the safety rods, level measurement devices and safety rods are located above the upper plate of the core tank.
(11) Pool tank wall. The bottom of the pool tank is 34 cm below the core tank. The side wall of the pool tank is at least 70 cm away from the side wall of the core tank.
(12) Hood and concrete wall of the reactor room.
(13) Other structures outside the core tank.

A detailed model that includes the structures (1)-(12) was constructed. The thickness of the hood is 7 mm. It is assumed the material of the hood is the same as the core tank. The thickness and other geometrical configurations of the hood and concrete wall for the detailed model are shown in Figure 3. The composition of the concrete was taken from the Criticality Safety Handbook of Japan.[a] MCNP calculations using both the standard benchmark model shown in Figure 5 and the detailed model were carried out for all cases. The neutron counters and the Pulsatron were modeled by homogenizing the real material components of these instruments. The calculated k_{eff}'s and effects of modeling simplifications are shown in Table 7. The detailed model is too complicated and the counter locations are case-dependent. Therefore, the detailed model was not adopted as the benchmark model. The input listing of MCNP for the detailed model of Run No. 14 is given in Appendix D.

Table 7. Effect of Modeling Simplifications.

Run. No.	Benchmark model	Detailed model	Simplification effect Δk_{eff}, %
14	1.00152±0.00022	1.00501±0.00022	-0.349±0.032
30	1.00344±0.00021	1.00629±0.00022	-0.285±0.030
32	1.00237±0.00021	1.00410±0.00020	-0.173±0.029
36	1.00497±0.00020	1.00646±0.00020	-0.149±0.028
49	1.00342±0.00019	1.00469±0.00019	-0.127±0.027

The differences of k_{eff}'s between the benchmark models and detailed models are included as biases in the benchmark-model k_{eff}'s.
In this benchmark model, Fe, Cr, and Ni are neglected. The reactivity effects of these impurities were obtained in Section 2. Because the impurity concentrations are maximum values and because

[a] Nuclear Safety Bureau / Science and Technology Agency Ed. "Nuclear Criticality Safety Handbook (English Translation)," JAERI-Review 95-013, Japan Atomic Energy Research Institute (1995).

the calculated effects were small, they are not included in the bias in the benchmark model k_{eff}, but their effects are included in the benchmark-model k_{eff} uncertainty.

3.2 Dimensions

The dimensions of the benchmark model are given in Figure 5. The critical heights of the benchmark model are shown in Table 8.

Table 8. Critical Sizes of the Benchmark Model.

Run No.	Uranium Concentration (gU/liter)	Solution Height (cm)
14	313.0	46.83
30	290.7	54.20
32	270.0	63.55
36	253.9	83.55
49	241.9	112.27

3.3 Material Data

Because the uranium concentration, density of the solution, and acid molarity for 25°C are known, the atom densities of the fuel solution can be obtained. The atom densities of the fuel solutions for 25°C are shown in Table 9. The derivations of these atom densities are given in Appendix C.

Table 9. Atom Densities of Fuel Solution.

Run No.	^{234}U	^{235}U	^{236}U	^{238}U	H	N	O
14	6.4430E-07	7.9954E-05	7.9854E-08	7.1216E-04	5.6707E-02	2.9406E-03	3.8084E-02
30	5.9840E-07	7.4257E-05	7.4165E-08	6.6142E-04	5.7176E-02	2.8156E-03	3.7836E-02
32	5.5579E-07	6.8970E-05	6.8884E-08	6.1432E-04	5.8085E-02	2.6927E-03	3.7826E-02
36	5.2265E-07	6.4857E-05	6.4776E-08	5.7769E-04	5.8115E-02	2.6292E-03	3.7560E-02
49	4.9795E-07	6.1792E-05	6.1715E-08	5.5039E-04	5.8223E-02	2.5925E-03	3.7431E-02

The density of the stainless steel is 7.93 g/cm^3. The atom densities of the stainless steel used for the core tank are shown in Table 10.

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

C	Si	Mn	P
4.3736E-05	1.0627E-03	1.1561E-03	4.3170E-05
S	Ni	Cr	Fe
2.9782E-06	8.3403E-03	1.6775E-02	5.9421E-02

It is assumed that the void region above the surface of the solution is occupied by air of the density of 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,
O: 1.0409E-05.

3.4 Temperature Data

The temperature at which the critical solution heights were measured ranged from 23.5°C to 25.8°C. The temperature 25°C was used in the benchmark model calculations, because the chemical analysis results are obtained for 25°C. As shown in Section 3.5, this temperature difference results in a small bias in the benchmark-model k_{eff}.

3.5 Experimental and Benchmark-Model k_{eff}

Experimental value of k_{eff} is 1.

The sources of the bias in the benchmark model are:

(1) excluding impurities (Fe, Cr, Ni) from the fuel solution,
(2) simplification of the geometry of the benchmark model,
(3) neglecting the structures around the core tank,
(4) temperature difference between experimental temperature and 25°C.

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

For reasons discussed in Section 3.1, the effect of impurities is not included in the bias but is included in the benchmark-model k_{eff} uncertainty. The effect of structures is given in Table 7. The effect of the temperature difference can be obtained by TWOTRAN (convergence criterion of $1x10^{-6}$). The k_{eff}'s for experimental temperature and 25°C were calculated. The density formula (Appendix B) was used for obtaining atom densities at different temperatures. Cross section modifications due to the temperature difference are taken into account in the TWOTRAN calculations. Table 11 shows the TWOTRAN calculation results.

Table 11. TWOTRAN Calculation Results for Estimation of Temperature Bias.

Run No.	k_{eff} for 25°C	k_{eff} for Experimental Temperature	Bias of Temperature Effect Δk_{eff}, %
14	1.00623	1.00665	-0.042
30	1.00867	1.00853	0.014
32	1.00650	1.00625	0.025
36	1.00920	1.00896	0.024
49	1.00740	1.00784	-0.044

The effect of the temperature difference can be regarded as a bias in the benchmark model k_{eff}. The uncertainty of k_{eff}'s included in the benchmark models are obtained by the square root of sum of squares of individual uncertainties. Consequently, the benchmark model k_{eff}'s are:

Run 14: 0.9961 ± 0.0009,
Run 30: 0.9973 ± 0.0009,
Run 32: 0.9985 ± 0.0010,
Run 36: 0.9988 ± 0.0011,
Run 49: 0.9983 ± 0.0011.

4.0 RESULTS OF SAMPLE CALCULATIONS

Sample calculation results using MCNP with the JENDL-3.2 library are shown in Table 12. In addition, APOLLO 2-MORET IV with CEA93 Library 172 groups was used for sample calculations. These libraries are based on JEF2 data. The results are shown in Table 13. The results using KENO V.a with 238-group ENDF/B-V cross sections and MCNP with ENDF/B-V continuous-energy cross sections are given in Table 14.

Table 12. Sample Calculation Results (Japan).

Code (Cross Section Set)→ Run No.↓	MCNP 4B (Continuous Energy JENDL-3.2)
14	1.0015 ± 0.0002
30	1.0034 ± 0.0002
32	1.0024 ± 0.0002
36	1.0050 ± 0.0002
49	1.0034 ± 0.0002

Table 13. Sample Calculation Results (France).[a]

Code (Cross Section Set)→ Run No.↓	APOLLO 2-MORET IV (CEA93 Library 172-Group)
14	0.99508 ± 0.0003
30	0.99754 ± 0.0003
32	0.99538 ± 0.0003
36	0.99786 ± 0.0010
49	0.99680 ± 0.0010

(a) Results provided by G. Poullot.

Table 14. Sample Calculation Results (United States).[a]

Code (Cross Section Set) → Run No. ↓	KENO (238-Group ENDF/B-V)	MCNP (Continuous Energy ENDF/B-V)
14	0.9960 ± 0.0007	0.9966 ± 0.0007
30	0.9977 ± 0.0007	0.9992 ± 0.0007
32	0.9976 ± 0.0007	0.9960 ± 0.0006
36	0.9995 ± 0.0006	0.9978 ± 0.0006
49	0.9986 ± 0.0006	0.9981 ± 0.0006

(a) Results provided by V. F. Dean.

5.0 REFERENCES

1. Y. Miyoshi, T. Umano, Kotaro Tonoike, Naoki Izawa, Susumu Sugikawa and Shuji Okazaki, “Critical Experiments on 10 % Enriched Uranyl Nitrate Solution Using a 60-cm-Diameter Cylindrical Core,” *Nucl. Technol.* **118**, 69 (1997).

2. H. Sono, S. Onedera, H. Hirose, Y. Takatsuki, T. Kodama, A. Ohno, K. Sakuraba, N. Izawa, K. Tonoike, T. Umano and Y. Miyoshi, “Annual Report of STACY in 1995 –600 mm Diameter Cylindrical Core and 10% Enriched Uranyl Nitrate Solution,” JAERI-Tech 97-005 (1995) (in Japanese).

APPENDIX A: TYPICAL INPUT LISTINGS

A.1 MCNP Input Listing

The MCNP 4B calculations were performed using 2000 active generations of 5000 neutrons each, after skipping 50 generations.

MCNP Input Listing Run No. 14 of Table 12.

```
file name=run014 ; STACY ( model 2 )
c    R014(bare)   ;U=313.0(g/lit) A=2.25(mol/lit) D=1.4881(g/cc)
c    Critical level  46.83(cm)
c
c    cellcard
c
1    1  9.85238254E-02          1  -2 -10        imp:n=1 u=1
2    3  4.94250000E-05          2  -3 -10        imp:n=1 u=1
3    2  8.68449842E-02   #1 #2                   imp:n=1 u=1
4    0                    -4   5 -20       imp:n=1 fill=1
5    0              #1 #2 #4                    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     46.83
 3   pz    150.0
 4   pz    152.5
 5   pz     -2.0
10   cz     29.5
20   cz     29.8

c
c    data cards
c
mode  n                    $ transport neutrons only
c
c    material cards
c    run014
c    atomic density =  9.85238254E-02
m1    1001.37c     5.6707E-02
      7014.37c     2.9406E-03
      8016.37c     3.8084E-02
     92234.37c     6.4430E-07
     92235.37c     7.9954E-05
     92236.37c     7.9854E-08
     92238.37c     7.1216E-04
mt1   lwtr.01t    $  300K
c
c    sus304 7.93g/cm3 ; atomic density  8.68449842E-02
m2    6012.37c 4.3736e-5   $ C
     14000.37c 1.0627e-3   $ Si
     25055.37c 1.1561e-3   $ Mn
     15031.37c 4.3170e-5   $ P
     16000.37c 2.9782e-6   $ S
     28000.37c 8.3403e-3   $ Ni
     24000.37c 1.6775e-2   $ Cr
     26000.37c 5.9421e-2   $ Fe
c
c     Air (0.001184 g/cm3)
c     atomic density  4.9425E-05
m3    7014.37c 3.9016e-5
      8016.37c 1.0409e-5
c
c    criticality cards
c
kcode   5000 1.0 50 2000
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 4:1
```

MCNP Input Listing Run No. 14 of Table 12 (cont'd).

```
sp1       1
c
si2    h   0.0   29.50
sp2   -21  1
c
si3    h   0.0   46.83
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```

MCNP Input Listing Run No. 30 of Table 12.

```
file name=run030 ; STACY ( model 2 )
c    R030(bare)   ;U=290.7(g/lit) A=2.23(mol/lit) D=1.4572(g/cc)
c    Critical level  54.20(cm)
c
c    cellcard
c
1    1  9.85636637E-02         1  -2 -10       imp:n=1 u=1
2    3  4.94250000E-05         2  -3 -10       imp:n=1 u=1
3    2  8.68449842E-02   #1 #2                 imp:n=1 u=1
4    0                     -4   5 -20      imp:n=1 fill=1
5    0           #1 #2 #4                  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     54.20
 3   pz    150.0
 4   pz    152.5
 5   pz     -2.0
10   cz     29.5
20   cz     29.8

c
c    data cards
c
mode  n                  $ transport neutrons only
c
c    material cards
c    atomic density =  9.85636637E-02
m1    1001.37c     5.7176E-02
      7014.37c     2.8156E-03
      8016.37c     3.7836E-02
     92234.37c     5.9840E-07
     92235.37c     7.4257E-05
     92236.37c     7.4165E-08
     92238.37c     6.6142E-04
mt1   lwtr.01t    $  300K
c
c    sus304 7.93g/cm3 ; atomic density  8.68449842E-02
m2    6012.37c 4.3736e-5   $ C
     14000.37c 1.0627e-3   $ Si
     25055.37c 1.1561e-3   $ Mn
     15031.37c 4.3170e-5   $ P
     16000.37c 2.9782e-6   $ S
     28000.37c 8.3403e-3   $ Ni
     24000.37c 1.6775e-2   $ Cr
     26000.37c 5.9421e-2   $ Fe
c
c     Air (0.001184 g/cm3)
c     atomic density  4.9425E-05
m3    7014.37c 3.9016e-5
      8016.37c 1.0409e-5
c
c    criticality cards
c
kcode   5000 1.0 50 2000
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 4:1
sp1       1
```

MCNP Input Listing Run No. 30 of Table 12 (cont'd).

```
c
si2    h   0.0   29.50
sp2   -21  1
c
si3    h   0.0   54.20
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```

MCNP Input Listing Run No. 32 of Table 12.

```
file name=run032 ; STACY ( model 2 )
c    R032(bare)   ;U=270.0(g/lit) A=2.20(mol/lit) D=1.4348(g/cc)
c    Critical level  63.55(cm)
c
c    cellcard
c
1    1  9.92878750E-02         1  -2 -10       imp:n=1 u=1
2    3  4.94250000E-05         2  -3 -10       imp:n=1 u=1
3    2  8.68449842E-02   #1 #2                 imp:n=1 u=1
4    0                        -4   5 -20       imp:n=1 fill=1
5    0             #1 #2 #4                    imp:n=0

c    surface cards (origin x=0.0 y=0.0 z=0.0)
c    cylinder
 1   pz      0.0
 2   pz     63.55
 3   pz    150.0
 4   pz    152.5
 5   pz     -2.0
10   cz     29.5
20   cz     29.8

c
c    data cards
c
mode  n                  $ transport neutrons only
c
c    material cards
c    atomic density =  9.92878750E-02
m1    1001.37c     5.8085E-02
      7014.37c     2.6927E-03
      8016.37c     3.7826E-02
     92234.37c     5.5579E-07
     92235.37c     6.8970E-05
     92236.37c     6.8884E-08
     92238.37c     6.1432E-04
mt1   lwtr.01t    $  300K
c
c    sus304 7.93g/cm3 ; atomic density  8.68449842E-02
m2    6012.37c 4.3736e-5   $ C
     14000.37c 1.0627e-3   $ Si
     25055.37c 1.1561e-3   $ Mn
     15031.37c 4.3170e-5   $ P
     16000.37c 2.9782e-6   $ S
     28000.37c 8.3403e-3   $ Ni
     24000.37c 1.6775e-2   $ Cr
     26000.37c 5.9421e-2   $ Fe
c
c     Air (0.001184 g/cm3)
c     atomic density  4.9425E-05
m3    7014.37c 3.9016e-5
      8016.37c 1.0409e-5
c
c    criticality cards
c
kcode   5000 1.0 50 2000
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 4:1
sp1       1
c
```

MCNP Input Listing Run No. 32 of Table 12 (cont'd).

```
si2    h   0.0   29.50
sp2   -21  1
c
si3    h   0.0   63.55
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```

MCNP Input Listing Run No. 36 of Table 12.

```
file name=run036 ; STACY ( model 2 )
c    R036(bare)   ;U=253.9(g/lit) A=2.23(mol/lit) D=1.4102(g/cc)
c    Critical level  83.55(cm)
c
c    cellcard
c
1    1  9.89471078E-02          1  -2 -10        imp:n=1 u=1
2    3  4.94250000E-05          2  -3 -10        imp:n=1 u=1
3    2  8.68449842E-02   #1 #2                   imp:n=1 u=1
4    0                          -4   5 -20       imp:n=1 fill=1
5    0              #1 #2 #4                     imp:n=0

c    surface cards (origin x=0.0 y=0.0 z=0.0)
c    cylinder
 1   pz      0.0
 2   pz     83.55
 3   pz    150.0
 4   pz    152.5
 5   pz     -2.0
10   cz     29.5
20   cz     29.8

c
c    data cards
c
mode  n                    $ transport neutrons only
c
c    material cards
c    atomic density =  9.89471078E-02
m1    1001.37c     5.8115E-02
      7014.37c     2.6292E-03
      8016.37c     3.7560E-02
     92234.37c     5.2265E-07
     92235.37c     6.4857E-05
     92236.37c     6.4776E-08
     92238.37c     5.7769E-04
mt1   lwtr.01t    $  300K
c
c    sus304 7.93g/cm3 ; atomic density  8.68449842E-02
m2    6012.37c 4.3736e-5   $ C
     14000.37c 1.0627e-3   $ Si
     25055.37c 1.1561e-3   $ Mn
     15031.37c 4.3170e-5   $ P
     16000.37c 2.9782e-6   $ S
     28000.37c 8.3403e-3   $ Ni
     24000.37c 1.6775e-2   $ Cr
     26000.37c 5.9421e-2   $ Fe
c
c     Air (0.001184 g/cm3)
c     atomic density  4.9425E-05
m3    7014.37c 3.9016e-5
      8016.37c 1.0409e-5
c
c    criticality cards
c
kcode   5000 1.0 50 2000
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 4:1
sp1       1
c
```

MCNP Input Listing Run No. 36 of Table 12 (cont'd).

```
si2    h   0.0   29.50
sp2   -21  1
c
si3    h   0.0   83.55
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```

MCNP Input Listing Run No. 49 of Table 12.

```
file name=run049 ; STACY ( model 2 )
c    R049(bare)   ;U=241.9(g/lit) A=2.27(mol/lit) D=1.3941(g/cc)
c    Critical level  112.27(cm)
c
c    cellcard
c
1    1  9.88589302E-02          1  -2 -10        imp:n=1 u=1
2    3  4.94250000E-05          2  -3 -10        imp:n=1 u=1
3    2  8.68449842E-02   #1 #2                   imp:n=1 u=1
4    0                      -4   5 -20       imp:n=1 fill=1
5    0             #1 #2 #4                  imp:n=0

c    surface cards (origin x=0.0 y=0.0 z=0.0)
c    cylinder
 1   pz      0.0
 2   pz    112.27
 3   pz    150.0
 4   pz    152.5
 5   pz     -2.0
10   cz     29.5
20   cz     29.8

c
c    data cards
c
mode  n                  $ transport neutrons only
c
c    material cards
c    atomic density =  9.88589302E-02
m1    1001.37c     5.8223E-02
      7014.37c     2.5925E-03
      8016.37c     3.7431E-02
     92234.37c     4.9795E-07
     92235.37c     6.1792E-05
     92236.37c     6.1715E-08
     92238.37c     5.5039E-04
mt1   lwtr.01t    $  300K
c
c    sus304 7.93g/cm3 ; atomic density  8.68449842E-02
m2    6012.37c 4.3736e-5   $ C
     14000.37c 1.0627e-3   $ Si
     25055.37c 1.1561e-3   $ Mn
     15031.37c 4.3170e-5   $ P
     16000.37c 2.9782e-6   $ S
     28000.37c 8.3403e-3   $ Ni
     24000.37c 1.6775e-2   $ Cr
     26000.37c 5.9421e-2   $ Fe
c
c     Air (0.001184 g/cm3)
c     atomic density  4.9425E-05
m3    7014.37c 3.9016e-5
      8016.37c 1.0409e-5
c
c    criticality cards
c
kcode   5000 1.0 50 2000
sdef  cel=d1 pos=0 0 0 axs=0 0 1 rad=d2 ext=d3 erg=d4
c
si1  l 4:1
sp1       1
c
```

MCNP Input Listing Run No. 49 of Table 12 (cont'd).

```
si2    h   0.0   29.50
sp2   -21  1
c
si3    h   0.0  112.27
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```

A.2 MORET – APOLLO Input Listing

The k_{eff} calculation is run in two steps using a code system, including two codes:

APOLLO 2 + MORET IV

1. APOLLO is one dimensional multigroup cell code. It is used to determine material buckling B_m^2, $k_{infinity}$, and homogeneous macroscopic medium cross sections.
2. MORET is a three-dimensional multigroup Monte Carlo code. It uses macroscopic cross sections coming from APOLLO. Each calculation employed 500 histories per stage and was run to achieve precision of 0.00033 or 0.0010. The APOLLO Library used is CEA93 (cross sections coming from JEF2, 172 groups for APOLLO 2. Notice that the natural elements iron (Fe), chromium (Cr), and nickel (Ni) do not exist in this library, and they are, therefore, divided into isotopes. MORET IV uses P9 anisotropic treatment.

   A code called PREAPOL is used to generate the APOLLO input, in particular it models natural Fe, Cr and Ni as the combination of their isotopes. The input for PREAPOL, APOLLO 2 and MORET IV are provided for case 1 and PREAPOL and MORET IV for other cases. APOLLO 2 and MORET IV were run on RS 6000, PREAPOL on a personal computer.

MORET – APOLLO Input Listing for Case 14 of Table 13.

```
***************************************************************
*         C.E.A./I.P.S.N. SYSTEM CODES ( FRANCE )       *
*     CRISTAL : APOLLO 2 ( CEA93 lib. 172 Gr.- MORET 4  *
*.......................................................*
*          LEU-SOL-THERM-007    case 14                 *
*                                                       *
*           STACY no reflected cases                    *
***************************************************************
*        Keff(bench.) = 0.9957 +/- 0.0009               *
*.......................................................*
*    G.POULLOT            reviewer  G. COURTOIS         *
*////////////////////////////////////////////////////////
(
 air ( japan )
*------------------------------------------
*--- APOLLO SPECTRE: MILIEU DE STRUCTURE ---
*------------------------------------------
)
OPTION  GROU 172 P9 FINOPTION
 GEOM HOMO
CHIMIE
*air ( japan )
 MICRO 1 2
        N14       O16
   CONC  3.9016E-05 1.0409E-05
FINC
SECTION NOCOND TOUT
FIN
(
 stainless steel SUS304
*------------------------------------------
*--- APOLLO SPECTRE: MILIEU DE STRUCTURE ---
*------------------------------------------
)
OPTION  GROU 172 P9 TEMPER  25  FINOPTION
 GEOM HOMO
CHIMIE
*stainless steel SUS304
 MICRO 1 7
        FE        CR        NI        MN55
        SI        C         P31
   CONC  5.9421E-02 1.6775E-02 8.3403E-03 1.1561E-03
        1.0627E-03 4.3736E-05 4.3170E-05
FINC
SECTION NOCOND TOUT
FIN
*--------------------------------------------------------------------------
*                RAPPEL GEOMETRIE
*--------------------------------------------------------------------------
* GEOMETRIE HOMOGENE    BIBLIO CEA93.V3 172 groupes ANISOTROPIE P9
*--------------------------------------------------------------------------
*==========================================================================
* MILIEU FISSILE 1:
* LOI DE DILUTION : Nitrate analyse
*    Densit* :1.4881
*--------------------------------------------------------------------------
*    VECTEUR ISOTOPIQUE    MASSE
*--------------------------------------------------------------------------
*    Uranium:
*    U234:  0.0800
*    U235:  9.9700
```

MORET – APOLLO Input Listing for Case 14 of Table 13 (cont'd).

```
*     U236:  0.0100
*     U238: 89.9400
*--------------------------------------------------------------------------
*  Delta Date (Analyse chimique - Analyse isotopique) :
*  Delta Date (Exp□ience - Analyse chimique) :
*  Impuret□ (g/l) : 0.00
*--------------------------------------------------------------------------
* MASSES ATOMIQUES MOYENNES
* Uranium: 237.74411 - Plutonium:  - Uranium+Plutonium:
*--------------------------------------------------------------------------
*     POISON (g/l) :  Gd=.0    Cd=.0   B       =.0
*     ACIDITE : 2.250 N  dans SOLUTION
*--------------------------------------------------------------------------
* EXPRESSION DE LA MODERATION :
* C(U) = 313.0 g/l
*==========================================================================
(
U(9.97%)O2(NO3)2                                   CAS N* 3
*Nitrate analyse   C(U)=313.000  C(PU)=0.000    H+=2.25    GD=0.00
SORTIE SECTIONS CELLULE
)
OPTION GROU 172 P9 TEMPER  25  FINOPTION
GEOMETRIE HOMOGENE
CHIMIE
*Nitrate analyse   C(U)=313.000  C(PU)=0.000    H+=2.25    GD=0.00
 MICRO 1 7
              U234         U235         U236         U238
              H2O          O16          N14
   VERIF 1.4881 6.443036E-07 7.995369E-05 7.985395E-08 7.121566E-04
              2.835342E-02 9.730108E-03 2.940641E-03
FINC
 CALCUL LES2 SECTION NOCOND TOUT
FIN

FIND
*///////////////////////////////////////////////////////////////////////
*                    MORET 4    input listing
*///////////////////////////////////////////////////////////////////////
DEBUT_MORET4
*** ICSBEP ******** LEU-SOL-THERM   007 ******* CASE  14 ***************
*                       BENCH STACY
*        URANYLE NITRATE SOLUTION 9.98 235U enrit. C(U) = 313.0 g/l
*                   critical height 46.83 cm
*                     NO REFLECTED CASE
*......................................................................
*Experiment KEFF +/- uncertainties delta(keff): Keff = 0.9957 +/- 0.0009
*************************************************************************
* precision
SIGI 0.000330 SIGE 0.000330  MINI 100 PAS  20 NOBIL
* medium
* 1 * air
* 2 * stainless steel SUS304L
* 3 * uranyle nitrate solution             25.0 °C
CHIMIE
SEALINK 3 APO2 3   1 2 3   FINCHIMIE
GEOMETRY
*.....................................
***  stainless steel tank
*.....................................
TYPE 1 CYLZ 29.8  77.25
      VOLUME 1 0 1 2 0.0  0.0  77.25
```

MORET – APOLLO Input Listing for Case 14 of Table 13 (cont'd).

```
***  air
TYPE 2 CYLZ 29.5 75.0
      VOLUME 2 1 2 1 0.0  0.0   77.0
*......................................
**  nitrate solution  Hc = 46.83 cm
*......................................
TYPE 3 PLAZ INF 48.83
      VOLUME 3 2 3 3  0.0 0.0  30  ETSUP 1 2
*......................................
***   sources
*......................................
SOURCE 3 3  300  0.0  0.0   19.0
        3  400  0.0  0.0   24.0
        3  300  0.0  0.0   29.0
FINGEOMETRY
GRAPH X 0.0 FGRAPH
SORTIE
MAIL 1 5 21 48 95 135 172
GLOBAL
FINS
FINDATA
FIN_MORET4
_
```

A.3 KENO Input Listing

238-Group ENDF/B-V Cross Sections

SCALE4.3 KENO V.a with CSAS 238-group ENDF/B-V cross sections was run with 500 generations of 2000 neutrons each, after skipping 20 generations, for a total of 1 million neutron histories.

KENO-V.a Input Listing for Run 30 of Table 14 (SCALE4.3 238-group ENDF/B-V cross sections)

KENO Input Listing for Run 30 of Table 14.

```
=CSAS25      PARM=SIZE=200000
LST007, Run 30, STACY Bare cylinder of LEU soln, 291 gU/l
238GR
INFH
'SOLN
U-234 1 0 5.9840E-7 298  END
U-235 1 0 7.4257E-5 298  END
U-236 1 0 7.4165E-8 298  END
U-238 1 0 6.6142E-4 298  END
H     1 0 5.7176E-2 298  END
N     1 0 2.8156E-3 298  END
O     1 0 3.7836E-2 298  END
'STEEL
FE    2 0 5.9421E-2 298  END
CR    2 0 1.6775E-2 298  END
NI    2 0 8.3403E-3 298  END
S     2 0 2.9782E-6 298  END
P     2 0 4.3170E-5 298  END
MN    2 0 1.1561E-3 298  END
SI    2 0 1.0627E-3 298  END
C     2 0 4.3736E-5 298  END
'AIR
N     3 0 3.9016E-5 298 END
O     3 0 1.0409E-5 298 END
'STEEL
FE    4 0 5.9421E-2 298  END
CR    4 0 1.6775E-2 298  END
NI    4 0 8.3403E-3 298  END
S     4 0 2.9782E-6 298  END
P     4 0 4.3170E-5 298  END
MN    4 0 1.1561E-3 298  END
SI    4 0 1.0627E-3 298  END
C     4 0 4.3736E-5 298  END
END COMP
MORE DATA  RES=2 SLAB 0.3 RES=4 SLAB 2.0 END MORE
LST0071, Run 30, STACY Bare cylinder of LEU soln, 291 gU/l
READ PARAM
TME=99999 NPG=2000 GEN=520 NSK=20
END PARAM
READ GEOM
UNIT 1
CYLINDER 1 1 29.5 54.2 0.0
CYLINDER 3 1 29.5 150.0 0.0
CYLINDER 2 1 29.8 150.0 0.0
CYLINDER 4 2 29.8 152.5 -2.0
END GEOM
END DATA
END
```

A.4 MCNP (ENDF/B-V) Input Listing

MCNP4a with ENDF/B-V continuous-energy cross sections was run with 520 generations of 2000 neutrons each with 20 generations skipped, for a total of 1,000,000 active neutron histories.

MCNP Input Listing for Run 36 of Table 14.

```
c    LEU-SOL-THERM-007, Case 4, STACY, bare, 254 gU/l
1    1 0.09894733 -1 5 -6
2    2 0.086845 1 -2 5 -7
3    3 0.000049425 -1 6 -7
4    2 0.086845 -2 -5 9
5    2 0.086845 -2 7 -8
6    0 2:8:-9

1    cz 29.5
2    cz 29.8
5    pz 0
6    pz 83.55  $critical height
7    pz 150
8    pz 152.5
9    pz -2.0

mode n
imp:n 1 4r 0
c    fissile solution
m1   92234.50c 5.2265e-7
     92235.50c 6.4857e-5
     92236.50c 6.4776e-8
     92238.50c 5.7769e-4
     1001.50c 5.8115e-2
     7014.50c 2.6292e-3
     8016.50c 3.7560e-2
mt1  lwtr.01t
c    stainless steel
m2   26000.50c 5.9421e-2
     24000.50c 1.6775e-2
     28000.50c 8.3403e-3
     16032.50c 2.9782e-6
     15031.50c 4.3170e-5
     25055.50c 1.1561e-3
     14000.50c 1.0627e-3
      6000.50c 4.3736e-5
c    air
m3   7014.50c  3.9016e-5
     8016.50c  1.0409e-5
kcode 2000 1.0 20 520
ksrc  0 0 42
print
```

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:

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

where

ρ = density of solution at T°C (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}: molarity of nitric acid at 25°C (mol),
T: Temperature (°C).

This 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,
10°C < 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 (VI) and nitric acid,” JAERI-M88-127 (1988) (in Japanese).

APPENDIX C: DERIVATION OF ATOM DENSITIES OF FUEL SOLUTION

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 density (g/l)=	UD=	310.1
Acidity (mol/l)=	AC=	2.17
Density (g/cc)=	D=	1.4827
Avogadro's number=	AV=	0.60221
Atom density of U234= N24=	UD/1000*W24/100/A24*AV=	6.3833E-07
Atom density of U235= N25=	UD/1000*W25/100/A25*AV=	7.9213E-05
Atom density of U236= N26=	UD/1000*W26/100/A26*AV=	7.9114E-08
Atom density of U238= N28=	UD/1000*W28/100/A28*AV=	7.0556E-04
Total Uranium atom density=	UN=	7.8549E-04
	HNO3	
NH(HNO3)=	AC/1000*AV=	1.3068E-03
NN(HNO3)=	AC/1000*AV=	1.3068E-03
NO(HNO3)=	AC/1000*AV*3=	3.9204E-03
Density of HNO3(g/cc)= DN=	AC*(A1+A7+3*A8)/1000=	0.136737776
	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=	0.513588816
Density of H2O= DH=	D-DU-DN=	0.832373408
NH(H2O)=	DH/(2*A1+A8)*AV*2=	5.5649E-02
NO(H2O)=	DH/(2*A1+A8)*AV=	2.7824E-02
Atom density of H=	NH(HNO3)+NH(H2O)=	5.6956E-02
Atom density of O=	NO(H2O)+NO(HNO3)+8*UN=	3.8029E-02
Atom density of N=	NN(HNO3)+2*UN=	2.8778E-03

APPENDIX D: MCNP INPUT LISTING OF DETAILED MODEL

The MCNP 4B input listing of detailed model of Run No. 14 is given as follows. This input listing is not available for MCNP 4A or other former versions of MCNP.

```
file name=bare14 ; STACY ( model 5 )
c    FUEL UO2(NO3)2  235U 9.97wt%  U 313.0 g/l  HNO3 2.25 mol/l
c    Hc = 46.83 cm
c    BARE
c    Tank is all considered.
c
c    cellcard
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  9.85238254E-02   -500 501 -233       imp:n=1 u=2
1    1  9.85238254E-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)  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
c    74   2  8.68449842E-02  4  -176 -175        imp:n=1 u=2
75   2  8.68449842E-02  4  -177             imp:n=1 u=2
76   2  8.68449842E-02  4  -178             imp:n=1 u=2
77   2  8.68449842E-02  4  -179             imp:n=1 u=2
210  2  8.68449842E-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
173  4  4.94250000E-05  3 -224 -225         imp:n=1 u=2
174  4  4.94250000E-05  3 -4 -229           imp:n=1 u=2
78   4  4.94250000E-05  #(-33 1 -3)  #3 #70 #71 #72
                  #210 #73 #75 #76 #77
                  #170 #171 #172 #173 #174 #226
                  #261 #262 #263 #264
                                  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 52 -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 -79 -51 -5 43):
            (-68 70 63 -62 -5 43) imp:n=1 u=3
c fuel feed pipe 1
227  1  9.85238254E-02  -233 234  -5    imp:n=1 u=3
228  2  8.68449842E-02   233 -232 234 -5 imp:n=1 u=3
c fuel feed pipe 2
230  1  9.85238254E-02  -236  237 -238  imp:n=1 u=3
231  2  8.68449842E-02   236 -235 237 -238  imp:n=1 u=3
c fuel feed pipe 3
233  1  9.85238254E-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
13   2  8.68449842E-02 (-43 44 -45 46 -47 48) 410 imp:n=1 u=3
c
c    Beam
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
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   4  4.94250000E-05   -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   4  4.94250000E-05   -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   4  4.94250000E-05   -113  #27  137             imp:n=1 u=3
c    ch-7
30   4  4.94250000E-05   -136  137 -119         imp:n=1 u=3
31   7 -2.69900000E+00   -136  137  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 2
90   4  4.94250000E-05   -136  137 -180         imp:n=1 u=3
91   7 -2.69900000E+00   -136  137  180 -161     imp:n=1 u=3
440  6  1.24933300E-01   -162  161  163 -164     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-3
94   4  4.94250000E-05   -136  137 -190          imp:n=1 u=3
95   7 -2.69900000E+00   -136  137  190 -181     imp:n=1 u=3
450  6  1.24933300E-01    163 -164  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
33  17  2.726620E-02     -325 -126 127           imp:n=1 u=3
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  137 #36      imp:n=1 u=3
38   7 -2.69900000E+00    131 -132 -136  137     imp:n=1 u=3
470  6  1.24933300E-01   -133  132 -138  139     imp:n=1 u=3
c   40   4  4.94250000E-05    132 -133 -136  137 #39 imp:n=1 u=3
c    st-b
41  11  1.25762000E-02   -140 -134  135          imp:n=1 u=3
42   4  4.94250000E-05   -140 -136  137 #41      imp:n=1 u=3
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  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
c    reflector support plate
c    300  23  8.6955000E-02   34 -250 251 -252
c                        #(-51 34 -70 71)
c                        #(-51 34 -69 68)
c                        #(-51 34 75 -74)
c                        #(-51 34 72 -73)     imp:n=1 u=3
c
199  4  4.94250000E-05   #79 #(-42 84 -530) #13
         #(-161 -136 137) #94 #95 #450 #270 #33 #460
         #(-101 137) #401 #(-107 137) #410 #(-113 137) #420
         #30 #31 #430 #90 #91 #440 #(-132 -136 137) #470
         #(-141 -136 137) #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
203  0 #281 #282 #283 #284 #285 #286 #287 #288 #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    29.801
503  py    -29.801
504  cz     36.8
 1   pz      0.0
 2   pz     46.83
 3   pz    150.0
 4   pz    152.5
 5   pz     -2.0
33   cz     29.5
34   cz     29.8
35   cz     66.6
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   px     29.8
46   px    -70.2
47   py     50.0
48   py    -50.0
49   py     78.48
50   px    -71.42
c
60   p     1.  1. 0. 37.6180816
61   p     1.  1. 0. 39.0322943
62   p     1.  1. 0. -37.6180816
63   p     1.  1. 0. -39.0322943
64   p     1. -1. 0. 37.6180816
65   p     1. -1. 0. 39.0322943
```

```
66   p     1. -1. 0. -37.6180816
67   p     1. -1. 0. -39.0322943
68   p     1. -1. 0. 7.07106781
69   p     1. -1. 0. 8.48528137
70   p     1. -1. 0. -7.07106781
71   p     1. -1. 0. -8.48528137
72   p     1.  1. 0. 7.07106781
73   p     1.  1. 0. 8.48528137
74   p     1.  1. 0. -7.07106781
75   p     1.  1. 0. -8.48528137
76   py    33.6
77   p     1.  1. 0.  28.5671140
79   p     1.  1. 0. -28.5671140
c    51   px     33.6
51   cz    33.7315
52   p     1. -1. 0.  28.56711
53   px    -33.6
54   p     1. -1. 0. -28.56711
55   p     1. -1. 0. -33.94113
56   p     1.  1. 0.  33.94113
c
 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  ch-4
101  c/z    46.0   -15.0   1.75
102  pz     48.0
103  pz      0.0
104  c/z    46.0   -15.0   2.85
105  pz     23.0
106  pz    -15.0
c  ch-5
107  c/z   -46.0    17.5   2.25
108  pz     37.4
109  pz     -5.0
110  c/z   -46.0    17.5   3.35
111  pz     16.0
112  pz    -15.0
c  ch-6
113  c/z   -46.0   -17.5   2.25
114  pz     48.2
115  pz     -5.0
116  c/z   -46.0   -17.5   3.35
117  pz     16.0
118  pz    -15.0
c  ch-7
119  c/z    52.2  15.5  1.0
120  c/z    52.2  15.5  1.2
121  c/z    52.2  15.5  3.2
```

```
122  pz     36.3
123  pz    -14.8
124  pz     6.0
125  pz    -2.0
c  ch-1 and 2
180  c/z   -19.3 -31.605  1.0
161  c/z   -19.3 -31.605  1.2
162  c/z   -19.3 -31.605  3.2
163  pz    -3.5
164  pz     53.0
c  ch-3
190  c/z    29.42 26.5  1.0
181  c/z    29.42 26.5  1.2
182  c/z    29.42 26.5  3.2
c
c pulsartron
325  c/z    65.2  38.0  5.5
126  pz     66.33
127  pz      5.33
128  c/z    65.2  38.0 10.5
129  pz     36.53
130  pz      6.53
c  st-a
131  c/z    12.8   -49.0   1.95
132  c/z    12.8   -49.0   2.25
133  c/z    12.8   -49.0   3.25
134  pz    58.3
135  pz    24.01
136  pz    205.5
137  pz     -15.9999999
138  pz     69.0
139  pz     24.0
c  st-b
140  c/z   -12.8    49.0   1.95
141  c/z   -12.8    49.0   2.25
142  c/z   -12.8    49.0   3.25
c  lin-a
143  c/z    35.2   -35.00  4.7
144  c/z    35.2   -35.00  5.0
145  c/z    35.2   -35.00  5.5
146  pz     71.8
147  pz     24.0
148  pz    205.5
149  pz     -15.999
150  pz     76.5
151  pz     21.5
c  lin-b
152  c/z   -35.2   35.0    4.7
153  c/z   -35.2   35.0    5.0
154  c/z   -35.2   35.0    5.5
350  pz     78.0
351  pz     22.0
c  log-a
155  c/z   -33.0  -37.08   4.7
156  c/z   -33.0  -37.08   5.0
157  c/z   -33.0  -37.08   5.5
c  log-b
158  c/z    37.08  33.0    4.7
159  c/z    37.08  33.0    5.0
160  c/z    37.08  33.0    5.5
c
330  pz     185.35
335  pz     340.35
c  crd-1
171  c/z    0.00    15.5  3.815
221  c/z    0.00    15.5  3.095
```

```
331  c/z    0.00    15.5  2.73
c  crd-2
172  c/z    0.00   -15.5  3.815
222  c/z    0.00   -15.5  3.095
332  c/z    0.00   -15.5  2.73
c  crd-3
173  c/z  -15.50     0.0  3.815
223  c/z  -15.50     0.0  3.095
333  c/z  -15.50     0.0  2.73
c  crd-4
174  c/z   15.50     0.0  3.815
224  c/z   15.50     0.0  3.095
334  c/z   15.50     0.0  2.73
c  center
175  c/z    0.0      0.0  3.815
176  pz     184.5
c  n-4
177  c/z   -18.0    17.0   2.4
c  n-2
178  c/z    17.6    17.6   1.7
c  n-5
179  c/z    18.0   -15.0   2.13
c  n-7
220  c/z   -13.5   -23.383  1.6
225  pz     185.0
226  pz     5.5
227  pz     2.5
228  c/z   -13.5   -23.383  0.865
229  c/z   -13.5   -23.383  0.545
230  c/z   -13.5   -23.383  1.475
231  c/z   -13.5   -23.383  0.975
c    232  c/z    17.0   -14.5    1.36
232  c/z    12.257695 -23.49 1.36
233  c/z    12.257695 -23.49 1.02
234  pz    -9.6
c   235  gq    0.5 0.5 1. -1. 0. 0. -31.347797 31.347797 18. 570.492596
c   236  gq    0.5 0.5 1. -1. 0. 0. -31.347797 31.347797 18. 571.301796
235   c/x   -23.49 -11.0 1.36
236   c/x   -23.49 -11.0 1.02
c   238  p     1. 1. 0. 17.0382
c   237  p     1. 1. 0. -7.47719
238  px     12.257695
237  px    -12.257695
c    239  px      6.2
240  c/z    -12.257695 -23.49  1.36
241  c/z    -12.257695 -23.49  1.02
242  pz    -12.3601
c
c  Reflector support plate
c   250  pz  -1.5
c   251  pz  -4.0
c   252  cz  66.6
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  Pipe below base plate
410  c/z   14.8 17.0 7.76
411  c/z   14.8 17.0 8.26
412  pz    -20.0
413  pz    -34.0
414  px     14.8
415  px    -55.2
416  py     35.0
417  py    -35.0
418  px     22.65
419  px    -63.05
420  py     42.85
421  py    -42.85
422  px     21.95
423  px    -62.35
424  py     42.15
425  py    -42.15

c
c    data cards
c
mode  n                    $ transport neutrons only
c
c    material cards
c
c    FUEL UO2(NO3)2  235U 9.97wt%  U 313.0g/l  HNO3 2.25mol/l
c    atomic density =  9.85238254E-02
m1    1001.37c     5.6707E-02
      7014.37c     2.9406E-03
      8016.37c     3.8084E-02
     92234.37c     6.4430E-07
     92235.37c     7.9954E-05
     92236.37c     7.9854E-08
     92238.37c     7.1216E-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    alminum 2.699g/cm3
m7   13027.37c  -100.0     $ Al
c
c    sus304 7.93g/cm3  (d)daiza,annaikan etc.
m9    6012.37c  -0.05      $ C
     14000.37c  -0.41      $ Si
     25055.37c  -0.93      $ Mn
     15031.37c  -0.030     $ P
     16000.37c  -0.004     $ S
     28000.37c  -8.29      $ Ni
     24000.37c -18.36      $ Cr
     26000.37c -71.930     $ Fe
c
c    st-a,b  (1.25762e-2)
m11   6012.37c  1.51491E-7   $ C
      8016.37c  3.02982E-7   $ O
     13027.37c  1.25729E-2   $ Al
     18040.37c  2.85066E-6   $ Ar
c
c    lin-a,b,log-a,b (1.86958e-2)
m12   7014.37c  3.82159E-5   $ N
     13027.37c  1.86576E-2   $ Al
c
c    ch-4(wl)   (5.02274e-2)
m13   6012.37c  8.92716E-8   $ C
      8016.37c  1.78543E-7   $ O
     13027.37c  5.02254E-2   $ Al
     18040.37c  1.70771E-6   $ Ar
c
c    ch-5      (1.07067e-1)
m14   7014.37c  3.11542E-5   $ N
     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 Top plate
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 Bottom plate
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   29.500
sp2   -21  1
c
si3    h   0.0   46.83
```

```
sp3   -21  0
c
sp4    -3
c
prdmp  j -100 1 3
c
print -175
```