Y/DD-651

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VALIDATION OF NCSSHP FOR HIGHLY ENRICHED URANIUM SYSTEMS CONTAINING BERYLLIUM

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September 29, 1994

Prepared by the
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Oak Ridge, Tennessee 37831-8238
Managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U. S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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Abstract

This document describes the validation of KENO V.a using the 27-group ENDF/B-IV cross section library for highly enriched uranium and beryllium neutronic systems, and is in accordance with ANSI/ANS-8.1-1983(R1988) requirements for calculational methods. The validation has been performed on a Hewlett Packard 9000/Series 700 Workstation at the Oak Ridge Y-12 Plant Nuclear Criticality Safety Department using the Oak Ridge Y-12 Plant Nuclear Criticality Safety Software code package. Critical experiments from LA-2203, UCRL-4975, ORNL-2201, and ORNL/ENG-2 have been identified as having the constituents desired for this validation as well as sufficient experimental detail to allow accurate construction of KENO V.a calculational models. The results of these calculations establish the safety criteria to be employed in future calculational studies of these types of systems.

Prepared by: Allan W. Krass 9/29/94

Reviewed by: [signature] 9/29/94

Approved by: [signature] 9-29-94

Introduction

Extensive use is made of calculational methods in applied nuclear criticality safety to establish subcritical limits for operations involving fissionable material. ANSI/ANS-8.1-1983(R1988)[1], "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," requires that in the absence of directly applicable experimental measurements, the subcritical limits may be derived from calculations made by a method shown to be valid by comparison with experimental data, provided that sufficient allowances are made for uncertainties in the data and calculations.

CSAS25 is a control sequence of the Nuclear Criticality Safety Software (NCSS) that executes the functional modules BONAMI-S, NITAWL-S, and KENO-V.a. The CSAS25 control sequence and the 27-group ENDF/B-IV neutron cross section library has been maintained under configuration control and validated on the IBM 3033 mainframe computer at the Oak Ridge National Laboratory (NX10). The validation is documented in ORNL/CSD/TM-238[2].

A copy of CSAS25 as a portion of the NCSS has been installed to operate on a Hewlett Packard 9000/Series 700 Workstation (NCSSHP) at the Oak Ridge Y-12 Plant Nuclear Criticality Safety Department. NCSSHP is in compliance with MMES Y-12 software configuration control methodology[3]. The 27-group neutron cross section library is maintained as a database within NCSSHP. The validation has been repeated for the NCSSHP and is documented in Y/DD-573[4]. However, the existing validation does not include critical experiments with highly enriched uranium and beryllium systems that are documented in LA-2203[5], UCRL-4975[6], ORNL-2201[7], and ORNL/ENG-2[8]. Therefore, the purpose of this report is to satisfy ANSI/ANS requirements for the validation of highly enriched uranium and beryllium systems in support of ongoing criticality safety work, using KENO-V.a in the CSAS25 control module and the 27-group ENDF/B-IV neutron cross section library on the Hewlett Packard Workstation at the Oak Ridge Y-12 Plant.

Code Description

The CSAS25 control sequence reads user-specified input data for the BONAMI-S, NITAWL-S, and KENO-V.a functional modules. The input data specifies the master cross section library, the material compositions, the nuclide resonance processing information (size, geometry, and temperature), and the detailed geometry model. Physical and neutronics information not specified but required by the functional modules is supplied by the Standard Composition Library or calculated by the Materials Information Processor.

BONAMI-S performs a resonance self-shielding correction to the cross section data through the application of the Bondarenko shielding factor method. This generates a smaller, problem-specific cross section library which is read by NITAWL-S. BONAMI-S reads the master format library and applies the Bondarenko correction to all nuclides that have Bondarenko data. However, no data processing is done in BONAMI-S for the 27-group ENDF/B-IV neutron cross section library.

The 27-group ENDF/B-IV neutron cross section library is activated in the CSAS25 control sequence by specifying 27GROUPNDF4 as the master cross section library name. The 27-group library is the broad-group companion library to the 218-group Criticality Safety Reference Library, which has been generated as a fine-group structure library based on ENDF/B-IV data for use in general criticality safety analyses and shipping cask calculations. The 27-group library is collapsed from the 218-group library using a characteristic Fission-(1/E)-Maxwellian spectral flux shape. Explicit ENDF/B-IV resonance parameters are carried for resonance nuclides in both the 27-group and 218-group libraries. These resonance parameters are used by NITAWL-S in the CSAS25 control sequence for calculating problem-dependent, self-shielded resonance region cross sections.

NITAWL-S applies the Nordheim Integral Treatment to perform neutron cross section processing in the resonance energy range for nuclides that have ENDF/B resonance parameter data. This technique involves the numerical integration of ENDF/B resonance parameters using a calculated flux distribution, which is based on the calculated collision density across each resonance, and subsequent weighting of the reaction cross section to the desired broad-group structure. Input data to NITAWL-S, automatically set up by the CSAS25 control sequence, includes information relating the physical and neutronic characteristics of the system being calculated. NITAWL-S uses this data to complete the processing of the problem-dependent master library from BONAMI-S. NITAWL-S assembles the group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks to produce a problem-dependent, working cross section library which can be used by KENO-V.a.

Finally, KENO-V.a determines the effective neutron multiplication factor (k_{eff}) for the physical system defined in the CSAS25 input data using the Monte Carlo method.

Critical Experiments and the KENO V.a Models

LA-2203

Critical masses are measured for 5-1/4 inch diameter highly enriched uranium metal cylinders in 1/2 inch and 1 inch thick reflectors. Similarly, critical masses of highly enriched uranium metal spheres in ~2 inch and ~4 inch thick reflectors are also measured. A variety of reflector materials are included in this report, but only those cases involving the beryllium isotope are of interest to this validation.

These experiments were conducted at the Pajarito remote-control laboratory of the Los Alamos National Laboratory prior to 1958 using the Comet universal machine. The machine consists of a hydraulic lift with a stationary platform. The reflector materials used in these experiments are Be, BeO, or Be and Fe of varying thicknesses. The fuel is uranium metal enriched to ~93.5 wt % ^{235}U, and the experiment is a subcritical neutron-multiplication measurement in which the two parts of the critical assembly are brought together, thus allowing a 1/M extrapolation to critical mass.

A total of four cylindrical Be-reflected experiments and five spherical Be-reflected experiments have been selected from the report for the purposes of this validation. The report provides sufficient data to generate an accurate KENO V.a model with few assumptions or approximations. It is assumed that U(93.5) is 93.5 wt % ^{235}U and 6.5 wt % ^{238}U, and it is further assumed that Fe(SAE 1020) can be reasonably modeled using the CARBONSTEEL data from the Standard Composition Library adjusted to the reported experimental density. Where critical mass uncertainties are reported, the lower bound of the data is used to produce a lower calculated k_{eff}, resulting in a more conservative subcritical limit. No other assumptions are necessary.

UCRL-4975

The critical thickness of Be reflectors are determined for highly enriched uranium metal spheres ranging from 10.765 Kg to 32.654 Kg. These experiments were conducted at the University of California Radiation Laboratory in Livermore, CA prior to October, 1957. The reflector materials consist of hemispherical nesting shells of about 0.25 inch thickness. The fuel is uranium metal enriched to 93.17 wt % ^{235}U, and the experiment is a subcritical inverse neutron-multiplication measurement extrapolated to zero, yielding the corresponding reflector thickness for delayed critical.

A total of eight spherical Be-reflected experiments have been selected from the report for the purposes of this validation. The only assumption necessary for these KENO V.a models is that U(93.17) is taken to be 93.17 wt % ^{235}U and 6.83 wt % ^{238}U. All other data crucial to generating an accurate KENO V.a model are provided in the report.

ORNL-2201

These two Be-moderated experiments, designated as CA-1 and CA-18, were conducted at the Oak Ridge National Laboratory Critical Experiments Facility during the period from 1951 to 1954. The experiments utilized the Honeycomb split-table machine which is a 24 x 24 array of three inch square aluminum tubes into which the materials are inserted.

In CA-1, the assembly materials consisted of 0.01 inch thick U(93.4) disks separated by 1 inch thick Be blocks, which gives a Be:^{235}U ratio of 390 and a critical fuel loading of 18.08 Kg of ^{235}U.

In CA-18, the assembly materials consisted of 0.01 inch thick U(93.4) disks separated by 4 inch thick Be blocks, which gives a Be:^{235}U ratio of 1560 and a critical fuel loading of 7.65 Kg of ^{235}U.

To model both of these Be-moderated critical assemblies, a number of assumptions have been made due to a lack of detail in the report description. The uranium loading is reported as 16.774 g ^{235}U on average in each fuel disk, which measures 2.860 inches in diameter and 0.01 inches thick. This translates to a bulk uranium fuel density of 17.14 g/cc given 93.4 wt % ^{235}U and assuming 6.6 wt % ^{238}U. To account for the geometric effects of thin fuel "slabs" separated by thicker moderator "slabs," the LATTICECELL cross section processing option for slab geometry is employed in each case.

Little description is provided for the room itself, except for the steel table and the distance of the assembly from the floor. The model uses 3/4 inch CARBONSTEEL for the table and 12 inches of MGCONCRETE for the floor, which is consistent with the reported data. The walls and ceiling are excluded since no information is available. No mention is made about the type of steel used in the rods that hold the assemblies together, so they are taken to be SS304. The length of the aluminum tubes that make up the assembly is unclear, so it is modeled as equal to the length of the fuel/moderator element for each case. Finally, the elements are assumed to be centered in each tube, i.e., there is a constant-width gap around each element in each tube.

ORNL/ENG-2

A series of experiments using Experimental Beryllium Oxide Reactor fuel pins were performed at the Oak Ridge Critical Experiments Facility. The cases of interest for this validation are the heterogeneous lattices of the fuel pins in water.

The fuel pins are compressed ceramic fuel pellets contained in Hastelloy X-280 tubes. The pellets are a homogeneous mixture of U(62.4) and BeO, which gives a Be:^{235}U ratio of 13 and an average ^{235}U mass loading of 156.27 g per fuel pin.

The experiments differ in pin spacing and water height measurements to achieve criticality. A total of nine critical fuel pin configurations have been selected for the validation. Limitations of the geometry package in KENO V.a do not permit the modeling of the helical spacer around each fuel pin. It is only a 0.0205 inch thick by 0.062 inch wide wire wrapped around the fuel pin on a 7.50 pitch, so its omission should have a negligible effect. To simplify the model, the 0.005 inch groove in each fuel pellet is also omitted, and a fuel radius is used which yields the same volume for a constant height.

No material specifications could be found for Hastelloy X-280, so the material composition data for Hastelloy-X is substituted. This materials data is from the Nuclear Engineering Handbook[9] which gives a composition of 0.15 wt % Carbon, 22.0 wt % Chromium, 45.0 wt % Nickel, 9.0 wt % Molybdenum, and the remainder (23.85 wt %) Iron. The alloy is assumed to be volume-additive for a bulk density of 8.38 g/cc.

Little description is provided about the tank itself. The height of the water above the top of the fuel pins is provided, as well as the thickness of water below the bottom of the fuel pins. No other details are given, so the tank is taken to be a nine foot diameter tank with steel construction to approximate the effectively infinite water reflection provided by the tank used in the experiments.

Fuel pin spacings are assumed to be constant, based on the average spacings reported in the document. To account for the geometric effects of closely spaced, thin fuel rods with a moderator between the rods, the LATTICECELL cross section processing option for a square-pitch geometry is employed in each case.

Discussion and Conclusions

The benchmark calculational results for the highly enriched uranium and beryllium experiments show overall agreement with the experimental k_{eff} value of 1.0 for the workstation, as shown in Table 1. The KENO V.a input for the validation cases is included at the end of this report. The code used to perform the statistical analysis of the validation results is referenced in Y/DD-574[10].

Bias between the calculated values of k_{eff} and the measured value from the experiments was not calculated. The bias is a variable which may be a function of a number of parameters, such as geometry, material, enrichment, and the average energy group of the neutron causing fission. The bias is only meaningful as an average, and the average depends on the subgroup of experiments chosen for comparison. The average bias, whether positive or negative, is taken into account through a detailed statistical analysis of the validation results. In this manner, not only the average bias but also the variability of the calculated results is taken into account.

The detailed statistical analysis consists of determining tolerance bands, such that 99.9 percent of the distribution of calculated k_{eff} are within the tolerance bands with a confidence level of 95 percent. This analytical method permits the establishment of upper and lower tolerance band limits, although only the lower band limit is of importance for criticality safety purposes. The established tolerance band width takes into account the average k_{eff} of the validation calculations along with the dispersion of the data above and below the average. The larger the dispersion of data around the average, the greater the band width. The trend analysis is correlated to the average neutron energy group causing fission (AEG), a parameter calculated by KENO-V.a which is a weighted average of the 27 energy groups causing fission. This parameter allows for a direct comparison of the calculations with similar neutron energy spectra between the validation problems and the calculations in the criticality safety evaluation.

The lower tolerance band limit established by the method described above becomes the upper safety limit for the criticality safety evaluation. Acceptance criteria for subcriticality of KENO-V.a calculations, defined as the neutron multiplication factor plus two standard deviations ($k_{eff} + 2\sigma$), must be less than the lower tolerance band limit at the appropriate average energy group of neutrons causing fission.

Figure 1, Figure 2, and Figure 3 are the rough plots from the output of the statistical analysis code on the HP workstation. The statistical treatment provides the safety criteria against which all future calculations are to be compared for criticality or subcriticality. Given the results of this validation, KENO-V.a in the CSAS25 control module and the 27-group ENDF/B-IV neutron cross section library on the Hewlett Packard 9000/Series 700 Workstation at the Oak Ridge Y-12 Plant can be used to perform calculational studies of all systems containing highly enriched uranium, beryllium, oxygen, and hydrogen.

Table 1. Average k_{eff} for U/Be Validation Cases

Source Document	Case	AEG	$K_{eff} \pm \sigma$
LA-2203	case_01	6.72469	1.00566 ± 0.00180
	case_02	5.18590	1.01181 ± 0.00187
	case_03	5.12618	1.01414 ± 0.00193
	case_04	5.09398	1.01154 ± 0.00193
	case_05	6.72076	1.01250 ± 0.00192
	case_06	5.41756	1.01119 ± 0.00207
	case_07	5.44795	1.01964 ± 0.00207
	case_08	5.77429	1.03068 ± 0.00205
	case_09	5.44606	1.02493 ± 0.00196
UCRL-4975	case_10	8.13432	1.01663 ± 0.00207
	case_11	6.41742	1.01821 ± 0.00198
	case_12	6.18971	1.01162 ± 0.00199
	case_13	5.52504	1.01061 ± 0.00208
	case_14	5.48490	1.01565 ± 0.00207
	case_15	5.24620	1.00984 ± 0.00184
	case_16	5.15276	1.01260 ± 0.00200
	case_17	5.11391	1.00078 ± 0.00190
ORNL-2201	ca_1	17.8977	1.01797 ± 0.00178
	ca_18	22.1621	1.00218 ± 0.00189
ORNL/ENG-2	pin_02	20.3386	1.05559 ± 0.00107
	pin_03	21.7063	1.03869 ± 0.00117
	pin_04	22.4680	1.03079 ± 0.00114
	pin_05	22.9507	1.02494 ± 0.00118
	pin_06	23.2819	1.02093 ± 0.00109
	pin_07a	23.2622	1.01842 ± 0.00114
	pin_07b	23.6476	1.01310 ± 0.00102
	pin_08	23.4810	1.01859 ± 0.00111
	pin_09	23.7493	1.01021 ± 0.00099
	pin_10	23.4913	1.01598 ± 0.00101

Figure 1. k_{eff} vs. Average Energy Group Causing Fission for U/Be Systems

```
lower tolerance bound for
95.0 percent confidence on 99.9 percent of the population
yc =      b0      -    ksigma    + x *     b1
yc =  1.0118E+00 -  5.2450E-02 + x *  4.4380E-04
yc =  9.5937E-01               + x *  4.4380E-04
The value of y is:  9.6159E-01 when x is:  5.0000E+00
The value of y is:  9.7002E-01 when x is:  2.4000E+01

margin between the confidence band for a single
future calculation and the lower tolerance bound 3.3281E-02
```

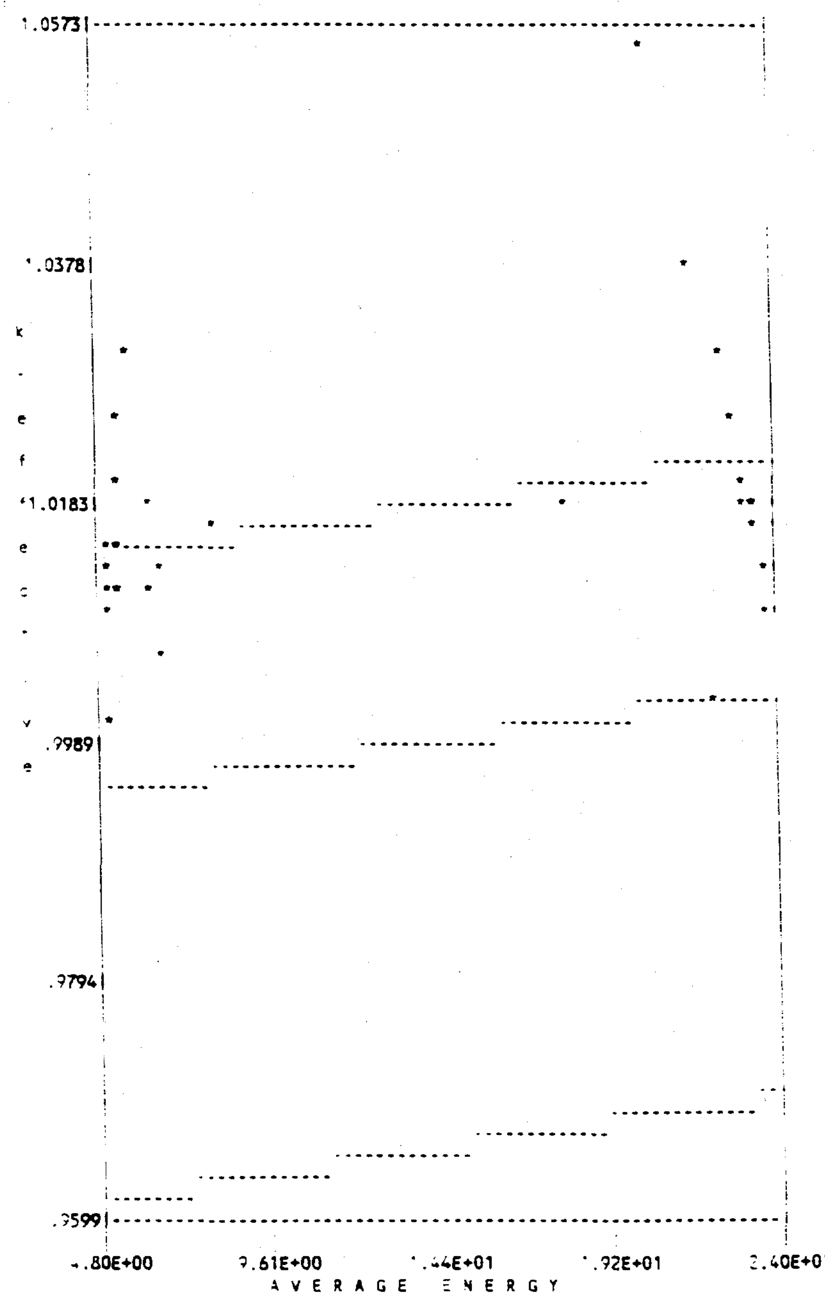


Figure 2. k_{eff} vs. Average Energy Group Causing Fission for U/Be Systems, Low Average Energy Groups

```
lower tolerance bound for
95.0 percent confidence on 99.9 percent of the population
yc =      b0       -     ksigma    + x *      b1
yc =  1.0091E+00 -  4.8682E-02 + x *  8.5309E-04
yc =  9.6039E-01                + x *  8.5309E-04
The value of y is:  9.6466E-01 when x is:  5.0000E+00
The value of y is:  9.6764E-01 when x is:  8.5000E+00

margin between the confidence band for a single
future calculation and the lower tolerance bound 3.1661E-02
```

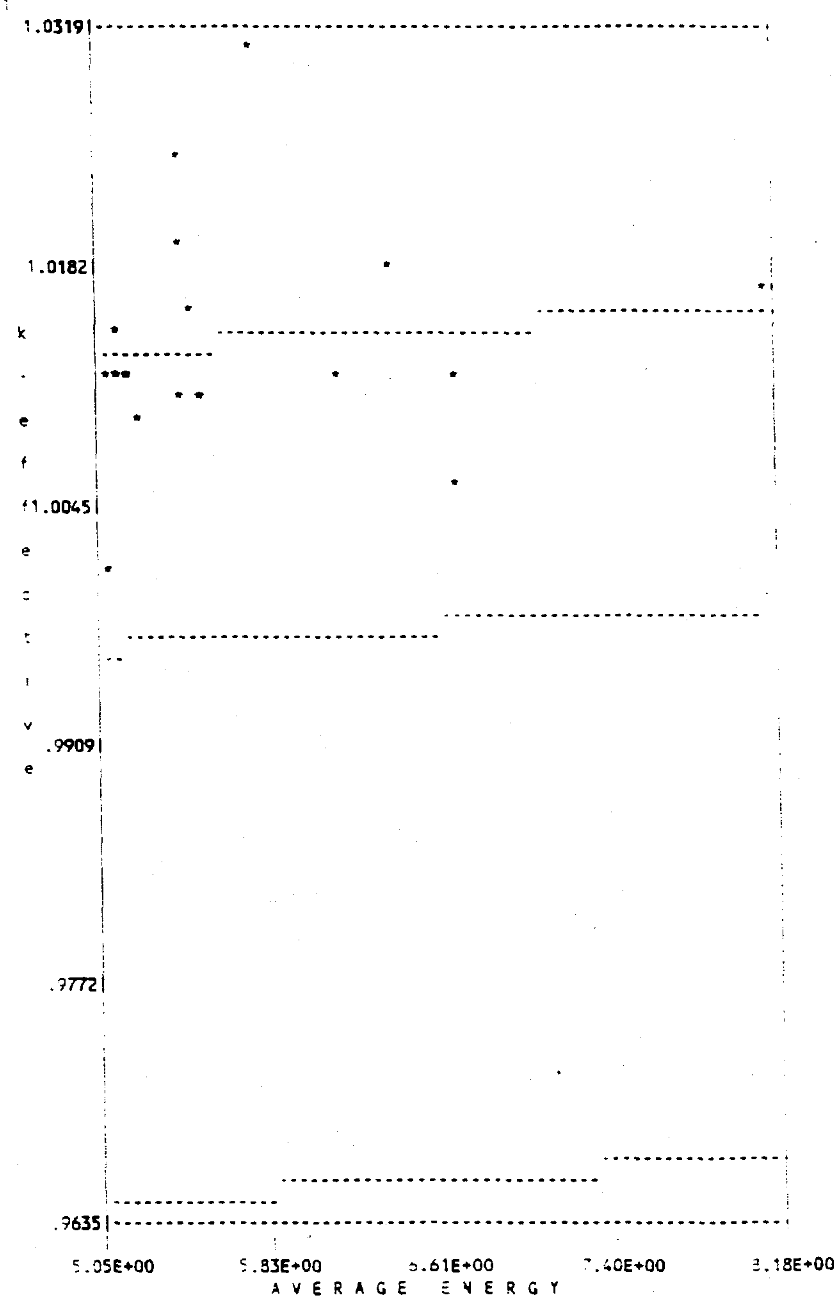
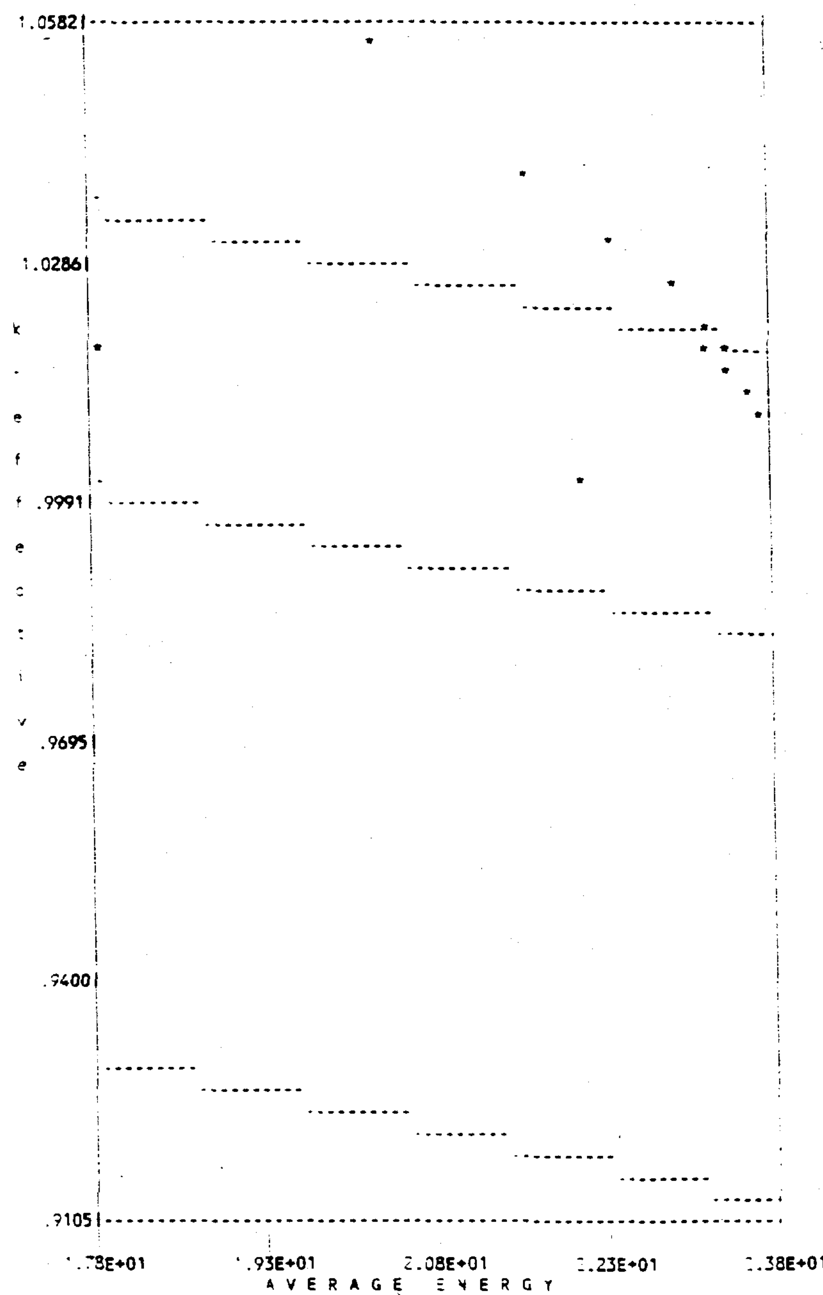


Figure 3. k_{eff} vs. Average Energy Group Causing Fission for U/Be Systems, High Average Energy Groups

```
lower tolerance bound for
95.0 percent confidence on 99.9 percent of the population
yc =      b0       -     ksigma    + x *      b1
yc =  1.0888E+00  -  1.0513E-01  + x * -2.9725E-03
yc =  9.8364E-01                 + x * -2.9725E-03
The value of y is:  9.3311E-01 when x is:  1.7000E+01
The value of y is:  9.1230E-01 when x is:  2.4000E+01

margin between the confidence band for a single
future calculation and the lower tolerance bound 7.0021E-02
```



```
=csas25          parm=size=500000
ORNL-2201 critical exp case CA-1
27groupndf4        latticecell
u-235        1  0  4.1017e-2  293  end
u-238        1  0  2.8618e-3  293  end
be           2  0  1.2429e-1  293  end
al           3  1.0  293  end
ss304        4  1.0  293  end
mgconcrete   5  1.0  293  end
carbonsteel  6  1.0  293  end
end comp
symmslabcell 2.5654 0.0254 1 2 end
case CA-1 from ORNL-2201, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=1000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=3 run=yes
end parm
read geom
unit 1
'empty al tubing'
cuboid      0  1  4p3.69062  58.9788  0.0
cuboid      3  1  4p3.81     58.9788  0.0
unit 2
'fuel in al tubing w/al skewer'
cylinder    3  1     0.238125  0.0254  0.0
cylinder    0  1     0.24892   0.0254  0.0
cylinder    1  1     3.6322    0.0254  0.0
cuboid      0  1  4p3.69062    0.0254  0.0
cuboid      3  1  4p3.81       0.0254  0.0
unit 3
'fuel in al tubing w/ss304 skewer'
cylinder    4  1     0.238125  0.0254  0.0
cylinder    0  1     0.24892   0.0254  0.0
cylinder    1  1     3.6322    0.0254  0.0
cuboid      0  1  4p3.69062    0.0254  0.0
cuboid      3  1  4p3.81       0.0254  0.0
unit 4
'be in al tubing w/al skewer'
cylinder    3  1     0.238125  2.54     0.0
cylinder    0  1     0.24892   2.54     0.0
cuboid      2  1  4p3.65125    2.54     0.0
cuboid      0  1  4p3.69062    2.54     0.0
cuboid      3  1  4p3.81       2.54     0.0
unit 5
'be in al tubing w/ss304 skewer'
cylinder    4  1     0.238125  2.54     0.0
cylinder    0  1     0.24892   2.54     0.0
cuboid      2  1  4p3.65125    2.54     0.0
cuboid      0  1  4p3.69062    2.54     0.0
cuboid      3  1  4p3.81       2.54     0.0
unit 6
'core assembly w/al skewer'
array       1     0  0  0
unit 7
'core assembly w/ss304 skewer'
array       2     0  0  0
global unit 8
array       3     0  0  0
replicate  6  1  2r0.0  0.0   1.905 2r0.0  1.0
replicate  0  1  2r304.8  0.0  66.04  2r304.8  1.0
replicate  5  1  2r0.0  0.0  30.48  2r0.0  1.0
end geom
read array
ara=1  nux=1 nuy=1 nuz=45
fill 4 2 4 21q2 end fill
ara=2  nux=1 nuy=1 nuz=45
fill 5 3 5 21q2 end fill
ara=3  nux=24 nuy=24 nuz=1
loop
1    1 24 1    1 24 1    1 1 1
6   10 16 1    9 15 1    1 1 1
7   13 13 1   10 10 1    1 1 1
7   15 15 1   11 11 1    1 1 1
7   11 15 2   13 13 1    1 1 1
7   13 13 1   15 15 1    1 1 1
end loop
end array
read start
nst=4  tfx=0.0 tfy=0.0 tfz=30.7721 nbx=6
end start
```

```
end

=csas25          parm=size=500000
ORNL-2201 critical exp case CA-18
27groupndf4       latticecell
u-235        1  0  4.1017e-2  293  end
u-238        1  0  2.8618e-3  293  end
be           2  0  1.2429e-1  293  end
al           3  1.0  293  end
ss304        4  1.0  293  end
rgconcrete   5  1.0  293  end
carbonsteel  6  1.0  293  end
end comp
symmslabcell 10.1854 0.0254 1 2 end
case CA-18 from ORNL-2201, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=1000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=3 run=yes
end parm
read geom
unit 1
'empty al tubing'
cuboid     0  1  4p3.69062  61.1124  0.0
cuboid     3  1  4p3.81     61.1124  0.0
unit 2
'fuel in al tubing w/al skewer'
cylinder   3  1     0.238125  0.0254  0.0
cylinder   0  1     0.24892   0.0254  0.0
cylinder   1  1     3.6322    0.0254  0.0
cuboid     0  1  4p3.69062    0.0254  0.0
cuboid     3  1  4p3.81       0.0254  0.0
unit 3
'fuel in al tubing w/ss304 skewer'
cylinder   4  1     0.238125  0.0254  0.0
cylinder   0  1     0.24892   0.0254  0.0
cylinder   1  1     3.6322    0.0254  0.0
cuboid     0  1  4p3.69062    0.0254  0.0
cuboid     3  1  4p3.81       0.0254  0.0
unit 4
'be in al tubing w/al skewer'
cylinder   3  1     0.238125  2.54    0.0
cylinder   0  1     0.24892   2.54    0.0
cuboid     2  1  4p3.65125    2.54    0.0
cuboid     0  1  4p3.69062    2.54    0.0
cuboid     3  1  4p3.81       2.54    0.0
unit 5
'be in al tubing w/ss304 skewer'
cylinder   4  1     0.238125  2.54    0.0
cylinder   0  1     0.24892   2.54    0.0
cuboid     2  1  4p3.65125    2.54    0.0
cuboid     0  1  4p3.69062    2.54    0.0
cuboid     3  1  4p3.81       2.54    0.0
unit 6
'quarter-fuel in al tubing'
cuboid     1  1  2p3.65125  0.0  -3.65125  0.0254  0.0
cuboid     0  1  4p3.69062  0.0254  0.0
cuboid     3  1  4p3.81     0.0254  0.0
unit 7
'quarter-be in al tubing'
cuboid     2  1  2p3.65125  0.0  -3.65125  2.54  0.0
cuboid     0  1  4p3.69062  2.54  0.0
cuboid     3  1  4p3.81     2.54  0.0
unit 8
'core assembly w/al skewer'
array      1      0  0  0
unit 9
'core assembly w/ss304 skewer'
array      2      0  0  0
unit 10
'quarter-core assembly'
array      3      0  0  0
global unit 11
array      4      0  0  0
replicate  6  1  2r0.0  0.0   1.905 2r0.0  1.0
replicate  0  1  2r304.8  0.0  66.04  2r304.8  1.0
replicate  5  1  2r0.0  0.0  30.48  2r0.0  1.0
end geom
read array
ara=1  nux=1 nuy=1 nuz=30
```

```
ara=2  nux=1 nuy=1 nuz=30
fill 5 5 3 5 5 5q5 end fill
ara=3  nux=1 nuy=1 nuz=30
fill 7 7 6 7 7 5q5 end fill
ara=4  nux=24 nuy=24 nuz=1
loop
1     1 24 1    1 24 1    1 1 1
8     8 15 1    8 16 1    1 1 1
10    8 15 1   17 17 1    1 1 1
9    15 15 1    8  8 1    1 1 1
9    13 13 1    9  9 1    1 1 1
9    11 15 2   12 12 1    1 1 1
9    11 11 1   13 13 1    1 1 1
9    13 13 1   16 16 1    1 1 1
end loop
end array
read start
nst=4 tfx=0.0 tfy=0.0 tfz=25.4635 nbx=8
end start
end data
end


=csas25
LA-2203 critical exp cyl
27groupnaf4       infhommedium
u-235         1  0  4.5037e-2  293  end
u-238         1  0  3.0914e-3  293  end
be            2  0  1.2295e-1  293  end
end comp
case_01, U(93.5) cyl w/0.5" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
cylinder   1  1     6.6294  15.9107      0.0
cylinder   2  1     7.8994  17.1807     -1.27
end geom
end data
end


=csas25
LA-2203 critical exp cyl
27groupnaf4       infhommedium
u-235         1  0  4.5037e-2  293  end
u-238         1  0  3.0914e-3  293  end
be            2  0  1.2295e-1  293  end
end comp
case_02, U(93.5) cyl w/1.0" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
cylinder   1  1     6.6383  11.9490      0.0
cylinder   2  1     9.1783  14.4890     -2.54
end geom
end data
end


=csas25
LA-2203 critical exp cyl
27groupnaf4       infhommedium
u-235         1  0  4.5037e-2  293  end
u-238         1  0  3.0914e-3  293  end
be            2  0  1.2295e-1  293  end
carbonsteel 3  0.994732   293  end
end comp
case_03, U(93.5) cyl w/0.5" Be or 1.0" Be on bottom + 0.5" Fe, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
cylinder   1  1     6.6401  12.7490      0.0
cylinder   2  1     7.9101  14.0190     -2.54
cylinder   3  1     9.1801  15.2890     -3.81
end geom
end data
end
```

```
LA-2203 critical exp cyl
27groupndf4      infhommedium
u-235          1  0  4.5037e-2  293  end
u-238          1  0  3.0914e-3  293  end
be             2  0  1.2295e-1  293  end
carbonsteel 3  0.994732   293  end
end comp
case_04, U(93.5) cyl w/0.5" Be + 0.5" Fe, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
cylinder   1  1    6.6284  13.2567     0.0
cylinder   2  1    7.8984  14.5267    -1.27
cylinder   3  1    9.1684  15.7967    -2.54
end geom
end data
end


=csas25
LA-2203 critical exp sph
27groupndf4      infhommedium
u-235          1  0  4.5037e-2  293  end
u-238          1  0  3.0914e-3  293  end
be             2  0  1.2295e-1  293  end
end comp
case_05, U(93.5) sph w/4.64" Be, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1     5.5688
sphere     2  1    17.3544
end geom
end data
end


=csas25
LA-2203 critical exp sph
27groupndf4      infhommedium
u-235          1  0  4.5037e-2  293  end
u-238          1  0  3.0914e-3  293  end
be             2  0  1.2295e-1  293  end
end comp
case_06, U(93.5) sph w/1.85" Be, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1     6.6444
sphere     2  1    11.3434
end geom
end data
end


=csas25
LA-2203 critical exp sph
27groupndf4      infhommedium
u-235          1  0  4.5037e-2  293  end
u-238          1  0  3.0914e-3  293  end
be             2  0  1.2295e-1  293  end
end comp
case_07, U(93.5) sph w/1.89" Be, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1     6.6444
sphere     2  1    11.4450
end geom
end data
end


=csas25
LA-2203 critical exp sph
27groupndf4      infhommedium
u-235          1  0  4.5037e-2  293  end
u-238          1  0  3.0914e-3  293  end
```

```
end comp
case_08, U(93.5) sph w/3.5" BeO, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere      1  1     6.0455
sphere      2  1    14.9355
end geom
end data
end


=csas25
LA-2203 critical exp sph
27groupndf4       infhommedium
u-235        1  0  4.5037e-2  293  end
u-238        1  0  3.0914e-3  293  end
be           2  0  6.4768e-2  293  end
o            2  0  6.4768e-2  293  end
end comp
case_09, U(93.5) sph w/2.35" BeO, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere      1  1     6.4161
sphere      2  1    12.3851
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4       infhommedium
u-235        1  0  4.4401e-2  293  end
u-238        1  0  3.2138e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_10, U(93.17) @ 18.6 g/cc sph w/7.98" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere      1  1     5.1432
sphere      2  1    25.0060
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4       infhommedium
u-235        1  0  4.4401e-2  293  end
u-238        1  0  3.2138e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_11, U(93.17) @ 18.6 g/cc sph w/4.0" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere      1  1     5.8251
sphere      2  1    15.9851
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4       infhommedium
u-235        1  0  4.4353e-2  293  end
u-238        1  0  3.2103e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_12, U(93.17) @ 18.58 g/cc sph w/3.65" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
```

```
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4        infhommedium
u-235        1  0  4.4377e-2  293  end
u-238        1  0  3.2120e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_13, U(93.17) @ 18.59 g/cc sph w/2.14" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1    6.5318
sphere     2  1   11.8912
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4        infhommedium
u-235        1  0  4.4401e-2  293  end
u-238        1  0  3.2138e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_14, U(93.17) @ 18.6 g/cc sph w/2.0" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1    6.6391
sphere     2  1   11.7191
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4        infhommedium
u-235        1  0  4.4377e-2  293  end
u-238        1  0  3.2120e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_15, U(93.17) @ 18.59 g/cc sph w/1.285" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1    7.1034
sphere     2  1   10.33428
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
27groupndf4        infhommedium
u-235        1  0  4.4401e-2  293  end
u-238        1  0  3.2138e-3  293  end
be           2  0  1.2295e-1  293  end
end comp
case_16, U(93.17) @ 18.6 g/cc sph w/1.0" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1    7.4256
sphere     2  1    9.9656
end geom
end data
end


=csas25
UCRL-4975 Be refl critical sphere
```

```
u-235          1  0  4.4377e-2  293  end
u-238          1  0  3.2120e-3  293  end
be             2  0  1.2295e-1  293  end
end comp
case_17, U(93.17) @ 18.59 g/cc sph w/0.875" Be refl, 27gr-free
read parm nub=yes gen=306 npg=500 nsk=6 run=yes end parm
read geom
unit 1
sphere     1  1     7.4788
sphere     2  1     9.63526
end geom
end data
end

=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 2
27groupndf4       latticecell
u-234          1  0  2.6338e-5  293  end
u-235          1  0  3.8964e-3  293  end
u-236          1  0  1.8025e-5  293  end
u-238          1  0  2.2750e-5  293  end
be             1  0  4.9803e-2  293  end
o              1  0  6.2229e-2  293  end
al             1  0  1.6774e-4  293  end
si             1  0  1.6115e-4  293  end
mg             1  0  7.4484e-5  293  end
fe             1  0  6.5282e-6  293  end
c              1  0  8.5829e-6  293  end
ti             1  0  1.4435e-6  293  end
nb             1  0  4.7361e-7  293  end
v-51           1  0  8.6376e-7  293  end
cr             1  0  1.6925e-7  293  end
mn             1  0  1.6019e-7  293  end
ag-109         1  0  5.8274e-8  293  end
ba-138         1  0  4.5772e-8  293  end
ni             1  0  8.5668e-8  293  end
cu             1  0  7.9135e-8  293  end
c              2  0  6.3024e-4  293  end
cr             2  0  2.1352e-2  293  end
ni             2  0  3.8687e-2  293  end
mo             2  0  4.7341e-3  293  end
fe             2  0  2.1552e-2  293  end
h2o            3  1.0  293  end
ss304          4  1.0  293  end
carbonsteel 5  1.0  293  end
end comp
squarepitch 1.242 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=o run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder   1  1     0.411613  193.04  0.0
cylinder   2  1     0.462413  193.04  0.0
cuboid     3  1  4p0.621      193.04  0.0
unit 2
'array position w/water but no fuel rod'
cuboid     3  1  4p0.621      193.04  0.0
global unit 3
array      1      -9.315  -9.315  0.0
cylinder   3  1     137.16   208.24  -15.24
cylinder   0  1     137.16   304.8   -15.24
replicate  4  1     0.1905  0.0  0.1905  1.0
replicate  5  1     0.9525  0.0  2.54    1.0
end geom
read array
ara=1  nux=15 nuy=15 nuz=1
loop
1     1 15  1    1 15  1    1 1 1
2     1  1  1    1  1  1    1 1 1
2    15 15  1    1  1  1    1 1 1
2    15 15  1   15 15  1    1 1 1
end loop
end array
read start
```

```
:nd data
:nd

=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 3
27groupndf4      latticecell
u-234        1  0  2.6338e-5  293  end
u-235        1  0  3.8964e-3  293  end
u-236        1  0  1.8025e-5  293  end
u-238        1  0  2.2750e-5  293  end
be           1  0  4.9803e-2  293  end
o            1  0  6.2229e-2  293  end
al           1  0  1.6774e-4  293  end
si           1  0  1.6115e-4  293  end
mg           1  0  7.4484e-5  293  end
fe           1  0  6.5282e-6  293  end
c            1  0  8.5829e-6  293  end
ti           1  0  1.4435e-6  293  end
-b           1  0  4.7361e-7  293  end
v-51         1  0  8.6376e-7  293  end
cr           1  0  1.6925e-7  293  end
mn           1  0  1.6019e-7  293  end
ag-109       1  0  5.8274e-8  293  end
ba-138       1  0  4.5772e-8  293  end
ni           1  0  8.5668e-8  293  end
cu           1  0  7.9135e-8  293  end
c            2  0  6.3024e-4  293  end
cr           2  0  2.1352e-2  293  end
ni           2  0  3.8687e-2  293  end
mo           2  0  4.7341e-3  293  end
fe           2  0  2.1552e-2  293  end
h2o          3  1.0  293  end
ss304        4  1.0  293  end
carbonsteel  5  1.0  293  end
end comp
squarepitch 1.488 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder    1  1    0.411613  193.04  0.0
cylinder    2  1    0.462413  193.04  0.0
cuboid      3  1  4p0.744     193.04  0.0
unit 2
'array position w/water but no fuel rod'
cuboid      3  1  4p0.744     193.04  0.0
global unit 3
array       1     -8.928  -8.928  0.0
cylinder    3  1    137.16   223.84  -15.24
cylinder    0  1    137.16   304.8   -15.24
replicate   4  1    0.1905  0.0  0.1905  1.0
replicate   5  1    0.9525  0.0  2.54    1.0
end geom
read array
ara=1  nux=12 nuy=12 nuz=1
loop
1     1 12  1    1 12  1    1  1  1
2     1  1  1    1  1  1    1  1  1
2    12 12  1    1  2  1    1  1  1
2     1  1  1   11 12  1    1  1  1
2    12 12  1   12 12  1    1  1  1
end loop
end array
read start
nst=4  tfx=0.0 tfy=0.0 tfz=96.52 nbx=1
end start
end data
end

=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 4
27groupndf4      latticecell
u-234        1  0  2.6338e-5  293  end
u-235        1  0  3.8964e-3  293  end
```

```
u-238        1  0  2.2750e-5  293  end
be           1  0  4.9803e-2  293  end
o            1  0  6.2229e-2  293  end
al           1  0  1.6774e-4  293  end
si           1  0  1.6115e-4  293  end
mg           1  0  7.4484e-5  293  end
fe           1  0  6.5282e-6  293  end
c            1  0  8.5829e-6  293  end
ti           1  0  1.4435e-6  293  end
nb           1  0  4.7361e-7  293  end
v-51         1  0  8.6376e-7  293  end
cr           1  0  1.6925e-7  293  end
mn           1  0  1.6019e-7  293  end
ag-109       1  0  5.8274e-8  293  end
ba-138       1  0  4.5772e-8  293  end
ni           1  0  8.5668e-8  293  end
cu           1  0  7.9135e-8  293  end
c            2  0  6.3024e-4  293  end
cr           2  0  2.1352e-2  293  end
ni           2  0  3.8687e-2  293  end
mo           2  0  4.7341e-3  293  end
fe           2  0  2.1552e-2  293  end
h2o          3  1.0  293  end
ss304        4  1.0  293  end
carbonsteel  5  1.0  293  end
end comp
squarepitch 1.742 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder    1  1    0.411613  171.74  0.0
cylinder    2  1    0.462413  171.74  0.0
cuboid      3  1  4p0.871     171.74  0.0
unit 2
'array position w/water but no fuel rod'
cuboid      3  1  4p0.871     171.74  0.0
unit 3
'array under water'
array       1      -9.581  -9.581  0.0
cylinder    3  1    137.16   171.74  -15.24
replicate   4  1    0.1905  0.0  0.1905  1.0
replicate   5  1    0.9525  0.0  2.54    1.0
cuboid      0  1  4p140.00  171.74  -18.00
unit 4
'array position w/fuel rod above water'
cylinder    1  1    0.411613  21.3  0.0
cylinder    2  1    0.462413  21.3  0.0
cuboid      0  1  4p0.871     21.3  0.0
unit 5
'array position above water but no fuel rod'
cuboid      0  1  4p0.871     21.3  0.0
unit 6
'array above water'
array       2      -9.581  -9.581  0.0
cylinder    0  1    137.16   133.06  0.0
replicate   4  1    0.1905  0.0  0.0  1.0
replicate   5  1    0.9525  0.0  0.0  1.0
cuboid      0  1  4p140.00  133.06  0.0
global unit 7
array       3     -140.00  -140.00  0.0
end geom
read array
ara=1  nux=11 nuy=11 nuz=1
loop
1    1 11  1   1 11  1    1 1 1
2    1  1  1   1  3  1    1 1 1
2   11 11  1   1  3  1    1 1 1
2    1  1  1   9 11  1    1 1 1
2   11 11  1   9 11  1    1 1 1
2    9 10  1   1 11 10    1 1 1
2    2  2  1   1 11 10    1 1 1
2    3  3  1   1  1  1    1 1 1
end loop
ara=2  nux=11 nuy=11 nuz=1
loop
```

```
5    1  1   1    1  3   1    1 1 1
5   11 11   1    1  3   1    1 1 1
5    1  1   1    9 11   1    1 1 1
5   11 11   1    9 11   1    1 1 1
5    9 10   1    1 11  10    1 1 1
5    2  2   1    1 11  10    1 1 1
5    3  3   1    1  1   1    1 1 1
end loop
ara=3  nux=1  nuy=1  nuz=2
fill  3 6  end fill
end array
read start
nst=6
tfx=0.0 tfy=0.0 tfz=70.0  lnu=700
tfx=0.0 tfy=0.0 tfz=120.0 lnu=1400
tfx=0.0 tfy=0.0 tfz=170.0 lnu=2000
end start
end data
end


=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 5
27groupndf4      latticecell
u-234        1  0  2.6338e-5  293  end
u-235        1  0  3.8964e-3  293  end
u-236        1  0  1.8025e-5  293  end
u-238        1  0  2.2750e-5  293  end
be           1  0  4.9803e-2  293  end
o            1  0  6.2229e-2  293  end
al           1  0  1.6774e-4  293  end
si           1  0  1.6115e-4  293  end
mg           1  0  7.4484e-5  293  end
fe           1  0  6.5282e-6  293  end
c            1  0  8.5829e-6  293  end
ti           1  0  1.4435e-6  293  end
nb           1  0  4.7361e-7  293  end
v-51         1  0  8.6376e-7  293  end
cr           1  0  1.6925e-7  293  end
mn           1  0  1.6019e-7  293  end
ag-109       1  0  5.8274e-8  293  end
ba-138       1  0  4.5772e-8  293  end
ni           1  0  8.5668e-8  293  end
cu           1  0  7.9135e-8  293  end
c            2  0  6.3024e-4  293  end
cr           2  0  2.1352e-2  293  end
ni           2  0  3.8687e-2  293  end
mo           2  0  4.7341e-3  293  end
fe           2  0  2.1552e-2  293  end
h2o          3  1.0  293  end
ss304        4  1.0  293  end
carbonsteel  5  1.0  293  end
end comp
squarepitch 1.999 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder    1  1    0.411613  193.04  0.0
cylinder    2  1    0.462413  193.04  0.0
cuboid      3  1  4p0.9995    193.04  0.0
unit 2
'array position w/water but no fuel rod'
cuboid      3  1  4p0.9995    193.04  0.0
global unit 3
array       1      -9.995  -9.995  0.0
cylinder    3  1    137.16   228.24  -15.24
cylinder    0  1    137.16   304.8   -15.24
replicate   4  1    0.1905  0.0  0.1905  1.0
replicate   5  1    0.9525  0.0  2.54    1.0
end geom
read array
ara=1  nux=10 nuy=10 nuz=1
loop
1    1 10   1    1 10   1    1 1 1
1    1  1   1    1  3   1    1 1 1
```

```
2    8 10  1    1  1  1    1 1 1
2   10 10  1    2  2  1    1 1 1
2    1  1  1    9 10  1    1 1 1
2    2  2  1   10 10  1    1 1 1
2    9  9  1   10 10  1    1 1 1
2   10 10  1    8 10  1    1 1 1
end loop
end array
read start
nst=4  tfx=0.0 tfy=0.0 tfz=96.52 nbx=1
end start
end data
end

=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 6
27groupndf4      latticecell
u-234         1  0  2.6338e-5  293  end
u-235         1  0  3.8964e-3  293  end
u-236         1  0  1.8025e-5  293  end
u-238         1  0  2.2750e-5  293  end
be            1  0  4.9803e-2  293  end
o             1  0  6.2229e-2  293  end
al            1  0  1.6774e-4  293  end
si            1  0  1.6115e-4  293  end
mg            1  0  7.4484e-5  293  end
fe            1  0  6.5282e-6  293  end
c             1  0  8.5829e-6  293  end
ti            1  0  1.4435e-6  293  end
nb            1  0  4.7361e-7  293  end
v-51          1  0  8.6376e-7  293  end
cr            1  0  1.6925e-7  293  end
mn            1  0  1.6019e-7  293  end
ag-109        1  0  5.8274e-8  293  end
ba-138        1  0  4.5772e-8  293  end
ni            1  0  8.5668e-8  293  end
cu            1  0  7.9135e-8  293  end
c             2  0  6.3024e-4  293  end
cr            2  0  2.1352e-2  293  end
ni            2  0  3.8687e-2  293  end
mo            2  0  4.7341e-3  293  end
fe            2  0  2.1552e-2  293  end
h2o           3  1.0  293  end
ss304         4  1.0  293  end
carbonsteel   5  1.0  293  end
end comp
squarepitch 2.276 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder   1  1    0.411613  193.04  0.0
cylinder   2  1    0.462413  193.04  0.0
cuboid     3  1  4p1.138     193.04  0.0
unit 2
'array position w/water but no fuel rod'
cuboid     3  1  4p1.138     193.04  0.0
global unit 3
array      1      -10.242  -10.242   0.0
cylinder   3  1    137.16   208.24  -15.24
cylinder   0  1    137.16   304.8   -15.24
replicate  4  1    0.1905  0.0  0.1905  1.0
replicate  5  1    0.9525  0.0  2.54    1.0
end geom
read array
ara=1  nux=9 nuy=9 nuz=1
loop
1    1  9  1    1  9  1    1 1 1
2    1  1  1    1  1  1    1 1 1
2    9  9  1    1  1  1    1 1 1
2    9  9  1    9  9  1    1 1 1
end loop
end array
read start
```

```
end data
end

=csas25        parm=size=500000
ORNL/ENG-2 fuel pin critical exp 7a
27groupndf4     latticecell
u-234      1  0  2.6338e-5  293  end
u-235      1  0  3.8964e-3  293  end
u-236      1  0  1.8025e-5  293  end
u-238      1  0  2.2750e-5  293  end
be         1  0  4.9803e-2  293  end
o          1  0  6.2229e-2  293  end
al         1  0  1.6774e-4  293  end
si         1  0  1.6115e-4  293  end
mg         1  0  7.4484e-5  293  end
fe         1  0  6.5282e-6  293  end
c          1  0  8.5829e-6  293  end
ni         1  0  1.4435e-6  293  end
nb         1  0  4.7361e-7  293  end
v-51       1  0  8.6376e-7  293  end
cr         1  0  1.6925e-7  293  end
mn         1  0  1.6019e-7  293  end
ag-109     1  0  5.8274e-8  293  end
ba-138     1  0  4.5772e-8  293  end
ni         1  0  8.5668e-8  293  end
cu         1  0  7.9135e-8  293  end
c          2  0  6.3024e-4  293  end
cr         2  0  2.1352e-2  293  end
ni         2  0  3.8687e-2  293  end
mo         2  0  4.7341e-3  293  end
fe         2  0  2.1552e-2  293  end
h2o        3  1.0  293  end
ss304      4  1.0  293  end
carbonsteel 5  1.0  293  end
end comp
squarepitch 2.253 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder   1  1    0.411613  189.14  0.0
cylinder   2  1    0.462413  189.14  0.0
cuboid     3  1  4p1.1265    189.14  0.0
unit 2
'array position w/water but no fuel rod'
cuboid     3  1  4p1.1265    189.14  0.0
unit 3
'array under water'
array      1     -11.265  -11.265  0.0
cylinder   3  1    137.16   189.14  -15.24
replicate  4  1    0.1905  0.0  0.1905  1.0
replicate  5  1    0.9525  0.0  2.54    1.0
cuboid     0  1  4p140.00  189.14  -18.00
unit 4
'array position w/fuel rod above water'
cylinder   1  1    0.411613  3.9  0.0
cylinder   2  1    0.462413  3.9  0.0
cuboid     0  1  4p1.1265    3.9  0.0
unit 5
'array position above water but no fuel rod'
cuboid     0  1  4p1.1265    3.9  0.0
unit 6
'array above water'
array      2     -11.265  -11.265  0.0
cylinder   0  1    137.16   115.66  0.0
replicate  4  1    0.1905  0.0  0.0  1.0
replicate  5  1    0.9525  0.0  0.0  1.0
cuboid     0  1  4p140.00   115.66  0.0
global unit 7
array      3     -140.00  -140.00  0.0
end geom
read array
ara=1  nux=10 nuy=10 nuz=1
loop
  .   1 10  1   1 10  1   1 1 1
```

```
2    1  2  1    2  9  7    1 1 1
2    1  1  1    3  8  5    1 1 1
2    8 10  1    1 10  9    1 1 1
2    9  9  1    2  2  1    1 1 1
2   10 10  1    2  9  7    1 1 1
2   10 10  1    3  8  5    1 1 1
end loop
ara=2  nux=10 nuy=10 nuz=1
loop
4    1 10  1    1 10  1    1 1 1
5    1  3  1    1 10  9    1 1 1
5    1  2  1    2  9  7    1 1 1
5    1  1  1    3  8  5    1 1 1
5    8 10  1    1 10  9    1 1 1
5    9  9  1    2  2  1    1 1 1
5   10 10  1    2  9  7    1 1 1
5   10 10  1    3  8  5    1 1 1
end loop
ara=3  nux=1  nuy=1  nuz=2
fill  3 6  end fill
end array
read start
nst=6
tfx=0.0 tfy=0.0 tfz=70.0  lnu=700
tfx=0.0 tfy=0.0 tfz=120.0 lnu=1400
tfx=0.0 tfy=0.0 tfz=170.0 lnu=2000
end start
end data
end


=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 7b
27groupndf4       latticecell
u-234         1  0  2.6338e-5  293  end
u-235         1  0  3.8964e-3  293  end
u-236         1  0  1.8025e-5  293  end
u-238         1  0  2.2750e-5  293  end
be            1  0  4.9803e-2  293  end
o             1  0  6.2229e-2  293  end
al            1  0  1.6774e-4  293  end
si            1  0  1.6115e-4  293  end
mg            1  0  7.4484e-5  293  end
fe            1  0  6.5282e-6  293  end
c             1  0  8.5829e-6  293  end
ti            1  0  1.4435e-6  293  end
nb            1  0  4.7361e-7  293  end
v-51          1  0  8.6376e-7  293  end
cr            1  0  1.6925e-7  293  end
mn            1  0  1.6019e-7  293  end
ag-109        1  0  5.8274e-8  293  end
ba-138        1  0  4.5772e-8  293  end
ni            1  0  8.5668e-8  293  end
cu            1  0  7.9135e-8  293  end
c             2  0  6.3024e-4  293  end
cr            2  0  2.1352e-2  293  end
ni            2  0  3.8687e-2  293  end
mo            2  0  4.7341e-3  293  end
fe            2  0  2.1552e-2  293  end
h2o           3  1.0  293  end
ss304         4  1.0  293  end
carbonsteel 5  1.0  293  end
end comp
squarepitch 2.779 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder    1  1     0.411613  149.84  0.0
cylinder    2  1     0.462413  149.84  0.0
cuboid      3  1  4p1.3895     149.84  0.0
unit 2
'array position w/water but no fuel rod'
cuboid      3  1  4p1.3895     149.84  0.0
unit 3
```

```
:ylinder   3  1     137.16   149.84  -15.24
replicate  4  1     0.1905  0.0  0.1905  1.0
replicate  5  1     0.9525  0.0  2.54    1.0
cuboid     0  1  4p140.00  149.84  -18.00
unit 4
'array position w/fuel rod above water'
cylinder   1  1     0.411613  43.2  0.0
cylinder   2  1     0.462413  43.2  0.0
cuboid     0  1  4p1.3895    43.2  0.0
unit 5
'array position above water but no fuel rod'
cuboid     0  1  4p1.3895    43.2  0.0
unit 6
'array above water'
array      2     -13.895  -13.895  0.0
cylinder   0  1     137.16   154.96  0.0
replicate  4  1     0.1905  0.0  0.0  1.0
replicate  5  1     0.9525  0.0  0.0  1.0
cuboid     0  1  4p140.00   154.96  0.0
global unit 7
array      3     -140.00  -140.00  0.0
end geom
read array
ara=1  nux=10 nuy=10 nuz=1
loop
1    1 10  1    1 10  1    1 1 1
2    1  3  1    1 10  9    1 1 1
2    1  2  1    2  9  7    1 1 1
2    1  1  1    3  8  5    1 1 1
2    8 10  1    1 10  9    1 1 1
2    9  9  1    2  2  1    1 1 1
2   10 10  1    2  9  7    1 1 1
2   10 10  1    3  8  5    1 1 1
end loop
ara=2  nux=10 nuy=10 nuz=1
loop
4    1 10  1    1 10  1    1 1 1
5    1  3  1    1 10  9    1 1 1
5    1  2  1    2  9  7    1 1 1
5    1  1  1    3  8  5    1 1 1
5    8 10  1    1 10  9    1 1 1
5    9  9  1    2  2  1    1 1 1
5   10 10  1    2  9  7    1 1 1
5   10 10  1    3  8  5    1 1 1
end loop
ara=3  nux=1  nuy=1  nuz=2
fill  3 6  end fill
end array
read start
nst=6
tfx=0.0 tfy=0.0 tfz=70.0  lnu=700
tfx=0.0 tfy=0.0 tfz=120.0 lnu=1400
tfx=0.0 tfy=0.0 tfz=170.0 lnu=2000
end start
end data
end


=csas25           parm=size=500000
ORNL/ENG-2 fuel pin critical exp 8
27groupndf4       latticecell
u-234        1  0  2.6338e-5  293  end
u-235        1  0  3.8964e-3  293  end
u-236        1  0  1.8025e-5  293  end
u-238        1  0  2.2750e-5  293  end
be           1  0  4.9803e-2  293  end
o            1  0  6.2229e-2  293  end
al           1  0  1.6774e-4  293  end
si           1  0  1.6115e-4  293  end
mg           1  0  7.4484e-5  293  end
fe           1  0  6.5282e-6  293  end
c            1  0  8.5829e-6  293  end
ti           1  0  1.4435e-6  293  end
mo           1  0  4.7361e-7  293  end
v-51         1  0  8.6376e-7  293  end
cr           1  0  1.6925e-7  293  end
mn           1  0  1.6019e-7  293  end
ag-109       1  0  5.8274e-8  293  end
ba-138       1  0  4.5772e-8  293  end
```

```
cu           1  0  7.9135e-8  293  end
c            2  0  6.3024e-4  293  end
cr           2  0  2.1352e-2  293  end
ni           2  0  3.8687e-2  293  end
mo           2  0  4.7341e-3  293  end
fe           2  0  2.1552e-2  293  end
h2o          3  1.0  293  end
ss304        4  1.0  293  end
carbonsteel  5  1.0  293  end
end comp
squarepitch 2.507 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder   1  1   0.411613  193.04  0.0
cylinder   2  1   0.462413  193.04  0.0
cuboid     3  1  4p1.2535   193.04  0.0
unit 2
'array position w/water but no fuel rod'
cuboid     3  1  4p1.2535   193.04  0.0
global unit 3
array      1     -12.535  -12.535   0.0
cylinder   3  1   137.16   208.24  -15.24
cylinder   0  1   137.16   304.8   -15.24
replicate  4  1   0.1905  0.0  0.1905  1.0
replicate  5  1   0.9525  0.0  2.54    1.0
end geom
read array
ara=1  nux=10 nuy=10 nuz=1
loop
1    1 10  1    1 10  1    1 1 1
2    1  2  1    1  2  1    1 1 1
2    9 10  1    1  2  1    1 1 1
2    1  2  1    9 10  1    1 1 1
2    9 10  1    9 10  1    1 1 1
2    3  8  5    1 10  9    1 1 1
2    1 10  9    3  8  5    1 1 1
2    7  7  1   10 10  1    1 1 1
end loop
end array
read start
nst=4  tfx=0.0 tfy=0.0 tfz=96.52 nbx=1
end start
end data
end


=csas25          parm=size=500000
ORNL/ENG-2 fuel pin critical exp 9
27groupndf4      latticecell
u-234        1  0  2.6338e-5  293  end
u-235        1  0  3.8964e-3  293  end
u-236        1  0  1.8025e-5  293  end
u-238        1  0  2.2750e-5  293  end
be           1  0  4.9803e-2  293  end
o            1  0  6.2229e-2  293  end
al           1  0  1.6774e-4  293  end
si           1  0  1.6115e-4  293  end
mg           1  0  7.4484e-5  293  end
fe           1  0  6.5282e-6  293  end
c            1  0  8.5829e-6  293  end
ti           1  0  1.4435e-6  293  end
nb           1  0  4.7361e-7  293  end
v-51         1  0  8.6376e-7  293  end
cr           1  0  1.6925e-7  293  end
mn           1  0  1.6019e-7  293  end
ag-109       1  0  5.8274e-8  293  end
ba-138       1  0  4.5772e-8  293  end
ni           1  0  8.5668e-8  293  end
cu           1  0  7.9135e-8  293  end
c            2  0  6.3024e-4  293  end
cr           2  0  2.1352e-2  293  end
ni           2  0  3.8687e-2  293  end
mo           2  0  4.7341e-3  293  end
```

```
s304       4  1.0  293  end
arbonsteel 5  1.0  293  end
nd comp
quarepitch 2.995 0.823226 1 3 0.924826 2 end
ritical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
ead parm
ub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
nd parm
ead geom
nit 1
'array position w/fuel rod in water'
ylinder   1  1     0.411613  158.94  0.0
ylinder   2  1     0.462413  158.94  0.0
uboid     3  1  4p1.4975     158.94  0.0
nit 2
'array position w/water but no fuel rod'
uboid     3  1  4p1.4975     158.94  0.0
nit 3
'array under water'
rray      1      -14.975  -14.975  0.0
ylinder   3  1     137.16   158.94  -15.24
eplicate  4  1     0.1905   0.0  0.1905   1.0
eplicate  5  1     0.9525   0.0  2.54     1.0
uboid     0  1  4p140.00   158.94  -18.00
nit 4
'array position w/fuel rod above water'
ylinder   1  1     0.411613  34.1  0.0
ylinder   2  1     0.462413  34.1  0.0
uboid     0  1  4p1.4975     34.1  0.0
nit 5
'array position above water but no fuel rod'
uboid     0  1  4p1.4975     34.1  0.0
nit 6
'array above water'
rray      2      -14.975  -14.975  0.0
ylinder   0  1     137.16   145.86  0.0
eplicate  4  1     0.1905   0.0  0.0  1.0
eplicate  5  1     0.9525   0.0  0.0  1.0
uboid     0  1  4p140.00   145.86  0.0
lobal unit 7
rray      3    -140.00  -140.00  0.0
nd geom
ead array
ra=1  nux=10 nuy=10 nuz=1
oop
     1 10  1   1 10  1   1 1 1
2    1  3  1   1 10  9   1 1 1
2    1 10  9   2  9  7   1 1 1
2    9 10  1   1 10  9   1 1 1
2    1  1  1   3  3  1   1 1 1
2    8  8  1   1  1  1   1 1 1
2   10 10  1   8  8  1   1 1 1
nd loop
ra=2  nux=10 nuy=10 nuz=1
oop
4    1 10  1   1 10  1   1 1 1
5    1  3  1   1 10  9   1 1 1
5    1 10  9   2  9  7   1 1 1
5    9 10  1   1 10  9   1 1 1
5    1  1  1   3  3  1   1 1 1
5    8  8  1   1  1  1   1 1 1
5   10 10  1   8  8  1   1 1 1
nd loop
ra=3  nux=1  nuy=1  nuz=2
ill  3 6  end fill
nd array
ead start
st=6
fx=0.0 tfy=0.0 tfz=70.0  lnu=700
fx=0.0 tfy=0.0 tfz=120.0 lnu=1400
fx=0.0 tfy=0.0 tfz=170.0 lnu=2000
nd start
nd data
nd


csas25         parm=size=500000
ORNL/ENG-2 fuel pin critical exp 10
27groupndf4       latticecell
```

```
u-235        1  0  3.8964e-3  293  end
u-236        1  0  1.8025e-5  293  end
u-238        1  0  2.2750e-5  293  end
be           1  0  4.9803e-2  293  end
o            1  0  6.2229e-2  293  end
al           1  0  1.6774e-4  293  end
si           1  0  1.6115e-4  293  end
mg           1  0  7.4484e-5  293  end
fe           1  0  6.5282e-6  293  end
c            1  0  8.5829e-6  293  end
ti           1  0  1.4435e-6  293  end
nb           1  0  4.7361e-7  293  end
v-51         1  0  8.6376e-7  293  end
cr           1  0  1.6925e-7  293  end
mn           1  0  1.6019e-7  293  end
ag-109       1  0  5.8274e-8  293  end
ba-138       1  0  4.5772e-8  293  end
ni           1  0  8.5668e-8  293  end
cu           1  0  7.9135e-8  293  end
c            2  0  6.3024e-4  293  end
cr           2  0  2.1352e-2  293  end
ni           2  0  3.8687e-2  293  end
mo           2  0  4.7341e-3  293  end
fe           2  0  2.1552e-2  293  end
h2o          3  1.0  293  end
ss304        4  1.0  293  end
carbonsteel  5  1.0  293  end
end comp
squarepitch 2.497 0.823226 1 3 0.924826 2 end
critical pin exp from ORNL/ENG-2, 27gr-free, latticecell treatment
read parm
nub=yes gen=306 npg=2000 nsk=6 nb8=2000 nl8=8000 tme=180 tba=6 run=yes
end parm
read geom
unit 1
'array position w/fuel rod in water'
cylinder   1  1    0.411613  182.64  0.0
cylinder   2  1    0.462413  182.64  0.0
cuboid     3  1  2p1.2485  2p1.269    182.64  0.0
unit 2
'array position w/water but no fuel rod'
cuboid     3  1  2p1.2485  2p1.269    182.64  0.0
unit 3
'array under water'
array      1      -19.976  -7.614  0.0
cylinder   3  1    137.16   182.64  -15.24
replicate  4  1    0.1905  0.0  0.1905  1.0
replicate  5  1    0.9525  0.0  2.54    1.0
cuboid     0  1  4p140.00  182.64  -18.00
unit 4
'array position w/fuel rod above water'
cylinder   1  1    0.411613  10.4  0.0
cylinder   2  1    0.462413  10.4  0.0
cuboid     0  1  2p1.2485  2p1.269    10.4  0.0
unit 5
'array position above water but no fuel rod'
cuboid     0  1  2p1.2485  2p1.269    10.4  0.0
unit 6
'array above water'
array      2      -19.976  -7.614  0.0
cylinder   0  1    137.16   122.16  0.0
replicate  4  1    0.1905  0.0  0.0  1.0
replicate  5  1    0.9525  0.0  0.0  1.0
cuboid     0  1  4p140.00   122.16  0.0
global unit 7
array      3     -140.00  -140.00  0.0
end geom
read array
ara=1  nux=16 nuy=6 nuz=1
loop
1    1 16  1   1  6  1   1 1 1
end loop
ara=2  nux=16 nuy=6 nuz=1
loop
4    1 16  1   1  6  1   1 1 1
end loop
ara=3  nux=1  nuy=1  nuz=2
fill  3 6  end fill
end array
```

```
nst=6
tfx=0.0 tfy=0.0 tfz=70.0  lnu=700
tfx=0.0 tfy=0.0 tfz=120.0 lnu=1400
tfx=0.0 tfy=0.0 tfz=170.0 lnu=2000
end start
end data
end
```

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