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VALIDATION CHECKS OF THE "ANISN" AND
"KENO" CODES BY CORRELATION WITH
EXPERIMENTAL DATA

G. R. Handley
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UNION
CARBIDE

OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

*prepared for the U.S. ATOMIC ENERGY COMMISSION
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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

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Oak Ridge Y-12 Plant

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ABSTRACT

The one-dimensional, discrete-ordinates transport computer code ANISN and the Monte Carlo computer code KENO are employed to calculate critical experiments of various geometries, materials, and uranium-235 enrichments. The input parameters to the codes are included in an Appendix. It is concluded that reliable criticality safety calculations can be made for a wide range of systems of general interest, provided the limits of validated applicability are not exceeded.

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SUMMARY

This report documents an independent validation of the ANISN and KENO codes and 16-energy-group cross sections by calculating the k_{eff} for a number of experimental critical assemblies. These assemblies were of many different geometries and contained a variety of materials such that a wide range of neutron-energy spectra is covered.

Thirty-five critical experiments were calculated—six with both the ANISN and the KENO codes, and twenty-nine with the KENO codes alone. The lowest ANISN calculated k_{eff} was 0.99145, and the lowest KENO calculated $k_{\text{eff}} \pm \sigma$ was 0.98245 ± 0.00526 . Therefore, it was concluded that at least for the materials and configurations considered, and with the methods presented, the codes and cross sections are adequate; and, for nuclear safety purposes, any calculated k_{eff} or $k_{\text{eff}} + 2\sigma$ which exceeds 0.97 must be considered as critical, and all lower values are considered subcritical.

INTRODUCTION

In the criticality safety field, experimental data are often supplemented by calculations. Each calculational method must be correlated with relevant experimental data in order to establish a bias over a specified area of applicability. Two computer programs have been employed for several years to supplement data from physical experiments for nuclear criticality safety analyses—the ANISN⁽¹⁾ and KENO⁽²⁾ codes. ANISN is a one-dimensional, discrete-ordinates transport code with general anisotropic scattering; KENO is a multigroup Monte Carlo criticality code which contains special geometry packages allowing complex three-dimensional systems to be described. These codes were validated⁽³⁾ by the Oak Ridge Y-12 Plant^(a) for intended applications. Since that early validation, many improvements have been made to the codes which were validated to the satisfaction of the programmers. An extensive and independent validation after each code change is prohibitively expensive because of the frequency of code changes. Therefore, versions of the codes and cross sections have been obtained which are under Y-12 control and which will be updated and validated annually or as otherwise required.

A total of 35 assemblies were calculated; and, of course, it was necessary to develop simplified calculational mockups since the use of exact representations, while possible with KENO, is usually prohibited by time and expense. Therefore, included in Appendix A is a listing of all input parameters; in Appendix B, the list of cross-section identification numbers is included. With these, the reader may examine any mockup of interest in detail.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Atomic Energy Commission.

VALIDATION OF THE TWO CODES

METHOD OF CALCULATION

Calculations employed the Hansen-Roach⁽⁴⁾ 16-energy-group cross sections in most cases. The uranium cross sections used were corrected for resonance self shielding, and the Watt-Cranberg fission spectrum weighted hydrogen was used for cases with cores having hydrogen-to-uranium-235 atomic ratios less than ten and dE/E weighting for more than ten.⁽⁵⁾ The JRK modified uranium-238 cross sections were used for enrichments below 70 percent (see Appendix B).

The ANISN calculations employed the S_g approximation, convergence criteria of 10^{-4} , and fixed mesh size in each material of no more than one mean free path for thermal neutrons. The KENO calculations were for approximately 53 batches of 400 neutrons each, of which the first three batches in each case were skipped. The neutrons were started in a flat distribution across the fissile material for single units and arrays of similar units. In dissimilar arrays, the neutrons were started in that portion of the problem which was assumed to have the greatest fission density. This technique prevents underestimation of k_{eff} due to slow upward convergence, but may slightly overestimate k_{eff} .⁽⁶⁾ When possible, instead of tracking complete neutron histories, the reflector employed adjoint biasing⁽⁷⁾ for cases with edge dimensions less than 100 centimeters, and differential current albedos⁽⁸⁾ for larger cases. No special effort was made to force agreement between experiments and calculations.

RESULTS OF CALCULATIONS

The calculated k_{eff} 's for the critical experiments considered are presented in Table 1 with short descriptions of the experiments and references to the experimental results. For comparison of the two codes, both were used when possible. The standard deviation of k_{eff} is based wholly on statistical analysis of the number of neutrons tracked and their histories; and, thus, does not include any possible uncertainties in such factors as cross sections, dimensions, and densities.

CONCLUSIONS

The calculated k_{eff} 's from Table 1 have been plotted in Figure 1. The error bars on the KENO cases are plus-or-minus two standard deviations from the calculated k_{eff} . It will be noted that the lowest lower-limit bar is at 0.971913 for Case A-10; the lowest ANISN calculated k_{eff} is 0.99145 for Case A-17. Therefore, it is concluded that at least for the materials and configurations considered, and with the methods presented, the codes and cross sections are adequate; and, for nuclear safety purposes, any calculated k_{eff} or $k_{eff} + 2\sigma$ which exceeds 0.97 must be considered as critical, and all lower values are considered subcritical.

The method of calculation may seem to imply a "cookbook" approach. However, that is not the intent, since a competent Criticality Safety Specialist will always be needed to establish the range of applicability of any calculational method as well as performing the whole analysis complete with contingencies and safeguards.

Table 1

"ANISN" AND "KENO" CALCULATED k_{eff} RESULTS
FOR EXPERIMENTALLY CRITICAL SYSTEMS

Experiment ^(a)	Reference	Code	$k_{eff} \pm \sigma$
A. Single Critical Units			
1. Unreflected spherical reactor (Godiva I) of U(93.8); 8.718-cm radius.	Hansen ⁽⁹⁾	KENO ANISN	0.99725 ± 0.00661 0.99434
2. Unreflected cylindrical reactor of U(93.2) alloyed to 10 weight percent Mo; 10.16-cm radius, 14.78-cm height.	Mihalcz ⁽¹⁰⁾	KENO	0.98868 ± 0.00474
3. Unreflected cylindrical annulus reactor of U(93.2) alloyed to 10 weight percent Mo; 2.54-cm IR, 10.16-cm OR, 19.74-cm height.	Mihalcz ⁽¹⁰⁾	KENO	0.99843 ± 0.00498
4. Unreflected spherical reactor of U(93.2)O ₂ F ₂ and H ₂ O with a H/U-235 = 1,393. Solution radius of 34.6 cm and aluminum container wall thickness of 0.32 cm.	Fox ⁽¹¹⁾	KENO ANISN	1.00125 ± 0.00482 1.01144
5. Unreflected spherical reactor of U(93.18)O ₂ (NO ₃) ₂ and H ₂ O with an H/U-235 = 1,378. Solution radius of 34.6 cm and aluminum container wall thickness of 0.32 cm.	Gwin ⁽¹²⁾	KENO ANISN	1.00606 ± 0.00446 1.00818
6. Reflected hemispherical shell reactor of U(93.5); 12.7-cm IR, 15.24-cm OR, and minimum H ₂ O reflector thickness of 15.2 cm.	Paxton ⁽¹³⁾	KENO	0.99492 ± 0.00642
7. Reflected cylindrical annulus reactor of U(93.2); 8.89-cm IR, 13.97-cm OR, and 6.88-cm height, ^(b) with graphite reflector thickness of 17.78 cm and graphite filling the central cavity.	Mihalcz ⁽¹⁴⁾	KENO	1.01096 ± 0.00566
8. Reflected cylindrical annulus reactor of U(93.2); 13.97-cm IR, 19.05-cm OR, with a graphite reflector thickness of 7.62 cm.	Mihalcz ⁽¹⁴⁾	KENO	1.01500 ± 0.00571
9. Reflected rectangular prism reactor of U(94); 7.62 cm x 8.89 cm x 15.24 cm with a natural uranium reflector thickness of 22.2 cm.	Paxton ⁽¹³⁾	KENO	0.98795 ± 0.00474
10. Reflected spherical shell reactor of U(93.1); 4.016-cm IR, 7.3933-cm OR, with extrapolated full oil reflection, and oil filling the central cavity.	Tuck ⁽¹⁵⁾	KENO ANISN	0.98245 ± 0.00526 1.00717

(a) Experiments A1 through A9 and B1 through B14 were calculated previously with older versions of the codes, and those other results are reported by Crum.⁽³⁾

(b) A height of 6.85 cm for the 8.89-cm IR to 11.43-cm OR, and a height of 6.92 cm for the 11.43-cm IR to 13.97-cm OR.

Table 1 (continued)

Experiment ^(a)	Reference	Code	$k_{\text{eff}} \pm \sigma$
11. Reflected spherical shell reactor of U(93.1); 4.016-cm IR, 7.832-cm OR, with extrapolated full oil reflection, and steel filling the central cavity.	Tuck ⁽¹⁵⁾	KENO ANISN	0.99701 ± 0.00586 1.00562
12. Reflected hemispherical shell reactor of U(93.1); 6.679-cm IR, 10.5254-cm OR, with extrapolated full oil reflection, and oil filling the central cavity.	Tuck ⁽¹⁵⁾	KENO	1.00989 ± 0.00611
13. Reflected hemispherical shell reactor of U(93.1); 6.012-cm IR, 10.488-cm OR, with extrapolated full oil reflection, and steel filling the central cavity.	Tuck ⁽¹⁵⁾	KENO	0.98721 ± 0.00666
14. Unreflected cylindrical reactor of laminated U(93.3) and copper; 10.05 cm radius and 9.779-cm height.	Paxton ⁽¹³⁾	KENO	1.00437 ± 0.00579
15. Reflected rectangular prism reactor of U(2)F ₄ and paraffin with an H/U-235 = 406.3; 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 bottom.	Raffety ⁽¹⁶⁾	KENO	0.99203 ± 0.00444
16. Reflected rectangular prism reactor of U(3)F ₄ and paraffin with an H/U-235 = 133.4; 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 bottom.	Raffety ⁽¹⁶⁾	KENO	1.01001 ± 0.00469
17. Unreflected spherical reactor of U(4.98)O ₂ F ₂ and H ₂ O with an H/U-235 = 490. Solution radius of 25.3873 cm and stainless steel container wall thickness of 0.0608 cm.	Johnson ⁽¹⁷⁾	KENO ANISN	0.99203 ± 0.00562 0.99145
18. Unreflected cylindrical reactor comprised of laminated U(93.3) and U(N) discs simulating an overall average enrichment of U(56.6) with a 19.05-cm radius and a 11.684-cm total height.	Paxton ⁽¹⁸⁾	KENO	0.98301 ± 0.00535
19. Unreflected cylindrical reactor comprised of laminated U(93.3) and U(N) discs simulating an overall average enrichment of U(75.1) with a 19.05-cm radius and a 9.5758-cm total height.	Paxton ⁽¹⁸⁾	KENO	1.00124 ± 0.00504

(a) Experiments A1 through A9 and B1 through B14 were calculated previously with older versions of the codes, and those other results are reported by Crume.⁽³⁾

Table 1 (continued)

Experiment ^(a)	Reference	Code	$k_{\text{eff}} \pm \sigma$
B. Critical Arrays			
1. Unreflected U(93.2) cylindrical annulus; 13.97-cm IR, 19.05-cm OR, 10.11-cm height, with a U(93.2) cylinder, an 8.89-cm radius, 10.11 cm high, located in its central cavity touching the wall. The annulus and cylinder axes were parallel.	Irving ⁽¹⁹⁾	KENO	1.00216 ± 0.00462
2. Unreflected U(93.2) cylindrical annulus; 13.97-cm IR, 19.05-cm OR, 12.98-cm height, with a U(93.2) rectangular prism, 12.70 cm x 12.70 cm x 12.98 cm high, located in its central cavity touching the wall with two edges.	Irving ⁽¹⁹⁾	KENO	1.00360 ± 0.00695
3. Unreflected U(93.2) pieces of various geometries, arranged approximately as a circle with a center piece. Critical mass of 206.5 kgs U(93.2).	Irving ⁽¹⁹⁾	KENO	1.00007 ± 0.00570
4. Cubic ^(c) array of 27 U(93.2) cylinders. The average dimensions of the cylinders were: a 5.7545-cm radius, a 5.382-cm height, and a 10.484-kg mass. Unmoderated and unreflected. Using the notation of Thomas, this array is described: ^(d) $A_{27}^2 [0; 2.007; 7.767; 0.55].$	Thomas ⁽²⁰⁾	KENO	0.98425 ± 0.00520
5. Unit array (3 x 3 x 5) of 45 U(93.2) cylinders. The average dimensions of the cylinders were: 5.747-cm radius, 5.382-cm height, and 10.458-kg mass. Unmoderated and unreflected. Described as: $A_{45}^5 [0; 3.442; 5.313; 0.99].$	Thomas ⁽²⁰⁾	KENO	0.98810 ± 0.00620
6. Cubic array of 64 U(93.2) cylinders. The average dimensions of the cylinders were: 5.7405-cm radius, 5.382-cm height, and 10.434-kg mass. Unmoderated and unreflected. Described as: $A_{64}^6 [0; 3.952; 4.693; 0.61].$	Thomas ⁽²⁰⁾	KENO	0.98800 ± 0.00450

(a) Experiments A1 through A9 and B1 through B14 were calculated previously with older versions of the codes, and those other results are reported by Crume.⁽³⁾

(c) That is, an equal number of units in each Cartesian direction.

(d) Notation is of the form: $X_n^i [t; \delta; \rho; r]$

where:

- X_n^i represents the average unit in the array described in Table 1 from Thomas.⁽²⁰⁾
- n the number of units in the array,
- t the paraffin reflector thickness (cm),
- δ the surface separation of units (cm) equal in three directions,
- ρ the average uranium density in the array (gms U/cc), and
- r the ratio of the array height to the square root of its base area.

Table 1 (continued)

Experiment ^(a)	Reference	Code	$k_{\text{eff}} \pm \sigma$
7. Unit array (3 x 3 x 1) of 9 U(93.2) cylinders. The average dimensions of the cylinders were: 5.744-cm radius, 10.765-cm height, and 20.896-kg mass. Unmoderated and unreflected. Described as: C_9^4 [0; 0.658; 12.400; 0.31].	Thomas ⁽²⁰⁾	KENO	0.99332 ± 0.00581
8. Cubic array of 8 U(93.2) stacked cylinder units. Each stacked cylinder unit consists of one Type E ³ cylinder stacked coaxially with and between two Type E ¹ cylinders. The average dimensions of a Type E ³ cylinder were: 4.558-cm radius, 4.320-cm height, and 5.245-kg mass. The average dimensions of a Type E ¹ cylinder were: 5.747-cm radius, 2.691-cm height, and 5.225-kg mass. Unmoderated and unreflected. Described as: B_8^3 [0; 0.229; 11.497; 0.85].	Thomas ⁽²⁰⁾	KENO	0.99243 ± 0.00536
9. Reflected cubic array of 8 Type B ³ units, as described under Item 8. Unmoderated but reflected by 15.2 cm of paraffin. Described as: B_8^3 [15.2; 6.904; 2.792; 0.90].	Thomas ⁽²⁰⁾	KENO	0.99032 ± 0.00553
10. Reflected cubic array of 8 U(93.2) cylinders. The average dimensions of the cylinders were: 4.558-cm radius, 17.282-cm height, and 21.008-kg mass. Unmoderated but reflected by 15.2 cm of paraffin. Described as: C_8^6 [15.2; 10.328; 2.013; 1.42].	Thomas ⁽²⁰⁾	KENO	0.99496 ± 0.00516
11. Moderated cubic array of 8 U(93.2) cylinders. The cylinders were type C ² and had average dimensions of: 5.753-cm radius, 10.765-cm height, and 20.960-kg mass. The array was unreflected but moderated by enclosing the cylinders in Type P ³ containers. These containers were Plexiglas boxes of average dimensions: 17.9-cm x 17.9-cm x 17.2-cm height, 1.27-cm wall thickness. Described as: $(C^2 - P^3)_8$ [0; 6.619; 3.670; 0.96].	Thomas ⁽²⁰⁾	KENO	0.99068 ± 0.00530
12. Moderated and reflected cubic array of 8 Type C ² cylinders (see Item 11). The array was reflected by 15.2 cm of paraffin and moderated by enclosing	Thomas ⁽²⁰⁾	KENO	0.99270 ± 0.00522

(a) Experiments A1 through A9 and B1 through B14 were calculated previously with older versions of the codes, and those other results are reported by Crume.⁽³⁾

Table 1 (continued)

Experiment ^(a)	Reference	Code	$k_{\text{eff}} \pm \sigma$
the cylinders in Type P ⁴ containers. These containers are Plexiglas boxes of average dimensions: 21.4-cm x 21.4-cm x 20.7-cm height, 2.38-cm wall thickness. Described as: (C ² - P ⁴) ₈ [15.2; 16.447; 0.986; 0.97].			
13. Cubic array of 27 cylinders of U(92.6)O ₂ (NO ₃) ₂ and H ₂ O. The containers had average dimensions: 10.16-cm OR, 19.05-cm height, 0.64-cm-thick walls. Each container was filled with 5 liters of solution at a H/U-235 atomic ratio of 59 and a N/U-235 atomic ratio of 2.006, which corresponds to a uranium mass of 2.075 kgs. Unreflected and unmoderated. Described as: F ₂₇ ¹ [0; 6.48; 0.114; 0.95].	Thomas ⁽²¹⁾	KENO	0.98704 ± 0.00670
14. Cubic array of 27 cylinders of aqueous uranyl nitrate solution. The containers described in Item 13 were used. Each container was filled with 5 liters of solution at a H/U-235 of 440, which corresponds to a uranium mass of 0.316 kgs. Unmoderated and unreflected. Described as: F ₂₇ ³ [0; 2.41; 0.029; 0.95].	Thomas ⁽²¹⁾	KENO	0.98999 ± 0.00729
15. Array of 16 cylinders (6.8-cm radius x 61-cm height) positioned on a slab (120.7 cm x 120.7 cm x 3.8 cm) all of U(93.2)O ₂ (NO ₃) ₂ aqueous solution with a 505 gm/liter uranium concentration. Reflection was provided with a 10.2-cm-thick Plexiglas box (inside dimensions of approximately 120.85 cm wide x approximately 120.85 cm long x 160.0 cm high) which was closely fitted to the base of the slab.	Tuck ⁽²²⁾	KENO	1.00952 ± 0.00583
16. Graphite moderated array of 8 U(93.2) cylinders with a 5.747-cm radius, 8.077-cm height, and weighing 15.692 kgs. Units had a uranium side surface-to-surface separation of 18.60 cm and an end surface-to-surface separation of 15.93 cm. The array was reflected with 15.24 cm of polyethylene.	Crume ⁽²³⁾	KENO	1.00477 ± 0.00567

(a) Experiments A1 through A9 and B1 through B14 were calculated previously with older versions of the codes, and those other results are reported by Crume.⁽³⁾

Figure 1. "ANISN" AND "KENO" CALCULATED CRITICAL EXPERIMENTS.

ACKNOWLEDGEMENTS

The authors are very grateful to E. C. Crume and G. E. Whitesides of the ORNL for their advice and help with this report, to L. M. Petrie and J. R. Knight of the ORNL for making the codes and cross sections available and giving the initial assistance in their use, and to G. W. Morrison of the ORNL for the geometry description of Case B-3.

APPENDIX A

COMPLETE LISTING OF THE INPUT PARAMETERS EMPLOYED IN THE CALCULATIONS

16** 22 0.0001 42 1.0 0.0 0.5 0.0001 0.01 0.002 0.75 T
 135\$ 12 13 20 9 115 124 13 131 19 4 355 356 367 368 T
 3** F1.0 T
 4** 7CIG.0 25.387 25.438
 85\$ 71R1 2
 95\$ 15 17
 105\$ 6R15 2R16 7R17 3F18
 115\$ 0 1 3 4 5 6 0 2 0 7 3 9 10 11 13 0 12 14
 12** 0.0 5.69086-2 3.30623-2 4.6085-3 1.1614-4 2.18811-3 0.0 1.707258-1
 0.0 6.036-2 1.6471-2 8.4834-3 3.1691-4 1.7321-3 1.694-3 0.0 5.1963-3
 5.082-3
 195\$ 1 1
 20** 0.0 0.0
 1** .204 .344 .168 .180 .390 .014 102
 6* 0.0 .05330038 .10117273 .13775341 .20777348
 .20777348 .13775341 .10117273 .05330038 7* -1.0
 -.9511897 -.7867958 -.5773503 -.2182179 +.2182179 +.5773503
 +.7867958 +.9511897 T

T
 1.0
 KENO VALIDATION CASE F-1
 53 400 3 16 6 2 1 2 2 0 1 1 1
 2 0 0 1 0 0 0 0
 1 -925010.04534243
 1 928590.00233960
 SPHERE 1 8.718
 CUBE 0 8.718 -8.713

2.0
 KENO VALIDATION CASE A-2
 53 400 3 16 6 3 1 3 2 0 1 1 1
 3 0 0 1 0 0 0 0
 1 421000.01072200
 1 -925000.03659900
 1 928600.00259030
 CYLINDER 1 10.16 7.39 -7.39
 CUBE 0 10.16 -10.16

3.0
 KENO VALIDATION CASE A-3
 53 400 3 16 6 3 1 3 3
 3 0 0 1 0 0 0 0
 1 421000.01072200
 1 -925000.03659900
 1 928600.00259030
 CYLINDER 0 2.54 9.87 -9.87
 CYLINDER 1 10.16 9.87 -9.87
 CUBE 0 10.16 -10.16

15.C

KENO VALIDATION CASE A-4
 53 400 3 16 6 7 2 7 3
 7 0 0 1
 1 1102.0669
 1 8100.0336
 1 9100.000103
 1 -92500.0000479
 1 92800.00000345
 2 13100.059888
 2 26100.00029226
 SPHERE 1 34.6
 SPHERE 2 34.92
 CUBE 0 35.0 -35.0

15.C
 KENO VALIDATION CASE A-5
 53 400 3 16 6 7 2 7 3
 7 0 0 1
 1 1102.066228
 1 7100.0001869
 1 8100.0337764
 1 -92500.000048066
 1 92800.000002807
 2 13100.059888
 2 26100.00029226
 SPHERE 1 34.6
 SPHERE 2 34.92
 CUBE 0 35.0 -35.0

20.0
 KENO VALIDATION CASE A-6
 53 400 3 16 6 3 2 3 3
 3 0 0 1
 1 -92501.044922
 1 92860.0030835
 2 501 1.0
 HEMISEHERE 2 12.7
 HEMISEHERE 1 15.24
 CUBOIL 2 31.0 -31.0 31.0 -31.0 31.0 -16.0

15.C
 KENO VALIDATION CASE A-7
 53 400 3 16 6 3 2 3 6
 3 0 0 1
 1 6100.086747
 2 -92501.044647
 2 92860.0031633
 CYLINDER 18.89 3.425 -3.425

CYLINDER 2 11.43 3.425 -3.425
 CYLINDER 1 11.43 3.495 -3.425
 CYLINDER 2 13.97 3.495 -3.425
 CYLINDER 1 31.75 21.275 -21.205
 CUBE 0 32.0 -32.0

3.0
 KENO VALIDATION CASE 7-8
 53 400 3 16 6 3 2 3 4
 3 0 0 1
 1 6100.036747
 2 -92501.044692
 2 92860.0032156
 CYLINDER 0 13.97 5.5 -5.5
 CYLINDER 2 19.05 5.5 -5.5
 CYLINDER 1 26.67 13.12 -13.12
 CUBE 0 27.0 -27.0

15.0
 KENO VALIDATION CASE A-9
 53 400 3 16 6 3 2 4 3
 3 0 0 1
 1 -92501.045042
 1 92860.0028387
 2 -92501.00035101
 2 92856.047785
 CUBOID 1 3.81 -3.81 4.445 -4.445 7.62 -7.62
 CUBOID 2 26.01 -26.01 25.645 -26.645 29.82 -29.32
 CUBE 0 30.0 -30.0

15.0
 KENO VALIDATION CASE A-10
 53 400 3 16 6 5 2 7 4
 5 0 0 1
 1 1101.05919255
 1 6100.03830556
 1 16100.00000375
 2 -92501.0432940
 2 92860.0031987
 2 6100.0010318
 2 1101.0018758
 SPHERE 1 4.016
 SPHERE 2 7.3933

SPHERE 137.3933
 CUBE 0 40.0 -40.0

15.0
 KENO VALIDATION CASE A-11
 53 400 3 16 6 6 3 9 4
 5 0 0 1
 1 1101.069193
 1 6100.03831
 1 16100.000004
 2 -92501.043294
 2 92860.0031987
 2 6100.0010318
 2 1101.0018758
 3 26100.081676
 3 6100.0038358
 SPHERE 3 4.016

SPHERE 2 7.832
 SPHERE 1 37.832
 CUBE 0 40.0 -40.0

15.0
 KENO VALIDATION CASE A-12
 53 400 3 16 6 5 2 7 4
 5 0 0 1
 1 1101.06919255
 1 6100.03830956
 1 16100.00000375
 2 -92501.0432940
 2 92860.0031987
 2 6100.0010318
 2 1101.0018758
 HEMISPHERE 1 6.679
 HEMISPHERE 2 10.5254
 SPHERE 1 40.5254
 CUBE 0 42.00 -42.00

15.0
 KENO VALIDATION CASE A-13
 53 400 3 16 6 6 3 9 4
 6 0 0 1
 1 1101.069193
 1 6100.038310
 1 16100.000004
 2 -92501.043294
 2 92860.0031987

2 6100.0010318
 2 1101.0018758
 3 26100.081676
 3 6100.0038358
 HEMISPHERE 3 6.012

HEMISPHERE 2 10.488

SPHERE 1 40.488

CUBE 0 41.0 -41.0

10.0

KENO VALIDATION CASE A-14

53 400 3 16 6 3 2 3 5

3 0 0 1
 1 -92501.04484912
 1 92860.00317999
 2 29100.08166596

CYLINDER 1 19.05 1.8818 -1.8818

CYLINDER 2 19.05 2.8318 -2.8318

CYLINDER 1 19.05 6.5954 -2.8318

CYLINDER 2 19.05 6.9472 -2.8318

CUBE 0 20.00 -20.00

30.0

KENO VALIDATION CASE A-15

53 400 3 16 6 6 3 8 4

6 0 0 1
 1 -92512.000111912
 1 92827.005415249
 1 1102.045472123
 1 6100.021861238
 1 9100.022109080
 2 6100.039716
 2 1102.079433
 3 602 1.0

CUBOID 1 26.8350-26.8350 26.8350-26.8350 27.1450-27.1450

CUBOID 2 42.0350-42.0350 42.0350-42.0350 42.3450-27.1450

CUBOID 3 42.0350-42.0350 42.0350-42.0350 42.3450-42.3450

CUBE 0 43.0 -43.0

30.0

KENO VALIDATION CASE A-16

53 400 3 16 6 6 3 8 4

6 0 0 1
 1 -92510.000234940

1 92821.007499891
 1 1102.03134101
 1 6100.015067188
 1 9100.030939126
 2 6100.039716
 2 1102.079433
 3 602 1.0

CUBOID 1 25.570 -25.570 25.570 -25.570 25.635 -25.635

CUBOID 2 40.770 -40.770 40.770 -40.770 40.770 -25.635

CUBOID 3 40.770 -40.770 40.770 -40.770 40.770 -40.770

CUBE 0 43.0 -43.0

5.0

KENO VALIDATION CASE A-17

53 400 3 16 6 11 2 11 3

11 0 0 1
 1 1102.0569086
 1 8100.0330628
 1 9100.0046085
 1 -92508.00011614
 1 92862.00218811
 2 26100.060360
 2 24100.016471
 2 28100.0064634
 2 6100.00031691
 2 25100.0017321
 2 14100.0016940
 2 1 25.3873

SEHERE

SEHERE 2 25.4381

CUBE 0 26.0 -26.0

3.0

KENO VALIDATION CASE A-18

53 400 3 16 6 3 2 4 5

3 0 0 1
 1 -92501.04301613
 1 92859.00305002
 2 -92501.00034882
 2 92801.04749162

CYLINDER 1 19.05 1.2 -1.2

CYLINDER 2 19.05 2.7 -2.7

CYLINDER 1 19.05 5.1 -5.1

CYLINDER 2 19.05 5.1 -6.6

CUBE 0 20.0 -20.0

3.0
KENC VALIDATION CASE A-19
53 400 3 16 6 3 2 4 9

3 0 0 1
1 -92501.04458919
1 92359.003161E6
2 -92501.00030076
2 92356.04094916
CYLINDER 1 19.05 0.6 -C.6
CYLINDER 2 19.05 0.9 -C.9
CYLINDER 1 19.05 2.1 -2.1
CYLINDER 2 19.05 2.4 -2.4
CYLINDER 1 19.05 3.6 -3.6
CYLINDER 2 19.05 3.9 -3.9
CYLINDER 1 19.05 4.2 -5.1
CYLINDER 2 19.05 4.2 -5.4
CUBE 0 20.0 -20.0

15.0
KENO VALIDATION CASE B-1
53 400 3 16 6 2 1 2 3

2 0 0 1 0 3
1 -92501.044802
1 92360.0032275
GENERAL 1
GENERAL 0 19.10 -19.10 19.10 -19.10 5.0546 -5.0546
CUBOID 0 19.10 -19.10 19.10 -19.10 5.0546 -5.0546

2 MALE MARRIED
X ZONE -19.10, 19.10
Y ZONE -19.10, 19.10
Z ZONE -5.0546, 5.0546
ZONE 1 1 1
X BLOCK -19.10, 19.10
Y BLOCK -19.10, 19.10
Z BLOCK -5.0546, 5.0546
BLOCK 1 1 1
MEDIA 2, 1, 1, 2
SURFACES 1, 2, 3
SECTOR +1 -1 0
SECTOR -1 0 0
SECTOR 0 +1 -1
SECTOR 0 0 +1
3

1.0XSQ 1.0YSQ 10.16X -53.2257 \$
1.0XSQ 1.0YSQ -195.1609 \$
1.0XSQ 1.0YSQ -362.9025 \$
1 1 1 -5.08 0.0 0.0

15.0
KENO VALIDATION CASE B-2
53 400 3 16 6 2 1 2 4 1
2 0 0 1 0 3
1 -92501.044802
1 92360.0032275
CUBOID 1 0.3434 -12.4434 5.35 -6.35 6.49 -6.49
CYLINDER 0 13.97 6.49 -5.49
CYLINDER 1 19.05 6.49 -5.49
CUBE 0 20.00 -20.00

1 1 1 -6.0500 0.0 0.0
9.0
KENO VALIDATION CASE E-3
53 400 3 16 6 2 1 2 3 0 1 1 1
2 1 3
1 -92501.0448017
1 92360.0032275

GENERAL 1
GENERAL 024.353 -23.319 21.686 -22.841 15.24 -1.755
CUBOID 024.353 -23.319 21.686 -22.841 15.24 -1.755

2 MALE MARRIED
X ZONE -23.319, 24.353
Y ZONE -22.841, 21.686
Z ZONE -1.755, 15.24
ZONE 1 1 1
X BLOCKS -23.319, -5.7569, 6.9433, 24.353
Y BLOCKS -22.841, -6.9433, 5.7569, 21.686
Z BLOCKS -1.755, 15.24
BLOCK 1 1 1
MEDIA 1, 2, 2, 2
SURFACES 26, 27, 28
SECTOR -1 +1 -1
SECTOR 0 0 +1
SECTOR +1 0 0
SECTOR 0 -1 0
BLOCK 2 1 1
MEDIA 1, 1, 1, 2, 2, 2, 2, 2, 2
SURFACES 20, 21, 22, 23, 24, 25, 26, 27, 28
SECTOR -1 +1 -1 0 0 0 0 0 0
SECTOR 0 0 0 -1 +1 -1 0 0 0
SECTOR 0 0 0 0 0 0 -1 +1 -1
SECTOR 0 0 +1 0 0 +1 0 0 +1
SECTOR 0 -1 0 0 0 +1 0 0 +1

SECTOR +1 0 0 0 0 +1 0 0 +1
 SECTOR 0 0 +1 0 -1 0 0 0 +1
 SECTOR 0 0 +1 +1 0 0 0 0 +1
 SECTOR 0 0 +1 0 0 0 +1 0 -1 0
 SECTOR 0 0 +1 0 0 +1 +1 0 0

BLOCK 3 1 1
 MEDIA 1, 1, 2, 2, 2, 2, 2
 SURFACES 20, 21, 22, 23, 24, 25

SECTOR -1 +1 -1 0 0 0
 SECTOR 0 0 0 -1 +1 -1
 SECTOR 0 0 +1 0 0 +1
 SECTOR +1 0 0 0 0 +1
 SECTOR 0 -1 0 0 0 +1
 SECTOR 0 0 +1 +1 0 0
 SECTOR 0 0 +1 0 -1 0

BLOCK 1 2 1
 MEDIA 1, 1, 1, 2, 2, 2, 2, 2, 2
 SURFACES 1, 2, 3, 4, 36, 37, 38, 39

SECTOR 0 0 -1 +1 -1 0 0 +1
 SECTOR -1 0 0 0 +1 0 -1 +1 0
 SECTOR 0 -1 0 +1 -1 0 +1 0
 SECTOR +1 0 0 0 0 0 0 0
 SECTOR 0 0 0 -1 0 0 0 0
 SECTOR 0 0 0 0 +1 0 0 0
 SECTOR 0 0 0 0 0 0 0 -1
 SECTOR 0 +1 0 0 0 +1 0 0
 SECTOR 0 0 +1 0 0 0 -1 0

BLOCK 1 3 1
 MEDIA 1, 2, 2, 2
 SURFACES 5, 6, 7

SECTOR -1 +1 -1
 SECTOR 0 0 +1
 SECTOR +1 0 0
 SECTOR 0 -1 0

BLOCK 2 3 1
 MEDIA 1, 1, 2, 2, 2, 2, 2
 SURFACES 5, 6, 7, 8, 9, 10

SECTOR -1 +1 -1 0 0 0
 SECTOR 0 0 0 -1 +1 -1
 SECTOR 0 0 +1 0 0 +1
 SECTOR +1 0 0 0 0 +1
 SECTOR 0 -1 0 0 0 +1
 SECTOR 0 0 +1 +1 0 0
 SECTOR 0 0 +1 0 -1 0

BLOCK 3 3 1
 MEDIA 1, 1, 2, 2, 2, 2, 2
 SURFACES 8, 9, 10, 11, 12, 13

SECTOR -1 +1 -1 0 0 0
 SECTOR 0 0 0 -1 +1 -1
 SECTOR 0 0 +1 0 0 +1
 SECTOR +1 0 0 0 0 +1
 SECTOR 0 -1 0 0 0 +1
 SECTOR 0 0 +1 +1 0 0
 SECTOR 0 0 +1 0 -1 0

BLOCK 3 2 1
 MEDIA 1, 1, 1, 1, 2, 2, 2, 2, 2, 2
 SURFACES 11, 12, 13, 20, 21, 22, 34, 14, 35, 15

SECTOR -1 +1 +1 0 0 0 0 0 0 0 0 0
 SECTOR 0 0 0 -1 +1 -1 0 0 0 0 0 0
 SECTOR 0 0 0 0 0 0 -1 +1 -1 0 0 0
 SECTOR 0 0 0 0 0 0 0 -1 0 +1 -1 +1
 SECTOR 0 0 +1 0 0 +1 +1 0 0 0 0 0
 SECTOR 0 0 +1 0 0 +1 0 +1 +1 0 0 0
 SECTOR 0 0 +1 0 0 +1 0 -1 0 0 +1 0
 SECTOR 0 0 +1 0 0 +1 0 -1 0 0 -1 0
 SECTOR 0 0 +1 0 0 +1 0 -1 0 0 0 +1 0
 SECTOR 0 0 +1 0 0 +1 0 -1 0 0 0 0 -1
 SECTOR 0 0 +1 0 0 +1 0 0 0 -1 0 0
 SECTOR +1 0 -1 0 0 0 0 0 0 0 0 0
 SECTOR 0 -1 -1 0 0 0 0 0 0 0 0 0
 SECTOR 0 0 0 -1 -1 0 0 0 0 0 0 0
 SECTOR 0 0 +1 0 -1 0 0 0 0 0 0 0

BLOCK 2 2 1
 MEDIA 2, 1, 1, 1, 2, 2
 SURFACES 31, 32, 33, 29, 30
 SECTOR 0 -1 +1 0 0
 SECTOR -1 +1 0 0 0
 SECTOR 0 0 -1 +1 0
 SECTOR 0 0 0 -1 -1
 SECTOR +1 0 +1 0 0
 SECTOR 0 0 0 -1 +1

39 QUADRIC SURFACES IN GEOMETRY
 .02356X +.99972Z -13.1339 \$
 .02356X +.99972Z -12.8151 \$
 .02356X +.99972Z -10.9048 \$
 .02356X +.99972Z +.25011 \$
 1.487E-02X -1.938E-02Y 9.997E-01Z -1.262E+01 \$
 1.487E-02X -1.938E-02Y 9.997E-01Z 3.557E-01 \$
 9.998E-01XSQ 9.998E-01YSQ 5.969E-04ZSQ 5.766E-04XY
 -2.974E-02XZ 3.876E-02YZ 1.772E+01X -2.309E+01Y
 -7.112E-01Z 1.911E+02 \$
 -3.424E-03X -3.005E-02Y 9.935E-01Z -1.299E+01 \$
 -3.424E-03X -3.005E-02Y 9.935E-01Z 4.817E-01 \$
 1.006E+00XSQ 5.991E-01YSQ 9.149E-04ZSQ -2.058E-04XY
 6.845E-03XZ 6.008E-02YZ -3.602E+00X -3.162E+01Y
 -9.629E-01Z 2.202E+02 \$
 -2.610E-02X -2.229E-02Y 9.994E-01Z -1.246E+01 \$
 -2.610E-02X -2.229E-02Y 9.994E-01Z 5.056E-01 \$
 9.993E-01XSQ 9.995E-01YSQ 1.178E-03ZSQ -1.163E-03XY
 5.216E-02XZ 4.455E-02YZ -2.238E+01X -1.911E+01Y
 -1.011E+00Z 1.960E+02 \$
 -.04507X +.99898Z -8.3852 \$
 -.04507X +.99898Z +.5252 \$
 .99898X +.04507Z -24.34 \$
 .99898X +.04507Z -11.64 \$
 1.0Y -3.2168 \$

```

1.0Y      +4.4032      $
-2.183E-02X  1.566E-02Y  9.996E-01Z  -1.252E+C1  $
-2.183E-02X  1.566E-02Y  9.996E-01Z  4.557E-C1  $
9.995E-01XSQ  9.996E-01YSQ  8.625E-04ZSQ  8.582E-C4XY
4.364E-02XZ  -3.929E-02YZ  -2.304E+01X  2.074E+C1Y
-5.110E-C1Z  2.157E+02      $
-2.129E-03X  2.434E-02Y  9.997E-01Z  -1.306E+C1  $
-2.129E-03X  2.434E-02Y  9.997E-01Z  4.176E-C1  $
1.000E+00XSQ  9.994E-01YSQ  5.969E-04ZSQ  1.037E-C4XY
4.258E-03XZ  -4.866E-02YZ  -2.977E+00X  3.403E+C1Y
-8.349E-01Z  2.585E+02      $
1.182E-02X  1.513E-02Y  9.996E-01Z  -1.266E+C1  $
1.182E-02X  1.513E-02Y  9.998E-01Z  2.966E-C1  $
9.999E-01XSQ  5.958E-01YSQ  3.685E-04ZSQ  -3.576E-C4XY
-2.363E-02XZ  -3.025E-02YZ  1.902E+01X  2.434E+C1Y
-5.932E-01Z  2.175E+02      $
1.0Z      -0.9374      $
1.0XSQ      +1.0YSQ      -33.142      $
1.0XSQ      +1.0YSQ      +1.0ZSQ      -1.7226X
+.6502Y      -13.3122Z      +8.1601      $
1.0XSQ      +1.0YSQ      +1.0ZSQ      -1.7226X
+.6502Y      -13.3122Z      +45.0945      $
1.0Z      -6.6562      $
-4.507E-02X  5.990E-01Z  -1.270E+01      $
9.980E-01XSQ  1.000E+00YSQ  2.032E-03ZSQ  9.005E-C2XZ
-3.239E-C1X  1.186E+00Y  -1.461E+00Z  2.422E+C2      $
.99972X      -.02356Z      +10.613      $
.99972X      -.02356Z      +15.693      $
.99972X      -.02356Z      +20.773      $
.99972X      -.02356Z      +23.316      $
1      1      1      0.0      2.0      5.08
10.0
KENO VALIDATION CASE E-4
53 400 3 16 6 11 3 11 5 1 3 3 3
11 0 0 1
1 -92501.044778
1 92860.0032513
2 200 1.0
3 28100.062155
3 24100.015435
3 26100.0090751
3 25100.00092253
3 6100.00063293
3 29100.00039878
3 14100.00090226
3 16100.000023709
GENERAL 1
GENERAL 2
GENERAL 3
GENERAL 0 6.758 -6.758 6.758 -6.758 3.7169 -3.7169

```

CUBOID C 6.758 -6.758 6.758 -6.758 3.7169 -3.7169

```

2 MALE MARRIED
X ZONE -6.758, 6.758
Y ZONE -6.758, 6.758
Z ZONE -3.7169, 3.7169
ZONE 1 1 1
X BLOCK -6.758, 6.758
Y BLOCK -6.758, 6.758
Z BLOCK -3.7169, -2.691, 2.691, 3.7169
BLOCK 1 1 1
MEDIA 2, 2, 3, 3, 4
SURFACES 2, 3, 4, 5
SECTOR -
SECTOR -1
SECTOR -1
SECTOR 1 -1
SECTOR 1 1
BLOCK 1 1 2
MEDIA 1, 2, 2, 4
SURFACES 1, 2, 3
SECTOR -1 1
SECTOR -
SECTOR -1
SECTOR 1
BLOCK 1 1 3
MEDIA 2, 2, 3, 3, 4
SURFACES 2, 3, 4, 5
SECTOR -1
SECTOR -1
SECTOR 1 -1
SECTOR 1 -1
SECTOR 1 1
5
1.0XSQ 1.0YSQ -33.1142 $
1.0XSQ 1.0YSQ -8.547X 18.198286 $
1.0XSQ 1.0YSQ 8.547X 18.198286 $
1.0XSQ 1.0YSQ -8.547X 18.117641 $
1.0XSQ 1.0YSQ 8.547X 18.117641 $

```

```

10.0
KENO VALIDATION CASE B-5
53 400 3 16 6 11 3 11 5 1 3 3 5
11 0 0 1
1 -92501.044778
1 92860.0032513
2 200 1.0
3 28100.062155
3 24100.015435
3 26100.0090751
3 25100.00092253
3 6100.00063293
3 29100.00039878
3 14100.00090226
3 16100.000023709

```

GENERAL 1
 GENERAL 2
 GENERAL 3
 GENERAL 0 7.468 -7.468 7.468 -7.468 4.436 -4.436
 CUBOID 0 7.468 -7.468 7.468 -7.468 4.436 -4.436

2 MALE MARRIED
 X ZONE -7.468, 7.468
 Y ZONE -7.468, 7.468
 Z ZONE -4.436, 4.436
 ZONE 1 1 1
 X BLOCK -7.468, 7.468
 Y BLOCK -7.468, 7.468
 Z BLOCK -4.436, -2.691, 2.691, 4.436
 BLOCK 1 1 1
 MEDIA 2, 2, 3, 3, 4
 SURFACES 2, 3, 4, 5
 SECTOR -1
 SECTOR -1
 SECTOR 1 -1
 SECTOR 1 -1
 SECTOR 1 1
 BLOCK 1 1 2
 MEDIA 1, 2, 2, 2, 4
 SURFACES 1, 2, 3
 SECTOR -1 1 1
 SECTOR -1
 SECTOR -1
 SECTOR 1
 BLOCK 1 1 3
 MEDIA 2, 2, 3, 3, 4
 SURFACES 2, 3, 4, 5
 SECTOR -1
 SECTOR -1
 SECTOR 1 -1
 SECTOR 1 -1
 SECTOR 1 1
 5
 1.OXSQ 1.OYSQ -33.1142 \$
 1.OXSQ 1.OYSQ -8.547X 18.198286 \$
 1.OXSQ 1.OYSQ 8.547X 18.198286 \$
 1.OXSQ 1.OYSQ -8.547X 18.117641 \$
 1.OXSQ 1.OYSQ 8.547X 18.117641 \$

10.0
 KENO VALIDATION CASE B-6
 53 400 3 16 6 11 3 11 5 1 4 4 4
 11 0 0 1
 1 -92501.044778
 1 5286J.C032513
 2 200 1.0

3 28100.062155
 3 24100.015435
 3 26100.0090751
 3 25100.00092253
 3 6100.00063293
 3 29100.00039878
 3 14100.00090226
 3 16100.000023709
 GENERAL 1
 GENERAL 2
 GENERAL 3
 GENERAL 0 7.7165 -7.7165 7.7165 -7.7165 4.70707-4.70707
 CUBOID 0 7.7165 -7.7165 7.7165 -7.7165 4.70707-4.70707

2 MALE MARRIED
 X ZONE -7.7165, 7.7165
 Y ZONE -7.7165, 7.7165
 Z ZONE -4.70707, 4.70707
 ZONE 1 1 1
 X BLOCK -7.7165, 7.7165
 Y BLOCK -7.7165, 7.7165
 Z BLOCK -4.70707, -2.691, 2.691, 4.70707
 BLOCK 1 1 1
 MEDIA 2, 2, 3, 3, 4
 SURFACES 2, 3, 4, 5
 SECTOR -1
 SECTOR -1
 SECTOR 1 -1
 SECTOR 1 -1
 SECTOR 1 1
 BLOCK 1 1 2
 MEDIA 1, 2, 2, 2, 4
 SURFACES 1, 2, 3
 SECTOR -1 1 1
 SECTOR -1
 SECTOR -1
 SECTOR 1
 BLOCK 1 1 3
 MEDIA 2, 2, 3, 3, 4
 SURFACES 2, 3, 4, 5
 SECTOR -1
 SECTOR -1
 SECTOR 1 -1
 SECTOR 1 -1
 SECTOR 1 1
 5
 1.OXSQ 1.OYSQ -33.1142 \$
 1.OXSQ 1.OYSQ -8.547X 18.198286 \$
 1.OXSQ 1.OYSQ 8.547X 18.198286 \$
 1.OXSQ 1.OYSQ -8.547X 18.117641 \$

3.0 1.0XSC 1.0YSQ 8.547X 18.117641 \$

KENO VALIDATION CASE B-7

53	400	3	16	6	11	3	11	5	1	3	3	1
11	0	0	1									
1			-92501.04477E									
1			92860.0332513									
2			200 1.0									
3			28100.06215E									
3			24100.01543E									
3			26100.00907E1									
3			25100.00092253									
3			6100.00063293									
3			29100.00039E78									
3			14100.00090226									
3			16100.00002E709									

GENERAL 1

GENERAL 2

GENERAL 3

GENERAL 0 6.073 -6.073 6.073 -6.073 7.0 -7.0

CUBOID 0 6.073 -6.073 6.073 -6.073 7.0 -7.0

2 MALE MARRIED

X ZONE -6.073, 6.073

Y ZONE -6.073, 6.073

Z ZONE -7.0, 7.0

ZONE 1 1 1

X BLOCK -6.073, 6.073

Y BLOCK -6.073, 6.073

Z BLOCK -7.0, -5.3825, 5.3825, 7.0

BLOCK 1 1 1

MEDIA 2, 2, 3, 3, 4

SURFACES 2, 3, 4, 5

SECTOR -1

SECTOR -1

SECTOR 1 -1

SECTOR 1 1 1

BLOCK 1 1 2

MEDIA 1, 2, 2, 4

SURFACES 1, 2, 3

SECTOR -1 1 1

SECTOR -1

SECTOR -1

SECTOR 1 1

BLOCK 1 1 3

MEDIA 2, 2, 3, 3, 4

SURFACES 2, 3, 4, 5

SECTOR -1

SECTOR -1

SECTOR 1 -1

SECTOR 1 -1

SECTOR 1 1

5

1.0XSC	1.0YSQ	-33.1142	\$
1.0XSC	1.0YSQ	-8.547X	18.198286 \$
1.0XSC	1.0YSQ	8.547X	18.198286 \$
1.0XSC	1.0YSQ	-8.547X	18.117641 \$
1.0XSC	1.0YSQ	8.547X	18.117641 \$

1.0

KENO VALIDATION CASE B-8

53	400	3	16	6	2	1	2	4	1	2	2	2
2	0	0	1									
1			-92501.044623									
1			92860.0032146									

BOX TYPE 1

CYLINDER 1 4.558 2.16 -2.16

CYLINDER 0 5.747 2.16 -2.16

CYLINDER 1 5.747 4.851 -4.851

CUBOID 0 5.8554 -5.8554 5.8554 -5.8554 4.9771 -4.9771

25.0

KENO VALIDATION CASE B-9

53	400	3	16	6	4	2	4	7	1	2	2	2
4	0	0	1									
1			-92501.044604									
1			92860.0032132									
2			6100.009702									
2			1101.002581									

BOX TYPE 1

CYLINDER 1 4.558 2.160 -2.160

CYLINDER 0 5.747 2.160 -2.160

CYLINDER 1 5.747 4.851 -4.851

CUBOID 0 9.2082 -9.2083 9.2083 -9.2083 8.2875 -8.2875

CORE ELY 0 18.4166-18.4166 18.4166-18.4166 16.5750-16.5750

CUBOID 2 33.617 -33.617 33.617 -33.617 31.775 -31.775

CUBE 0 34.0 -34.0

20.0

KENO VALIDATION CASE E-10

53	407	3	16	6	4	2	4	5	1	2	2	2
4	0	0	1									
1			-92501.0447915									
1			92860.00320426									
2			6100.009702									

2 1101.0A2581
 BCX TYPE 1
 CYLINDER 1 4.558 8.641 -8.641
 CUBOID 0 9.7212 -9.7212 9.7212 -9.7212 13.8041-13.8041
 CORE BCY 0 19.4424-19.4424 19.4424-19.4424 27.6082-27.6082
 CUBOID 2 34.6424-34.6424 34.6424-34.6424 42.8082-42.8082
 CUBE 0 43.0 -43.0

25.0
 KENO VALIDATION CASE B-11
 53 400 3 16 6 3 2 3 4 1 2 2 2
 3 0 0 1
 1 -92501.044720
 1 92860.0032216
 2 601 1.0
 BCX TYPE 1
 CYLINDER 1 5.753 5.3825 -5.3825
 CUBOID 0 7.68 -7.68 7.68 -7.68 7.33 -7.33
 CUBOID 2 8.95 -8.95 8.95 -8.95 8.6 -8.6
 CUBOID 0 9.0599 -9.0599 9.0599 -9.0599 8.6975 -8.6975

30.0
 KENO VALIDATION CASE E-12
 53 400 3 16 6 5 3 5 7 1 2 2 2
 5 0 0
 1 -92501.044720
 1 92860.0032216
 2 601 1.0
 3 6100.039702
 3 1102.082581
 BCX TYPE 1
 CYLINDER 1 5.753 5.3825 -5.3825
 CUBOID 0 8.32 -8.32 8.32 -8.32 7.97 -7.97
 CUBOID 2 10.7 -10.7 10.7 -10.7 10.35 -10.35
 CUBOID 0 13.992 -13.992 13.992 -13.992 13.572 -13.572
 CORE BCY 0 27.984 -27.984 27.984 -27.984 27.144 -27.144
 CUBOID 3 43.184 -43.184 43.184 -43.184 42.344 -42.344
 CUBE 0 45.0 -45.0

5.0
 KENO VALIDATION CASE E-13

53 400 3 16 6 6 2 6 4 1 3 3 3
 6 0 0 1
 1 -92508.00098447
 1 92852.00007767
 1 7100.00197484
 1 8100.03705066
 1 1102.05808373
 2 602 1.0
 BOX TYPE 1
 CYLINDER 1 9.52 8.7804 -8.7804
 CYLINDER 0 9.52 8.9896 -8.7804
 CYLINDER 2 10.16 9.6296 -9.4204
 CUBOID 0 13.1077-13.1077 13.1077-13.1077 12.3681-12.3681

5.0
 KENO VALIDATION CASE B-14
 53 400 3 16 6 6 2 6 4 1 3 3 3
 6 0 0 1
 1 -92512.00015019
 1 92855.000011851
 1 7100.00032408
 1 8100.034338
 1 1102.066084
 2 602 1.0
 BOX TYPE 1
 CYLINDER 1 9.52 8.7804 -8.7804
 CYLINDER 0 9.52 8.9895 -8.7804
 CYLINDER 2 10.16 9.6295 -9.4204
 CUBOID 0 11.282-11.282 11.282 -11.282 10.7179-10.7179

30.0
 KENO VALIDATION CASE B-15
 53 400 3 16 6 10 3 10 11 2 4 4 2
 10 0 0 1
 1 -92508.00120603
 1 92852.00008688
 1 7100.00258582
 1 8100.037587
 1 1102.054487
 2 602 1.0
 3 26100.057995
 3 24100.016513
 3 28100.011375
 3 6100.00039714
 BOX TYPE 1
 CYLINDER 1 6.8 1.76 -1.76
 CYLINDER 3 7.08 1.76 -2.04

```

CUBOID      1 15.075 -15.075 15.075 -15.075 1.76 -2.04
BOX TYPE    2
CYLINDER    1 6.8      30.5 -30.5
CYLINDER    0 6.8      96.7 -30.5
CYLINDER    3 7.08     96.7 -30.5
CUBOID      0 15.075 -15.075 15.075 -15.075 125.7 -30.5
CORE BDY    0 60.3     -60.3 60.3 -60.3 80.0 -80.0
CUBOID      3 60.3     -60.3 60.3 -60.3 80.0 -80.635
CUBOID      2 70.5     -70.5 70.5 -70.5 90.2 -90.835
CUBE        0 95.0     -95.0

1 1 1 1 1 4 1 1 1 1
2 1 4 1 1 4 1 2 2 1
25.0
XENC VALIDATION CASE E-16
53 400 3 16 6 7 3 7 7 1 2 2 2
7 0 0 1
1 -92501.644778
1 92860.0032513
2 1101.00003437
2 5100.00000018
2 6100.0556845
2 26100.00103414
3 402 1.0
BOX TYPE    1
CYLINDER    1 5.747     3.9599 -4.1071
CYLINDER    0 5.777     4.1071 -4.1071
CUBOID      2 10.9195-10.9195 10.9195-10.9195 7.8755 -7.8755
CUBOID      0 15.047 -15.047 15.047 -15.047 12.0035-12.0035
CORE BDY    0 30.094 -30.094 30.094 -30.094 24.007 -24.007
CUBOID      3 45.334 -45.334 45.334 -45.334 39.247 -39.247
CUBE        0 46.0     -46.0

```

APPENDIX B

**CROSS-SECTION IDENTIFICATION NUMBERS AND SOURCES
OF THE CROSS SECTIONS**

Identification Number	Material	Source
<u>ANISN</u>		
1	Aluminum	Hansen-Roach ⁽⁴⁾
4	Carbon	Hansen-Roach
9	Fluorine	Hansen-Roach
10	Iron	Hansen-Roach
12	Hydrogen ANISO 1	Hansen-Roach
13	Hydrogen ANISO 2	Hansen-Roach
19	Nickel	Hansen-Roach
20	Oxygen	Hansen-Roach
87	U-238-Y Inf	Hansen-Roach
105	Nitrogen	Hansen-Roach
107	U-235-YR Inf	Hansen-Roach
108	U-235-1R Sig P = 20	Hansen-Roach
115	U-235-8R Sig P = 1000	Hansen-Roach
121	U-238-4R Sig P = 100	Hansen-Roach
122	U-238-5R Sig P = 200	Hansen-Roach
124	U-238-7R Sig P = 600	Hansen-Roach
131	Chromium	Aerojet ⁽²⁴⁾
355	Manganese ANISO 1	GAM II ⁽²⁵⁾
356	Manganese ANISO 2	GAM II
365	Sulfur ANISO 1	GAM II
366	Sulfur ANISO 2	GAM II
367	Silicon ANISO 1	GAM II
368	Silicon ANISO 2	GAM II
<u>KENO</u>		
200	304 Stainless Steel	Hansen-Roach, XSDRN ⁽²⁶⁾
402	Polyethylene dE/E	Hansen-Roach
502	Water dE/E	Hansen-Roach
602	Plexiglas dE/E	Hansen-Roach
1101	Hydrogen X(E)	Hansen-Roach
1102	Hydrogen dE/E	Hansen-Roach
6100	Carbon	Hansen-Roach
7100	Nitrogen	Hansen-Roach
8100	Oxygen	Hansen-Roach
9100	Fluorine	Hansen-Roach
13100	Aluminum	Hansen-Roach
14100	Silicon	XSDRN
16100	Sulfur	XSDRN
24100	Chromium	Aerojet
25100	Manganese	XSDRN
26100	Iron	Hansen-Roach
28100	Nickel	Hansen-Roach

Identification Number	Material	Source
29100	Copper	XSDRN
42100	Molybdenum	Hansen-Roach
92500	U-235-YR Inf	Hansen-Roach
92501	U-235-1R Sig P = 20	Hansen-Roach
92505	U-235-5R Sig P = 200	Hansen-Roach
92506	U-235-6R Sig P = 400	Hansen-Roach
92508	U-235-8R Sig P = 1000	Hansen-Roach
92800	U-238-Y Inf	Hansen-Roach
92801	U-238 Sig P = 12	Hansen-Roach, JRK Modified ^(a)
92808	U-238 Sig P = 45	Hansen-Roach, JRK Modified
92825	U-238 Sig P = 180	Hansen-Roach, JRK Modified
92852	U-238 Sig P = 20000	Hansen-Roach
92856	U-238-1R Sig P = 20	Hansen-Roach
92859	U-238-4R Sig P = 100	Hansen-Roach
92860	U-238-5R Sig P = 200	Hansen-Roach
92862	U-238-7R Sig P = 600	Hansen-Roach

(a) This cross-section set was modified by J. R. Knight to depict the large changes in the U-238 resonance region based on critical experiments performed at Hanford with two and three percent enriched uranium in paraffin.⁽²⁷⁾

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