LA-UR- 95-1931

Title: SHEBA-II AS A CRITICALITY SAFETY BENCHMARK EXPERIMENT

Author(s): R. J. LaBauve, J. L. Sapir

Submitted to: ICNC '95/Nuclear Criticality Safety
Albuquerque, NM
September 17-21, 1995

Los Alamos
NATIONAL LABORATORY

SHEBA-II AS A CRITICALITY SAFETY BENCHMARK EXPERIMENT

R. J. LaBauve and Joseph L. Sapir
Group TSA-12 MS 551
Los Alamos National Laboratory
Los Alamos, NM 87545
505 665.1561
505 667.3167-FAX

ABSTRACT

SHEBA-II (Solution High Energy Burst Assembly-II) is a critical assembly experiment currently (1995) being operated at the Los Alamos Critical Experiments Facility. It is a bare assembly fueled with an aqueous solution of about 5% enriched uranyl fluoride that is stored in four critically safe steel tanks. The solution is transferred to the critical assembly vessel (CAV) by applying gas pressure to the storage tanks. Reactivity is controlled by varying the solution level, and a safety rod may be inserted in a thimble along the central axis of the CAV for fast shutdown. The simple geometry provided by this cylindrical system allows for easily applied calculational methods, and thus SHEBA-II is ideally suited for use as a criticality safety benchmark experiment.

ASSEMBLY DESCRIPTION

The critical assembly vessel (CAV) of SHEBA-II [1] is basically a 30-in. length of 20-in., schedule 40 stainless steel 304L pipe, with a nominal I.D. of 18.814 in., a wall thickness of 0.593-in., and a weight of 123.11 lb/ft (density of 7.855 g/cm^3). The base plate consists of three SS 304L disks of thicknesses 0.5 in., 0.5-in., and 0.125 in., bolted together. The diameter of the top disk is machined to fit snugly into the pipe section. The center of the base plate contains a 2.5-in. hole for the safety rod thimble tube. This tube, also made of SS 304L, is 30.25-in. long and 2.5-in. O.D. with a 0.25-in. wall. The top cover of the CAV consists of 2 SS 304L disks 0.5-in. and 0.25-in. thick. Like the base plate, the lower disk fits snugly into the pipe, and the cover has a 2.5-in. central hole for the safety rod thimble tube. The safety rod and follower in the "out" position were not included in the criticality safety benchmark model, as calculations showed that effects of these on k_{eff} were small. The calculational model used for SHEBA-II, as derived from these dimensions, is shown in Fig. 1.

K_{eff} RESULTS

The measured critical height at 20 C was 45.0 cm, i.e. k_{eff} = 1.0000 for this experimental configuration [2]. Analysis of the experimental data determined the uncertainty in the calculated k_{eff} to be ± 0.0043. This uncertainty is due mainly to the uncertainty in the composition of the UO_2F_2+H_2O as indicated by results of several chemical analyses of the solution reported in [1]. Calculations using KENO in 16 multigroup Hansen-Roach data, KENO in 27 multigroup ENDF-IV data, MCNP continuous energy ENDF-V data, and TWODANT in 27 multigroup ENDF-IV data gave k_{eff} values of 0.9915, 1.0097, 1.0094, and 1.0096, respectively. The atom densities used in these calculations were derived from an average of constituents in the chemical analyses reported in [1].

CRITICAL HEIGHT RESULTS

The above codes/nuclear data were also used to calculate critical heights instead of k_{eff}. TWODANT was also used with the Hansen-Roach 16-group data and with 69-group ENDF-V data. Additional calculations were made with MCNP using JENDL-E3.2 data [3]. These results are shown in Table I, along with earlier results using a somewhat different model and different atom densities reported by Butterfield in [4]. Finally, a set of specifications for SHEBA-II was published in an issue of the Criticality Safety Quarterly [5] and readers were invited to make calculations based on these specifications. Their results were included in subsequent issues of the newsletter [6 and 7], and are also included in Table I.

As can be seen from Table I, the calculated critical height is quite sensitive to the model/methodology used, but on average, the calculated critical height is low by about 4% compared with the measured height of 45 cm. This is much greater than the estimated experimental uncertainty, indicating that additional chemical analyses of the aqueous solution in SHEBA-II need to be made. A closer value to the measured critical height would be calculated, for example, if the ^{235}U enrichment were reduced by about .05%.

ADDITIONAL EXPERIMENTS

In addition to the eigenvalue experiment, other experimental results were obtained in the course of running SHEBA-II. These include measurements of the temperature coefficient of reactivity, void coefficients, and reactivity as a function of solution height [8]. Two- and three -dimensional discrete ordinates calculations are in good agreement with experimental results as demonstrated below.

Temperature Coefficient

Three effects were taken into consideration in calculating SHEBA-II temperature coefficient, namely:

a. Changes in cross sections,
b. Vessel expansion, and
c. Solution expansion, according to Johnson/Kraus [9] considering both volume and density changes.

The total increase in critical height due to these effects was calculated to be 1.5 cm for a temperature increase of 15 C. These calculations were done using TWODANT. ENDF-V nuclear data in 69 groups were used to calculate the cross-section changes and vessel expansion effects, and ENDF-IV data in 27 groups were used for solution effects. These gave 0.66 and 0.84 cm. changes, respectively. Figure 2 shows the measured and calculated results of solution critical height vs temperature. A linear fit to the measured data yields a critical height of 44.91 cm at 20 C, which was used as the base point for the calculation.

Void Coefficients

The experimental setup to determine SHEBA-II void coefficients employed two aluminum blocks that were sectors of cylinders. One was an 87-degree sector of a 3.15-in. high cylinder with an I.R. of 8.62 in. and an O.R. of 9.41 in. This piece approximately fitted the outside of the CAV. Measurements of critical height were made with the block at the center and top of the solution. Taking into consideration the displacement of solution by the block, the measurements gave an increase of critical height of 0.32 cm with the block at the center and a decrease in critical height of 0.11 cm with the block at the top of the solution. Calculated values using 3-DANT and 27-group, ENDF-IV nuclear data were +0.32 and -0.17 cm, respectively. These calculations were done using Al blocks; voids gave approximately double these effects.

The other block was a 90-degree sector with a height of 1.16 in., an I.R. of 1.258 in., and an O.R. of 2.82-in., so that this Al piece fit closely to the central thimble tube. Measurements were taken at the center, 5 cm, 10 cm, and 15 cm above the center, and at the top of the solution. Experimental and calculated results are compared in the Fig. 3.

Reactivity as Function of Solution Height

Calculations to obtain reactivity change as a function of solution height were performed using the TWODANT code and 27-group ENDF-IV nuclear data. Calculations were made for heights from 45.0 to 46.0 cm, in increments of 0.2 cm. Using the 45.0 cm calculation as a base case, differences in k_{eff} were obtained for the other cases. These differences were converted into units of cents using a value of $\beta_{eff} = 0.0076$. This value was obtained using the methodology suggested by Palmer [10]. In applying this method, two TWODANT problems were run, one using the total χs and the second using the prompt χs for ^{235}U, thereby obtaining values of total k_{eff} (k_T)

and prompt k_{eff} (k_P). The value of β_{eff} is determined from

$\beta_{eff} = k_T - k_P \times (1 - \beta)$, $\beta = 0.0065$ for ^{235}U.

CONCLUSIONS

We have shown the rather large sensitivity of the SHEBA-II critical height calculations to model, methodology, and nuclear data used, and have also indicated a need for additional chemical analyses of the aqueous uranyl fluoride solution in the assembly. Calculations of temperature coefficient, void coefficient, and criticality vs solution height, which are performed as differences from a base calculation, agree quite well with experimenal results.

REFERENCES

1. Paternoster, R., Anderson, R., Butterfield, K., Cappiello, C., Malenfant, R., and Partain, B., "Safety Analysis Report for the Los Alamos Critical Experiments Facility (LACEF) and TA-18," LA-CP-92-235, Rev. 1.0 (Jun 1, 1994).

2. Private communication - to LaBauve, R. from Butterfield, K., LANL June 1994.

3. Private communication - to LaBauve, R. from Miyoshi, Y., JAERI, Dec 1994.

4. Kenneth B. Butterfield, "The SHEBA Experiment," Trans. Am. Nucl. Soc., **70**, 199, (1994).

5. Lutz, H., ed.,"Criticality Safety Quarterly" Spring 1994,UCRL-MI-115565-94-1.

6. Lutz, H., ed.,"Criticality Safety Quarterly" Summer 1994,UCRL-MI-115565-94-2.

7. Lutz, H., ed.,"Criticality Safety Quarterly" Fall 1994,UCRL-MI-115565-94-3.

8. Private communication - to LaBauve, R. from Anderson, R., Butterfield, K., and Cappiello, C., LANL, Aug 1994.

9. Johnson, J. and Kraus, K., "Density and Refractive Index of Uranyl Fluoride Solutions," Journal of American Chemical Society, Vol. 75 (Sept. 1953).

10. Palmer, R., "A Direct Method of Calculating the Effective Delayed Neutron Fraction in a Fast Reactor," TRG Report 83 (D), UKAEA (1961).

Table I Calculated Critical Heights

Model	Code	Nuclear Data	Number of Groups	Critical Height
This report	KENO	Hansen-Roach	16	47.2
This report	TWODANT	Hansen-Roach	16	47.2
This report	KENO	ENDF-IV	27	42.5
This report	MCNP	ENDF-V	Cont. Energy	42.6
This report	TWODANT	ENDF-IV	27	42.6
This report	TWODANT	ENDF-V	69	41.3
This report	MCNP	JENDL-E3.2	Cont. Energy	41.4[1]
This report	MCNP	JENDL-E3.2	Cont. Energy	42.5[2]
Ref. 4	MCNP	ENDF-V	Cont. Energy	41.3
Ref. 4	TWODANT	Hansen-Roach	16	44.7
Ref. 4	THREEDANT	Hansen-Roach	16	44.1
Ref. 5	MCNP	ENDF-V	Cont. Energy	42.7
Ref. 5	MCNP	ENDF-V	Cont. Energy	42.5
Ref. 5	KENO	ENDF-IV	27	43.5
Ref. 5	TWODANT	ENDF-IV	27	42.4

1. 1×10^6 histories
2. 1×10^5 histories

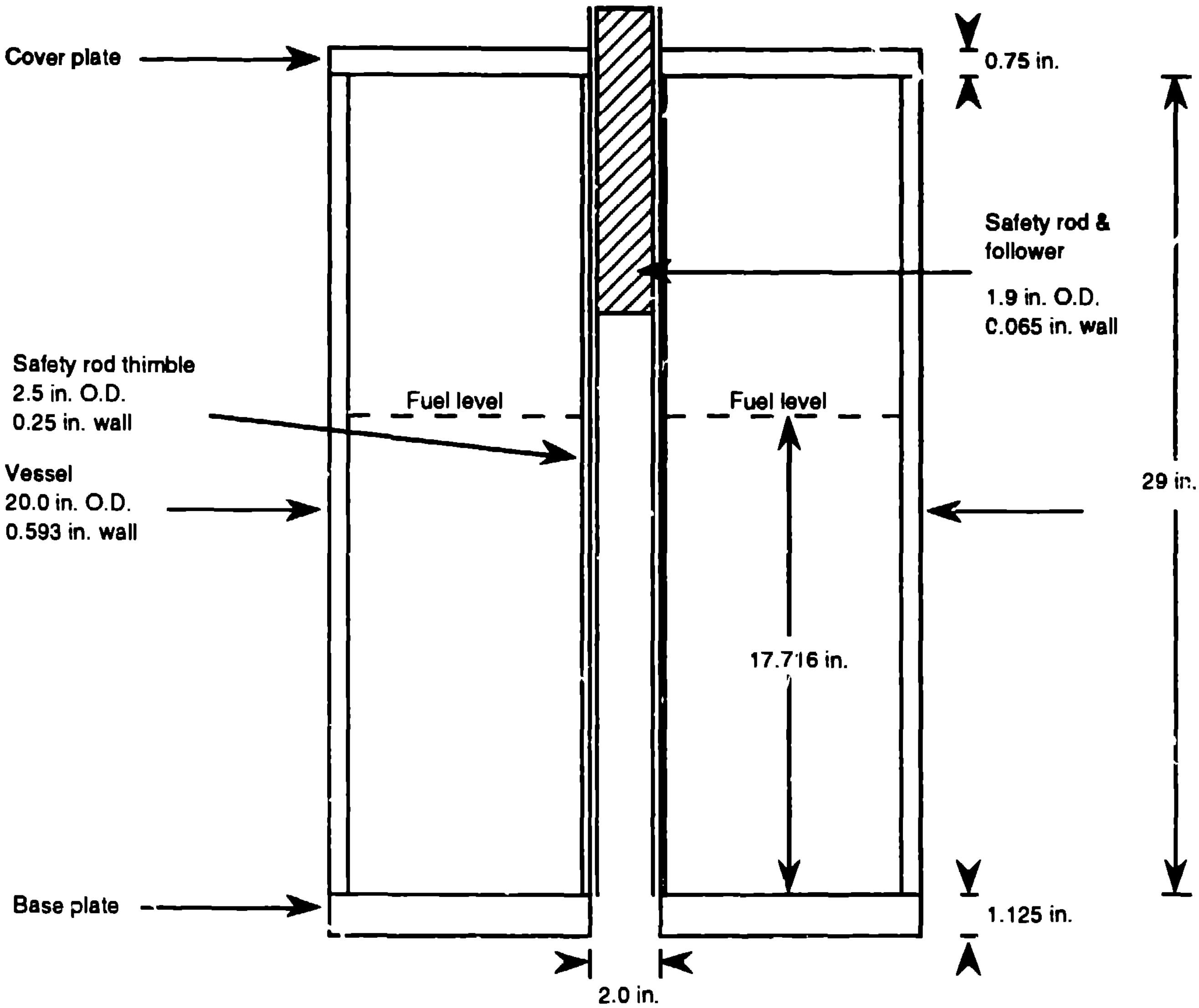

Fig. 1. SHEBA-II calculational model.

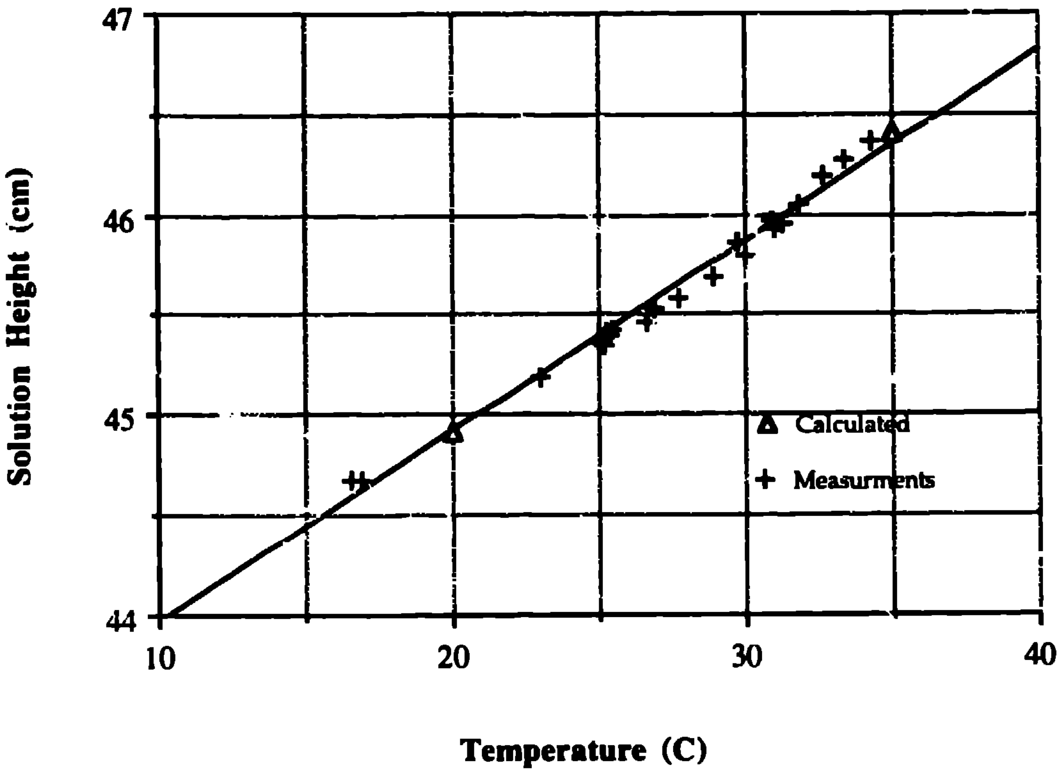

Fig. 2. SHEBA-II temperature coefficient

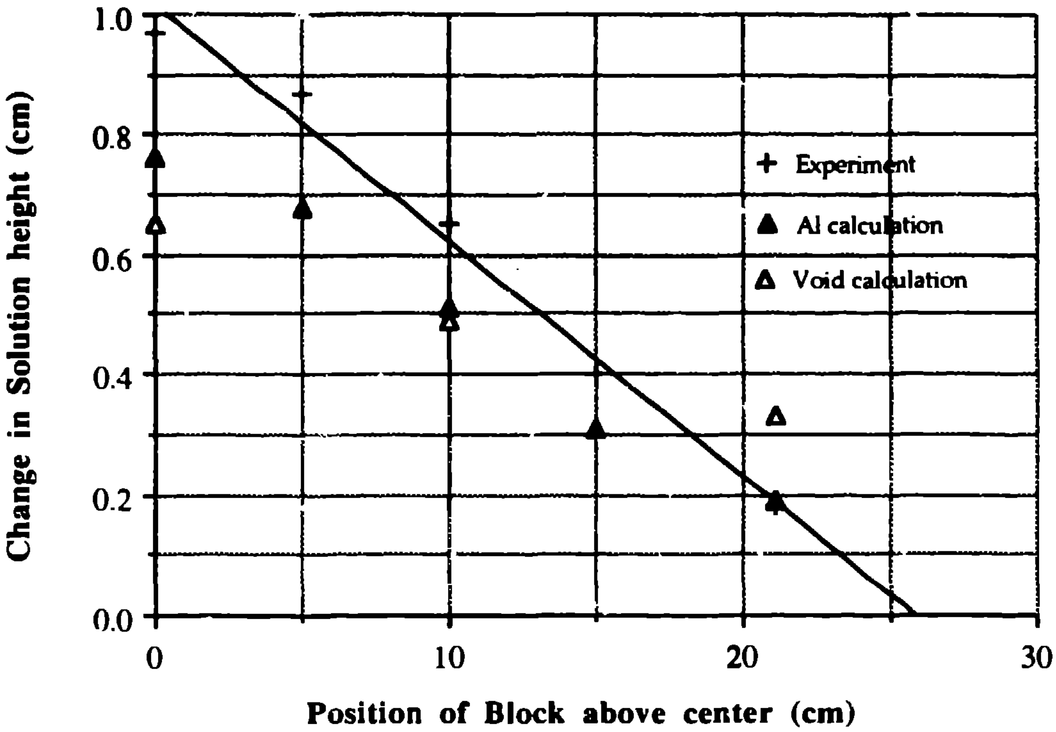

Fig. 3. SHEBA-II void (Al block) coefficient.

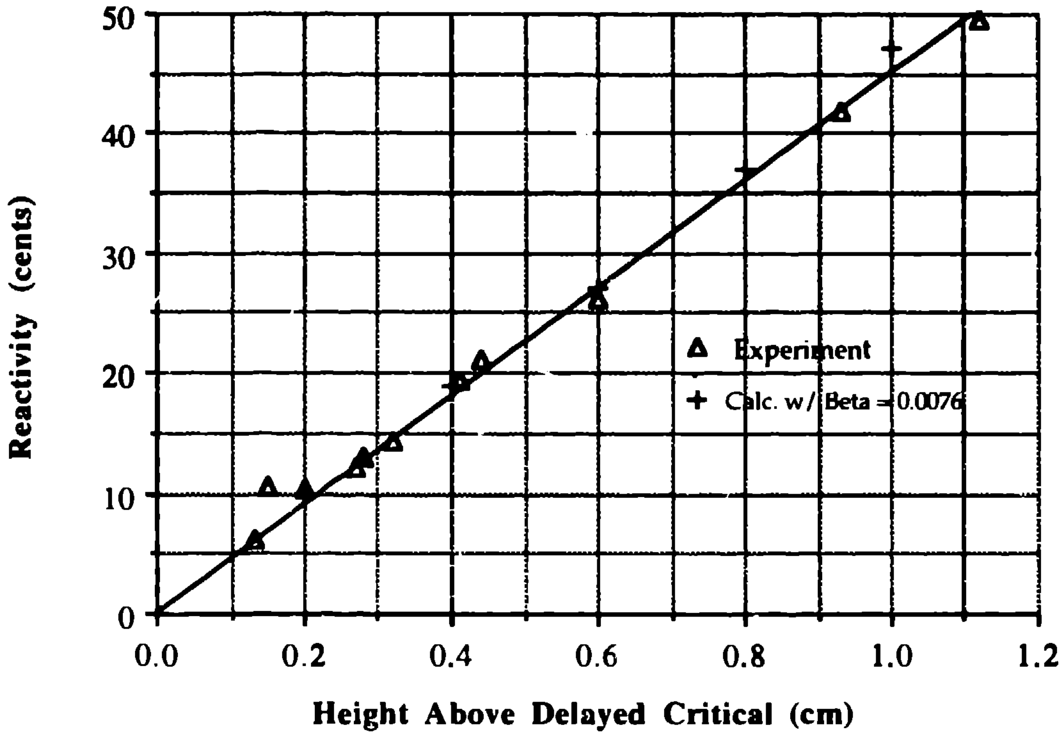

Fig. 4. SHEBA-II reactivity as a function of height above delayed critical.