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VALIDATION OF KENO V.a AND TWO CROSS-SECTION LIBRARIES FOR CRITICALITY CALCULATIONS OF LOW-ENRICHED URANIUM SYSTEMS

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ABSTRACT

The SCALE[1] code system, utilizing the Monte Carlo computer code KENO V.a,[2] was employed to calculate 37 critical experiments. The critical assemblies had ^{235}U enrichments of 5% or less and cover a variety of geometries and materials. Values of k_{eff} were calculated using two different cross-section libraries for each experiment to determine if certain experimental parameters affected results using either of the cross-section libraries. The 16-energy-group Hansen-Roach and the 27-energy-group ENDF/B-IV cross-section libraries, available in SCALE, were used in this validation study, and both give good results for the experiments considered. It is concluded that the code and cross sections are adequate for low-enriched uranium systems and that reliable criticality safety calculations can be made for such systems provided the limits of validated applicability are not exceeded.

SUMMARY

Recently a new version of the KENO Monte Carlo criticality code was released for testing. This new version, KENO V.a,[2] is an extensive revision of KENO IV[3] and includes an improved geometry package. The purpose of this work is to validate[4] the SCALE[1] version of the KENO V.a criticality code when used with either 16-energy-group Hansen-Roach or 27-energy-group ENDF/B-IV cross sections for low-enriched uranium systems. The effective neutron multiplication factor, k_{eff}, was calculated for 37 critical assemblies which have ^{235}U enrichments of 5% or less. Some of the critical assemblies were included in an earlier validation report by Handley and Hopper[5] and some were taken from a series of interstitially moderated and plexiglas reflected damp U_3O_8 experiments performed at the Rocky Flats Plant[6-8] (RFP).

The RFP criticals are of interest because of their low $H:^{235}U$ atomic ratios (<50). However, these results cannot be compared directly with results from the other experiments because of the heterogeneous effect of the interstitial moderator. Eight RFP experiments were modeled, four were optimum-moderated (2.44-cm-thick interstitial moderator) and the other four were under-moderated (0.929-cm-thick interstitial moderator). It is noted that the k_{eff}'s calculated using Hansen-Roach cross sections are consistently higher than the ENDF/B-IV k_{eff}'s for all of the Rocky Flats criticals.

For the 29 experiments common to this study and Ref. 5, an effort has been made to define trends in k_{eff} relative to the experimental parameters. The parameters investigated include $H:^{235}U$ atom ratio, $H:^{238}U$ atom ratio, and enrichment. Also, the average energy of a neutron causing fission weighted by energy group number (AE), a calculated parameter, was used to investigate trends. This parameter was used in an earlier validation report[5] and consists of summing the products of energy group number times the fission fraction for that group and then dividing by the sum of the fission fractions. However, the calculated parameter and the $H:^{235}U$ atom ratio cannot be considered independent because there is a strong correlation between the two.

The values of k_{eff} calculated using 27-group ENDF/B-IV cross-section data show a strong correlation with H:U-235 ratio, average energy, and enrichment. Two linear models developed to describe these trends are:

1) $k_{eff} = 1.0098 - 2.9875E\text{-}5 * (H:^{235}U) + 2.2407E\text{-}3 * (\text{enrichment})$
2) $k_{eff} = 1.1710 - 7.6653E\text{-}3 * (AE) + 4.1472E\text{-}3 * (\text{enrichment})$.

The first model employs $H:^{235}U$ and enrichment and accounts for 61% of the variation in 29 experiments, while the second model uses average energy and enrichment and accounts for 59% of the variation in the same 29 experiments. The mean value for all 29 experiments using the 27-group data is 1.0053 with standard deviation 0.0096.

The values of k_{eff} calculated using 16-group cross-section data exhibit a correlation with only one parameter, average energy. This trend is described by the following linear model:

$$k_{eff} = 1.2267 - 1.5297E\text{-}2 * (AE)$$

This model accounts for 59% of the variation in 29 experiments. The mean value for all 29 experiments using Hansen-Roach data is 0.9997 with standard deviation 0.0094.

The results of this work indicate that trends in k_{eff} obtained using KENO V.a with 16-group Hansen-Roach data can be generally described by a linear model for the validated range of average energy. Similarly, when using KENO V.a with the 27-group ENDF/B-IV data, trends in k_{eff} can be generally described by linear models which depend on the validated range of $H:^{235}U$ atomic ratio, average energy group, and enrichment. Both cross-section sets used with KENO V.a provide good agreement with experimental results for low-enriched uranium systems.

1. INTRODUCTION

In order to analyze nuclear criticality safety without undue conservatism or expense, experimental data are often supplemented by calculations. Therefore, each calculational method must be correlated with relevant experimental data in order to establish a bias (if one exists) in the method over a specific area of applicability. The Oak Ridge Gaseous Diffusion Plant (ORGDP) Criticality Safety Group has previously used KENO IV for criticality safety calculations of plant operations. With the introduction of KENO V.a, which is an extensive revision of KENO IV, ORGDP has decided to validate KENO V.a as found in the SCALE code system (see Appendix A for a brief description of SCALE). This validation effort will allow the application of KENO V.a in the analysis of low-enriched (<5%) uranium systems commonly found at ORGDP.

The purpose of this investigation is twofold, first to determine biases in calculated k_{eff}'s for systems with uranium enrichments of 5% or less and, second, to validate a standardized procedure for performing criticality calculations. The effort to standardize criticality calculations utilizes the CSAS25 control module available in SCALE. This module requires a minimal amount of engineering data about the problem to run a successful calculation. From the input data, the control module calculates atomic number densities and certain resonance parameters; then it calls an established sequence of functional modules to process the cross sections and perform the criticality calculation. A check on the number densities calculated by SCALE is included in Appendix B.

The KENO V.a code was also validated by the Oak Ridge Y-12 plant for application to systems of highly enriched uranium. A frozen version of the SCALE code system, containing the KENO V.a code and all the programs and cross-section data used by SCALE, was prepared by the Oak Ridge National Laboratory Computer Sciences Division to be used in the Y-12 validation. This special SCALE package was named Y12CSG and is under the control of the Y-12 Criticality Safety Group for quality assurance purposes. The same version of SCALE was used in this validation because of the strict quality assurance precautions taken by the Y-12 plant.

A total of 37 low-enriched, experimentally critical systems applicable to the ORGDP, were modeled. Each experiment was modeled using the 16-group Hansen-Roach library and the 27-group ENDF/B-IV library yielding two values of k_{eff} for each experiment. Appendix C contains listings for all experiments modeled, and Appendix D contains some additional information about the Rocky Flats Plant criticals.

2. DESCRIPTION OF EXPERIMENTS

Included in this section are descriptions of the critical experiments and the k_{eff} calculated by KENO V.a (see Table 2.1). The first part of this section describes the experiments investigated in Ref. 5 and employs the same notation for case number. Experiments in Ref. 5 were excluded if experimental documentation could not be found or if they were not of interest. Proper documentation could not be found for cases 1, 2, 3, 7, 8, 9, and 10 in Ref. 5. Pipe intersections found in cases 37, 38, 39, and 40 are not included since the frozen version of KENO V.a does not include generalized geometry.

The second part of this section describes low-enriched damp oxide (i.e., $H:^{235}U < 50$) experiments that are of special interest because of limited analysis previously available in this area. These experiments were performed at the RFP using fuel cubes 6 inches on a side at three different H:U atomic ratios.[6-8] Cases 41 through 48 consist of eight interstitially moderated and Plexiglas reflected damp oxide experiments.

2.1 Y-1948 CRITICAL EXPERIMENTS

Case 4 - An unreflected rectangular parallelepiped of homogeneous $U(1.4)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 421.8. Dimensions of the homogenized assembly are 93.1 cm x 93.0 cm x 123.8 cm (Ref. 5).

Case 5 - An unreflected rectangular parallelepiped of homogeneous $U(1.4)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 421.8. Dimensions of the homogenized assembly are 100.0 cm x 99.9 cm x 103.1 cm (Ref. 5).

Case 6 - An unreflected rectangular parallelepiped of homogeneous $U(1.4)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 421.8. Dimensions of the homogenized assembly are 130.7 cm x 130.6 cm x 74.2 cm (Ref. 5).

Case 11 - A reflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 195.2. Dimensions of the homogenized fuel assembly are 56.22 cm x 56.22 cm x 112.88 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 12 - An unreflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 195.2. Dimensions of the homogenized fuel assembly are 56.22 cm x 56.22 cm x 112.88 cm (Ref. 5).

Case 13 - A reflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 293.9. Dimensions of the homogenized fuel assembly are 51.11 cm x 51.11 cm x 73.87 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 14 - An unreflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 293.9. Dimensions of the homogenized fuel assembly are 56.22 cm x 56.22 cm x 122.47 cm (Ref. 5).

Case 15 - A reflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 406.3. Dimensions of the homogenized fuel assembly are 53.67 cm x 53.67 cm x 54.29 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 16 - A reflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 495.9. Dimensions of the homogenized fuel assembly are 46.00 cm x 46.00 cm x 96.57 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 17 - A reflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 613.6. Dimensions of the homogenized fuel assembly are 56.32 cm x 61.29 cm x 54.08 cm, reflected with 15.2 cm of polyethylene on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Table 2.1 Calculated k-effectives

Case no.	Ref.	k-effective ± 1 sigma: ENDF/B-IV		k-effective ± 1 sigma: Hansen-Roach	
04	5	1.001 ±	0.003	0.996 ±	0.003
05	5	0.992	0.003	0.998	0.003
06	5	0.994	0.003	1.008	0.003
11	5	0.998	0.004	0.996	0.004
12	5	1.009	0.004	0.997	0.003
13	5	0.999	0.004	1.003	0.003
14	5	1.000	0.004	0.996	0.004
15	5	0.998	0.004	1.001	0.004
16	5	0.999	0.004	0.997	0.003
17	5	0.996	0.003	0.984	0.003
18	5	1.000	0.003	0.989	0.004
19	5	0.992	0.002	0.995	0.003
20	5	0.991	0.003	0.988	0.003
21	5	1.016	0.004	1.014	0.004
22	5	1.014	0.004	1.017	0.004
23	5	1.022	0.005	1.009	0.005
24	5	1.014	0.005	1.012	0.005
25	5	1.014	0.005	1.010	0.005
26	5	1.017	0.004	1.006	0.004
27	5	1.016	0.004	1.019	0.004
28	5	1.013	0.004	1.009	0.004
29	5	1.015	0.004	0.995	0.005
30	5	1.012	0.004	0.993	0.004
31	5	1.021	0.004	1.001	0.005
32	5	1.004	0.004	0.992	0.004
33	5	0.993	0.004	1.000	0.004
34	5	1.003	0.004	0.996	0.004
35	5	1.009	0.004	0.986	0.004
36	5	1.003	0.005	0.987	0.004
1[a]	6	1.009	0.003	1.025	0.003
2[a]	6	1.007	0.004	1.012	0.003
3[b]	6	0.992	0.003	1.012	0.004
1[b]	7	1.012	0.003	1.016	0.003
2[b]	7	1.009	0.003	1.018	0.003
3[a]	7	1.009	0.003	1.018	0.003
F[b]	8	1.027	0.004	1.041	0.004
G[a]	8	1.027	0.004	1.033	0.003

[a]Optimum moderated experiment.

[b]Undermoderated experiment.

Case 18 - An unreflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 613.6. Dimensions of the homogenized fuel assembly are 56.32 cm x 61.29 cm x 54.08 cm (Ref. 5).

Case 19 - A reflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 971.7. Dimensions of the homogenized fuel assembly are 76.51 cm x 76.44 cm x 82.42 cm, reflected with 15.2 cm of polyethylene on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 20 - An unreflected rectangular parallelepiped of homogeneous $U(2)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 971.7. Dimensions of the homogenized fuel assembly are 81.45 cm x 86.70 cm x 88.22 cm (Ref. 5).

Case 21 - A reflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 51.14 cm x 51.14 cm x 51.27 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 22 - A reflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 43.47 cm x 43.47 cm x 86.39 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 23 - A reflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 46.02 cm x 46.02 cm x 67.57 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 24 - A reflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 56.25 cm x 56.25 cm x 43.41 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 25 - A reflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 61.36 cm x 61.36 cm x 38.67 cm, reflected with 15.2 cm of paraffin on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 26 - An unreflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 56.47 cm x 56.47 cm x 86.64 cm (Ref. 5).

Case 27 - An unreflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 56.25 cm x 61.36 cm x 74.38 cm (Ref. 5).

Case 28 - An unreflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 133.4. Dimensions of the homogenized fuel assembly are 61.40 cm x 61.40 cm x 66.00 cm (Ref. 5).

Case 29 - A reflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 276.9. Dimensions of the homogenized fuel assembly are 40.81 cm x 40.80 cm x 39.49 cm, reflected with 15.2 cm of polyethylene on top and sides and 15.2 cm of Plexiglas on the bottom (Ref. 5).

Case 30 - An unreflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 276.9. Dimensions of the homogenized fuel assembly are 40.90 cm x 40.93 cm x 116.80 cm (Ref. 5).

Case 31 - An unreflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 276.9. Dimensions of the homogenized fuel assembly are 48.59 cm x 51.14 cm x 48.53 cm (Ref. 5).

Case 32 - An unreflected rectangular parallelepiped of homogeneous $U(3)F_4$ and paraffin with a $H:^{235}U$ atomic ratio of 276.9. Dimensions of the homogenized fuel assembly are 81.71 cm x 81.66 cm x 31.34 cm (Ref. 5).

Case 33 - A composite cadmium/steel/water side reflected stainless steel cylinder filled to a height of 54.45 cm with $U(4.98)O_2F_2$ solution at a $H:^{235}U$ atomic ratio of 488. The cylinder inner radius is 19.545 cm with wall thickness 0.079 cm and height 106.2 cm. The adjacent reflector consisted of 0.002 cm of cadmium, 2.54 cm of steel, and surrounded by an effectively infinite amount of water (Ref. 5).

Case 34 - A composite steel/water side reflected stainless steel cylinder filled to a height of 143.0 cm with $U(4.98)O_2F_2$ solution at a $H:^{235}U$ atomic ratio of 488. The cylinder inner radius is 16.51 cm with wall thickness 0.079 cm and height 243.9 cm. The adjacent reflector consisted of 2.54 cm of steel surrounded by an effectively infinite amount of water (Ref. 5).

Case 35 - An unreflected stainless steel sphere filled with $U(4.98)O_2F_2$ solution at a $H:^{235}U$ atomic ratio of 490. The sphere inner radius is 25.3873 cm with wall thickness 0.0508 cm (Ref. 5).

Case 36 - An unreflected stainless steel cylinder filled to a height of 101.7 cm with $U(4.98)O_2F_2$ solution at a $H:^{235}U$ atomic ratio of 496. The cylinder inner radius is 19.55 cm with wall thickness 0.07874 cm and height 125.09 cm (Ref. 5).

2.2 ROCKY FLATS PLANT CRITICAL EXPERIMENTS

Case 41 - This is experiment number 1 as described in the report NUREG/CR-1071.[6] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 0.77. These cans were then placed in a three dimensional array with plexiglas moderator between cans and a plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 2.5 cm putting the experiment in the optimum moderated category. Criticality was achieved with an array of 42 fuel cans with critical table separation of 3.1 mm.

Case 42 - This is experiment number 2 as described in the report NUREG/CR-1071.[6] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 0.77. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 2.5 cm putting the experiment in the optimum moderated category. Criticality was achieved with an array of 100 fuel cans with critical table separation of 15.2 mm.

Case 43 - This is experiment number 3 as described in the report NUREG/CR-1071.[6] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 0.77. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 1.0 cm putting the experiment in the undermoderated category. Criticality was achieved with an array of 100 fuel cans with critical table separation of 10.5 mm.

Case 44 - This is the first interstitially moderated experiment described in the report NUREG/CR-1653.[7] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 1.25. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 2.5 cm putting the experiment in the optimum moderated category. Criticality was achieved with an array of 38 fuel cans with critical table separation of 12.608 mm.

Case 45 - This is the second interstitially moderated experiment described in the report NUREG/CR-1653.[7] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 1.25. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 1.0 cm putting the experiment in the undermoderated category. Criticality was achieved with an array of 78 fuel cans with critical table separation of 7.98 mm.

Case 46 - This is the third interstitially moderated experiment described in the report NUREG/CR-1653.[7] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 1.25. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 1.0 cm putting the experiment in the undermoderated category. Criticality was achieved with an array of 80 fuel cans with critical table separation of 15.61 mm.

Case 47 - This is experiment F as described in the report NUREG/CR-2500.[8] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 2.03. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 1.0 cm putting the experiment in the undermoderated category. Criticality was achieved with an array of 48 fuel cans with critical table separation of 4.1 mm.

Case 48 - This is experiment G as described in the report NUREG/CR-2500.[8] Fuel for this experiment consisted of $U(4.46)_3O_8$ packed inside aluminum cans at a H:U of 2.03. These cans were then placed in a three-dimensional array with a Plexiglas moderator between cans and a Plexiglas reflector surrounding the array. The thickness of the interstitial moderator is approximately 2.5 cm putting the experiment in the optimum moderated category. Criticality was achieved with an array of 30 fuel cans with critical table separation of 5.7 mm.

3. CALCULATIONAL METHOD

The experiments considered in this work are modeled with the SCALE code system using the CSAS25 control module. This routine calculates number densities in a standardized fashion from the given experimental data and then calls a sequence of functional modules to process the data. Resonance parameters for the heavy absorbers used in the calculation are performed by BONAMI and/or NITAWL, with NITAWL converting the data into a working library. ICE next prepares the cross sections for the different mixtures of materials, and then KENO V.a performs the Monte Carlo criticality calculation.

The SCALE input for each calculation was submitted individually to an IBM-3033 computer. Unless otherwise specified, each calculation utilized default values available in SCALE. The experiments reflected with paraffin on top and sides and with Plexiglas on the bottom employed reflector biasing. The KENO V.a code does not have reflector biasing data available for Plexiglas or polyethylene which were employed as reflectors in some of the experiments. Due to the similar hydrogen density of polyethylene and paraffin, paraffin biasing data can be safely used in polyethylene reflectors. Plexiglas has a lower hydrogen density than paraffin so some calculations were performed with and without reflector biasing to determine if there was an effect on the results (these results reported in Section 3).

4. VALIDATION OF KENO V.a AND TWO CROSS-SECTION LIBRARIES

Calculational methods for predicting criticality safety are validated to ensure confidence in the method. In all processes involving fissionable material, specific conditions are required to maintain the safety of the operation. The calculational methods available are used to predict limits for safe operation, thus requiring a high level of confidence in the calculational methods. This report validates the SCALE version of KENO V.a when used with either the 27-group ENDF/B-IV library or the 16-group Hansen-Roach library by means of comparing experimental results with calculated results. Table 3.1 contains calculated k_{eff}'s and their associated standard deviations (rounded off to three decimal places) for the 37 critical experiments considered in this validation study. For the benefit of future validation studies, Table A.1 in Appendix A contains the values of k_{eff} as given in the computer output.

Included in this section are comparative studies of KENO V.a versus KENO IV, and KENO V.a with default options versus KENO V.a with specific options. An error was detected in the resonance treatment of the Hansen-Roach cross-section library during this study. The cross-section library and code were promptly modified to make them compatible. Tables 4.2, 4.4, and 4.6 contain values calculated before the change was made. All other tables containing 16-group library results are calculated with the new version. A more detailed explanation of the problem is included at the end of the section.

Five experiments were chosen to compare KENO V.a with KENO IV, cases 11, 12, 21, 22, and 26. These calculations were performed using 103 generations at 300 neutrons per generation and reflector biasing was not used in the reflected cases. Table 4.1 shows the results of these calculations when the 27-group ENDF/B-IV cross-section library is used. It is noted that case 22 did not properly converge for the given number of histories. Case 22 shown in Table 4.1 is case 22 with reflector biasing and it is within one standard deviation of the KENO IV result. Table 4.2 shows the results of the same experiments when the 16-group Hansen-Roach library is used. The KENO V.a result and KENO IV result are within two standard deviations for each experiment (most comparisons are within one sigma), thus establishing the mechanics of the KENO V.a code to be in good working order. However, it is noted that the calculated value of k_{eff} can differ by as much as 3% according to which cross-section library is used, independent of the version KENO used.

Another item under investigation is the effect of changing the default number of generations and histories per generation while keeping the total number of histories approximately constant. This involves changing the number of generations from 103 to 53 and the number of neutrons per generation from 300 to 600. Ten experiments at five different H:^{235}U atom ratios (reflected and unreflected at each H:^{235}U) were modeled with this change, and the results are shown in Tables 4.3 and 4.4. The default version k_{eff}'s and modified version k_{eff}'s are within two standard deviations for each experiment according to cross-section library. Again, large differences in k_{eff} exist depending on which cross-section library is used with the Hansen-Roach value being consistently higher.

The KENO V.a code has a reflector biasing option that helps reduce the amount of computer time used in a calculation. To evaluate this option several test cases were run with and without biasing to determine if biasing forced the calculation to diverge from the true solution. Table 4.5 contains the results of the 27-group calculations, and Table 4.6 contains the results of the Hansen-Roach calculations. The results with and without reflector biasing are within two standard deviations (all but one is within one standard deviation) for each experiment, thus giving a high level confidence in this option. Again, it is noted that there is a significant difference (as much as 3%) in the value of k_{eff} according to which cross-section library is used.

The large differences in k_{eff}'s according to cross-section library were further investigated in an effort to explain why the values calculated by Hansen-Roach data were consistently higher than those calculated by ENDF/B-IV data. It was suggested that the value of sigma P (also known

Table 4.1 Comparison of KENO V.a with KENO IV using 27-group library

Case no.	Reflected	KENO V.a	Std dev	KENO IV	Std dev	Within one sigma
11	YES	0.994	0.003	1.005	0.004	NO
12	NO	1.009	0.004	1.005	0.004	YES
21	YES	1.016	0.004	1.010	0.004	YES
22	YES	1.024	0.004	1.019	0.004	NO
22[a]	YES	1.015	0.004			YES
26	NO	1.017	0.004	1.013	0.004	YES

[a]Optimum moderated experiment.

Table 4.2 Comparison of KENO V.a with KENO IV using 16-group library

Case no.	Reflected	KENO V.a	Std dev	KENO IV	Std dev	Within one sigma
11	YES	1.033	0.003	1.033	0.004	YES
12	NO	1.024	0.004	1.031	0.004	YES
21	YES	1.049	0.004	1.040	0.004	YES
22	YES	1.040	0.004	1.034	0.004	YES
26	NO	1.040	0.005	1.035	0.004	YES

Table 4.3 KENO V.a with default histories and modified histories using the 27-group library

Case no.	Default histories	Std dev	Modified histories	Std dev	Within one sigma
11	0.998	0.004	1.003	0.004	YES
12	1.009	0.004	1.002	0.004	YES
13	0.999	0.004	1.000	0.004	YES
14	1.000	0.004	1.003	0.004	YES
17	0.996	0.003	1.003	0.003	NO
18	1.000	0.003	1.004	0.003	YES
19	0.992	0.002	0.981	0.003	NO
20	0.991	0.003	0.984	0.003	YES
25	1.014	0.005	1.009	0.004	YES
26	1.017	0.004	1.012	0.004	YES

Table 4.4 KENO V.a with default histories and modified histories using the 16-group library

Case no.	Default histories	Std dev	Modified histories	Std dev	Within one sigma
11	1.028	0.004	1.030	0.004	YES
12	1.024	0.004	1.023	0.004	YES
13	1.031	0.004	1.018	0.004	NO
14	1.024	0.004	1.012	0.003	NO
17	1.018	0.004	1.004	0.003	NO
18	1.008	0.003	1.012	0.002	YES
19	1.003	0.003	1.013	0.003	NO
20	1.002	0.002	1.002	0.003	YES
25	1.037	0.005	1.042	0.004	YES
26	1.040	0.005	1.033	0.004	YES

Table 4.5 Comparison of reflector biasing using 27-group library

Case no.	With biasing	Std dev	Without biasing	Std dev	Within one sigma
11	0.998	0.004	0.994	0.003	YES
13	0.999	0.004	1.004	0.003	YES
21	1.016	0.004	1.017	0.004	YES
22	1.015	0.004	1.024	0.004	NO
24	1.014	0.005	1.011	0.004	YES

Table 4.6 Comparison of reflector biasing using 27-group library

Case no.	With biasing	Std dev	Without biasing	Std dev	Within one sigma
11	1.028	0.004	1.033	0.003	YES
13	1.039	0.004	1.027	0.003	YES
21	1.0496	0.004	1.042	0.004	YES
22	1.0415	0.005	1.041	0.004	YES
24	1.036	0.005	1.038	0.004	YES

as sigma m_{eff}) calculated by SCALE should be compared with the values of sigma P used in Ref. 5. The results of this comparison are listed in Table 4.7, which indicates that, when using the Hansen-Roach library, the sigma P value is underestimated by about 20%. This in turn caused the self-shielding calculation for ^{238}U to underestimate the capture cross section, thus leading to a higher value of k_{eff}. The problem was traced to a routine in BONAMI that calculated sigma P. This calculation required the total cross section but instead it was using a transport-corrected cross section from the Hansen-Roach cross-section library. This inconsistency was corrected and resulted in Hansen-Roach k_{eff}'s much closer to the ENDF/B-IV k_{eff}'s. Table 4.8 contains results of the first 29 experiments for both the old version and the new version.

Table 4.7 Values of sigma P

Case no.	Value in ref. 5	SCALE used with 27 gp.	SCALE used with old 16 gp.	SCALE used with new 16 gp.
04	160	160.8	128.3	165.7
05	160	160.8	128.3	165.7
06	160	160.8	128.3	165.7
11	120	114.7	93.8	119.8
12	120	114.7	93.8	119.8
13	160	160.8	128.7	166.2
14	160	160.8	128.7	166.2
15	220	213.5	168.5	219.0
16	260	255.5	199.2	261.2
17	330	310.6	242.0	316.5
18	330	310.6	242.0	316.5
19	400	479.1	369.4	485.5
20	400	479.1	369.4	485.5
21	120	118.2	96.2	124.0
22	120	118.2	96.2	124.0
23	120	118.2	96.2	124.0
24	120	118.2	96.2	124.0
25	120	118.2	96.2	124.0
26	120	118.2	96.2	124.0
27	120	118.2	96.2	124.0
28	120	118.2	96.2	124.0
29	220	220.0	174.2	226.3
30	220	220.0	174.2	226.3
31	220	220.0	174.2	226.3
32	220	220.0	174.2	226.3
33	600	602.3	464.9	609.1
34	600	602.0	464.9	609.1
35	600	602.2	465.0	609.2
36	600	602.4	464.9	609.1

Table 4.8 Comparison of results from SCALE after revision

Exp. no.	k-effective ± 1 sigma: Old version		New version	
04	1.02051 ±	0.00318	0.99647 ±	0.00337
05	1.03049	0.00318	0.99776	0.00326
06	1.02484	0.00329	1.00764	0.00311
11	1.02801	0.00399	0.99587	0.00365
12	1.02386	0.00371	0.99744	0.00327
13	1.03082	0.00446	1.00337	0.00335
14	1.02370	0.00368	0.99609	0.00395
15	1.01288	0.00363	1.00108	0.00378
16	1.01583	0.00341	0.99737	0.00325
17	1.017[illegible]7	0.00369	0.98408	0.00342
18	1.00822	0.00309	0.98871	0.00361
19	1.00263	0.00276	0.99527	0.00292
20	1.00172	0.00239	0.98804	0.00273
21	1.04861	0.00437	1.01363	0.00401
22	1.04053	0.00459	1.01660	0.00445
23	1.03795	0.00380	1.00874	0.00485
24	1.03600	0.00478	1.01190	0.00479
25	1.03692	0.00465	1.00980	0.00498
26	.03993	0.00492	1.00565	0.00397
27	1.04139	0.00448	1.01929	0.00407
28	1.02522	0.00447	1.00860	0.00411
29	1.02674	0.00513	0.99487	0.00462
30	1.01798	0.00578	0.99257	0.00382
31	1.02314	0.00407	1.00132	0.00450
32	1.01886	0.00447	0.99154	0.00420
33	0.99709	0.00404	1.00028	0.00374
34	1.00070	0.00402	0.99565	0.00413
35	0.99341	0.00457	0.98574	0.00415
36	0.99651	0.00478	0.98733	0.00416

5. TESTS FOR TRENDS AND BIASES

In this study two different cross-section libraries were used to obtain corresponding values of k_{eff} for each experiment. These calculated values differ slightly from the reported experimental values of k_{eff} which could be caused in part by the statistical nature of the Monte Carlo solution. It is of interest to ascertain if a trend exists in the solution which is related to some quantity associated with the experiments. If such trends exist and can be defined, then some departure from the expected value of k_{eff} could be predicted based on information from the experiment and cross-section library used.

Some of the quantities investigated include H:^{235}U atom ratio, enrichment, H:^{238}U ratio, and a calculated parameter, average energy of a neutron causing fission weighted by energy group number (AE). Some of the parameters considered are not independent; that is for a given H:^{235}U ratio and enrichment, the H:^{238}U ratio can be calculated. Also there is a relation between average energy and the H:^{235}U ratio which is not known. This implies that separate models must be developed for H:^{235}U and average energy, and also a model cannot contain the three parameters H:^{235}U, H:^{238}U, and enrichment. Linear relationships between k_{eff} (according to cross-section library) and experimental parameters can be determined, if any exist, from the data in Table 5.1. Tests for trends and biases are performed only on the homogeneous experiments thus excluding experiments 41 through 48 because of the interstitial moderation.

The statistical analysis of the experimental parameter effects on k_{eff} consisted of first finding the simple correlation coefficients (Pearson Product Moment) between the k_{eff}'s (according to cross-section library) and each of the experimental parameters. The correlation coefficient is defined only on the interval -1 to +1, where +1 implies perfect positive correlation and -1 is perfect negative correlation. Each correlation coefficient has associated with it a significance level which is a measure of the uncertainty in the correlation coefficient. Table 5.2 contains the values of the correlation coefficients and their significance level for selected parameters.

When k_{eff}'s were calculated using the Hansen-Roach cross-section library results were correlated with average energy and were found to have a large correlation coefficient (-0.8) and a corresponding low significance level (0.0001). When the Hansen-Roach k_{eff}'s were correlated with H:^{235}U the correlation coefficient was not as high as the one for average energy. A similar analysis was performed using the k_{eff}'s calculated using the 27-group library and it was found that the correlation coefficients were nearly identical for average energy and H:^{235}U. It was found that for both cross-section libraries the H:^{238}U ratio was not as highly correlated as was the H:^{235}U ratio, and since these ratios are coupled by hydrogen, the H:^{238}U ratio was dropped from the investigation.

The above results indicate that there are three important models that can be developed to describe the effects of the parameters on the resulting k_{eff}. There would be one model for Hansen-Roach results that would show k_{eff} as a function of average energy and two separate models for 27-group results, the first being a function of average energy and the second being a function of H:^{235}U. The results of this study are presented in Section 6.

Table 5.1 Experiment parameters considered in trend analysis

Case no.	H: ^{238}U	H: ^{235}U	% Wt ^{235}U	AE 27-group	AE 16-group
04	6.1	421.8	1.4	23.13	14.82
05	6.1	421.8	1.4	23.11	14.81
06	6.1	421.8	1.4	23.12	14.83
11	4.0	195.2	2.0	22.33	14.44
12	4.0	195.2	2.0	22.07	14.28
13	6.1	293.9	2.0	23.08	14.84
14	6.1	293.9	2.0	22.87	14.73
15	8.4	406.2	2.0	23.55	15.08
16	10.3	495.9	2.0	23.80	15.20
17	12.7	613.6	2.0	24.03	15.31
18	12.7	613.6	2.0	23.93	15.26
19	20.1	971.7	2.0	24.39	15.50
20	20.1	971.7	2.0	24.36	15.49
21	4.2	133.4	3.0	22.04	14.36
22	4.2	133.4	3.0	22.07	14.36
23	4.2	133.4	3.0	22.09	14.36
24	4.2	133.4	3.0	22.05	14.38
25	4.2	133.4	3.0	22.07	14.35
26	4.2	133.4	3.0	21.59	14.10
27	4.2	133.4	3.0	21.62	14.12
28	4.2	133.4	3.0	21.60	14.10
29	8.7	276.9	3.0	23.42	15.04
30	8.7	276.9	3.0	23.17	14.90
31	8.7	276.9	3.0	23.20	14.90
32	8.7	276.9	3.0	23.16	14.90
33	25.9	488.0	4.98	24.15	15.43
34	25.9	488.0	4.98	24.17	15.44
35	26.0	490.0	4.98	24.18	15.43
36	26.3	496.0	4.98	24.18	15.43

Table 5.2 Correlation coefficients and significance levels obtained by comparing results from 27-group and 16-group calculations with certain experiment parameters

Experiment parameter	Correlation coefficient (significance level)	
	27-group library	16-group library
AE	-0.62 (0.0004)	-0.76 (0.0001)
H:^{235}U	-0.74 (0.0001)	-0.66 (0.0001)
H:^{238}U	-0.42 (0.02)	-0.60 (0.0005)
Enrichment	0.31 (0.08)	-0.05 (0.8)

6. RESULTS AND CONCLUSIONS

The results obtained using KENO V.a and two cross-section libraries to analyze 37 individual critical experiments are presented in Table 3.1. Results from the tests for trends and biases indicate that there is a relationship between the experimental parameters and the cross-section library used. Linear models were developed to describe the relation between k_{eff} (according to cross-section library) and the independent variables considered. These simple linear models were estimated from the results of the 29 homogeneous experiments in Ref. 5. In addition, lower tolerance limits were approximated for the distribution of k_{eff} values around the model on a prescribed closed interval of the independent variable. The tolerance limits are such that one can say that 99.9% of the distribution of k_{eff} values, for a given value of the independent variable, will lie above the tolerance limits with 95% confidence. A discussion of the tolerance limits is included in Appendix E.

When the 16-group Hansen-Roach library is used in the calculation of k_{eff}, there is a significant change in the value of k_{eff} from the experimental value depending on the average energy of a neutron causing fission (AE). This trend can be described by the following linear model:

1) k_{eff} = 1.2267 - 1.5297E-2*(AE).

This model accounts for 59% of the variation (i.e., corrected total sum of squares) for the 29 observations. Figure 6.1 illustrates how the value of k_{eff} varies over the range of AE and includes the lower tolerance limit for 99.9% of the population with a 95% confidence level. The tolerance limit is defined only on the closed interval of values of AE ranging from 14.1 to 15.5 (see Appendix E).

When the 27-group ENDF/B-IV library is used in the calculation of k_{eff}, there is a significant deviation from the reported critical value of k_{eff} for some of the cases. There are two separate trends associated with these deviations, one of which can be described by the following linear model:

2) k_{eff} = 1.0098 + 2.2407E-3*(enrichment) - 2.9875E-5*(H:^{235}U).

This model accounts for 61% of the variation for the 29 observations. The other trend can be described by the following model:

3) k_{eff} = 1.1710 + 4.1472E-3*(enrichment) - 7.6653E-3*(AE).

This model accounts for 59% of the variation for the 29 observations. Both of the linear models developed for the 27-group library contain two variables making the resulting plots of k_{eff} and their associated tolerance limits extremely difficult to interpret. In order to reduce the confusion, both of the above stated models and their tolerance limits are shown at specific values of enrichment. Equation 2 and its associated tolerance limits are shown in Figs. 6.2-6.5 at enrichment values of 1.4, 2.0, 3.0, and 4.98, respectively. Similarly, Equation 3 is shown in Figs. 6.6-6.9. The tolerance limits for Equation 2 are defined only on the interval of AE values ranging from 21.5 to 22.5 and the tolerance limits for Equation 3 are defined only on the interval of H:^{235}U values ranging from 133 to 975.

In conclusion, the results of this work indicate that trends in k_{eff} obtained using KENO V.a and the 16-group Hansen-Roach library can be generally described a linear model for the validated range of AE. Similarly, when using KENO V.a with the 27-group ENDF/B-IV library, trends in k_{eff} can be generally described by two independent linear models dependent on the validated ranges of H:^{235}U ratio, AE, and enrichment. The mean value of k_{eff} using the Hansen-Roach library is 0.9997 with standard deviation 0.0094, while the mean value using the 27-group library is 1.0053 with standard deviation 0.0096. Based on the results of this work for homogeneous UF systems, a safe upper limit for predicting criticality would be k_{eff} + 2σ below the prescribed lower tolerance limit. Overall, both cross-section libraries give good results when used with KENO V.a in the SCALE code system.

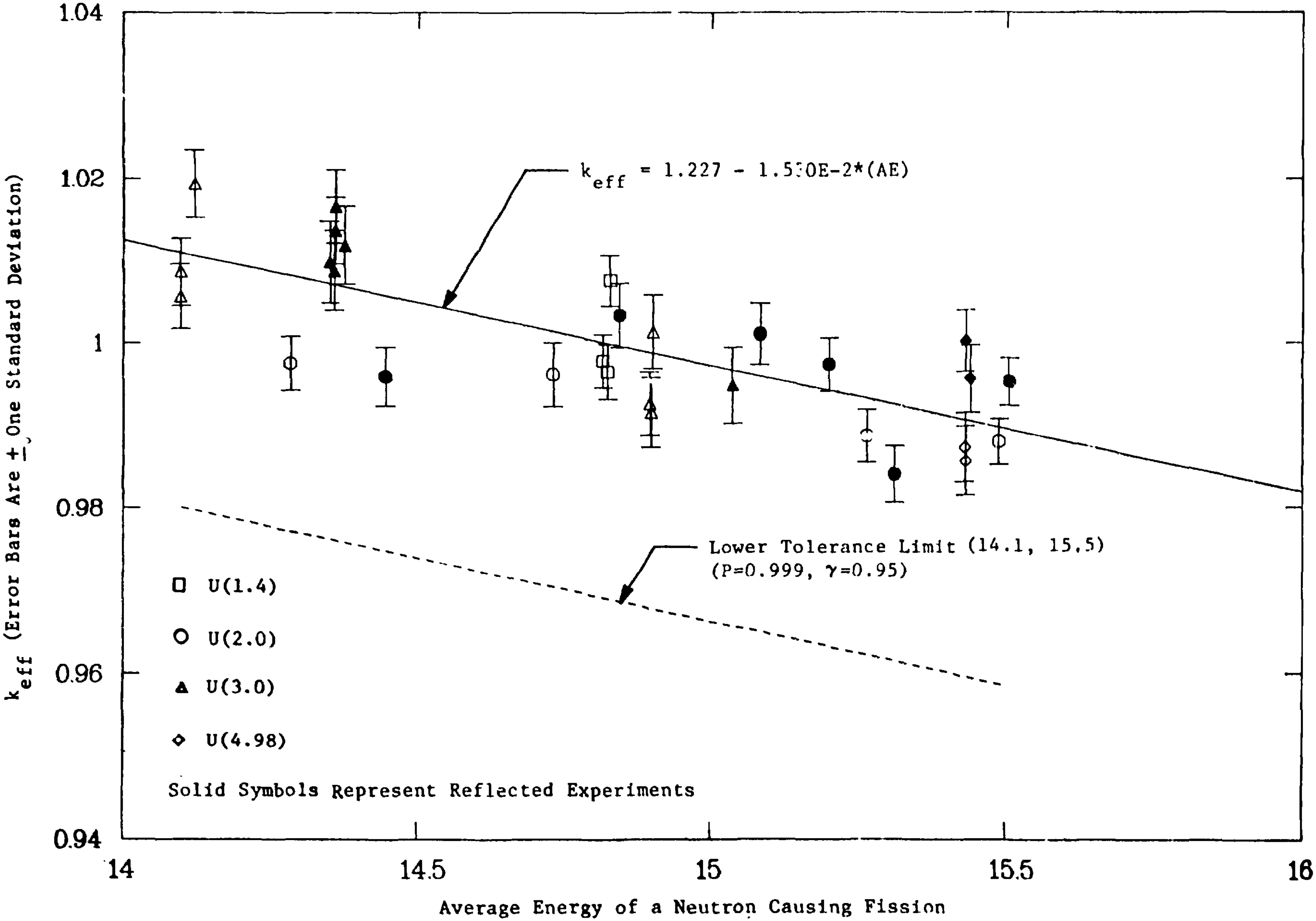

Fig. 6.1 k_{eff} (16-group) versus AE, linear model and lower tolerance limit

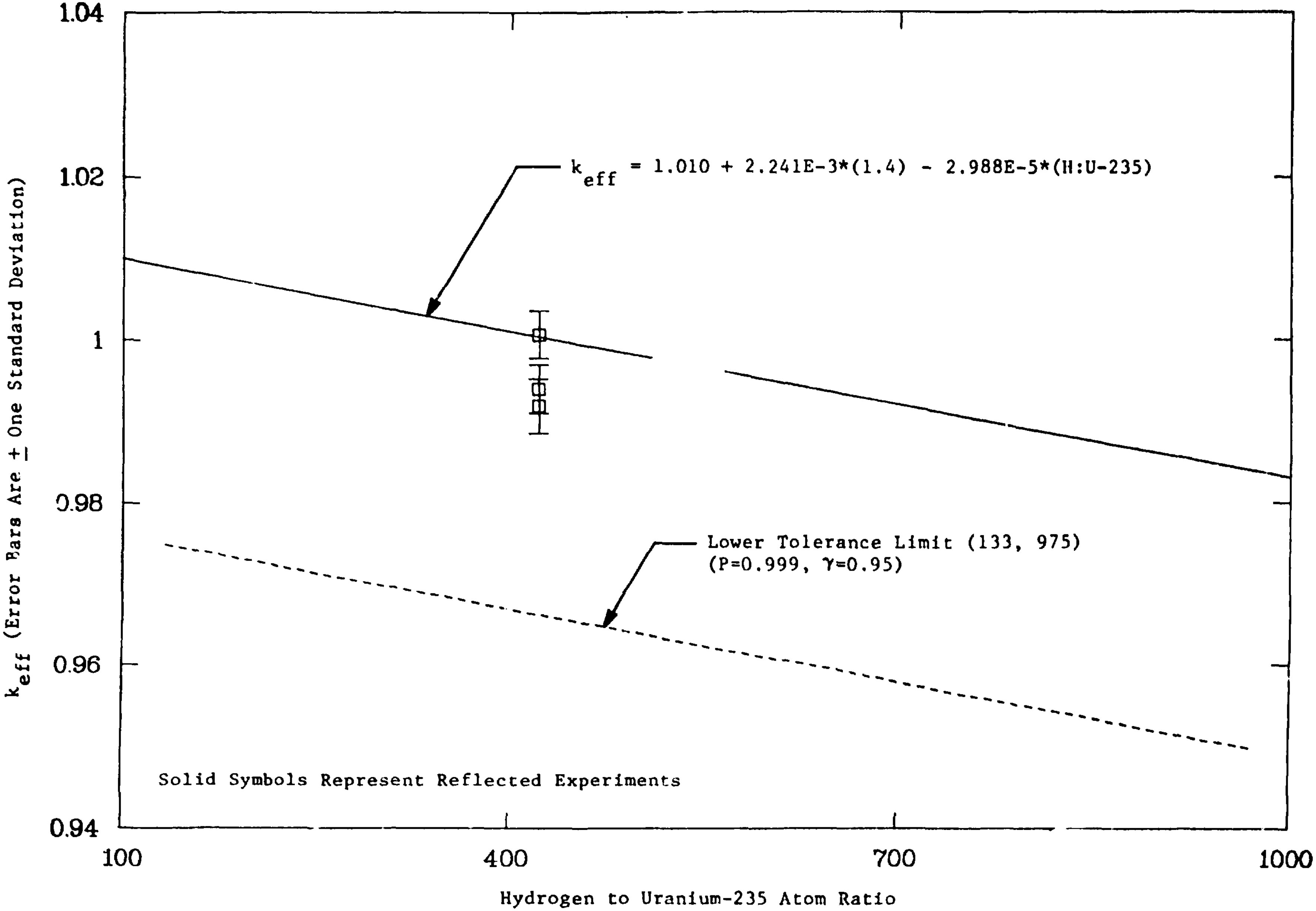

Fig. 6.2 k_{eff} (27-group) versus H:^{235}U for U(1.4), linear model and lower tolerance limit

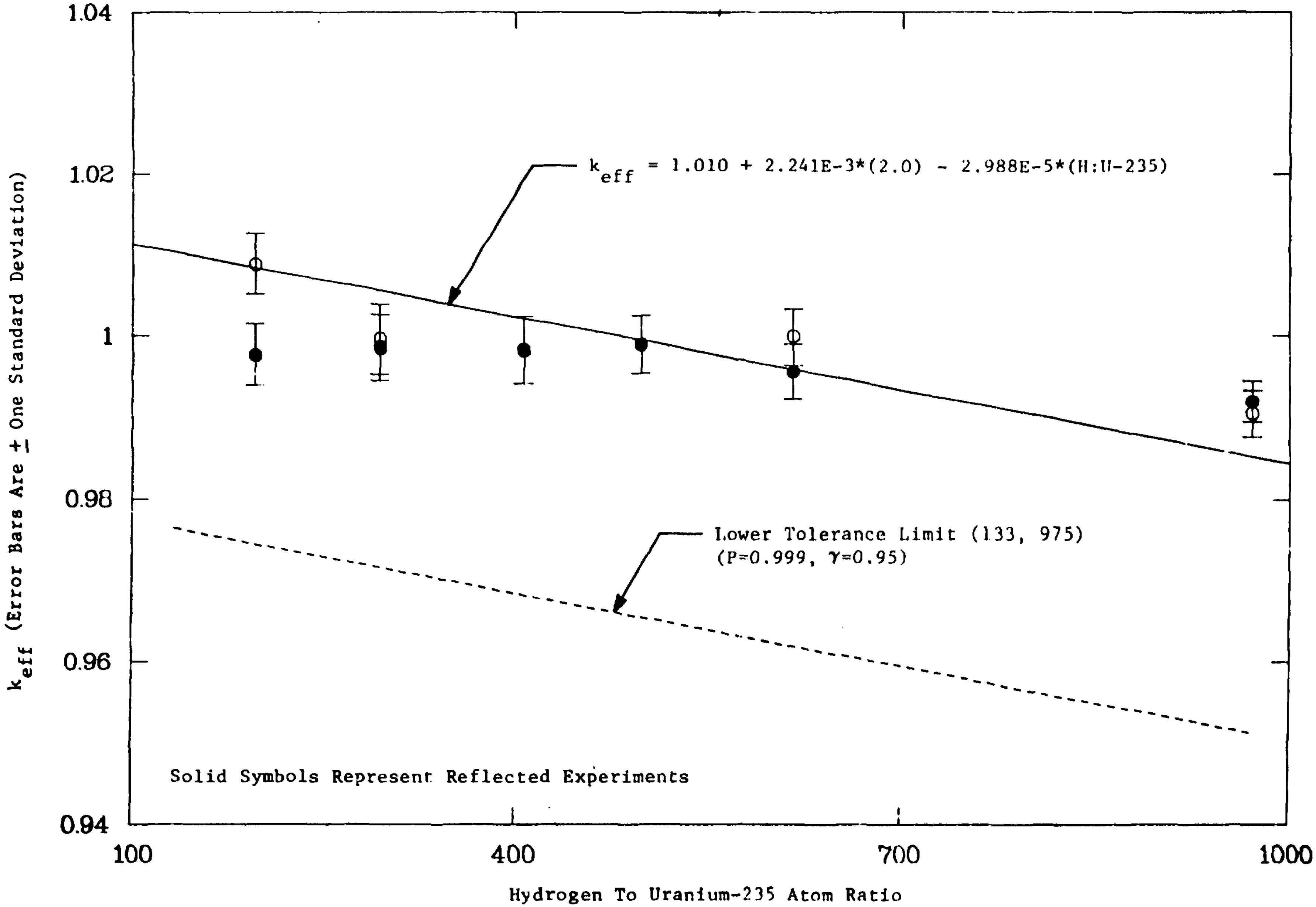

Fig. 6.3 k_{eff} (27-group) versus H:^{235}U for U(2.0), linear model and lower tolerance limit

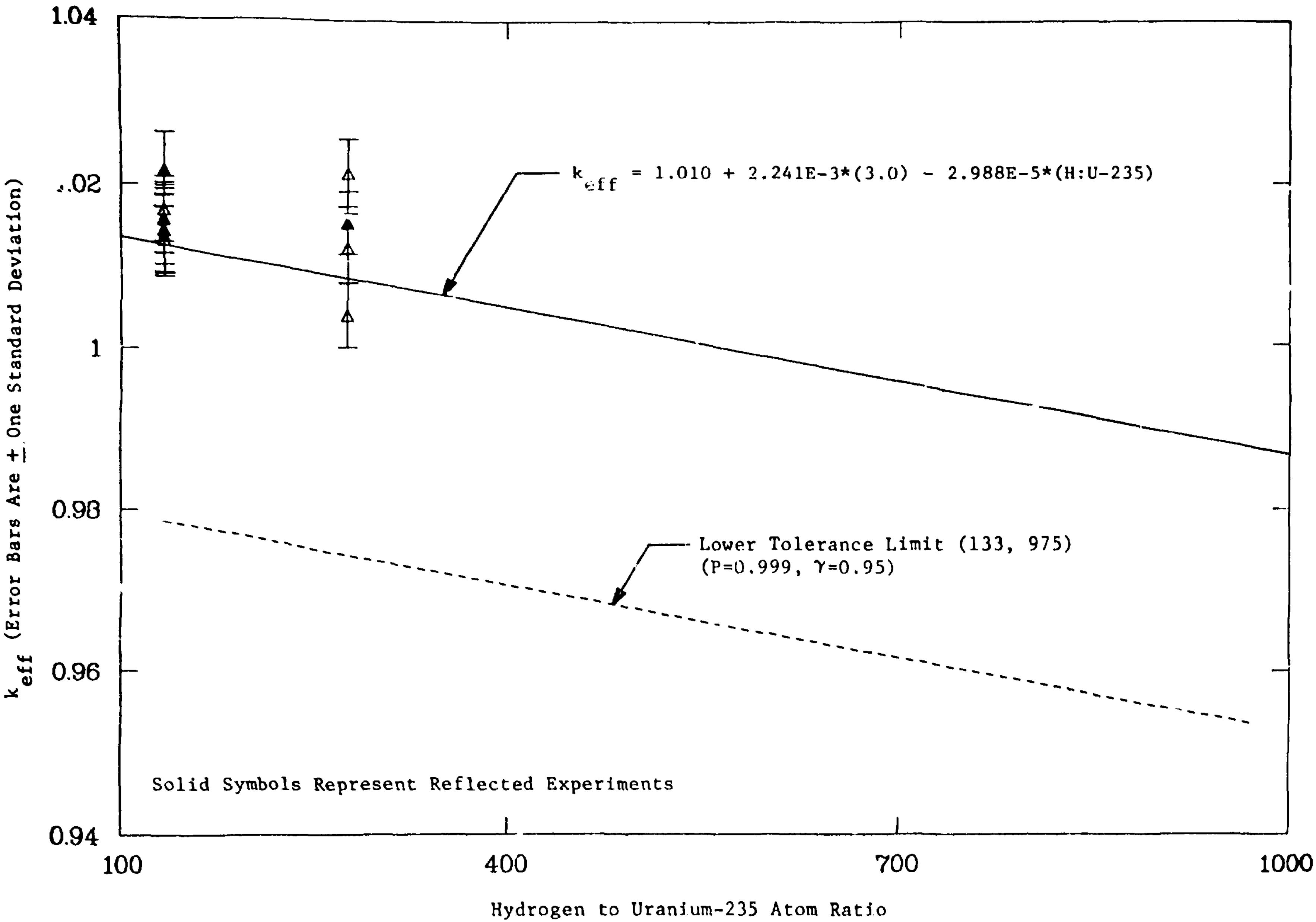

Fig. 6.4 k_{eff} (27-group) versus H:^{235}U for U(3.0), linear model and lower tolerance limit

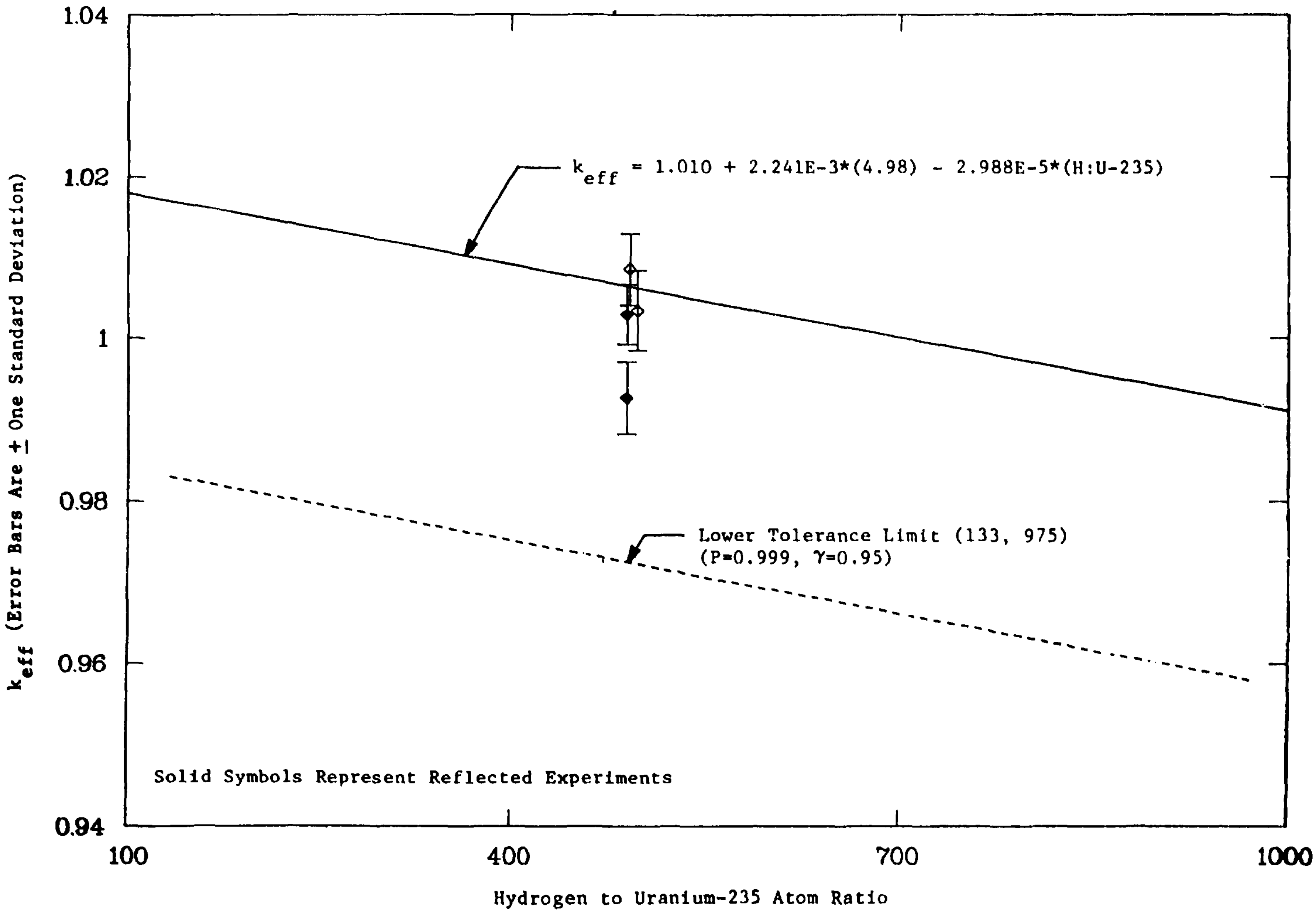

Fig. 6.5 k_{eff} (27-group) versus $H:^{235}U$ for U(4.98), linear model and lower tolerance limit

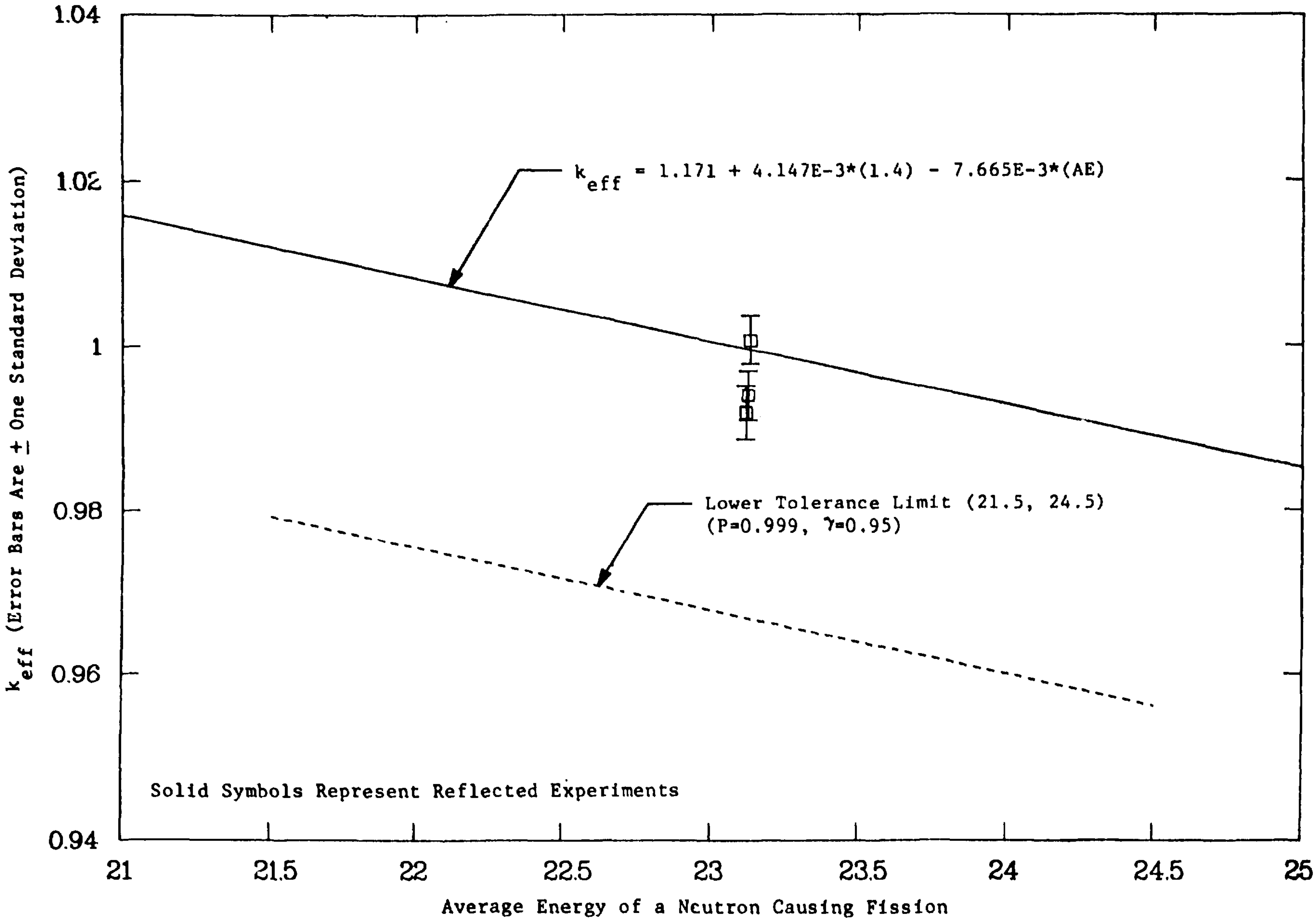

Fig. 6.6 k_{eff} (27-group) versus AE for U(1.4), linear model and lower tolerance limit

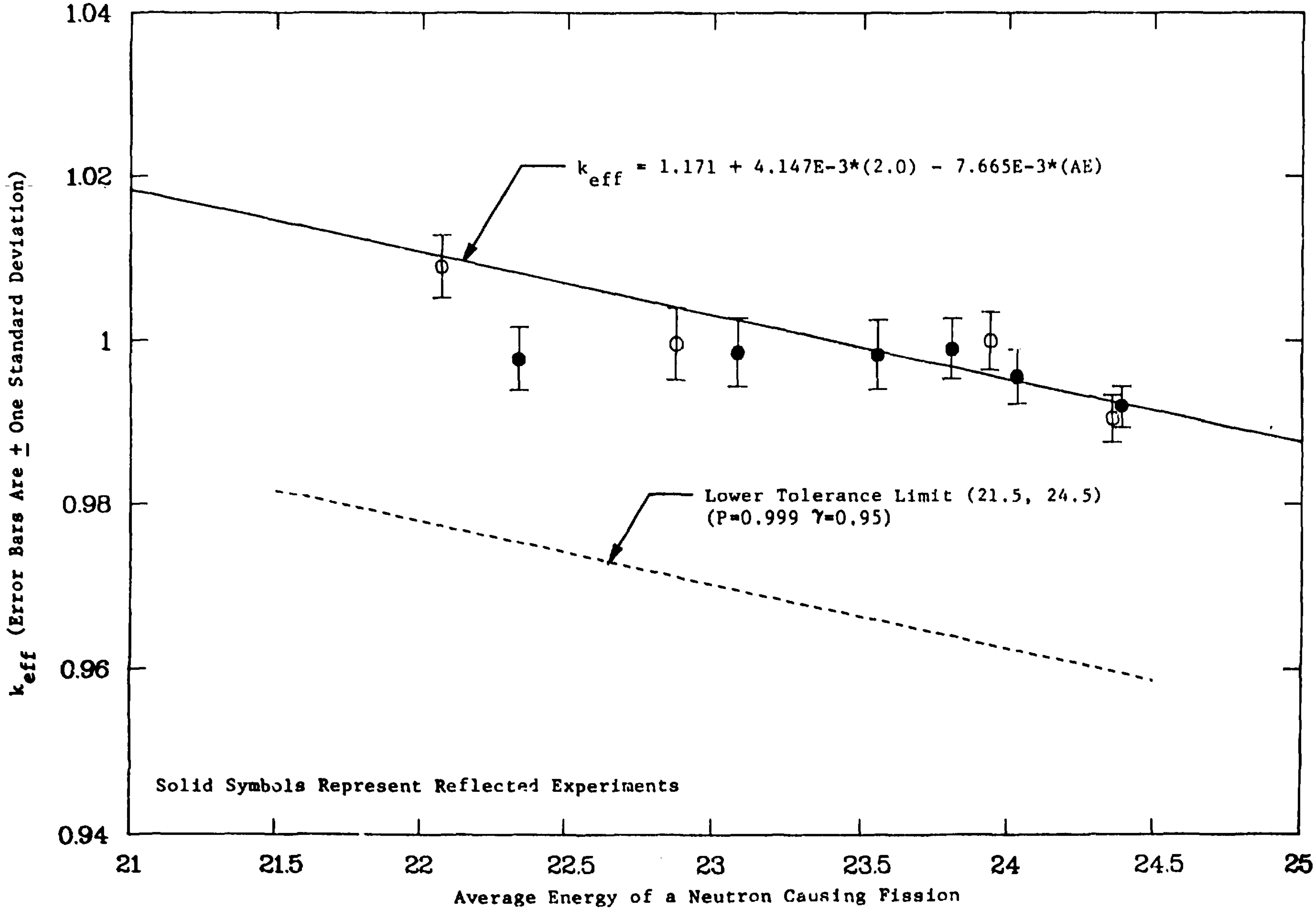

Fig. 6.7 k_{eff} (27-group) versus AE for U(2.0), linear model and lower tolerance limit

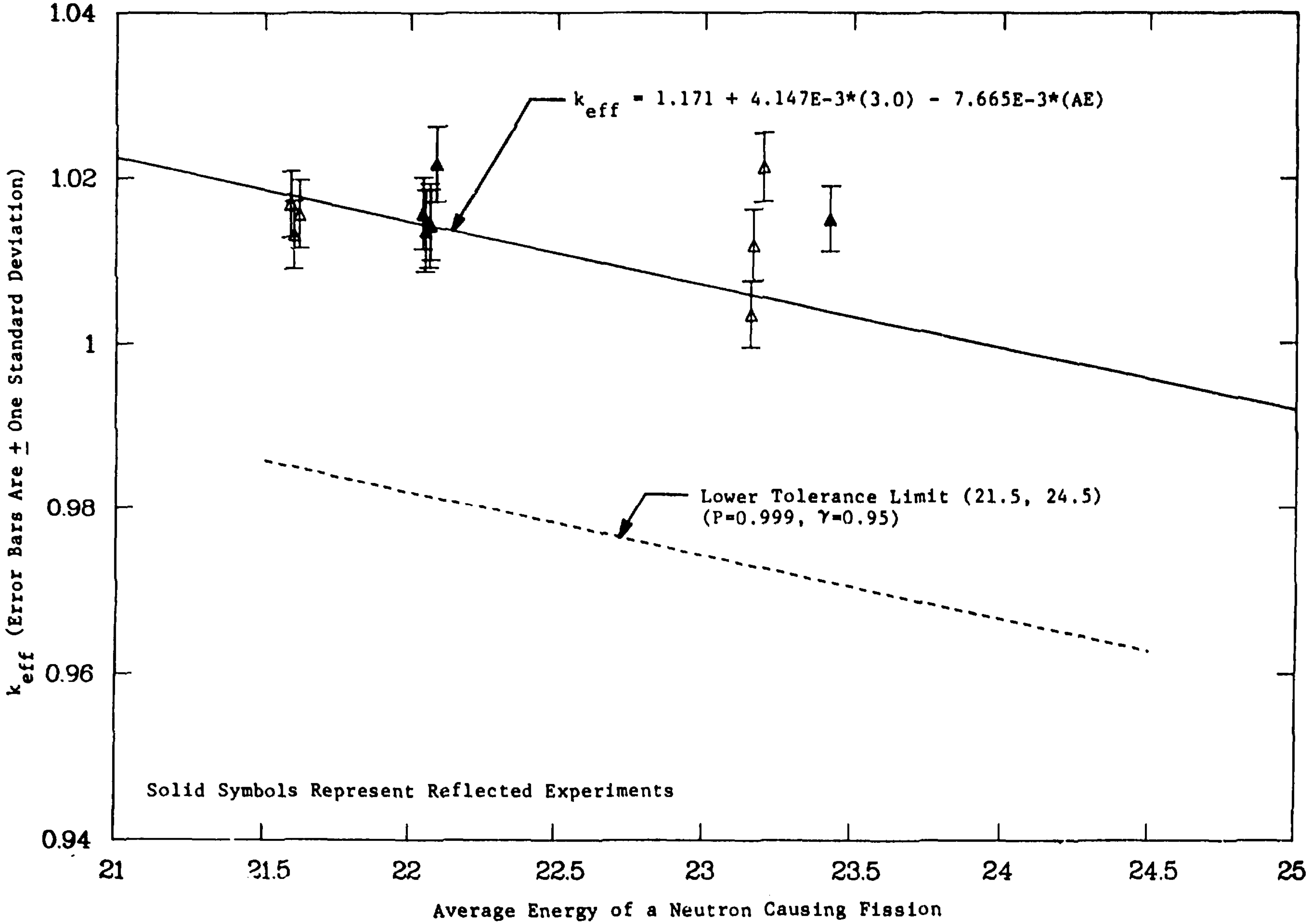

Fig. 6.8 k_{eff} (27-group) versus AE for U(3.0), linear model and lower tolerance limit

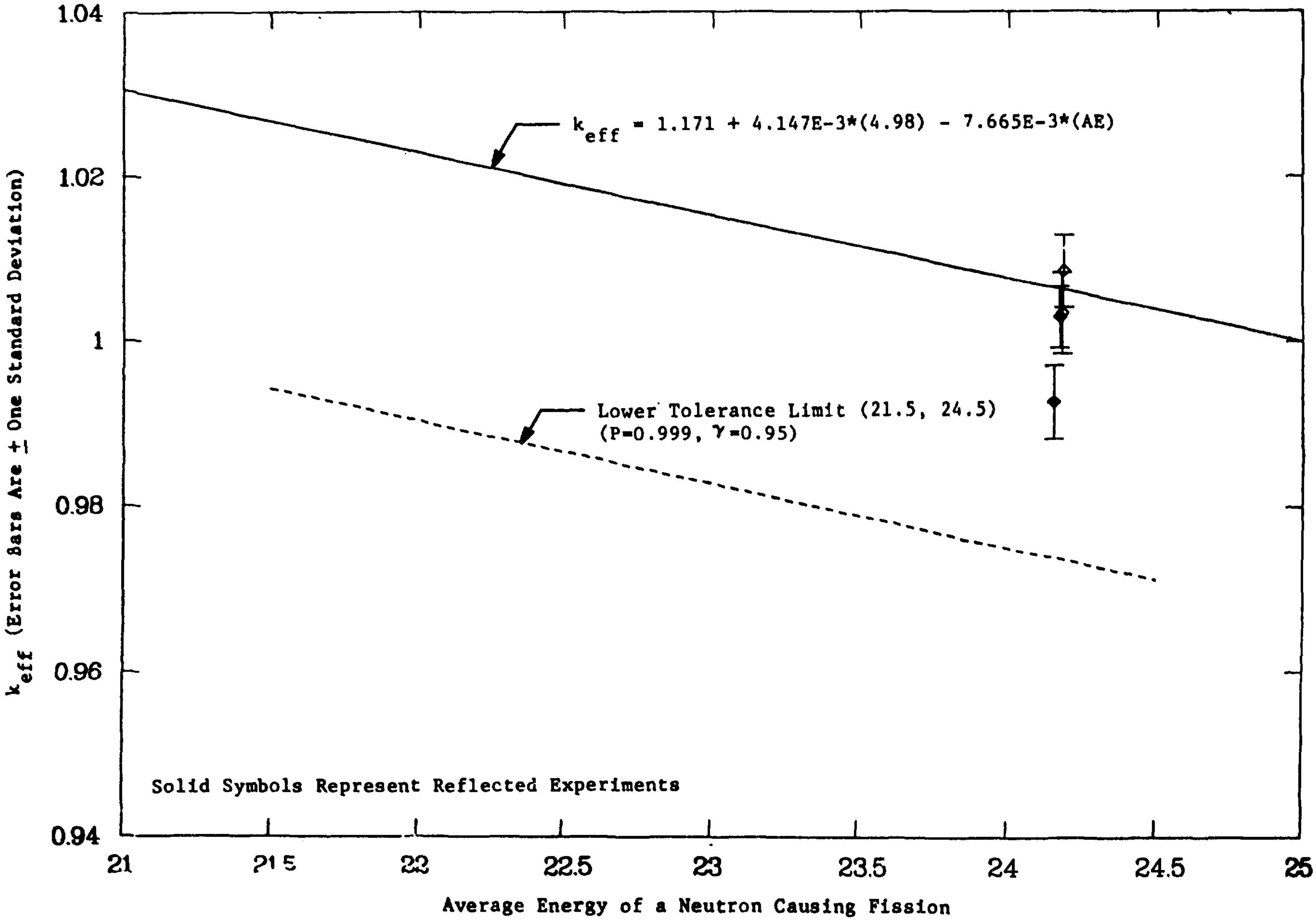

Fig. 6.9 k_{eff} (27-group) versus AE for U(4.98), linear model and lower tolerance limit

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APPENDIXES

APPENDIX A

DESCRIPTION OF SCALE CODE SYSTEM

A computational system called SCALE has been developed to provide a standard analysis tool for use by the NRC staff and licensees in evaluating nuclear fuel facility and package design. The SCALE system consists of several individual programs running in sequence which perform criticality, shielding, and/or heat transfer calculations with a minimum of user-required input. A detailed description of the entire SCALE code system is provided in Ref. 1.

The SCALE system employs automated analytic sequences (control modules) to perform the necessary data processing (cross-section preparation) and manipulation of well-established computer codes (functional modules) required by the calculation. The application of KENO V.a in SCALE requires the CSAS25 (Criticality Safety Analysis Sequence Number 25) control module to be called. CSAS25 first reads input data and then calls BONAMI and/or NITAWL to process the cross-section data; next the information is passed to ICE where the cross sections are mixed for the designated materials, and then the criticality calculation is performed by KENO V.a.

KENO V.a is a multigroup Monte Carlo criticality program used to calculate the k_{eff} of a three-dimensional system. Special features include simplified data input, supergrouping of energy-dependent data, the ability of specify origins for spherical and cylindrical geometry regions, a P_n scattering treatment, extended use of differential albedo reflection, and an improved restart capability. The most noted improvement in KENO geometry is the addition of the "array of arrays" and "holes" capabilities. The array of arrays option allows the construction of arrays from other arrays. The depth of nesting is limited only by computer space restrictions. This option greatly simplifies the setup for arrays involving different units at different spacing. The hole option allows placing a unit of an array at any desired location within a geometry region. The emplaced unit or array cannot intersect any geometry region and must be wholly contained within a region. As many holes as will snugly fit without intersecting can be placed in a region. This option is especially useful for describing shipping casks and reflectors that have gaps or other geometrical features. Any number of holes can be described in a problem and holes can be nested to any depth.

Cross-section libraries used in this report include the 27-energy-group ENDF/B-IV and the 16-energy-group Hansen-Roach library. The data for the 27-group ENDF/B-IV library were collapsed from the Evaluated Nuclear Data File/B-Version IV[9] (ENDF/B-IV). This broad group library was developed specifically for criticality analysis of a wide variety of thermal systems and has undergone extensive evaluation. The Hansen-Roach library is based on the original Los Alamos report by Hansen and Roach[10] and was developed primarily for the analysis of fast systems. Data for a few nuclides missing in the original library were generated by collapsing the 218-group ENDF/B-IV to 16 group.

Table A.1 Calculated k-effectives

Exp.	Ref.	k-effective ± 1 sigma			
		ENDF/B-IV		Hansen-Roach	
04	5	1.00066 ±	0.00294	0.99647 ±	0.00337
05	5	0.99184	0.00329	0.99776	0.00326
06	5	0.99397	0.00296	1.00764	0.00311
11	5	0.99773	0.00373	0.99587	0.00365
12	5	1.00890	0.00381	0.99744	0.00327
13	5	0.99858	0.00406	1.00337	0.00335
14	5	0.99958	0.00430	0.99609	0.00395
15	5	0.99827	0.00411	1.00108	0.00378
16	5	0.99899	0.00356	0.99737	0.00325
17	5	0.99567	0.00334	0.98408	0.00342
18	5	0.99997	0.00348	0.98871	0.00361
19	5	0.99202	0.00248	0.99527	0.00292
20	5	0.99054	0.00287	0.98804	0.00273
21	5	1.01583	0.00434	1.01363	0.00401
22	5	1.01445	0.00431	1.01660	0.00445
23	5	1.02178	0.00453	1.00874	0.00485
24	5	1.01373	0.00498	1.01190	0.00479
25	5	1.01434	0.00509	1.00980	0.00498
26	5	1.01696	0.00398	1.00565	0.00397
27	5	1.01569	0.00412	1.01929	0.00407
28	5	1.01319	0.00414	1.00860	0.00411
29	5	1.01522	0.00393	0.99487	0.00462
30	5	1.01205	0.00434	0.99257	0.00382
31	5	1.02146	0.00410	1.00132	0.00450
32	5	1.00366	0.00400	0.99154	0.00420
33	5	0.99256	0.00443	1.00028	0.00374
34	5	1.00288	0.00370	0.99565	0.00413
35	5	1.00853	0.00442	0.98574	0.00415
36	5	1.00339	0.00498	0.98733	0.00416
1[a]	6	1.00855	0.00337	1.02455	0.00341
2[a]	6	1.00712	0.00381	1.01249	0.00336
3[b]	6	0.99188	0.00323	1.01210	0.00358
1[b]	7	1.01199	0.00309	1.01562	0.00335
2[b]	7	1.00864	0.00338	1.01787	0.00313
3[a]	7	1.00875	0.00344	1.01798	0.00308
F[b]	8	1.02662	0.00357	1.04097	0.00355
G[a]	8	1.02662	0.00359	1.03289	0.00348

[a]Optimum moderated experiment.

[b]Undermoderated experiment.

APPENDIX B

COMPARISON OF NUMBER DENSITY CALCULATIONS

In an effort to standardize the calculation of number densities, and reduce the amount of user required input needed for a successful calculation, SCALE internally calculates number densities. From the Standard Composition Library[1] the user can designate the material to be a mixture of one or more standard compositions. These compositions include elements, compounds, alloys, solutions, and arbitrary materials (used to build compounds and alloys not available in the Standard Composition Library). For standard compositions taken from the Standard Composition Library, the user will have to enter the volume fraction or theoretical density of the standard composition in the mixture, and other engineering type data (see Ref. 1).

For selected experiments, the number densities were calculated by hand and compared with number densities used in Ref. 5 and the number densities generated by SCALE. Table A.1 contains these values and from the comparison it is determined that SCALE accurately calculates material number densities in a standardized form.

Table B.1 Comparison of number densities*

Case no.	Element	Hand calculation	Value from ref. 5	SCALE calculation
4-6	^{235}U	8.9821E-5	8.9443E-5	8.9447E-5
	^{238}U	6.2356E-3	6.2094E-3	6.2097E-3
	F	2.5304E-2	2.5195E-2	2.5197E-2
	H	3.7886E-2	3.7727E-2	3.7755E-2
	C	1.8215E-2	1.8138E-2	1.8152E-2
33,34	^{235}U	1.1599E-4	1.1601E-4	1.1644E-4
	^{238}U	2.1852E-3	2.1856E-3	2.1936E-3
	F	4.6024E-3	4.6031E-3	4.6201E-3
	H	5.6605E-2	5.6612E-2	5.6891E-2
	O	3.2904E-2	3.2909E-2	3.3067E-2
35	^{235}U	1.1613E-4	1.1614E-4	1.1642E-4
	^{238}U	2.1878E-3	2.1881E-3	2.1932E-3
	F	4.6080E-3	4.6085E-3	4.6192E-3
	H	5.6947E-2	5.6909E-2	5.6893E-2
	O	3.3081E-2	3.3063E-2	3.3066E-2
36	^{235}U	1.1501E-4	1.1499E-4	1.1644E-4
	^{238}U	2.1666E-3	2.1664E-3	2.1936E-3
	F	4.5632E-3	4.5628E-3	4.6201E-3
	H	3.3086E-2	3.3082E-2	3.3066E-2
	O	5.7045E-2	5.7038E-2	5.6891E-2

*atoms/barn-cm

APPENDIX C

CODE INPUT FOR ALL CASES

Case 4

```
=CSAS25
BRITISH HANDBOOK OF CRITICALITY SAFETY U(1.42)F4 & PARAFFIN (CASE 04)
HANSEN-ROACH  INFHOMMEDIUM
UF4     1 0.4903 293 92235 1.4023 92238 98.5977 END
PARAFFIN 1 0.4572 END
END COMP
BRITISH HANDBOOK OF CRITICALITY SAFETY U(1.42)F4 & PARAFFIN (CASE 04)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 2P46.55 2P46.50 2P61.9
END GEOM
END DATA
END
```

Case 5

```
=CSAS25
BRITISH HANDBOOK OF CRITICALITY SAFETY U(1.42)F4 & PARAFFIN (CASE 05)
HANSEN-ROACH  INFHOMMEDIUM
UF4     1 0.4903 293 92235 1.4023 92238 98.5977 END
PARAFFIN 1 0.4572 END
END COMP
BRITISH HANDBOOK OF CRITICALITY SAFETY U(1.42)F4 & PARAFFIN (CASE 05)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 2P50.00 2P49.95 2P51.55
END GEOM
END DATA
END
```

Case 6

```
=CSAS25
BRITISH HANDBOOK OF CRITICALITY SAFETY U(1.42)F4 & PARAFFIN (CASE 06)
HANSEN-ROACH  INFHOMMEDIUM
UF4     1 0.4903 293 92235 1.4023 92238 98.5977 END
PARAFFIN 1 0.4572 END
END COMP
BRITISH HANDBOOK OF CRITICALITY SAFETY U(1.42)F4 & PARAFFIN (CASE 06)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 2P65.35 2P65.3 2P37.1
END GEOM
END DATA
END
```

Case 11

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-1 REFLECTED (CASE 11)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.5811E-4 END
U-238  1 0 7.6467E-3 END
H      1 0 3.0864E-2 END
C      1 0 1.4839E-2 END
F      1 0 3.1219E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL          3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-1 REFLECTED (CASE 11)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 4P28.110 2P56.44
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 4P28.110 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 11 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=146
XLR=88  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 12

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-1 UNREFLECTED (CASE 12)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.5811E-4 END
U-238  1 0 7.6467E-3 END
H      1 0 3.0864E-2 END
C      1 0 1.4839E-2 END
F      1 0 3.1219E-2 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-1 UNREFLECTED (CASE12)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 35.735 -35.735 35.735 -35.735 47.07 -47.07
END GEOM
END DATA
END
```

Case 13

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-2 REFLECTED (CASE 13)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.3303E-4 END
U-238  1 0 6.4370E-3 END
H      1 0 3.9097E-2 END
C      1 0 1.8797E-2 END
F      1 0 2.6280E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL        3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-2 REFLECTED (CASE 13)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 4P25.555 2P36.935
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 4P25.555 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 13 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=106
XLR=83  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 14

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-2 UNREFLECTED (CASE 14)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.3303E-4 END
U-238  1 0 6.4370E-3 END
H      1 0 3.9097E-2 END
C      1 0 1.8797E-2 END
F      1 0 2.6280E-2 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-2 UNREFLECTED (CASE 14)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 28.11 -28.11 28.11 -28.11 61.235 -61.235
END GEOM
END DATA
END
```

Case 15

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-3 REFLECTED (CASE 15)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.1191E-4 END
U-238  1 0 5.4152E-3 END
H      1 0 4.5472E-2 END
C      1 0 2.1861E-2 END
F      1 0 2.2109E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL         3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-3 REFLECTED (CASE 15)
READ PARM  RUN=YES PLT=YES  END PARM
READ GEOM
UNIT  1
CUBOID  1 1 4P26.835 2P27.145
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 4P26.835 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 15 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=86
XLR=86  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 16

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-4 REFLECTED (CASE 16)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 0.9924E-4 END
U-238  1 0 4.7998E-3 END
H      1 0 4.9212E-2 END
C      1 0 2.3660E-2 END
F      1 0 1.9596E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL         3 0.062 END
END COMP
```

```
RAFFETY AND MALHALCZO U(2)F4-4 REFLECTED (CASE 16)
READ PARM  RUN=YES PLT=YES  END PARM
READ GEOM
UNIT  1
CUBOID  1 1 4P23.000 2P48.285
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 4P23.000 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 16 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=129
XLR=79  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 17

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-5 REFLECTED (CASE 17)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 0.8667E-4 END
U-238  1 0 4.1941E-3 END
H      1 0 5.3187E-2 END
C      1 0 2.5570E-2 END
F      1 0 1.7123E-2 END
POLYETHYLENE 2 1.0 END
PLEXIGLASS  3 0.918 END
AL          3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-5 REFLECTED (CASE 17)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 2P28.160 2P30.645 2P27.040
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 2P28.160 2P30.645 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
```

```
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 17 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=86
XLR=89  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 18

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-5 UNREFLECTED (CASE 18)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 0.8667E-4 END
U-238  1 0 4.1941E-3 END
H      1 0 5.3187E-2 END
C      1 0 2.5570E-2 END
F      1 0 1.7123E-2 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-5 UNREFLECTED (CASE18)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 30.65 -30.65 33.27 -33.27 33.26 -33.26
END GEOM
END DATA
END
```

Case 19

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-6 REFLECTED (CASE 19)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 0.6232E-4 END
U-238  1 0 3.0100E-3 END
H      1 0 6.0557E-2 END
C      1 0 2.9114E-2 END
F      1 0 1.2309E-2 END
POLYETHYLENE  2 1.0 END
PLEXIGLASS  3 0.918 END
AL          3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-6 REFLECTED (CASE 19)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 2P38.255 2P38.220 2P41.210
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 2P38.255 2P38.220 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
```

```
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 19 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=115
XLR=108  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 20

```
=CSAS25
RAFFETY AND MILHALCZO U(2)F4-6 UNREFLECTED (CASE 20)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 0.6232E-4 END
U-238  1 0 3.0100E-3 END
H      1 0 6.0557E-2 END
C      1 0 2.9114E-2 END
F      1 0 1.2309E-2 END
END COMP
RAFFETY AND MALHALCZO U(2)F4-6 UNREFLECTED (CASE20)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 40.725 -40.725 43.35 -43.35 44.110 -44.110
END GEOM
END DATA
END
```

Case 21

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 REFLECTED (CASE 21)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL          3 0.062 END
END COMP
RAFFETY AND MILHALCZO U(3)F4-1 REFLECTED (CASE 21)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
```

```
UNIT 1
CUBOID 1 1 2P25.57 2P25.57 2P25.635
REPLICATE 2 2 5*3.048 0.0 5
UNIT 2
CUBOID 3 1 2P25.57 2P25.57 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1 NUY=1 NUZ=2
FILL 2 1 END FILL
END ARRAY
READ BIAS ID=400 2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 21 SHOWING BIASING REGIONS'
XUL=-1 YUL=20 ZUL=83
XLR=83 YLR=20 ZLR=-3
UAX=1 WDN=-1 NAX=130 NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 22

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 REFLECTED (CASE 22)
HANSEN-ROACH INFHOMMEDIUM
U-235 1 0 2.3494E-4 END
U-238 1 0 7.4999E-3 END
H     1 0 3.1341E-2 END
C     1 0 1.5067E-2 END
F     1 0 3.0939E-2 END
PARAFFIN 2 1.0 END
PLEXIGLASS 3 0.918 END
AL        3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-1 REFLECTED (CASE 22)
READ PARM RUN=YES PLT=YES END PARM
READ GEOM
UNIT 1
CUBOID 1 1 2P21.735 2P21.735 2P43.1950
REPLICATE 2 2 5*3.048 0.0 5
UNIT 2
CUBOID 3 1 2P21.735 2P21.735 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1 NUY=1 NUZ=2
FILL 2 1 END FILL
END ARRAY
READ BIAS ID=400 2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 22 SHOWING BIASING REGIONS'
```

```
XUL=-1 YUL=20 ZUL=129
XLR=79 YLR=20 ZLR=-3
UAX=1 WDN=-1 NAX=130 NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 23

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 REFLECTED (CASE 23)
HANSEN-ROACH INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
PARAFFIN 2 1.0 END
PLEXIGLASS 3 0.918 END
AL         3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-1 REFLECTED (CASE 23)
READ PARM RUN=YES PLT=YES END PARM
READ GEOM
UNIT 1
CUBOID 1 1 2P23.010 2P23.010 2P33.785
REPLICATE 2 2 5*3.048 0.0 5
UNIT 2
CUBOID 3 1 2P23.010 2P23.010 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1 NUY=1 NUZ=2
FILL 2 1 END FILL
END ARRAY
READ BIAS ID=400 2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 23 SHOWING BIASING REGIONS'
XUL=-1 YUL=20 ZUL=99
XLR=79 YLR=20 ZLR=-3
UAX=1 WDN=-1 NAX=130 NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 24

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 REFLECTED (CASE 24)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL         3 0.062 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-1 REFLECTED (CASE 24)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 2P28.125 2P28.125 2P21.705
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 2P28.125 2P28.125 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 24 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=75
XLR=88  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 25

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 REFLECTED (CASE 25)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
PARAFFIN  2 1.0 END
PLEXIGLASS  3 0.918 END
AL         3 0.062 END
END COMP
```

```
RAFFETY AND MALHALCZO U(3)F4-1 REFLECTED (CASE 25)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 2P30.680 2P30.680 2P19.335
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 2P30.680 2P30.680 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 25 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=71
XLR=93  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 26

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 UNREFLECTED (CASE 26)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-1 UNREFLECTED (CASE 26)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 28.235 -28.235 28.235 -28.235 43.32 -43.32
END GEOM
END DATA
END
```

Case 27

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 UNREFLECTED (CASE 27)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-1 UNREFLECTED (CASE 27)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 28.125 -28.125 30.68 -30.68 37.19 -37.19
END GEOM
END DATA
END
```

Case 28

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-1 UNREFLECTED (CASE 28)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 2.3494E-4 END
U-238  1 0 7.4999E-3 END
H      1 0 3.1341E-2 END
C      1 0 1.5067E-2 END
F      1 0 3.0939E-2 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-1 UNREFLECTED (CASE 28)
READ PARM  END PARM
READ GEOM
CUBOID  1 1 30.7 -30.7 30.7 -30.7 33.00 -33.00
END GEOM
END DATA
END
```

Case 29

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-2 REFLECTED (CASE 29)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.6709E-4 END
U-238  1 0 5.3355E-3 END
H      1 0 4.6262E-2 END
C      1 0 2.2241E-2 END
F      1 0 2.2011E-2 END
POLYETHYLENE  2 1.0 END
PLEXIGLASS  3 0.918 END
AL         3 0.062 END
END COMP
```

```
RAFFETY AND MALHALCZO U(3)F4-2 REFLECTED (CASE 29)
READ PARM  RUN=YES PLT=YES END PARM
READ GEOM
UNIT  1
CUBOID  1 1 2P20.405 2P20.400 2P19.745
REPLICATE  2 2 5*3.048 0.0 5
UNIT  2
CUBOID  3 1 2P20.405 2P20.400 2*0.0
REPLICATE 3 2 4*3.048 0.0 3.048 5
END GEOM
READ ARRAY
NUX=1  NUY=1  NUZ=2
FILL  2 1 END FILL
END ARRAY
READ BIAS ID=400  2 6 END BIAS
READ PLOT TTL='XZ SLICE OF CASE 29 SHOWING BIASING REGIONS'
XUL=-1  YUL=20  ZUL=71
XLR=73  YLR=20  ZLR=-3
UAX=1  WDN=-1 NAX=130  NCH='0123456'
PIC=WTS
END PLOT
END DATA
END
```

Case 30

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-2 UNREFLECTED (CASE 30)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.6709E-4 END
U-238  1 0 5.3355E-3 END
H      1 0 4.6262E-2 END
C      1 0 2.2241E-2 END
F      1 0 2.2011E-2 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-2 UNREFLECTED (CASE 30)
READ PARM  RUN=YES  END PARM
READ GEOM
CUBOID  1 1 2P20.450 2P20.465 2P58.400
END GEOM
END DATA
END
```

Case 31

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-2 UNREFLECTED (CASE 31)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.6709E-4 END
U-238  1 0 5.3355E-3 END
H      1 0 4.6262E-2 END
C      1 0 2.2241E-2 END
F      1 0 2.2011E-2 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-2 UNREFLECTED (CASE 31)
READ PARM  RUN=YES  END PARM
READ GEOM
CUBOID  1 1 2P24.295 2P25.570 2P24.265
END GEOM
END DATA
END
```

Case 32

```
=CSAS25
RAFFETY AND MILHALCZO U(3)F4-2 UNREFLECTED (CASE 32)
HANSEN-ROACH  INFHOMMEDIUM
U-235  1 0 1.6709E-4 END
U-238  1 0 5.3355E-3 END
H      1 0 4.6262E-2 END
C      1 0 2.2241E-2 END
F      1 0 2.2011E-2 END
END COMP
RAFFETY AND MALHALCZO U(3)F4-2 UNREFLECTED (CASE 32)
READ PARM  RUN=YES  END PARM
READ GEOM
CUBOID  1 1 2P40.855 2P40.830 2P15.670
END GEOM
END DATA
END
```

Case 33

```
=CSAS25
CRITICAL REFLECTED CYLINDER OF AQUEOUS U(4.98)O2F2 (CASE 33)
HANSEN-ROACH  INFHOMMEDIUM
SOLNUO2F2  1 910.36 0.0 1 298 92235 4.98 92238 95.02 END
SS304  2 1.0 END
H2O    3 1.0 END
CD     4 1.0 END
END COMP
CRITICAL REFLECTED CYLINDER OF AQUEOUS U(4.98)O2F2 (CASE 33)
READ PARM  RUN=YES  END PARM
READ GEOM
```

```
UNIT 1
CYLINDER  1 1 19.545 2P27.225
CYLINDER  0 1 19.545 78.975 -27.225
CYLINDER  2 1 19.624 79.054 -27.304
CYLINDER  4 1 19.705 79.054 -27.304
CYLINDER  2 1 22.245 79.054 -27.304
CYLINDER  3 1 45.000 79.054 -27.304
CUBOID    0 1 4P45.000 79.054 -27.304
END GEOM
READ PLOT TTL='XZ SLICE OF CYLINDER CASE 33'
XUL=-45 YUL=0.0 ZUL=81
XLR=45  YLR=0.0 ZLR=-29
UAX=1  WDN=-1  NAX=130  NCH='01234'END
TTL='ENLARGEMENT OF LOWER RIGHT HAND CORNER OF CYLINDER'
XUL=18  YUL=0.0 ZUL=-25
XLR=23  YLR=0.0 ZLR=-28
UAX=1  WDN=-1  NAX=130  NCH='01234'
END PLOT
END DATA
END
```

Case 34

```
=CSAS25
CRITICAL REFLECTED CYLINDER OF AQUEOUS U(4.98)O2F2 (CASE 34)
HANSEN-ROACH  INFHOMMEDIUM
SOLNUO2F2  1 910.36 0.0 1 298 92235 4.98 92238 95.02 END
SS304  2 1.0 END
H2O    3 1.0 END
END COMP
CRITICAL REFLECTED CYLINDER OF AQUEOUS U(4.98)O2F2 (CASE 34)
READ PARM  RUN=YES  END PARM
READ GEOM
UNIT 1
CYLINDER  1 1 16.510 2P71.500
CYLINDER  0 1 16.510 172.400 -71.500
CYLINDER  2 1 16.589 172.479 -71.579
CYLINDER  2 1 19.129 172.479 -71.579
CYLINDER  3 1 45.000 172.479 -71.579
CUBOID    0 1 4P45.000 172.479 -71.579
END GEOM
READ PLOT TTL='XZ SLICE OF CYLINDER CASE 34'
XUL=-45  YUL=0.0 ZUL=174
XLR=45   YLR=0.0 ZLR=-73
UAX=1  WDN=-1  NAX=130  NCH='0123'END
TTL='ENLARGEMENT OF LOWER RIGHT CORNER OF CYLINDER'
XUL=15  YUL=0.0 ZUL=-69
XLR=20   YLR=0.0 ZLR=-73
UAX=1  WDN=-1  NAX=130  NCH='0123'
END PLOT
END DATA
END
```

Case 35

```
=CSAS25
CRITICAL SPHERE OF AQUEOUS U(4.98)O2F2 (CASE 35)
HANSEN-ROACH  INFHOMMEDIUM
SOLNUO2F2  1 910.18 0.0 1 292 92235 4.98 92238 95.02 END
SS304  2 1.0 END
END COMP
CRITICAL SPHERE OF AQUEOUS U(4.98)O2F2 (CASE 35)
READ PARM  RUN=YES  END PARM
READ GEOM
UNIT  1
SPHERE  1 1 25.3873
SPHERE  2 1 25.4127
CUBOID    0 1 6P25.4127
END GEOM
READ PLOT TTL='XZ SLICE OF SPHERE CASE 35'
XUL=-26  YUL=0.0 ZUL=26
XLR=26   YLR=0.0 ZLR=-26
UAX=1  WDN=-1  NAX=130  NCH='012'
TTL='ENLARGEMENT OF SPHERE WALL'
XUL=24  YUL=0.0 ZUL=2
XLR=26  YLR=0.0 ZLR=-2
UAX=1  WDN=-1  NAX=130  NCH='012'
END PLOT
END DATA
END
```

Case 36

```
=CSAS25
CRITICAL CYLINDER OF AQUEOUS U(4.98)O2F2 (CASE 36)
HANSEN-ROACH  INFHOMMEDIUM
SOLNUO2F2  1 910.36 0.0 1 298 92235 4.98 92238 95.02 END
SS304  2 1.0 END
END COMP
CRITICAL CYLINDER OF AQUEOUS U(4.98)O2F2 (CASE 36)
READ PARM  RUN=YES  END PARM
READ GEOM
UNIT  1
CYLINDER  1 1 19.5500 2P50.85
CYLINDER  0 1 19.5500 74.16 -50.85
CYLINDER  2 1 19.6287 74.16 -50.9287
CUBOID    0 1 4P19.6287 74.16 -50.9287
END GEOM
READ PLOT TTL='XZ SLICE OF CYLINDER CASE 36'
XUL=-21  YUL=0.0 ZUL=76
XLR=21   YLR=0.0 ZLR=-52
UAX=1  WDN=-1  NAX=130  NCH='012'END
TTL='ENLARGEMENT OF LOWER RIGHT CORNER OF CYLINDER'
XUL=18  YUL=0.0 ZUL=-49
XLR=21  YLR=0.0 ZLR=-52
UAX=1  WDN=-1  NAX=130  NCH='012'
END PLOT
END DATA
END
```

Case 41

```
//JOBCARD
// EXEC SPDASCR
T.GEE00000.RST1.HSNRCH.RFP1
//* PREVIOUS TWO LINES CLEAR T.GEE00000.RST1.HSNRCH.RFP1 SO
//* A RESTART FILE CAN BE WRITTEN ON UNIT 30 IN THIS FILE
//MIKE EXEC Y12CSG,REGION.GO=1024K
//FT84F001 DD DSN=T.GEE00000.HSNRCH1,DISP=SHR
//FT30F001 DD DSN=T.GEE00000.RST1.HSNRCH.RFP1,UNIT=SPDA,
// SPACE=(TRK,(20,10)),DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3156,BUFL=4038),
// DISP=(,CATLG)
//GO.SYSIN DD *
=CSAS25
ROCKY FLATS CRITICALS NUREG/CR-1071 EXPERIMENT NUMBER 1 (HANSEN-ROACH)
27GROUPNDF4 LATTICECELL
HAVEREDEFINED
U3O8 1 5.4078E-1 293.0 92234 0.03 92235 4.46 92236 0.08 92238 95.43 END
H2O 1 8.9514E-2 END
ARBM-BAGGIE 1.0 3 0 0 0 1001 14.01 6012 84.9 8016 1.20 1 1.9134E-2
  END
ARBM-AL1100 1.0 3 0 0 1 13027 99.18 26000 0.5 29000 0.2 2 9.5390E-1
  END
ARBM-TAPE(VINYL) 1.0 7 0 0 0 1001 5.92 6012 45.91 8016 10.82 17000
  25.73 20040 6.9 22000 1.6 82000 1.1 2 1.1115E-2 END
ARBM-TAPE(MYLAR) 1.0 3 0 0 0 1001 6.83 6012 65.50 8016 27.02 2
  1.7491E-2 END
ARBM-MODERATOR 1.185 3 0 0 0 1001 7.83 6012 59.49 8016 32.48 3 END
ARBM-PLEX(REG) 1.0 3 0 0 0 1001 7.84 6012 59.59 8016 32.23 4
  1.1773 END
ARBM-PLEX(PAPER) 1.0 3 0 0 0 1001 6.48 6012 42.17 8016 49.5 4
  3.7534E-3 END
ARBM-PLEX(GLUE) 1.0 3 0 0 0 1001 11.67 6012 86.29 8016 1.20 4
  1.1648E-3 END
ARBM-PLEX(TRIS) 1.0 8 0 0 1 1001 7.16 6012 52.03 7014 0.16 8016 29.82
  15031 1.02 17000 1.81 35079 4.260 35081 2.840 5 1.2757 END
ARBM-PLEX(PAPER) 1.0 3 0 0 0 1001 6.48 6012 42.17 8016 49.5 5
  3.7534E-3 END
ARBM-PLEX(GLUE) 1.0 3 0 0 0 1001 11.67 6012 86.29 8016 1.20 5
  1.1648E-3 END
ARBM-FILLER 1.185 3 0 0 0 1001 7.83 6012 59.49 8016 32.48 6 .88 END
END COMP
SPHTRIANGP 19.9462 18.5857 1 3 18.9579 2 END
ROCKY FLATS CRITICALS NUREG/CR-1071 EXPERIMENT NUMBER 1 (HANSEN-ROACH)
READ PARM RUN=YES NPG=500 RES=103 WRS=30
END PARM
READ GEOM
UNIT 1
COM='FUEL BOX 15.28 CM ON A SIDE WITH .15 CM WALLS .05CM STACKING VOID'
CUBOID 1 1 6P7.49
CUBOID 2 1 6P7.64
CUBOID 0 1 6P7.6650
```

```
UNIT 2
COM='X-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 2P1.2200 4P7.665
UNIT 3
COM='Y-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 2P7.665 2P1.2200 2P7.665
UNIT 4
COM='Z-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 4P7.665 2P1.2200
UNIT 5
COM='MORE X-FACE MODERATOR'
CUBOID 3 1 4P1.2200 2P7.665
UNIT 6
COM='MORE Y-FACE MODERATOR'
CUBOID 3 1 2P7.665 4P1.2200
UNIT 7
COM='MORE Z-FACE MODERATOR'
CUBOID 3 1 2P1.2200 2P7.665 2P1.2200
UNIT 8
COM='LAST OF INTERSTITIAL MODERATOR'
CUBOID 3 1 6P1.2200
UNIT 9
COM='NORTH SPLIT TABLE CORE'
ARRAY 1 3*0.0
UNIT 10
COM='SOUTH SPLIT TABLE CORE'
ARRAY 2 3*0.0
UNIT 11
COM='PLEXIGLASS REFLECTOR SHEET WITHOUT TRIS, NORTH BOTTOM REFLECTOR'
CUBOID 4 1 2P16.5500 2P38.7500 2P0.6150
UNIT 12
COM='PLEXIGLASS REFLECTOR SHEET WITH TRIS, NORTH BOTTOM REFLECTOR'
CUBOID 5 1 2P16.5500 2P38.7500 2P0.6150
UNIT 13
COM='UPPER PORTION NORTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 5 1 2P16.550 2P38.75 2P8.24
UNIT 14
COM='LOWER PORTION NORTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 5 1 2P16.550 2P38.75 2P3.69
UNIT 15
COM='NORTH BOTTOM REFLECTOR INCLUDES REGULAR AND TRIS'
ARRAY 3 3*0.0
UNIT 16
COM='PLEXIGLAS SHEET BOTTOM SOUTH REFLECTOR WITHOUT TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P0.615
CUBOID 4 1 44.3 -5.1 2P38.75 2P0.615
UNIT 17
COM='PLEXIGLAS SHEET BOTTOM SOUTH REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P0.615
CUBOID 5 1 44.3 -5.1 2P38.75 2P0.6150
```

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UNIT 18
COM='LOWER PORTION SOUTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P8.855
CUBOID 5 1 44.3 -5.1 2P38.75 2P8.855
UNIT 19
COM='SOUTH BOTTOM REFLECTOR WITH REGULAR AND TRIS'
ARRAY 4 3*0.0
UNIT 20
COM='EAST AND WEST REFLECTORS FOR NORTH REFLECTOR WITH TRIS'
CUBOID 5 1 2P16.550 2P12.65 2P54.2825
UNIT 21
COM='ARRAY FOR EAST AND WEST REFLECTORS FOR NORTH REFLECTOR'
ARRAY 5 3*0.0
UNIT 22
COM='EAST AND WEST REFLECTORS FOR SOUTH REFLECTOR WITH TRIS'
CUBOID 5 1 2P24.700 2P12.65 2P54.2825
UNIT 23
COM='ARRAY FOR EAST AND WEST REFLECTORS FOR SOUTH REFLECTOR'
ARRAY 6 3*0.0
UNIT 24
COM='NORTH TOP REFLECTOR WITH TRIS'
CUBOID 5 1 2P29.100 2P64.05 2P12.15
UNIT 25
COM='ARRAY FOR NORTH TOP REFLECTOR'
ARRAY 7 3*0.0
UNIT 26
COM='SOUTH TOP REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P12.15
CUBOID 5 1 69.4 -5.1 2P64.05 2P12.15
UNIT 27
COM='ARRAY FOR SOUTH TOP REFLECTOR'
ARRAY 8 3*0.0
UNIT 28
COM='NORTH END REFLECTOR 9.8CM PORTION WITHOUT TRIS'
CUBOID 4 1 2P4.9000 2P64.0500 2P54.2825
UNIT 29
COM='NORTH END RELFECTOR 5.2 CM PORTION WITH TRIS'
CUBOID 5 1 2P2.6 2P64.0500 2P54.2825
UNIT 30
COM='NORTH END RELFECTOR 10.1 CM PORTION WITHOUT TRIS'
CUBOID 4 1 2P5.05 2P64.05 2P54.2825
UNIT 31
COM='ARRAY FOR NORTH END REFLECTOR'
ARRAY 9 3*0.0
UNIT 32
COM='SOUTH END REFLECTOR'
CUBOID 5 1 2P12.55 2P64.05 2P54.2825
UNIT 33
COM='ARRAY FOR SOUTH END REFLECTOR'
ARRAY 10 3*0.0
UNIT 34
COM='BOTTOM MODERATING PLASTIC NORTH CORE'
CUBOID 6 1 2P16.550 2P38.7500 2P13.0500
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UNIT 35
COM='TOP MODERATING PLASTIC NORTH CORE'
CUBOID 6 1 2P16.550 2P38.7500 2P3.2525
UNIT 36
ARRAY 11 3*0.0
UNIT 37
ARRAY 12 3*0.0
UNIT 38
COM='NORTH CORE WITH BOTTOM REFLECTOR'
ARRAY 13 3* 0.0
UNIT 39
COM='NORTH CORE WITH EAST AND WEST REFLECTOR'
ARRAY 14 3*0.0
UNIT 40
COM='NORTH CORE WITH END REFLECTOR'
ARRAY 15 3*0.0
UNIT 41
COM='NORTH SPLIT TABLE FACEPLATE'
CUBOID 3 1 2P0.6150 2P64.0500 2P66.4325
UNIT 42
COM='NORTH CORE WITH TOP REFLECTOR'
ARRAY 16 3*0.0
UNIT 43
COM='NORTH CORE WITH FACEPLATE'
ARRAY 17 3*0.0
UNIT 44
COM='12.95 CM THICK MODERATOR SOUTH CORE'
CUBOID 6 1 2P23.924 2P6.475 2P40.183
UNIT 45
COM='2.95 THICK MODERATOR SOUTH CORE'
CUBOID 6 1 2P23.924 2P38.5285 2P1.475
UNIT 46
COM='COMBINATION OF CORE WITH 12.95 THICK MODERATOR'
ARRAY 18 3*0.0
UNIT 47
COM='COMBINATION OF CORE WITH 2.95 THICK MODERATOR'
ARRAY 19 3*0.0
UNIT 48
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
ARRAY 20 3*0.0
UNIT 49
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
ARRAY 21 3*0.0
UNIT 50
COM='SOUTH CORE END REFLECTOR'
ARRAY 22 3*0.0
UNIT 51
COM='FACEPLATE FOR SOUTH SPLIT TABLE'
CUBOID 3 1 2P0.4620 2P64.0500 2P66.4325
UNIT 52
COM='SOUTH CORE WITH TOP REFLECTOR'
ARRAY 23 3*0.0
```

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UNIT 53
COM='SOUTH CORE WITH FACEPLATE'
ARRAY 24 3*0.0
UNIT 54
COM='AIR GAP'
CUBOID 0 1 2P0.1550 2P64.0500 2P66.4325
GLOBAL
UNIT 55
COM='TOTAL'
ARRAY 25 3*0.0
UNIT 56
COM='EMPTY FUEL LOCATION'
CUBOID 0 1 6P7.6650
UNIT 57
COM='SIDE MODERATOR'
CUBOID 6 1 2P16.550 2P4.4300 2P25.4350
UNIT 58
COM='END MODERATOR'
CUBOID 3 1 2P8.1500 2P38.7500 2P25.4350
UNIT 59
COM='SOUTH CORE BOTTOM MODERATING PLASTIC'
CUBOID 6 1 2P24.7000 2P38.7500 2P13.0500
UNIT 60
COM='SOUTH CORE TOP MODERATING PLASTIC'
CUBOID 6 1 2P24.7000 2P38.7500 2P3.2525
UNIT 61
COM='Y-FACE MODERATOR VOID'
CUBOID 0 1 2P7.665 2P1.2200 2P7.665
END GEOMETRY
READ ARRAY
ARA=1 NUX=3 NUY=7 NUZ=5
COM='NORTH SPLIT TABLE CORE'
FILL 1 2 1 3 5 3 2Q6 1 2 1
    4 7 4 6 8 6 2Q6 4 7 4
    1Q42
    56 2 1 3 5 3 1 2 1 3 5 3 1Q6 56 2 1  END FILL
ARA=2 NUX=3 NUY=7 NUZ=5
COM='SOUTH SPLIT TABLE CORE'
FILL 1 2 1 3 5 3 2Q6 1 2 1
    4 7 4 6 8 6 2Q6 4 7 4
    1Q42
    1 2 56 3 5 61 2Q6 1 2 56  END FILL
ARA=3 NUX=1 NUY=1 NUZ=3
COM='NORTH BOTTOM REFLECTOR'
FILL 14 11 13  END FILL
ARA=4 NUX=1 NUY=1 NUZ=7
COM='SOUTH BOTTOM REFLECTOR'
FILL 18 16 17 16 16 17 17  END FILL
ARA=5 NUX=1 NUY=1 NUZ=1
COM='EAST AND WEST WALLS OF NORTH REFLECTOR'
FILL 20 END FILL
ARA=6 NUX=1 NUY=1 NUZ=1
COM='EAST AND WEST WALLS OF SOUTH REFLECTOR'
FILL 22  END FILL
```

```
ARA=7  NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR NORTH TOP REFLECTOR'
FILL  24  END FILL
ARA=8  NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR SOUTH TOP REFLECTOR'
FILL  26 END FILL
ARA=9  NUX=3 NUY=1 NUZ=1
COM='ARRAY FOR NORTH END REFLECTOR'
FILL  28 29 30  END FILL
ARA=10  NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR SOUTH END REFLECTOR'
FILL  32  END FILL
ARA=11  NUX=1 NUY=2 NUZ=1
COM='COMBINARION OF CORE WITH SIDE MODERATOR'
FILL  9 57  END FILL
ARA=12 NUX=1 NUY=1 NUZ=3
COM='COMBINATION OF PREVIOUS ARRAY WITH TOP AND BOTTOM MODERATOR'
FILL  34 36 35  END FILL
ARA=13  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF NORTH CORE WITH BOTTOM REFLECTOR'
FILL  15 37  END FILL
ARA=14  NUX=1 NUY=3 NUZ=1
COM='NORTH CORE WITH SIDE REFLECTORS'
FILL  21 38 21  END FILL
ARA=15  NUX=2 NUY=1 NUZ=1
COM='NORTH CORE WITH END REFLECTOR'
FILL  31 39  END FILL
ARA=16  NUX=1 NUY=1 NUZ=2
COM='NORTH CORE WITH TOP REFLECTOR'
FILL  40 25  END FILL
ARA=17  NUX=2 NUY=1 NUZ=1
COM='NORTH CORE WITH FACEPLATE'
FILL  42 41  END FILL
ARA=18  NUX=1 NUY=2 NUZ=1
COM='COMBINATION OF S. CORE WIT I SIDE MODERATOR'
FILL  10 57  END FILL
ARA=19  NUX=2 NUY=1 NUZ=1
COM='COMBINATION OF CORE WITH END MODERATOR'
FILL  46 58  END FILL
ARA=20  NUX=1 NUY=1 NUZ=4
COM='SOUTH CORE WITH BOTTOM MODERATOR AND REFLECTOR'
FILL  19 59 47 60  END FILL
ARA=21 NUX=1 NUY=3 NUZ=1
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
FILL  23 48 23  END FILL
ARA=22 NUX=2 NUY=1 NUZ=1
COM='SOUTH CORE WITH END REFLECTOR'
FILL  49 33  END FILL
ARA=23  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF CORE WITH TOP REFLECTOR'
FILL  50 27  END FILL
```

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ARA=24  NUX=2 NUY=1 NUZ=1
COM='SOUTH CORE WITH FACEPLATE'
FILL  51 52  END FILL
ARA=25  NUX=3 NUY=1 NUZ=1
COM='TOTAL'
FILL  43 54 53  END FILL
END ARRAY
READ PLOT TTL='XZ SLICE OF RFP1 SHOWING MATERIAL REGIONS'
XUL=-2  YUL=32.3 ZUL=136
XLR=137 YLR=32.3 ZLR=-2
UAX=1  WDN=-1 NAX=130  NCH='0123456'END
TTL='YZ SLICE OF NORTH CORE SECOND ROW'
XUL=28  YUL=-2   ZUL=136
XLR=[illegible]  YLR=136 ZLR=-2
VAX=[illegible]  WDN=-1 NAX=130  NCH='0123456'END
TTL=[illegible]YZ SLICE OF SOUTH CORE FIRST ROW'
XUL=62 YUL=-2   ZUL=136
XLR=62 YLR=136  ZLR=-2
VAX=1  WDN=-1 NAX=130  NCH='0123456'END
TTL='TOP VIEW OF SOURCE HOLE'
XUL=-2 YUL=136 ZUL=125
XLR=136 YLR=-2 ZLR=125
UAX=1 VDN=-1 NAX=130 NCH='0123456'
END PLOT
END DATA
END
```

Case 42

```
//JOBCARD
// EXEC SPDASCR
T.GEE00000.RST1.HSNRCH.RFP2
//* PREVIOUS TWO LINES CLEAR T.GEE00000.RST1.HSNRCH.RFP2 SO
//* A RESTART FILE CAN BE WRITTEN ON UNIT 30 IN THIS FILE
//MIKE EXEC Y12CSG,REGION.GO=1024K
//FT84F001 DD DSN=T.GEE00000.HSNRCH1,DISP=SHR
//FT30F001 DD DSN=T.GEE00000.RST1.HSNRCH.RFP2,UNIT=SPDA,
//  SPACE=(TRK,(20,10)),DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3156,BUFL=4088),
//  DISP=(,CATLG)
//GO.SYSIN DD *
=CSAS25
ROCKY FLATS CRITICALS NUREG/CR-1071 EXPERIMENT NUMBER 2 (HANSEN-ROACH)
218GROUPNDF4  LATTICECELL
HAVEREDEFINED
U3O8  1 5.4078E-1 293.0 92234 0.03 92235 4.46 92236 0.08 92238 95.43 END
H2O  1 8.9514E-2 END
ARBM-BAGGIE  1.0 3 0 0 0 1001 14.01 6012 84.9 8016 1.20 1 1.9134E-2
  END
ARBM-AL1100  1.0 3 0 0 1 13027 99.18 26000 0.5 29000 0.2 2 9.5390E-1
  END
```

```
ARBM-TAPE(VINYL) 1.0 7 0 0 0 1001 5.92 6012 45.91 8016 10.82 17000
  25.73 20040 6.9 22000 1.6 82000 1.1 2 1.1115E-2 END
ARBM-TAPE(MYLAR) 1.0 3 0 0 0 1001 6.83 6012 65.50 8016 27.02 2
  1.7491E-2 END
ARBM-MODERATOR 1.185 3 0 0 0 1001 7.83 6012 59.49 8016 32.48 3 END
ARBM-PLEX(REG) 1.0 3 0 0 0 1001 7.84 6012 59.59 8016 32.23 4
  1.1773 END
ARBM-PLEX(PAPER) 1.0 3 0 0 0 1001 6.48 6012 42.17 8016 49.5 4
  3.7534E-3 END
ARBM-PLEX(GLUE) 1.0 3 0 0 0 1001 11.67 6012 86.29 8016 1.20 4
  1.1648E-3 END
ARBM-PLEX(TRIS) 1.0 8 0 0 1 1001 7.16 6012 52.03 7014 0.16 8016 29.82
  15031 1.02 17000 1.81 35079 4.260 35081 2.840 5 1.2757 END
ARBM-PLEX(PAPER) 1.0 3 0 0 0 1001 6.48 6012 42.17 8016 49.5 5
  3.7534E-3 END
ARBM-PLEX(GLUE) 1.0 3 0 0 0 1001 11.67 6012 86.29 8016 1.20 5
  1.1648E-3 END
ARBM-FILLER 1.185 3 0 0 0 1001 7.83 6012 59.49 8016 32.48 6 .89 END
END COMP
SPHTRIANGP 19.9462 18.5857 1 3 18.9579 2 END
ROCKY FLATS CRITICALS NUREG/CR-1071 EXPERIMENT NUMBER 2 (HANSEN-ROACH)
READ PARM RUN=YES NPG=500 RES=103 WRS=30
END PARM
READ GEOM
UNIT 1
COM='FUEL BOX 15.28 CM ON A SIDE WITH .15 CM WALLS .05CM STACKING VOID'
CUBOID 1 1 6P7.49
CUBOID 2 1 6P7.64
CUBOID 0 1 6P7.6650
UNIT 2
COM='X-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 2P1.2200 4P7.665
UNIT 3
COM='Y-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 2P7.665 2P1.2200 2P7.665
UNIT 4
COM='Z-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 4P7.665 2P1.2200
UNIT 5
COM='MORE X-FACE MODERATOR'
CUBOID 3 1 4P1.2200 2P7.665
UNIT 6
COM='MORE Y-FACE MODERATOR'
CUBOID 3 1 2P7.665 4P1.2200
UNIT 7
COM='MORE Z-FACE MODERATOR'
CUBOID 3 1 2P1.2200 2P7.665 2P1.2200
UNIT 8
COM='LAST OF INTERSTITIAL MODERATOR'
CUBOID 3 1 6P1.2200
```

```
UNIT 9
COM='NORTH SPLIT TABLE CORE'
ARRAY 1 3*0.0
UNIT 10
COM='SOUTH SPLIT TABLE CORE'
ARRAY 2 3*0.0
UNIT 11
COM='PLEXIGLASS REFLECTOR SHEET WITHOUT TRIS, NORTH BOTTOM REFLECTOR'
CUBOID 4 1 2P16.5500 2P38.7500 2P0.6150
UNIT 12
COM='PLEXIGLASS REFLECTOR SHEET WITH TRIS, NORTH BOTTOM REFLECTOR'
CUBOID 5 1 2P16.5500 2P38.7500 2P0.6150
UNIT 13
COM='UPPER PORTION NORTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 5 1 2P16.550 2P38.75 2P8.24
UNIT 14
COM='LOWER PORTION NORTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 5 1 2P16.550 2P38.75 2P3.69
UNIT 15
COM='NORTH BOTTOM REFLECTOR INCLUDES REGULAR AND TRIS'
ARRAY 3 3*0.0
UNIT 16
COM='PLEXIGLAS SHEET BOTTOM SOUTH REFLECTOR WITHOUT TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P0.6150
CUBOID 4 1 44.3 -5.1 2P38.75 2P0.615
UNIT 17
COM='PLEXIGLAS SHEET BOTTOM SOUTH REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P0.6150
CUBOID 5 1 44.3 -5.1 2P38.75 2P0.6150
UNIT 18
COM='LOWER PORTION SOUTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P8.855
CUBOID 5 1 44.3 -5.1 2P38.75 2P8.855
UNIT 19
COM='SOUTH BOTTOM REFLECTOR WITH REGULAR AND TRIS'
ARRAY 4 3*0.0
UNIT 20
COM='EAST AND WEST REFLECTORS FOR NORTH REFLECTOR WITH TRIS'
CUBOID 5 1 2P16.550 2P12.65 2P54.2825
UNIT 21
COM='ARRAY FOR EAST AND WEST REFLECTORS FOR NORTH REFLECTOR'
ARRAY 5 3*0.0
UNIT 22
COM='EAST AND WEST REFLECTORS FOR SOUTH REFLECTOR WITH TRIS'
CUBOID 5 1 2P24.700 2P12.65 2P54.2825
UNIT 23
COM='ARRAY FOR EAST AND WEST REFLECTORS FOR SOUTH REFLECTOR'
ARRAY 6 3*0.0
UNIT 24
COM='NORTH TOP REFLECTOR WITH TRIS'
CUBOID 5 1 2P29.100 2P64.05 2P12.15
```

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UNIT 25
COM='ARRAY FOR NORTH TOP REFLECTOR'
ARRAY 7 3*0.0
UNIT 26
COM='SOUTH TOP REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.55 2P12.15
CUBOID 5 1 69.4 -5.1 2P64.05 2P12.15
UNIT 27
COM='ARRAY FOR SOUTH TOP REFLECTOR'
ARRAY 8 3*0.0
UNIT 28
COM='NORTH END REFLECTOR 9.8CM PORTION WITHOUT TRIS'
CUBOID 4 1 2P4.9000 2P64.0500 2P54.2825
UNIT 29
COM='NORTH END RELFECTOR 5.2 CM PORTION WITH TRIS'
CUBOID 5 1 2P2.6 2P64.0500 2P54.2825
UNIT 30
COM='NORTH END RELFECTOR 10.1 CM PORTION WITHOUT TRIS'
CUBOID 4 1 2P5.05 2P64.05 2P54.2825
UNIT 31
COM='ARRAY FOR NORTH END REFLECTOR'
ARRAY 9 3*0.0
UNIT 32
COM='SOUTH END REFLECTOR'
CUBOID 5 1 2P12.55 2P64.05 2P54.2825
UNIT 33
COM='ARRAY FOR SOUTH END REFLECTOR'
ARRAY 10 3*0.0
UNIT 34
COM='BOTTOM MODERATING PLASTIC NORTH CORE'
CUBOID 6 1 2P16.550 2P38.7500 2P13.0500
UNIT 35
COM='TOP MODERATING PLASTIC NORTH CORE'
CUBOID 6 1 2P16 550 2P38.7500 2P3.2525
UNIT 36
ARRAY 11 3*0.0
UNIT 37
ARRAY 12 3*0.0
UNIT 38
COM='NORTH CORE WITH BOTTOM REFLECTOR'
ARRAY 13 3* 0.0
UNIT 39
COM='NORTH CORE WITH EAST AND WEST REFLECTOR'
ARRAY 14 3*0.0
UNIT 40
COM='NORTH CORE WITH END REFLECTOR'
ARRAY 15 3*0.0
UNIT 41
COM='NORTH SPLIT TABLE FACEPLATE'
CUBOID 3 1 2P0.6150 2P64.0500 2P66.4325
```

```
UNIT 42
COM='NORTH CORE WITH TOP REFLECTOR'
ARRAY 16 3*0.0
UNIT 43
COM='NORTH CORE WITH FACEPLATE'
ARRAY 17 3*0.0
UNIT 44
COM='12.95 CM THICK MODERATOR SOUTH CORE'
CUBOID 6 1 2P23.924 2P6.475 2P40.183
UNIT 45
COM='2.95 THICK MODERATOR SOUTH CORE'
CUBOID 6 1 2P23.924 2P38.5285 2P1.475
UNIT 46
COM='COMBINATION OF CORE WITH 12.95 THICK MODERATOR'
ARRAY 18 3*0.0
UNIT 47
COM='COMBINATION OF CORE WITH 2.95 THICK MODERATOR'
ARRAY 19 3*0.0
UNIT 48
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
ARRAY 20 3*0.0
UNIT 49
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
ARRAY 21 3*0.0
UNIT 50
COM='SOUTH CORE END REFLECTOR'
ARRAY 22 3*0.0
UNIT 51
COM='FACEPLATE FOR SOUTH SPLIT TABLE'
CUBOID 3 1 2P0.4620 2P64.0500 2P66.4325
UNIT 52
COM='SOUTH CORE WITH TOP REFLECTOR'
ARRAY 23 3*0.0
UNIT 53
COM='SOUTH CORE WITH FACEPLATE'
ARRAY 24 3*0.0
UNIT 54
COM='AIR GAP'
CUBOID 0 1 2P0.7600 2P64.0500 2P66.4325
GLOBAL
UNIT 55
COM='TOTAL'
ARRAY 25 3*0.0
UNIT 56
COM='EMPTY FUEL LOCATION'
CUBOID 0 1 6P7.6650
UNIT 57
COM='SIDE MODERATOR'
CUBOID 6 1 2P16.550 2P4.4300 2P25.4350
UNIT 58
COM='END MODERATOR'
CUBOID 6 1 2P8.1500 2P38.7500 2P25.4350
```

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UNIT 59
COM='SOUTH CORE BOTTOM MODERATING PLASTIC'
CUBOID 6 1 2P24.7000 2P38.7500 2P13.0500
UNIT 60
COM='SOUTH CORE TOP MODERATING PLASTIC'
CUBOID 6 1 2P24.7000 2P38.7500 2P3.2525
UNIT 61
COM='Y-FACE MODERATOR VOID'
CUBOID 0 1 2P7.665 2P1.2200 2P7.665
END GEOMETRY
READ ARRAY
ARA=1 NUX=3 NUY=7 NUZ=5
COM='NORTH SPLIT TABLE CORE'
FILL 1 2 1 3 5 3 2Q6 1 2 1
    4 7 4 6 8 6 2Q6 4 7 4
    1Q42
    56 2 1 3 5 3 1 2 1 3 5 3 1Q6 56 2 1  END FILL
ARA=2 NUX=3 NUY=7 NUZ=5
COM='SOUTH SPLIT TABLE CORE'
FILL 1 2 1 3 5 3 2Q6 1 2 1
    4 7 4 6 8 6 2Q6 4 7 4
    1Q42
    1 2 56 3 5 3 1 2 1 3 5 3 1 2 56 3 5 61 1 2 56  END FILL
ARA=3 NUX=1 NUY=1 NUZ=3
COM='NORTH BOTTOM REFLECTOR'
FILL 14 11 13  END FILL
ARA=4 NUX=1 NUY=1 NUZ=7
COM='SOUTH BOTTOM REFLECTOR'
FILL 18 16 17 16 16 17 17  END FILL
ARA=5 NUX=1 NUY=1 NUZ=1
COM='EAST AND WEST WALLS OF NORTH REFLECTOR'
FILL 20 END FILL
ARA=6 NUX=1 NUY=1 NUZ=1
COM='EAST AND WEST WALLS OF SOUTH REFLECTOR'
FILL 22  END FILL
ARA=7 NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR NORTH TOP REFLECTOR'
FILL 24  END FILL
ARA=8 NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR SOUTH TOP REFLECTOR'
FILL 26 END FILL
ARA=9 NUX=3 NUY=1 NUZ=1
COM='ARRAY FOR NORTH END REFLECTOR'
FILL 28 29 30  END FILL
ARA=10 NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR SOUTH END REFLECTOR'
FILL 32  END FILL
ARA=11 NUX=1 NUY=2 NUZ=1
COM='COMBINARION OF CORE WITH SIDE MODERATOR'
FILL 9 57  END FILL
ARA=12 NUX=1 NUY=1 NUZ=3
COM='COMBINATION OF PREVIOUS ARRAY WITH TOP AND BOTTOM MODERATOR'
FILL 34 36 35  END FILL
```

```
ARA=13  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF NORTH CORE WITH BOTTOM REFLECTOR'
FILL  15 37  END FILL
ARA=14  NUX=1 NUY=3 NUZ=1
COM='NORTH CORE WITH SIDE REFLECTORS'
FILL  21 38 21  END FILL
ARA=15  NUX=2 NUY=1 NUZ=1
COM='NORTH CORE WITH END REFLECTOR'
FILL  31 39  END FILL
ARA=16  NUX=1 NUY=1 NUZ=2
COM='NORTH CORE WITH TOP REFLECTOR'
FILL  40 25  END FILL
ARA=17  NUX=2 NUY=1 NUZ=1
COM='NORTH CORE WITH FACEPLATE'
FILL  42 41  END FILL
ARA=18  NUX=1 NUY=2 NUZ=1
COM='COMBINATION OF S. CORE WITH SIDE MODERATOR'
FILL  10 57  END FILL
ARA=19  NUX=2 NUY=1 NUZ=1
COM='COMBINATION OF CORE WITH END MODERATOR'
FILL  46 58  END FILL
ARA=20  NUX=1 NUY=1 NUZ=4
COM='SOUTH CORE WITH BOTTOM MODERATOR AND REFLECTOR'
FILL  19 59 47 60  END FILL
ARA=21 NUX=1 NUY=3 NUZ=1
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
FILL  23 48 23  END FILL
ARA=22 NUX=2 NUY=1 NUZ=1
COM='SOUTH CORE WITH END REFLECTOR'
FILL  49 33  END FILL
ARA=23  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF CORE WITH TOP REFLECTOR'
FILL  50 27  END FILL
ARA=24  NUX=2 NUY=1 NUZ=1
COM='SOUTH CORE WITH FACEPLATE'
FILL  51 52  END FILL
ARA=25  NUX=3 NUY=1 NUZ=1
COM='TOTAL'
FILL  43 54 53  END FILL
END ARRAY
READ PLOT TTL='XZ SLICE OF RFP2 SHOWING MATERIAL REGIONS'
XUL=-2  YUL=32.3 ZUL=136
XLR=137 YLR=32.3 ZLR=-2
UAX=1  WDN=-1 NAX=130  NCH='0123456'END
TTL='YZ SLICE OF NORTH CORE SECOND ROW'
XUL=28  YUL=-2  ZUL=136
XLR=28  YLR=136 ZLR=-2
VAX=1  WDN=-1 NAX=130  NCH='0123456'END
TTL='YZ SLICE OF SOUTH CORE SECOND ROW'
XUL=80 YUL=-2  ZUL=136
XLR=80 YLR=136  ZLR=-2
VAX=1  WDN=-1 NAX=130  NCH='0123456'
END PLOT
END DATA
END
```

Case 43

```
//JOBCARD
// EXEC SPDASCR
T.GEE00000.RST1.HSNRCH.RFP3
//* PREVIOUS TWO LINES CLEAR T.GEE00000.RST1.HSNRCH.RFP3 SO
//* A RESTART FILE CAN BE WRITTEN ON UNIT 30 IN THIS FILE
//MIKE EXEC Y12CSG,REGION.GO=1024K
//FT84F001 DD DSN=T.GEE00000.HSNRCH1,DISP=SHR
//FT30F001 DD DSN=T.GEE00000.RST1.HSNRCH.RFP3,UNIT=SPDA,
// SPACE=(TRK,(20,10)),DCB=(RECFM=VBS,LRECL=X,BLKSIZE=3156,BUFL=4088),
// DISP=(,CATLG)
//GO.SYSIN DD *
=CSAS25
ROCKY FLATS CRITICALS NUREG/CR-1071 EXPERIMENT NUMBER 3 (HANSEN-ROACH)
218GROUPNDF4 LATTICECELL
HAVEREDEFINED
U3O8 1 5.4078E-1 293.0 92234 0.03 92235 4.46 92236 0.08 92238 95.43 END
H2O 1 8.9514E-2 END
ARBM-BAGGIE 1.0 3 0 0 0 1001 14.01 6012 84.9 8016 1.20 1 1.9134E-2
  END
ARBM-AL1100 1.0 3 0 0 1 13027 99.18 26000 0.5 29000 0.2 2 9.5390E-1
  END
ARBM-TAPE(VINYL) 1.0 7 0 0 0 1001 5.92 6012 45.91 8016 10.82 17000
  25.73 20040 6.9 22000 1.6 82000 1.1 2 1.1115E-2 END
ARBM-TAPE(MYLAR) 1.0 3 0 0 0 1001 6.83 6012 65.50 8016 27.02 2
  1.7491E-2 END
ARBM-MODERATOR 1.185 3 0 0 0 1001 7.83 6012 59.49 8016 32.48 3 END
ARBM-PLEX(REG) 1.0 3 0 0 0 1001 7.84 6012 59.59 8016 32.23 4
  1.1773 END
ARBM-PLEX(PAPER) 1.0 3 0 0 0 1001 6.48 6012 42.17 8016 49.5 4
  3.7534E-3 END
ARBM-PLEX(GLUE) 1.0 3 0 0 0 1001 11.67 6012 86.29 8016 1.20 4
  1.1648E-3 END
ARBM-PLEX(TRIS) 1.0 8 0 0 1 1001 7.16 6012 52.03 7014 0.16 8016 29.82
  15031 1.02 17000 1.81 35079 4.260 35081 2.840 5 1.2757 END
ARBM-PLEX(PAPER) 1.0 3 0 0 0 1001 6.48 6012 42.17 8016 49.5 5
  3.7534E-3 END
ARBM-PLEX(GLUE) 1.0 3 0 0 0 1001 11.67 6012 86.29 8016 1.20 5
  1.1648E-3 END
ARBM-FILLER 1.185 3 0 0 0 1001 7.83 6012 59.49 8016 32.48 6 .70 END
END COMP
SPHTRIANGP 19.00 18.5857 1 3 18.9579 2 END
ROCKY FLATS CRITICALS NUREG/CR-1071 EXPERIMENT NUMBER 3 (HANSEN-ROACH)
READ PARM RUN=YES NPG=500 RES=103 WRS=30
END PARM
READ GEOM
UNIT 1
COM='FUEL BOX 15.28 CM ON A SIDE WITH .15 CM WALLS .05CM STACKING VOID'
CUBOID 1 1 6P7.49
CUBOID 2 1 6P7.64
CUBOID 0 1 6P7.6650
```

```
UNIT 2
COM='X-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 2P0.4645 4P7.665
UNIT 3
COM='Y-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 2P7.665 2P0.4645 2P7.665
UNIT 4
COM='Z-FACE INTERSTITIAL MODERATOR'
CUBOID 3 1 4P7.665 2P0.4645
UNIT 5
COM='MORE X-FACE MODERATOR'
CUBOID 3 1 4P0.4645 2P7.665
UNIT 6
COM='MORE Y-FACE MODERATOR'
CUBOID 3 1 2P7.665 4P0.4645
UNIT 7
COM='MORE Z-FACE MODERATOR'
CUBOID 3 1 2P0.4645 2P7.665 2P0.4645
UNIT 8
COM='LAST OF INTERSTITIAL MODERATOR'
CUBOID 3 1 6P0.4645
UNIT 9
COM='NORTH SPLIT TABLE CORE'
ARRAY 1 3*0.0
UNIT 10
COM='SOUTH SPLIT TABLE CORE'
ARRAY 2 3*0.0
UNIT 11
COM='PLEXIGLASS REFLECTOR SHEET WITHOUT TRIS, NORTH BOTTOM REFLECTOR'
CUBOID 4 1 2P15.8000 2P38.7500 2P0.6150
UNIT 12
COM='PLEXIGLASS REFLECTOR SHEET WITH TRIS, NORTH BOTTOM REFLECTOR'
CUBOID 5 1 2P15.8000 2P38.7500 2P0.6150
UNIT 13
COM='UPPER PORTION NORTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 5 1 2P15.8 2P38.75 2P8.24
UNIT 14
COM='LOWER PORTION NORTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 5 1 2P15.8 2P38.75 2P3.69
UNIT 15
COM='NORTH BOTTOM REFLECTOR INCLUDES REGULAR AND TRIS'
ARRAY 3 3*0.0
UNIT 16
COM='PLEXIGLAS SHEET BOTTOM SOUTH REFLECTOR WITHOUT TRIS'
CUBOID 0 1 2P5.1 2P2.5 2P0.6150
CUBOID 4 1 44.3 -5.1 2P38.75 2P0.615
UNIT 17
COM='PLEXIGLAS SHEET BOTTOM SOUTH REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.5 2P0.6150
CUBOID 5 1 44.3 -5.1 2P38.75 2P0.6150
```

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UNIT 18
COM='LOWER PORTION SOUTH BOTTOM REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.5 2P8.855
CUBOID 5 1 44.3 -5.1 2P38.75 2P8.855
UNIT 19
COM='SOUTH BOTTOM REFLECTOR WITH REGULAR AND TRIS'
ARRAY 4 3*0.0
UNIT 20
COM='EAST AND WEST REFLECTORS FOR NORTH REFLECTOR WITH TRIS'
CUBOID 5 1 2P15.8 2P12.65 2P54.2825
UNIT 21
COM='ARRAY FOR EAST AND WEST REFLECTORS FOR NORTH REFLECTOR'
ARRAY 5 3*0.0
UNIT 22
COM='EAST AND WEST REFLECTORS FOR SOUTH REFLECTOR WITH TRIS'
CUBOID 5 1 2P24.700 2P12.65 2P54.2825
UNIT 23
COM='ARRAY FOR EAST AND WEST REFLECTORS FOR SOUTH REFLECTOR'
ARRAY 6 3*0.0
UNIT 24
COM='NORTH TOP REFLECTOR WITH TRIS'
CUBOID 5 1 2P28.35 2P64.05 2P12.15
UNIT 25
COM='ARRAY FOR NORTH TOP REFLECTOR'
ARRAY 7 3*0.0
UNIT 26
COM='SOUTH TOP REFLECTOR WITH TRIS'
CUBOID 0 1 2P5.1 2P2.5 2P12.15
CUBOID 5 1 69.4 -5.1 2P64.05 2P12.15
UNIT 27
COM='ARRAY FOR SOUTH TOP REFLECTOR'
ARRAY 8 3*0.0
UNIT 28
COM='NORTH END REFLECTOR 9.8CM PORTION WITHOUT TRIS'
CUBOID 4 1 2P4.9000 2P64.0500 2P54.2825
UNIT 29
COM='NORTH END RELFECTOR 5.2 CM PORTION WITH TRIS'
CUBOID 5 1 2P2.6 2P64.0500 2P54.2825
UNIT 30
COM='NORTH END RELFECTOR 10.1 CM PORTION WITHOUT TRIS'
CUBOID 4 1 2P5.05 2P64.05 2P54.2825
UNIT 31
COM='ARRAY FOR NORTH END REFLECTOR'
ARRAY 9 3*0.0
UNIT 32
COM='SOUTH END REFLECTOR'
CUBOID 5 1 2P12.55 2P64.05 2P54.2825
UNIT 33
COM='ARRAY FOR SOUTH END REFLECTOR'
ARRAY 10 3*0.0
```

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UNIT 34
COM='12.95 THICK MODERATING PLASTIC NORTH CORE'
CUBOID 6 1 2P15.7945 2P6.4750 2P40.1830
UNIT 35
COM='2.95 THICK MODERATING PLASTIC NORTH CORE'
CUBOID 6 1 2P15.7945 2P38.5285 2P1.475
UNIT 36
ARRAY 11 3*0.0
UNIT 37
ARRAY 12 3*0.0
REPLICATE 0 1 0.0 0.011 0.443 0.0 0.1590 0.0 1
UNIT 38
COM='NORTH CORE WITH BOTTOM REFLECTOR'
ARRAY 13 3* 0.0
UNIT 39
COM='NORTH CORE WITH EAST AND WEST REFLECTOR'
ARRAY 14 3*0.0
UNIT 40
COM='NORTH CORE WITH END REFLECTOR'
ARRAY 15 3*0.0
UNIT 41
COM='NORTH SPLIT TABLE FACEPLATE'
CUBOID 3 1 2P0.6150 2P64.0500 2P66.4325
UNIT 42
COM='NORTH CORE WITH TOP REFLECTOR'
ARRAY 16 3*0.0
UNIT 43
COM='NORTH CORE WITH FACEPLATE'
ARRAY 17 3*0.0
UNIT 44
COM='12.95 CM THICK MODERATOR SOUTH CORE'
CUBOID 6 1 2P23.924 2P6.475 2P40.183
UNIT 45
COM='2.95 THICK MODERATOR SOUTH CORE'
CUBOID 6 1 2P23.924 2P38.5285 2P1.475
UNIT 46
COM='COMBINATION OF CORE WITH 12.95 THICK MODERATOR'
ARRAY 18 3*0.0
UNIT 47
COM='COMBINATION OF CORE WITH 2.95 THICK MODERATOR'
ARRAY 19 3*0.0
REPLICATE 0 1 1.552 0.0 0.4430 0.0 0.159 0.0 1
UNIT 48
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
ARRAY 20 3*0.0
UNIT 49
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
ARRAY 21 3*0.0
UNIT 50
COM='SOUTH CORE END REFLECTOR'
ARRAY 22 3*0.0
```

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UNIT 51
COM='FACEPLATE FOR SOUTH SPLIT TABLE'
CUBOID 3 1 2P0.4620 2P64.0500 2P66.4325
UNIT 52
COM='SOUTH CORE WITH TOP REFLECTOR'
ARRAY 23 3*0.0
UNIT 53
COM='SOUTH CORE WITH FACEPLATE'
ARRAY 24 3*0.0
UNIT 54
COM='AIR GAP'
CUBOID 0 1 2P0.5250 2P64.0500 2P66.4325
GLOBAL
UNIT 55
COM='TOTAL'
ARRAY 25 3*0.0
END GEOMETRY
READ ARRAY
ARA=1 NUX=3 NUY=7 NUZ=9
COM='NORTH SPLIT TABLE CORE'
FILL 1 2 1 3 5 3 2Q6 1 2 1
    4 7 4 6 8 6 2Q6 4 7 4
    3Q42
    1 2 1 3 5 3 2Q6 1 2 1 END FILL
ARA=2 NUX=5 NUY=7 NUZ=9
COM='SOUTH SPLIT TABLE CORE'
FILL 1 2 1 2 1 3 5 3 5 3 2Q10 1 2 1 2 1
    4 7 4 7 4 6 8 6 8 6 2Q10 4 7 4 7 4
    3Q70
    1 2 1 2 1 3 5 3 5 3 2Q10 1 2 1 2 1 END FILL
ARA=3 NUX=1 NUY=1 NUZ=3
COM='NORTH BOTTOM REFLECTOR'
FILL 14 11 13 END FILL
ARA=4 NUX=1 NUY=1 NUZ=7
COM='SOUTH BOTTOM REFLECTOR'
FILL 18 16 17 16 16 17 17 END FILL
ARA=5 NUX=1 NUY=1 NUZ=1
COM='EAST AND WEST WALLS OF NORTH REFLECTOR'
FILL 20 END FILL
ARA=6 NUX=1 NUY=1 NUZ=1
COM='EAST AND WEST WALLS OF SOUTH REFLECTOR'
FILL 22 END FILL
ARA=7 NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR NORTH TOP REFLECTOR'
FILL 24 END FILL
ARA=8 NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR SOUTH TOP REFLECTOR'
FILL 26 END FILL
ARA=9 NUX=3 NUY=1 NUZ=1
COM='ARRAY FOR NORTH END REFLECTOR'
FILL 28 29 30 END FILL
```

```
ARA=10  NUX=1 NUY=1 NUZ=1
COM='ARRAY FOR SOUTH END REFLECTOR'
FILL  32  END FILL
ARA=11  NUX=1 NUY=2 NUZ=1
COM='COMBINARION OF CORE WITH 12.95CM THICK MODERATOR'
FILL  9 34  END FILL
ARA=12 NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF PREVIOUS ARRAY WITH 2.95CM THICK MODERATOR'
FILL  36 35  END FILL
ARA=13  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF NORTH CORE WITH BOTTOM REFLECTOR'
FILL  15 37  END FILL
ARA=14  NUX=1 NUY=3 NUZ=1
COM='NORTH CORE WITH SIDE REFLECTORS'
FILL  21 38 21  END FILL
ARA=15  NUX=2 NUY=1 NUZ=1
COM='NORTH CORE WITH END REFLECTOR'
FILL  31 39  END FILL
ARA=16  NUX=1 NUY=1 NUZ=2
COM='NORTH CORE WITH TOP REFLECTOR'
FILL  40 25  END FILL
ARA=17  NUX=2 NUY=1 NUZ=1
COM='NORTH CORE WITH FACEPLATE'
FILL  42 41  END FILL
ARA=18  NUX=1 NUY=2 NUZ=1
COM='COMBINATION OF S. CORE WITH 12.95 CM THICK MODERATOR'
FILL  10 44  END FILL
ARA=19  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF CORE WITH 2.95 CM THICK MODERATOR'
FILL  46 45  END FILL
ARA=20  NUX=1 NUY=1 NUZ=2
COM='SOUTH CORE WITH BOTTOM REFLECTOR'
FILL  19 47  END FILL
ARA=21 NUX=1 NUY=3 NUZ=1
COM='SOUTH CORE WITH EAST WEST REFLECTORS'
FILL  23 48 23  END FILL
ARA=22 NUX=2 NUY=1 NUZ=1
COM='SOUTH CORE WITH END REFLECTOR'
FILL  49 33  END FILL
ARA =23  NUX=1 NUY=1 NUZ=2
COM='COMBINATION OF CORE WITH TOP REFLECTOR'
FILL  50 27  END FILL
ARA=24  NUX=2 NUY=1 NUZ=1
COM='SOUTH CORE WITH FACEPLATE'
FILL  51 52  END FILL
ARA=25  NUX=3 NUY=1 NUZ=1
COM='TOTAL'
FILL  43 54 53  END FILL
END ARRAY
READ PLOT TTL='XZ SLICE OF RFP3 SHOWING MATERIAL REGIONS'
XUL=-1  YUL=32.3 ZUL=135
XLR=136 YLR=32.3 ZLR=-2
```

```
UAX=1  WDN=-1 NAX=130  NCH='0123456'END
TTL='YZ SLICE OF NORTH CORE SECOND ROW'
XUL=28  YUL=-2   ZUL=136
XLR=28  YLR=136 ZLR=-2
VAX=1  WDN=-1 NAX=130  NCH='0123456'END
TTL='YZ SLICE OF SOUTH CORE SECOND ROW'
XUL=90 YUL=-2   ZUL=136
XLR=90 YLR=136  ZLR=-2
VAX=1  WDN=-1 NAX=130  NCH='0123456'
END PLOT
END DATA
END
//
```

APPENDIX D

ADDITIONAL COMMENTS ABOUT THE ROCKY FLATS CRITICAL EXPERIMENTS

The reports describing the critical experiments performed at the Rocky Flats Plant (Refs. 6-8) include many details about the experiments. The following discussion wiil explain why certain values were used in the input for the calculational model. For the first set of critical experiments performed at an H:U of 0.77, an effort was made to verify the given H:U and calculate the H:^{235}U of the fuel. The most accurate description of the hydrogenous contents of the fuel cubes is given in Ref. 14 and is shown in condensed form in Table D.1. The atomic weight of the fuel is calculated to be 237.9122 for the isotopic weight percents given in Ref. 14, Table V. On page 28 of the same document the average assay of the oxide is given as 0.8449 and the average weight of the oxide in a can is 15 129.1 g (note: this also includes the weight of the initial moisture of 40.84 g, so the true average weight of the oxide is 15 088.26), therefore, the mass of uranium in the oxide is 12 748.1 g.

The H:U ratio can be calculated with the above information in the following fashion:

$$H:U = (mH / A(H)) / (mU / A(U)).$$

Where mH is the mass of hydrogen, A(H) is the atomic weight of hydrogen, mU is the mass of uranium, and A(U) is the atomic weight of the uranium for the given isotopic content. This yields a H:U of 0.769 for the experiments given in Ref. 6. A comment about this calculation is the true H:U should not include the hydrogen contribution from the mylar tape and the vinyl tape because it is not intimately mixed with the fuel. thus reducing the H:U to 0.760. The number densities calculated in SCALE give a H:U of 0.787 which is well within the 0.06 uncertainty associated with the H:U calculated in Ref. 14. Similarly, the H:^{235}U ratio is calculated to be 17.02 and the ratio of the number densities in SCALE give H:^{235}U equal to 17.4.

References 7 and 8 contain experiments performed at a higher H:U. The higher H:U is obtained by injecting the same amount of water into each fuel cube. In Ref. 7 the experimenters inject an additional 224.0 g of water into each fuel cube, and in Ref. 8 they inject an additional 360.0 g of water into each cube. The H:U values could not be reproduced from the data given in these individual reports. However, if the additional water injected in each experiment is added to the water in Table D.1 and the calculation of H:U is performed, the H:U values can be reproduced. Table D.2 compares the H:U values given in Refs. 6-8 with the values calculated from the information in the reports with and without the hydrogen contribution from the tape.

One of the problems confronted when modeling these experiments was localized absorption in the reflector. All of the experiments modeled used the same reflector shell with only minor changes due to the thickness of the interstitial moderator. At one point during the course of the experiments it was found that the reflector shells had been made from two types of Plexiglas, one type being regular Plexiglas and the other containing TRIS, a fire retardent chemical. It turns out that the Plexiglas containing TRIS has an increased absorption cross section due to chlorine and bromine contained in the TRIS. An analysis of the reflector shells indicated that nearly 80% of the Plexiglas in the reflector contained TRIS. Figure D.1 is a map showing the location of non-TRIS Plexiglas in the north reflector and Fig. D.2 is a similar map of the south reflector. These maps were obtained from J. A. Bucholz at ORNL, who received them from I. Oh of the RFP while working on the design of some of the RFP critical experiments.

For the reader who is familiar with KENO IV, the computer input previously listed may seem a little confusing. The array-of-arrays option in KENO V.a is actually very simple to use, but, if not properly documented, it can cause havoc. What is meant by documentation is that a comment is included about each unit (box type) describing its function and location in the model (e.g., top reflector north core means top portion of the north reflector). This is done to prevent confusion

Table D.1 Hydrogenous material in fuel at H/U = 0.77

Materal	Weight (grams)	Weight percent hydrogen	Hydrogen content (grams)
H_20 in U_3O_8	40.84	11.19	4.57
H_2O injected	259.52	11.19	29.04
Polyethelyne bags	53.2	14.01	7.45
Mylar tape	4.0	6.83	0.27
Vinyl tape	3.0	5.92	0.18
	Total hydrogen content per fuel cube		41.51

Table D.2 Comparison of H:U values

With Hydrogen from Tape		Without Hydrogen from Tape		
Ref. H:U	Calculated H:U	Calculated H:U	Calculated $H:^{235}U$	SCALE $H:^{235}U$
0.77	0.77	0.76	17.02	17.4
1.23	1.23	1.22	27.11	27.67
2.03	1.98	1.97	43.63	44.15

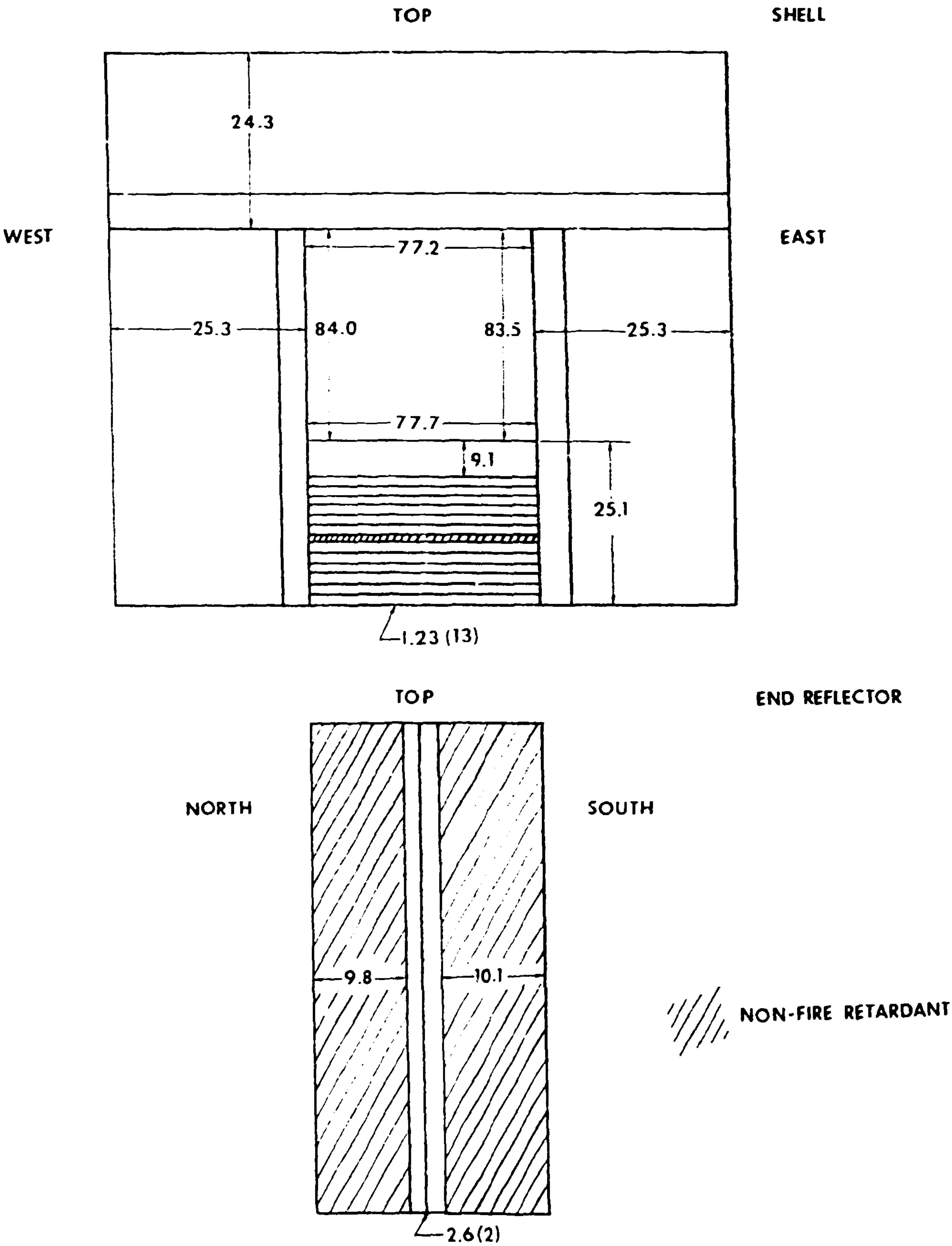
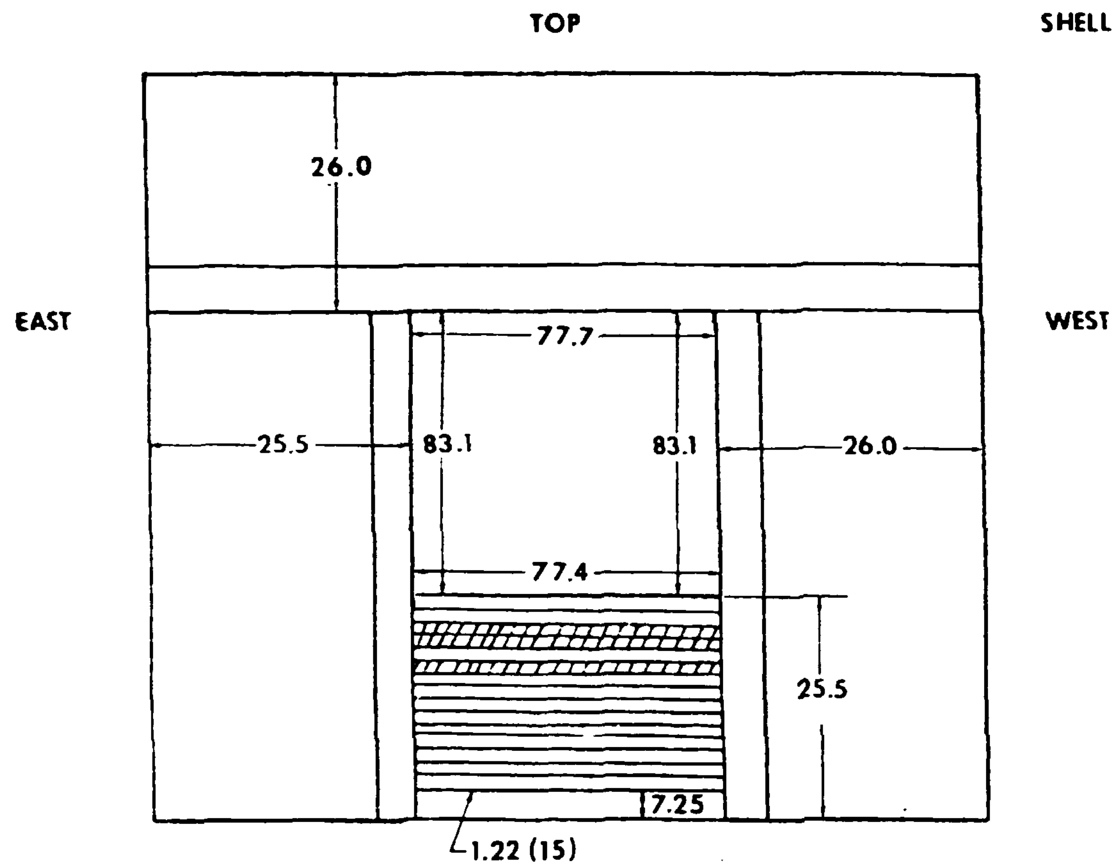


Fig. D.1 North split table reflector map showing location of non-fire retardent Plexiglas



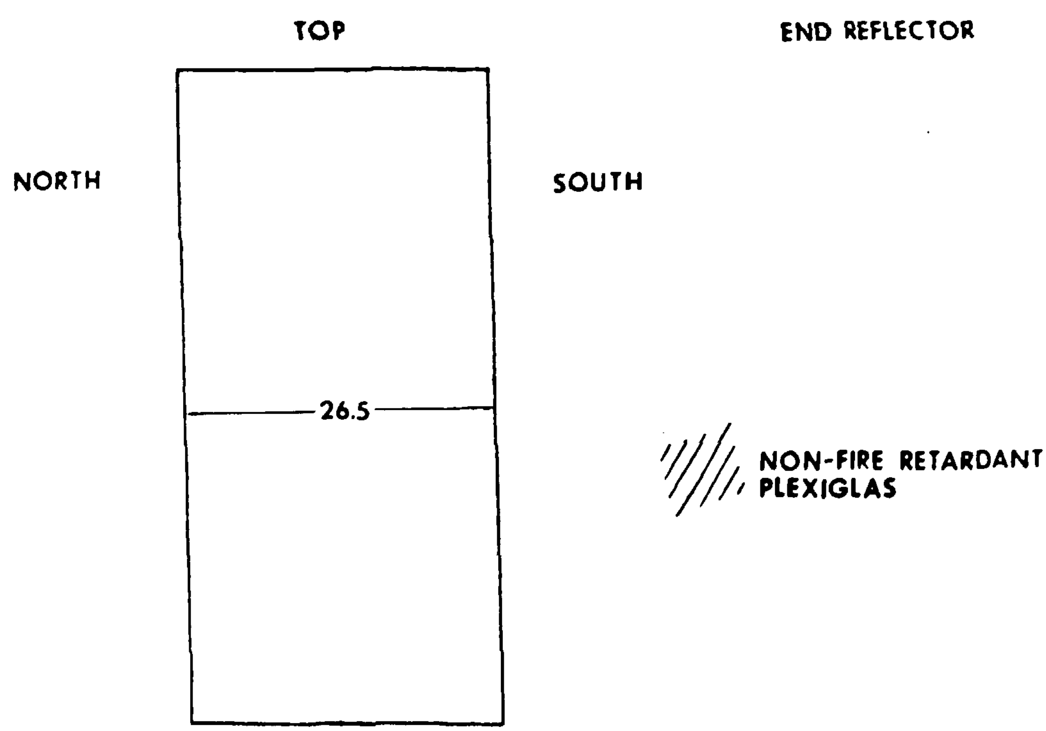


Fig. D.2 South split table reflector map showing location of non-fire retardent Plexiglas

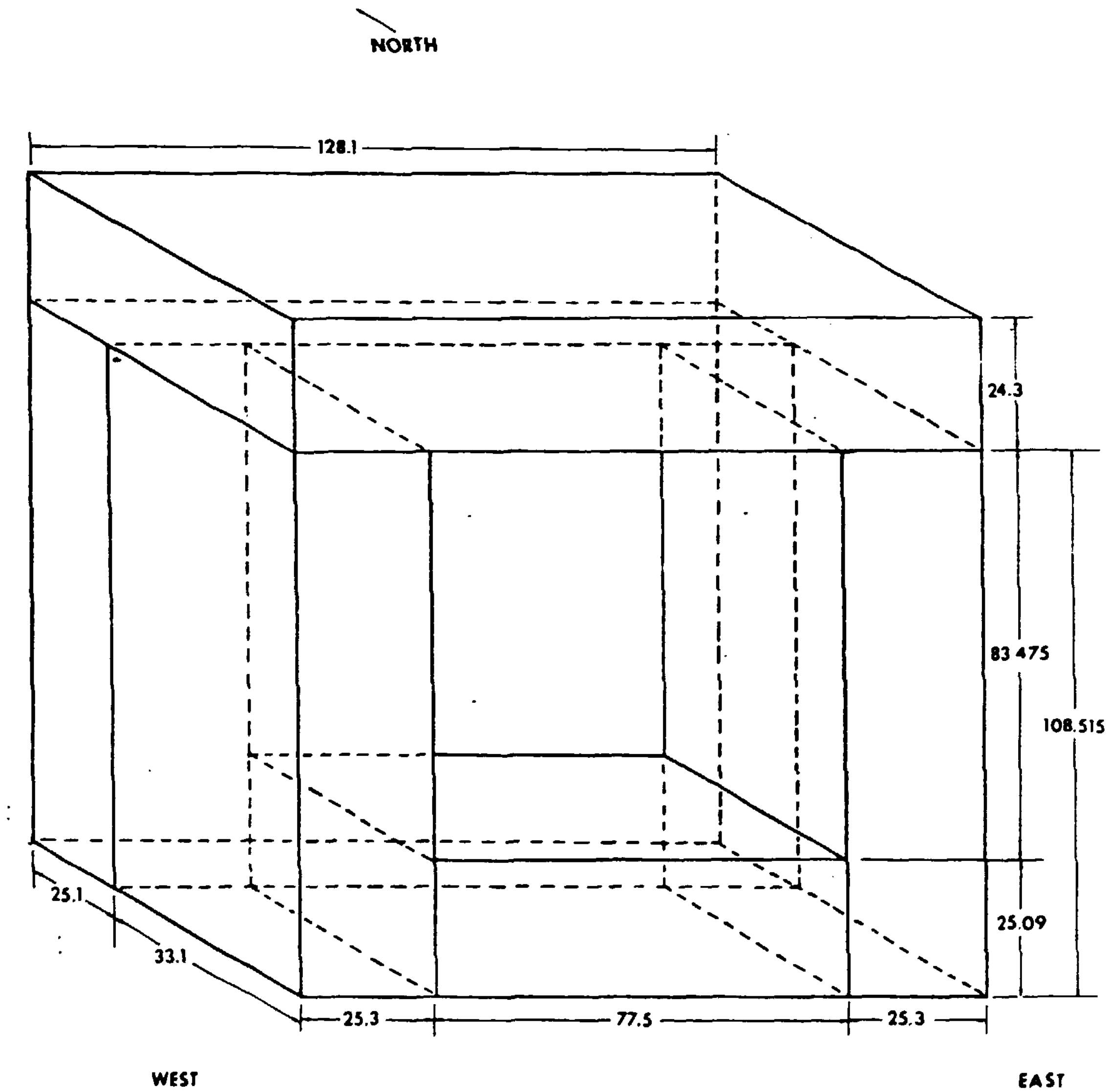


Fig. D.3 Dimensions of north split table reflector used in computer models

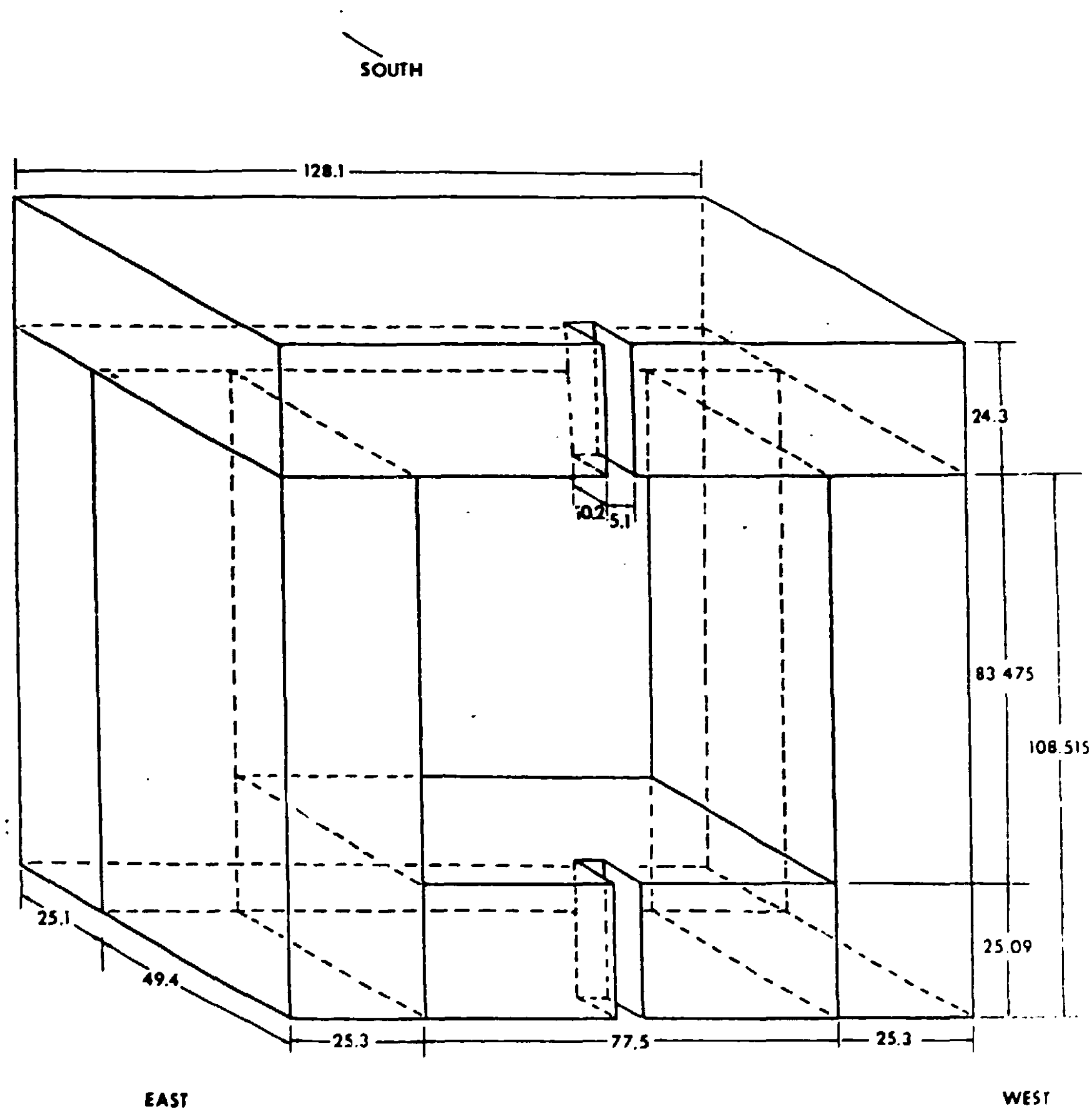


Fig. D.4 Dimensions of south split table reflector used in computer models when all of the pieces of the model are assembled in the READ ARRAY portion of the input. Figure D.3 shows the north reflector shell for undermoderated experiments (the thickness of the interstitial moderator between fuel cubes in the north-south direction will effect the north-south dimension of the reflector shell), and Fig. D.4 shows the south reflector shell for the same type of experiment.

APPENDIX E

CALCULATION OF LOWER TOLERANCE LIMITS

The lower tolerance limits associated with the equations given in Section 6 were derived from an article in Ref. 11, pp. 207-9. This article is a query about one-sided tolerance bands such that a portion of the population P lies above the lower tolerance limit with confidence alpha for all X in a stated interval. In criticality safety this is the same type of relation that will give a sound statistical basis to the safety associated with a calculation.

To illustrate the method used in this validation effort, we use the example in Ref. 11. We are looking for a tolerance limit about a curve based on the data from Ref. 11. These data are given in Table E.1. In this example the portion of the population considered is 95% (P=.95) with a confidence level of 95% (α=.95).

The lower tolerance limit is found by evaluating Equation 1 over

1) $Y = m^*X + B - k^*s$

the range of X. The first two terms in Equation 1 make up the simple linear model for the data in Table E.1. The last term, k*s, is constant over the range of X, thereby generating a uniform tolerance band. The value of k is to be determined and s is the square root of the mean square error (root MSE). The coefficients m and B are estimated by the method of least squares and can be easily found using a suitable regression program. In this example we used the PROC GLM command available in SAS.[12] From the SAS output the intercept (B) equals 51.41, the slope (m) equals -10.32, and the root MSE is equal to 0.095.

The variable k is defined to be:

$$k = C + Zp^*\sqrt{\frac{N-2}{\chi^2}}$$

where C is a constant, Zp is a standard normal deviate (e.g., a portion P of the standard normal area is enclosed above -Zp), and χ^2 is the χ^2 for N-2 degrees of freedom and percentage point = γ_2. To find the value of C, one must first find the values of g, h, A, and ρ. The reader is referred to Ref. 13, pp. 185-87 for the equations describing these variables. The values of g, h, A, and ρ depend on the interval over which the tolerance band is to be determined; this example has end-points, a = 4.26, b = 4.43. These endpoints, used in the equations given in Ref. 13, yield g=0.7299, h=0.3670, A-1.9888, and ρ=0.23. One of several typographical errors found in Ref. 11 is the quantity ΣX^2, which should be $\Sigma(X\ i - X)^2$. This latter quantity is easily found by squaring the standard deviation and multiplying by the number of samples minus one. In the example the value of this quantity is 0.0515.

From the values of A, ρ, and N-2, the reader is referred to Ref. 13 to find a value of D from the tables on pages 194-6. A new value used in the tables is γ_1, or 1 minus the confidence level (i.e., 1-α) which, in this example, is 0.05. By linear interpolation of Table III on page 194 we estimate a value of 2.47 for D. D is multiplied by g to obtain C. Zp is determined from the cumulative standard normal distribution according to P set forth in the problem. In this case P is selected to be 95% of the population, so we find the value of Zp in the table associated with an area of 0.05 which is -1.64 (the minus sign determines which side of the mean Zp is located). To find the value of the last variable, χ^2, we look in a χ^2 distribution table with N-2 degrees of freedom for the designated percentage point. This percentage point is found by solving the following expression for γ_2:

$$\alpha = 1 - \frac{\gamma_1}{2} - \gamma_2 \ .$$

Thus, α-0.95, γ_1=0.05, so γ_2=0.025 and the value of $\chi^2(6, 0.25)$ is 1.64.

With the above data, we can now solve Equation 1 and find the line which defines the lower limit. Figure E.1 shows the data with the linear model and the lower tolerance limit for P=0.95 and α = 0.95. The derivation of the tolerance limits for the linear models described in the report are calculated similarly for 99.9% of the population at a confidence level of 95%.

Table E.1 Example data

X	Y
4.52	4.75
4.49	5.00
4.46	5.26
4.43	5.68
4.40	5.96
4.36	6.56
4.32	6.69
4.27	7.28

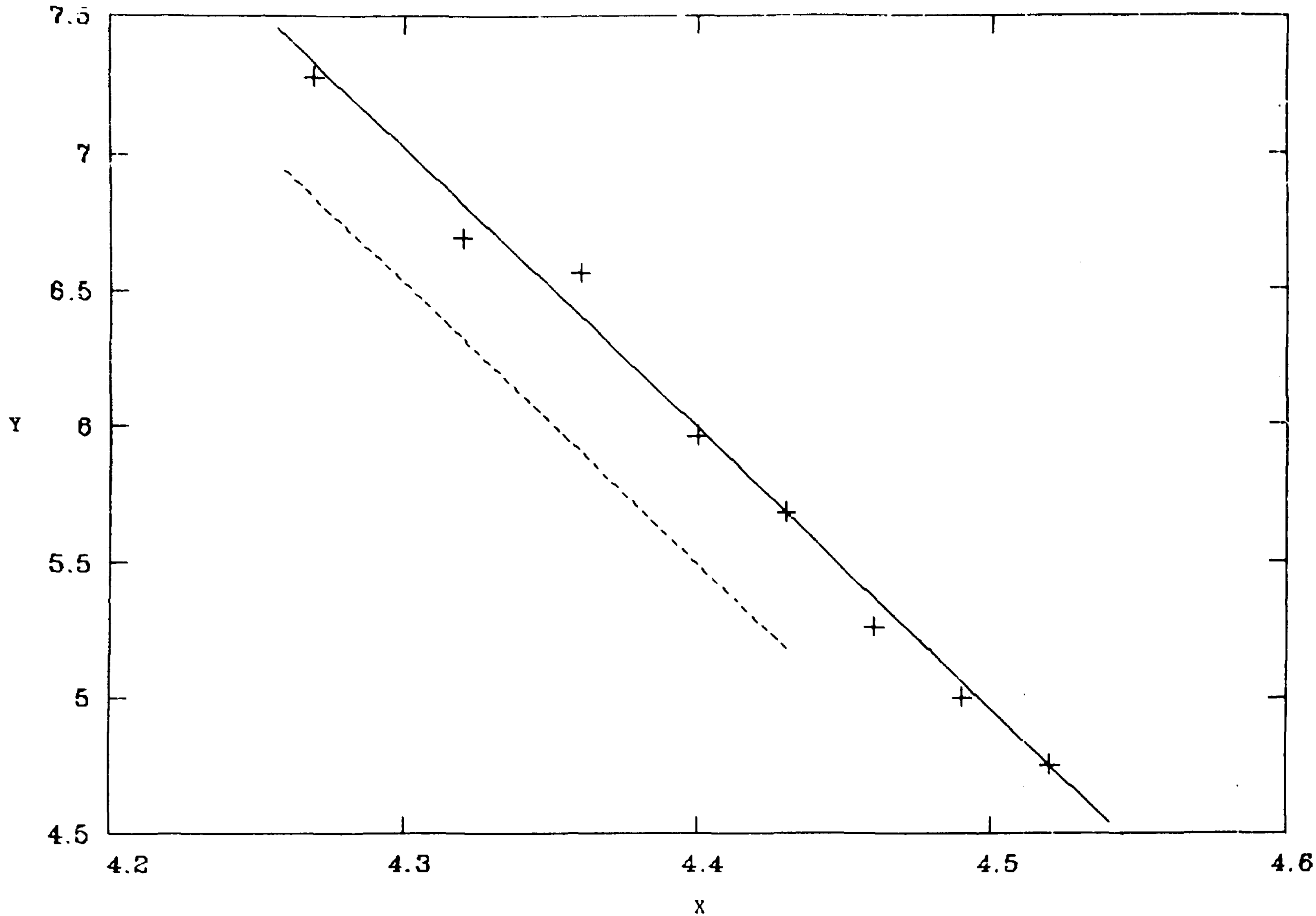


Fig. E.1 Plot of example data with linear model and lower tolerance limit

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