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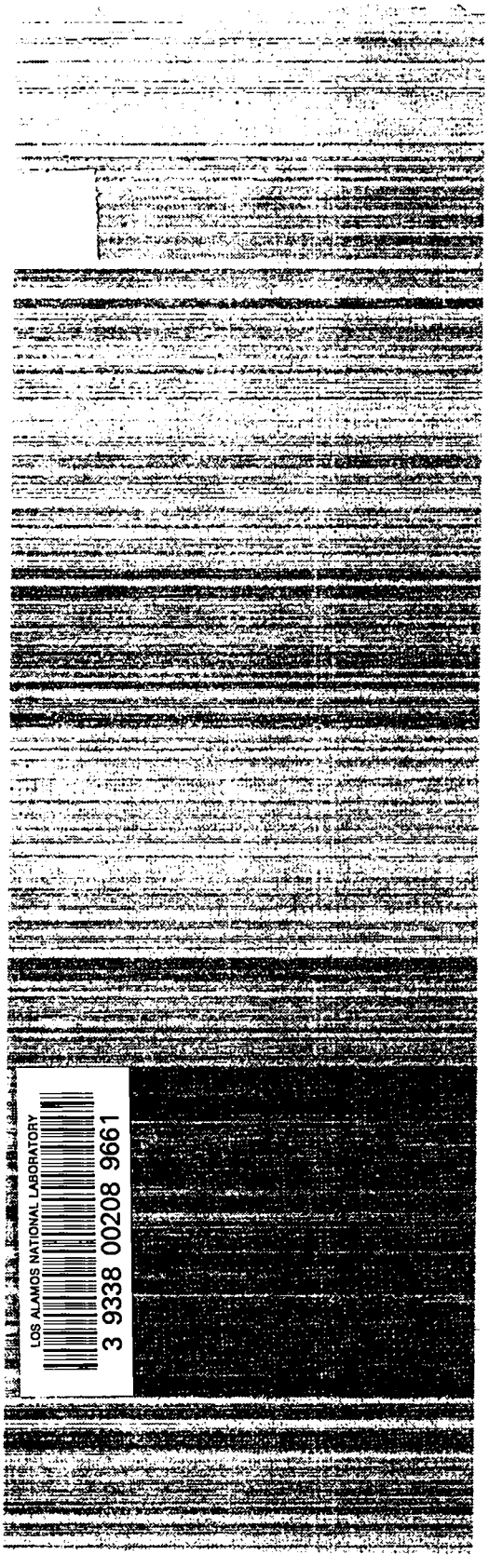

Reactivity Effects of Void Formations in a Solution Critical Assembly

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Reactivity Effects of Void Formations in a Solution Critical Assembly

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REACTIVITY EFFECTS OF VOID FORMATIONS IN A SOLUTION CRITICAL ASSEMBLY

by

Steven G. Walters

ABSTRACT

SHEBA II (Solution High Energy Burst Assembly) was constructed in order to better understand the neutronics of solutions of fissile materials. In order to estimate the effect on criticality from the formation of bubbles, models were devised in MCNP (Monte Carlo Neutron Photon transport code) and THREEDANT (THREE dimensional, Diffusion-Accelerated, Neutral-Particle Transport). It was found that the formation of voids in all but the outside bottom edge of the assembly cylinder tend to act as a negative insertion of reactivity. Also, an experiment has been designed which will verify the results of the codes.

CHAPTER 1

INTRODUCTION

The purpose of this traineeship was to aid Los Alamos National Laboratory in understanding the characteristics of SHEBA II (Solution High-Energy Burst Assembly) as well as to benchmark the newly developed discrete-ordinates code THREEDANT (THREE dimensional, Diffusion-Accelerated, Neutral-Particle Transport). SHEBA II uses a low enriched (4.95%) uranyl fluoride solution (Anderson and Paternoster, 1984), and is intended for the evaluation of accidental criticality alarm detectors for enrichment plants, to benchmark calculations on a low-enrichment solution system, and to provide radiation fields to calibrate personnel dosimetry. An illustration of SHEBA II can be found following the text. When SHEBA II operates at its high-power level (two kilowatts), radiolytic gases should form at the rate of one liter per minute (Anderson and Paternoster). This bubble formation and its effect on reactivity is the focus of this paper.

Understanding the physics of a solution reactor is important because most spent fuels are stored as solutions. When nuclear fuel materials from power or production reactors are reprocessed, the reprocessing is invariably done by a chemical separation technique. The fuel, which is usually in oxide form (e.g., UO_2), is first dissolved with some type of acid (e.g., nitric, sulfuric, or hydrochloric acid). This turns the fuel into an aqueous solution. The presence of fissile isotopes and water in these solutions leads to concerns

regarding accidental criticalities with the solutions. When transported through pipes and stored in vessels, the possibility exists for the formation of bubbles. These bubbles could alter the geometric configuration of the fissile solution and in turn, affect the multiplicative state.

The construction of SHEBA II provides a means for studying the formation of voids in a fissile solution. The assembly vessel is a stainless steel cylindrical tank with a single safety rod along the axis which provides emergency shutdown capability without changing cylindrical symmetry. Control of the assembly is achieved by varying the solution level with a combination of pressure and vacuum through a single control handle. Rapid shutdown is accomplished by draining the solution through a three-inch valve. The critical assembly and the dump tanks are mounted on a pallet so that the distance above the ground may be varied. The important dimensions of SHEBA II that are used in the analysis are as follows.

Vessel diameter (inside)	=	48.26 cm
Vessel wall thickness	=	1.27 cm
Vessel height	=	121.92 cm
Central thimble diameter (outside)	=	6.35 cm
Central thimble thickness	=	0.635 cm
Gap between thimble and rod	=	0.3175 cm
Rod Cladding thickness	=	0.7937 cm

The primary tools used for this research were the computer codes MCNP (Monte Carlo Neutron Photon transport) and THREEDANT. MCNP was chosen because at the time the project began, no other code existed that could effectively perform eigenvalue calculations on non-symmetrical three-dimensional geometries. The theory of Monte Carlo is quite simple. One of the leaders in the theory was Stanislaw Ulam, who was working on a neutron diffusion problem at Los Alamos National Laboratory in the late nineteen forties. The problem considered a mass of uranium. The neutron moving through the mass collides with many atomic nuclei, and in each collision it can either elastically or inelastically scatter off the nucleus or else be absorbed by it. If the neutron is absorbed or inelastically scatters there is a chance that the nucleus will undergo fission and thereby introduce more neutrons to the problem. Ulam was trying to estimate how many neutrons would eventually escape from the lump and how many would remain behind to sustain a fission reaction. This problem was solved by playing the part of the neutron. Ulam would imagine moving through a lattice, occasionally colliding with atomic nuclei. At each collision he would randomly decide what would happen next, based on known probabilities. By following a neutron for hundreds of collisions, and then repeating the calculation for thousands of neutrons, he found that one can estimate important statistical properties of the neutron trajectories. Ulam eventually refined his theory and developed the current Monte Carlo theory with colleagues at Los Alamos (Carter and Cashwell, 1975).

Monte Carlo codes used to be the only codes capable of

efficiently numerically duplicating a statistical process in complex three-dimensional geometries. Monte Carlo methods are very different from deterministic transport methods. Deterministic methods, the most common of which is the discrete-ordinates method used by THREEDANT, solve the transport equation for the average particle behavior. By contrast, Monte Carlo methods do not solve an explicit equation, but instead the theory obtains answers by simulating individual particles, and recording certain aspects of their behavior. The average behavior of the particles in the physical system is inferred by the Central Limit theorem, from the average behavior of all the simulated particles. The main advantage of Monte Carlo is that non-symmetrical systems and very complicated geometries can be modeled. The main disadvantage of Monte Carlo theory is that a vast number of particles need to be generated in order to properly sample the problem.

The history of THREEDANT, the code that was used to check the results of MCNP, does not go back as far as MCNP. The original one-dimensional version of the code was developed between 1980-1982 by a group (T-1) at Los Alamos National Laboratory (Alcouffe, Brinkley, Marr, O'Dell, 1982). After the one-dimensional code (ONEDANT) came the two-dimensional version (TWODANT), which was just recently followed by the three-dimensional version. THREEDANT solves the multigroup transport equation in X-Y-Z or R--Z geometries (Clark, 1993). Many types of problems can be solved using THREEDANT, such as regular, adjoint, inhomogeneous or homogeneous (k_{eff} and eigenvalue search) problems. Also, these problems can be subject to

vacuum, reflective, periodic, white, or albedo boundary flux conditions. THREEDANT numerically solves the three-dimensional, multigroup form of the neutral-particle, steady-state form of the Boltzmann transport equation. The discrete-ordinates approximation is used for treating the angular variation of the particle distribution and the diamond-difference scheme is used for space discretization (Alcouffe, Brinkley, Marr, O'Dell, 1989). Negative fluxes are eliminated by a local set-to-zero and correct algorithm. A standard inner (within-group) iteration, outer (energy-group dependent source) iteration technique is used. Both inner and outer iterations are accelerated using the diffusion synthetic acceleration method. This acceleration method is what enables the code to converge in a manageable number of iterations.

CHAPTER 2

INHERENT ERRORS IN CODE METHODOLOGY

Although MCNP and THREEDANT may be considered the most advanced open codes to date of their respective types (Monte Carlo and discrete ordinates), one must keep in mind the inherent numerical errors that are associated with the codes. We will consider how errors are dealt with in MCNP first.

Monte Carlo results represent an average of the contributions from many histories sampled during the problem. While it is obvious that the results are important, the statistical error or uncertainty associated with the results cannot be overlooked. The importance of understanding the error cannot be overemphasized because of the insight that can be gained into the quality of the result. Monte Carlo results are obtained by sampling possible random walks and assigning a score x_i to each random walk. The scores assigned to each random walk will generally vary. We define a probability density function p(x). By selecting a random walk, one adds x to the tally being estimated. The answer is the expected value of x, E(x), where E(x) is defined by the equation $E(x) = \int xp(x)dx$ = true mean. E(x) is seldom known because p(x) is not known directly, but E(x) can be estimated by Monte Carlo through the random walk process as , which is given by

$$= 1/N \sum_{i=1}^{N} x_i \qquad (1)$$

where x_i is the value of x selected from p(x) for the ith

history and N is the number of histories calculated in the problem. The Monte Carlo mean is the average value of the scores x_i for all the histories calculated in the problem. The relationship between E(x) and is given by the Strong Law of Large Numbers, which states that if E(x) is finite, tends to the limit E(x) as N approaches infinity (Briesmeister, 1986).

The variance of the population of x values is the measure of the spread in these values and is given by

$$^2 = \int (x - E(x))^2 \, p(x)dx = E(x^2) - (E(x))^2 \qquad (2)$$

The square root of the variance is , which is called the standard deviation of the population of scores. As with E(x), is seldom known but can be estimated by Monte Carlo for large N as S, given by the positive square root of

$$S^2 = \sum_{i=1}^{N} (x_i -)^2 \; / \; N-1 \qquad (3)$$

The quantity S is the estimated standard deviation of the population of x based on the value of that was actually sampled.

The estimated variance of is given by

$$(S)^2 = S^2 \; / \; N. \qquad (4)$$

These equations do not depend on any restriction on the distribution of x or beyond requiring that E(x) and ^{2} exist and are finite. S is the standard deviation of the mean of , and it is important to note that S is proportional to $1 \; / \; \sqrt{N}$, which is

the inherent drawback to the Monte Carlo method. For instance, in order to reduce the quantity S by half, we must calculate four times the original number of histories.

Now that the concepts of the mean, variance, and the estimated standard deviation have been discussed with regard to MCNP, we introduce the inherent numerical errors associated with the methodology of THREEDANT. We cannot discuss the term standard deviation with regards to THREEDANT, because this applies to stochastic processes. The term does not apply to deterministic solutions such as discrete-ordinates codes. This is not to say that THREEDANT does not have inherent numerical errors. The numerical errors are due to, among other factors, how fine the meshes are in the input file. The meshes that can cause errors are the spatial mesh, the angular quadrature mesh, and the energy mesh that is built into the cross-section library. One way to minimize the errors associated with the meshes is to run a problem, try a finer mesh and see if the answer does not vary more than an acceptable criterion.

There is another error associated with the convergence process itself. The THREEDANT solver module employs the diffusion synthetic method to accelerate the iterative procedure used in solving the transport equation (Alcouffe, Brinkley, Marr, O'Dell, 1989). There are two different iterative procedures, one for problems containing fissionable material or energy-group upscattering and one for problems with neither fissions nor upscattering. The iterative strategy is divided into two parts, the inner iterations and outer iterations. The inner iterations are concerned with convergence of the pointwise

scalar fluxes in each group for a given source distribution. The outer iterations are concerned with the convergence of the eigenvalue, the fission source distribution and the energy-group upscatter source if any or all are present. The convergence of the iterations is monitored at both the inner and the outer iteration level. The inner iterations for a given energy are said to be converged when the pointwise scalar fluxes from one inner iteration to the next satisfy the condition (Alcouffe, Brinkley, Marr, O'Dell, 1989):

$$\max \left| \left({}_{i,g}\phi^{j} - {}_{i,g}\phi^{j-1} \right) \right| < \text{epsi} \qquad (5)$$

where ${}_{i,g}\phi^{j}$ is the scalar flux for the mesh point i, group g, and inner iteration j, and epsi is the inner iteration convergence criterion set in the input file.

As the diffusion fluxes are calculated for each energy group, a new fission source rate distribution, F(x) is calculated which is used to generate new diffusion fluxes. This process is repeated until both F(x) and the pointwise fluxes are converged. The process of recalculation of F(x) is called the diffusion sub-outer iteration. The convergence of the diffusion sub-outer iteration requires the satisfaction of two criteria. If we let donate the outer iteration number and p donate the diffusion sub-outer iteration number, convergence of the diffusion sub-outer is then satisfied when both

$$\max \left| \left({}_{i,g}\phi^{p,} - {}_{i,g}\phi^{p-1,} \right) / {}_{i,g}\phi^{p,} \right| < 0.95*\text{epsx} \qquad (6)$$

and

$$\left| 1-{}_{D}{}^{p,} \right| < \text{epso} \tag{7}$$

where

$$\text{epsx} \equiv \text{epsi} * [1 + \text{ngroup} * e^{(-100*\text{epsi})}] \tag{8}$$

with ngroup being the number of energy groups.
The notation epso denotes the outer iteration convergence criterion, and

$${}_{D}{}^{p,} \equiv (F^{p,},1 \quad) \; / \; (F^{p-1,},1 \quad) \tag{9}$$

with the notation (F,G) denoting the inner product (volume integral), of the product $F^{*}G$.

Full convergence is achieved when the flux changes represented by Eqs. (5) and (6) are less than epsx with the additional requirements that (Alcouffe, Brinkley, Marr, O'Dell, 1989)

$$\max \left| \; ({}_{i,g}{}^{1,} - {}_{i,g}{}^{0,}) \; / \; {}_{i,g}{}^{0,} \; \right| \quad < \text{epsx} \tag{10}$$

and

$$\left| 1- \right| < \text{epso}, \tag{11}$$

where ${}_{i,g}{}^{1,}$ represents the scalar flux at point i, group g from the first diffusion sub-outer iteration for outer iteration and ${}_{i,g}{}^{0,}$ denotes the scalar flux at point i, group g from the last diffusion inner iteration of outer iteration .

The evaluation of the error in the result of THREEDANT is

not as straight forward as with MCNP. The rule of thumb is that the answer is within 3*eps, where eps is the convergence criteria. This rule of thumb is for well behaved convergence. That is, if the problem converges in only ten or twenty iterations, then there is a good assurance that the problem is well behaved[1] as long as the global balance is less than roughly 1.0e-6 for eigenvalue problems.

[1] In past discrete-ordinates codes, certain problems were very slow to converge. One such problem was one with a lot of upscatter in the cross-section set. These problems might change very little with outer iteration even though the k effective was still far from the converged value. But the code would have satisfied the convergence criterion that was in the input file, and one might think the final answer was at hand. Typically, these runs might take over 40 iterations. With the acceleration techniques used in THREEDANT, one does not experience these sorts of problems.

CHAPTER 3

MCNP COMPUTATIONAL STUDY AND RESULTS

MCNP was used to calculate the reactivity effects of the formation of radiolytic bubbles in SHEBA II. These bubbles were modeled as a very low density nitrogen (10^{-9} g/cm^3) in MCNP, because making a particular cell a void in the MCNP input file would result in no tallies being collected in that particular cell. The first summer[2] was spent at Los Alamos National Laboratory as an introduction to the theory of MCNP, its input structure, as well as a period of acclimation to the laboratory and its computer systems. The second summer was when most of the research for the project was conducted. The computational study of SHEBA II was conducted on a variety of machines. During the first summer, the computer modeling was performed mainly on a CRAY at Los Alamos. During the second summer, the computer modeling was conducted on a variety of machines that included a SPARC I, SPARC II, SPARC 10, and a DEC 5000 at North Carolina State University.

The modeling in MCNP considered four different void positions (low density nitrogen bubble), all with the same volume (581 cm^3). This volume was selected after a sensitivity study was performed which demonstrated that a volume of this magnitude was needed to overcome the statistical error inherent to Monte Carlo methods. The solution height in the input file

[2] A typical fifteen month M.N.E. program involves the initial two months of the program being spent performing preliminary research into the project. These two months are followed by two semesters of course work and then the final four months of research.

was set to take into account the displacement of the solution from the void (i.e., maintaining constant fluid volume). This displacement was consistent between both MCNP and THREEDANT and increased the initial voided solution height by 0.323397 centimeters. The void was modeled as a cylindrical annular segment Fig. 19. This configuration was chosen to maintain consistency between the geometric models of MCNP and THREEDANT[3]. The first position considered was the outside bottom of the cylinder. This position was selected for two reasons. First, this position will be the same as if the void was placed at the top of the solution along the edge of the cylinder, due to the effects of symmetry. Furthermore, of all the positions, this one originally was considered intuitively as the one with the greatest chance of acting as a positive insertion. The next position considered was at the midplane of the solution along the outside of the cylinder. The final two positions are at the same vertical positions as the other two voids, but they exist along the central thimble, slightly off the central axis of the cylinder.

The modeling was performed by creating an input file in the format of MCNP. The input file modeled SHEBA II and its immediate surroundings to a high amount of detail. An example input file for MCNP can be found in Appendix A. Because SHEBA II has only slightly different dimensions than SHEBA (a predecessor to SHEBA II) and the uranyl fluoride solution is the same, the approximate critical height was known. A height for

[3] MCNP is able to handle different coordinate systems in the same input file. This feature is quite different from THREEDANT, which is unable to mix coordinate systems .

the solution was selected initially that was within a few centimeters of the critical height of SHEBA.

During the first summer, a technique was acquired which lowered the estimated standard deviation of the selected output tallies from MCNP. This technique involved performing a pre-production run of approximately 80 cycles of each different void position. A source distribution file is created by MCNP, which is used in a production run to lower the estimated standard deviation. If a source distribution file was not used, the large estimated standard deviation from the first dozen cycles would be averaged into the final estimated standard deviation and thus increase the size of the final deviation. The production run was for 350 cycles. While this large number of cycles was computer and time intensive, a smaller number would produce a larger estimated standard deviation, but a larger number of cycles would not improve the statistics significantly since the estimated standard deviation is proportional to $1 / \sqrt{N}$, where N is the number of histories. A graph of the $1 / \sqrt{N}$ behavior of the estimated standard deviation can be found in Fig. 1.

Before any runs were conducted that contained voids, the critical height without any voids needed to be determined with MCNP. The input file was constructed and run, and the results were then examined. To verify that the input file was modeling the problem that was intended, the output was analyzed. For example, small cells were placed every 0.5 centimeter at the midplane of the cylinder from the central thimble to the outside of the cylinder in order to plot the neutron flux profile. This

plot can be seen in Fig. 2. As can be seen, the flux profile is acting as one would expect with the highest flux being towards the center of the cylinder while it decreases as it goes out radially from the center of the cylinder, in a $J_0(r)$-like behavior.

Once it was fairly certain that the input file was modeling the problem accurately, the critical height with no voids in the model needed to be determined. Nine different heights were run and their associated k effective (k_{eff}) were plotted versus the solution heights. The results of the runs can be seen in Table 1 below and the corresponding graph can be found in Fig. 3. As can be seen from Fig. 3, the approximate critical height is 41.31 ± 0.29 centimeters, where the deviation of the height is found from the linear fit of the line. The standard deviation of the height for two particular points was obtained by using the following procedure. By selecting two points on Fig. 3 such as the solution heights of 40.00 and 41.00 centimeters and their respective k_{eff} values of 0.99535 and 0.99874, the reactivity per centimeter ($0.5215) can be calculated. With the reactivity per centimeter and the reactivity of the estimated standard deviation ($0.1654), which is found in the output file, the estimated deviation of the height is obtained. For example using the for thermal U^{235} fissions (0.0065), the standard deviation of the height is found.

$$0.99874 - 0.99535 = 0.00339 \text{ per centimeter}$$

0.00339 / 0.0065 = $0.5215 per centimeter

0.0011 / 0.0065 = $0.1654

standard deviation of height =

$0.1654 / $0.5215 per cm = 0.3171 cm

TABLE 1

Solution heights and k_{eff}

(MCNP: no void in cylinder)

Solution Height (cm)	k_{eff}	Estimated Relative Standard Deviation (±)
39.50	0.991442	0.0010
40.00	0.995347	0.0012
40.50	0.996716	0.0009
41.00	0.998737	0.0010
41.25	0.999983	0.0010
41.50	1.000950	0.0010
42.00	1.003220	0.0009
42.50	1.005190	0.0010

The first void position that was analyzed was with the void at the outside bottom of the cylinder. A new input file was created with everything identical to the original input file

(no-void) except that a cell that represented a void was placed at the outside bottom of the cylinder. With the approximate critical height being known from the no-void case, a solution height was selected that was a few centimeters below critical height. The case was run and a new input file was created with a slightly higher solution height (0.25 cm). This cycle would continue until the solution height was a few centimeters above critical height. A comparison of k_{eff} versus the solution height can be found in Table 2. The graph of the data can be seen in Fig. 4.

TABLE 2

Solution and k_{eff}

(MCNP: void placed at outside bottom of cylinder)

Solution Height (cm)	k_{eff}	Estimated Relative Standard Deviation (±)
41.216	0.99669	0.00109
41.466	0.99782	0.00107
41.716	0.99976	0.00114
41.966	0.99978	0.00108
42.216	1.00019	0.00109
42.466	1.00193	0.00105
42.716	1.00296	0.00077
42.966	1.00325	0.00113

The next void position that was modeled was with the void at the outside midplane of the cylinder. A new input file was created with everything identical to the last input file (void at outside bottom) except for the void position. Following the same procedure as before, multiple cases were run. The solution height varied from 41.2 to 43.2 centimeters. A table of k_{eff} versus the solution height can be found in Table 3, and a graph of the data can be found in Fig. 5.

TABLE 3

Solution heights and k_{eff}

(MCNP: void placed at outside midplane of cylinder)

Solution Height (cm)	k_{eff}	Estimated Relative Standard Deviation (±)
41.216	0.99256	0.00109
41.466	0.99364	0.00116
41.716	0.99669	0.00113
41.966	0.99699	0.00108
42.216	0.99824	0.00111
42.466	0.99972	0.00106
42.716	1.00032	0.00102
42.966	1.00119	0.00109
43.216	1.00313	0.00109

The next void position that was modeled was with the void at the inside midplane of the cylinder. Following the same procedure as before, multiple cases were run. A table of the k_{eff} versus the solution height can be found in Table 4, and a graph of the data can be found in Fig. 6.

TABLE 4

Solution heights and k_{eff}

(MCNP: void placed at inside midplane of cylinder)

Solution Height (cm)	k_{eff}	Estimated Relative Standard Deviation (±)
41.466	0.99315	0.00122
41.716	0.99489	0.00116
41.966	0.99643	0.00132
42.216	0.99668	0.00129
42.466	0.99820	0.00111
42.716	0.99972	0.00106
42.966	1.00066	0.00102
43.216	1.00100	0.00122
43.466	1.00209	0.00134
43.716	1.00237	0.00111
43.966	1.00356	0.00106

The final void position that was modeled was with the void at the inside bottom of the cylinder. A new input file was created with everything identical to the last input file except for the void position. Following the same procedure as before, multiple cases were run. A table of k_{eff} versus the solution

height can be found in Table 5, and a graph of the data can be found in Fig. 7.

TABLE 5

Solution heights and k_{eff}

(MCNP: void placed at inside bottom of cylinder)

Solution Height (cm)	k_{eff}	Estimated Relative Standard Deviation (±)
41.466	0.99474	0.00117
41.716	0.99631	0.00123
41.966	0.99723	0.00126
42.216	0.99818	0.00114
42.466	0.99810	0.00126
42.716	1.00014	0.00106
42.966	1.00084	0.00124
43.216	1.00384	0.00127
43.466	1.00707	0.00134
43.716	1.00947	0.00111

The running of all void positions as well as the no-void case took approximately 550 CPU hours, or 23 days of constant CPU usage on a SPARC I. It must be noted that all void positions cannot be compared to each other. The voids placed at

the outside of the cylinder can be compared because these voids have the same dimensions, but are at different positions in the tank. The same argument can be made for the voids that are at the inside of the tank adjacent to the central thimble. The difference in void dimensions makes the comparison of the inside position and outside position impossible even though these voids have the same volume. But from MCNP results, it can be said that all voids act as a negative reactivity insertion when compared to the no-void case (Fig. 8).

The fact that the void at the outside of the cylinder has a negative worth, as seen in Fig. 9, is not surprising when one considers the physics of the matter. It is known that a void placed at the outside edge of the cylinder will increase leakage, lower the number of fission events, and hence lower the k_{eff}. It would seem apparent that the void positioned at the outside bottom of the cylinder would have a more negative worth when compared to the void at the outside midplane of the cylinder if one just considered the surface area of leakage. But the void positioned at the outside midplane of the cylinder encounters more neutrons due to its greater solid angle than the void positioned at the outside bottom. Another way of looking at why the void at the outside bottom of the cylinder does not have as negative a worth is to consider the importance of the different regions with respect to the neutrons. The region at the outside bottom of the cylinder does not encounter as many neutrons as the void at the midplane of the cylinder. This region can be considered to have a lower importance with respect to neutrons. When this region is replaced by a void, there is

increased leakage in the area which will act as a negative insertion. But this void displaces the top of the solution 0.323397 centimeters up. The solution that was in the volume that the void now occupies is spread out evenly over the top of the solution. While it is true that some of the solution is toward the outside of the cylinder, some is also in the center of the cylinder which has a higher importance. This displacement of solution around the central thimble acts as a slight positive insertion. This slight insertion offsets some of the negative insertion that is obtained from the leakage at the bottom of the cylinder.

If a void formation toward the center of the tank is considered (around the central thimble) it can be seen in Fig. 10 that both positions (midplane and bottom) act as a negative reactivity insertion. The reasons for the negative worths are different depending on the location of the void. For instance, if the void forms on the bottom of the tank around the central thimble there is a large increase in leakage due to the void. The void causes an increase in leakage because neutrons that would normally be in fissionable material, if the void was not there, are able to pass through the void and out of the system. This loss of neutrons reduces the number for fission, and hence decreases k_{eff}.

If one considers the formation of a void around the central thimble at the midplane of the solution height, it also acts as a negative insertion, but for different reasons. When a void is modeled around the central thimble, it displaces a large volume of fissionable material from an area of high importance

to one of low importance. This displacement of material is enough to account for the negative worth of the void, even though there is not any leakage.

CHAPTER 4

THREEDANT COMPUTATIONAL RESULTS AND BENCHMARKING

With the results from MCNP in hand, an experiment was designed in the second summer of my M.N.E (Master of Nuclear Engineering) traineeship that would have verified the results obtained through MCNP. Unfortunately, bureaucratic complications arose which made the experiment impossible to run in the time frame of my project. While this experiment will hopefully be performed sometime in the future, it was decided to verify the results of MCNP computationally. With the existence of a new code capable of modeling non-symmetrical geometries and a need for this code to be benchmarked, it was decided that this code would be used in place of the experiment to verify MCNP.

An input file for THREEDANT was created in order to obtain the k_{eff} of SHEBA II without the existence of voids. For all the THREEDANT runs, the angular quadrature order is eight, the number of mesh points are roughly 25,000, and the sixteen group cross-section set is ENDFB-V. The input files were run until the k_{eff} eigenvalue had converged to 1×10^{-4}. Even with this liberal convergence limit, at times the code did not converge to all criteria. When this happened it was effectively ignored and the last iteration number was used if there was convergence to at least four significant figures. Numbers were taken to six significant figures after the decimal, but only the first four are reliable. A sample input file for THREEDANT can be found in Appendix B. Similar to the procedure used in MCNP, various solution heights were run and the data can be found in the Table

6. The corresponding graph can be found in Fig 11.

TABLE 6

Solution heights and k_{eff}

(THREEDANT: no void in cylinder)

Solution Height (cm)	k_{eff}	Estimated Error (±)
41.46	0.988542	0.0003
42.46	0.993191	0.0003
43.00	0.995392	0.0003
43.50	0.997492	0.0003
44.00	0.999543	0.0003
44.50	1.001534	0.0003
45.00	1.003325	0.0003
45.46	1.005314	0.0003

As with MCNP, the first void position that was analyzed in THREEDANT was with the void at the outside bottom of the cylinder. A new input file was created with most things identical to the original input file (no void) except that a cell was set up at the outside bottom of the cylinder that represented a void. The void representation also changed the spatial mesh from the last case. A number of test cases were submitted where the spatial mesh was varied until there was no

significant change in the results. This procedure lead to confidence in the spatial mesh that was used in the problem. This procedure of varying the spatial mash in order to find a suitable mesh was used in all the different void positions. With the approximate critical height being known from the no-void case, a solution height was selected that was a few centimeters below critical height. The same procedure used in MCNP to obtain the critical height was used here. Different cases were run with the solution height varying. The outputs were analyzed, and the k_{eff} for each solution height was noted. A comparison of k_{eff} versus the solution height can be found in Table 7, and a graph of this data can be found in Fig. 12.

TABLE 7

Solution and k_{eff}

(THREEDANT: void placed at outside bottom of cylinder)

Solution Height (cm)	k_{eff}	Estimated Error (±)
41.96	0.988806	0.0003
42.46	0.992652	0.0003
42.72	0.993747	0.0003
42.96	0.994827	0.0003
43.22	0.995891	0.0003
43.46	0.997137	0.0003
43.72	0.998041	0.0003
43.96	0.999019	0.0003
44.46	1.001020	0.0003
44.96	1.002970	0.0003
45.46	1.004300	0.0003

The next void position that was modeled was with the void at the outside midplane of the cylinder. A new input file was created with everything identical to the last input file (void at outside bottom) except for the void position. Following the same procedure as before, multiple cases were run. The solution height was varied and a table of the k_{eff} versus the solution height can be found in Table 8. A graph of the data can be found in Fig. 13.

TABLE 8

Solution heights and k_{eff}

(THREEDANT: void placed at outside midplane of cylinder)

Solution Height (cm)	k_{eff}	Estimated Error (±)
41.96	0.987322	0.0003
42.46	0.989565	0.0003
42.96	0.991744	0.0003
43.46	0.993885	0.0003
43.96	0.995961	0.0003
44.46	0.998325	0.0003
44.96	1.000590	0.0003
45.46	1.002740	0.0003
45.96	1.004710	0.0003
46.96	1.006690	0.0003

A void at the inside midplane of the cylinder was modeled next. A new input file was created with the void position changed. Again, cases were run with varying solution heights. A table of the k_{eff} versus the solution height can be found in Table 9, and a graph of the data can be found in Fig. 14.

TABLE 9

Solution heights and k_{eff}

(THREEDANT: void placed at inside midplane)

Solution Height (cm)	k_{eff}	Estimated Error (±)
41.96	0.987420	0.0003
42.46	0.989865	0.0003
42.96	0.992044	0.0003
43.46	0.994192	0.0003
43.96	0.996261	0.0003
44.46	0.998625	0.0003
44.96	1.000620	0.0003
45.46	1.003040	0.0003
45.96	1.004820	0.0003
46.46	1.006990	0.0003

Finally, a void was modeled at the inside bottom of the cylinder. Following the same procedure as before, multiple cases were run of this new input file. The solution height varied from 42.46 centimeters to 46.96 centimeters. Table 10 contains a comparison of k_{eff} versus the solution height. A graph of the data can be found in Fig. 15.

TABLE 10

Solution and k_{eff}

(THREEDANT: void placed at inside bottom of cylinder)

Solution Height (cm)	k_{eff}	Estimated Error (±)
41.46	0.985762	0.0003
41.96	0.988098	0.0003
42.46	0.990384	0.0003
42.96	0.992586	0.0003
43.46	0.994760	0.0003
43.96	0.996853	0.0003
44.46	0.998898	0.0003
44.96	1.001004	0.0003
45.46	1.003110	0.0003
45.96	1.005853	0.0003

As with the run time per case in MCNP, each case in THREEDANT took approximately 12-25 hours depending on the computer used. Also as with the CPU time of MCNP, the total run time of THREEDANT was approximately 500 CPU hours on a SPARC I. It can be seen in Fig. 16 that all the void positions, except the void at the outside bottom of the cylinder, act as a negative worth. The void at the outside bottom of the cylinder has a slightly positive worth, as seen in Fig. 17, when one considers that the void automatically displaces the top of the

solution 0.323397 centimeters. The possibility of a positive insertion by this void was originally considered and is not startling when one considers that this position has a low importance, thus leakage is not severe. Also, fissile solution is being displaced from a region of low importance to a region of higher importance (on average), which would increase fissions and hence k_{eff}. While these results are different from MCNP, the trends (i.e., the voids worth relative to each other) that result from THREEDANT agree quite well with the results of MCNP. Also, as can be seen in figures 3-7 and 11-15, the slopes of all of these figures are similar. This fact provides a useful calculational benchmark for THREEDANT because the relatively consistent slopes lead to the calculation of roughly the same amount of reactivity per centimeter, regardless of which code is considered.

As can be seen in Fig. 18, the results from THREEDANT show that the formation of voids toward the inside of the cylinder (around the central thimble) act as a negative reactivity insertion as in MCNP. The reason for this negative worth is dependent on position. For instance, a void at the inside bottom of the cylinder promotes leakage while a void at the inside midplane displaces solution from an extremely important region to one of relatively low importance.

A comparison of the critical heights of all void positions calculated in THREEDANT and MCNP can be found in Table 11. If we take into account that the displacement of the void automatically raises the solution height 0.323397 cm, the change in height required to make the system critical can be

found in Table 12. As can be seen in the tables, for all the void cases there is roughly a two centimeter difference between the critical height in MCNP and THREEDANT for all void positions.

TABLE 11

Comparison of the critical heights

Void Position	MCNP	THREEDANT
No Void	41.31 ± 0.29 cm	44.13 cm
Outside bottom	42.13 ± 0.33 cm	44.26 cm
Outside midplane	42.61 ± 0.26 cm	44.62 cm
Inside bottom	42.64 ± 0.21 cm	44.78 cm
Inside midplane	42.71 ± 0.33 cm	44.72 cm

TABLE 12

Comparison of the change in heights to maintain criticality with the void displacement taken into account

Void Position	MCNP	THREEDANT
No Void	41.31 ± 0.29 cm	44.13 cm
Outside bottom	+ 0.50 ± 0.33 cm	- 0.19 cm
Outside midplane	+ 0.98 ± 0.26 cm	+ 0.17 cm
Inside bottom	+ 1.01 ± 0.21 cm	+ 0.33 cm
Inside midplane	+ 1.08 ± 0.33 cm	+ 0.27 cm

As to why there is the two centimeter difference remains to be seen. In 1991, an analysis of rod worths in SHEBA II was performed (Kornreich). It was discovered that TWODANT consistently gave a higher critical height (~ 2cm) than MCNP. Further analysis was performed which involved obtaining the critical height of SHEBA (which was known from experiment), with MCNP and TWODANT. TWODANT, using the same cross-section set as was used in this analysis, gave a more accurate answer than MCNP

as can be seen in Table 13.

TABLE 13

Comparison of the critical heights

	Experiment	MCNP	TWODANT
SHEBA	36.5 cm	34.9 cm	36.6 cm
SHEBA II	?	41.3 cm	44.1 cm

While no reason was given at the time for the critical height differences, it has been suspected that the problem existed in the cross-section set that was used. MCNP was used with a continuous energy cross-section set, while THREEDANT was used with a sixteen-group set. The continuous energy set has an apparent advantage in that it treats the energy range not as groups but as a continuos energy range, where the sixteen group set breaks the energy range into sixteen distinct groups. But, the cross-section set used in THREEDANT was constructed by Hansen and Roach. The strength of this set is that it treats the resolved and unresolved resonances and has been in use for decades with a high amount of success (i.e., has been benchmarked against many critical assemblies). As far as the benchmarking of THREEDANT goes, it is very encouraging that the trends that existed in the MCNP runs also exist in the THREEDANT results.

CHAPTER 5

FUTURE EXPERIMENTAL VERIFICATION

As was mentioned in Chapter 4, an experiment has been designed that will be used to test the accuracy of the codes. The experiment is designed to simulate the formation of voids in the reactor cylinder of SHEBA II. The voids are to be made of aluminum, which was selected due to its relatively small cross section to neutrons as well as its ability to form a protective oxide layer. Although this layer would ultimately be destroyed by the corrosive properties (pH = 1) of the uranyl fluoride solution, it would provide adequate protection for the time frame of the experiment. The details of the void design can be found in Fig. 19. A mechanism was also designed which would place the voids into the different positions. Although at this time the voids and support mechanism have not been fabricated, it is hoped that they will be done prior to the first approach to critical of SHEBA II. One point of safety should be noted. Because the void at the outside midplane of the cylinder has a more negative worth than a void placed below it at the outside bottom of the cylinder, care should be taken to insure that it does not fall after going critical with it in position. If a void at the outside midplane of the cylinder were to fall unexpectedly, this change in position would act as a positive insertion of roughly between \$0.19 and \$0.40.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The effect of a void formation in a solution critical assembly has been found. The modeling of these voids has been performed in two codes. The first, MCNP (Monte Carlo Neutron Photon transport), is a Monte Carlo code. The second, THREEDANT (THREE dimensional, Diffusion-Accelerated, Neutral-Particle Transport), is a discrete-ordinates code. Four voids were modeled in four distinct positions. It is apparent that the formation of a void in all but the outside bottom of the cylinder acts as a negative reactivity insertion. It also is evident that a void placed at the outside bottom of the cylinder does not have as negative a worth as a void placed at the other positions in the cylinder, or possibly even has a slightly positive worth. The reason for the less negative worth for a void placed at the outside bottom of the cylinder is due to competing effects. For instance, while it is true that a void in this position is increasing leakage, it is also displacing fissionable material to a region that is considered more important to neutron interaction.

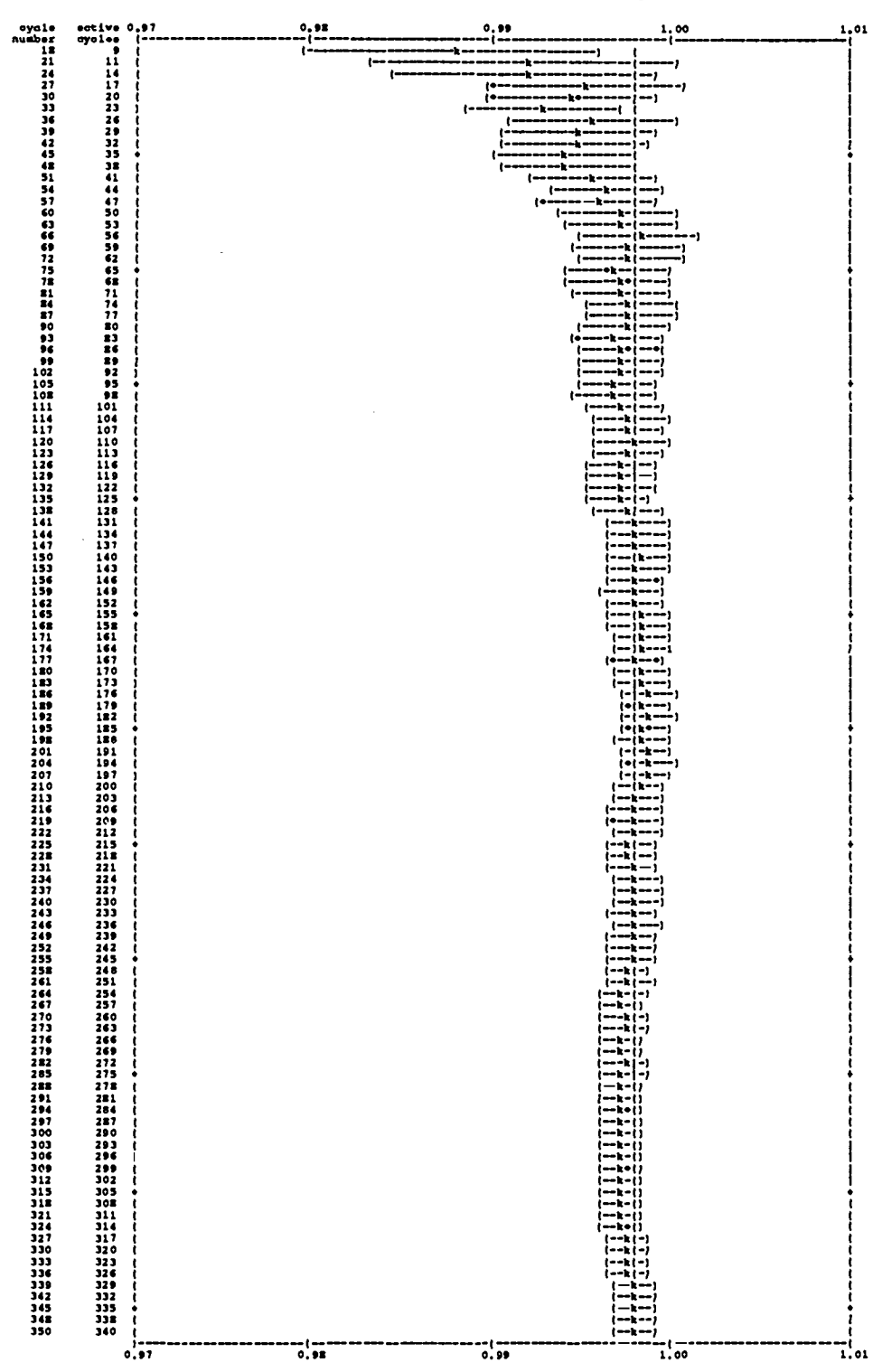
An experiment has been devised which will be able to verify the results of the codes. This experiment will hopefully be performed in the near future, and consists of inserting aluminum voids in the shape that was used in the codes. A mechanical device was also designed which would be able to insert the voids in various positions.

Finally, THREEDANT was used not only to verify

MCNP, but the need existed for the benchmarking of this new code. It was quite encouraging to see that both codes (MCNP and THREEDANT) gave results that have the same trend. Both codes resulted in roughly the same slopes when the k_{eff} versus solution height was plotted. This roughly consistent slope led to the calculation of similar worths per centimeter of the solution. Although the slopes were similar between the two codes, the critical heights were not. When voids where modeled in various positions, approximately two centimeters separated the critical heights given by MCNP and THREEDANT. A consistent discrepancy, as in this case, suggests that the discrepancy could be the result of differences in the cross-section sets. While the cross-section differences are a possible solution, future analysis will need to be conducted in order to have increased confidence in this solution. In conclusion, it seems that employing both neutronics codes has provided insight into the codes and their capabilities, as well as to the effects of the voids on reactivity.

Figure #1

(1 / √N characteristic of estimated standard deviation)



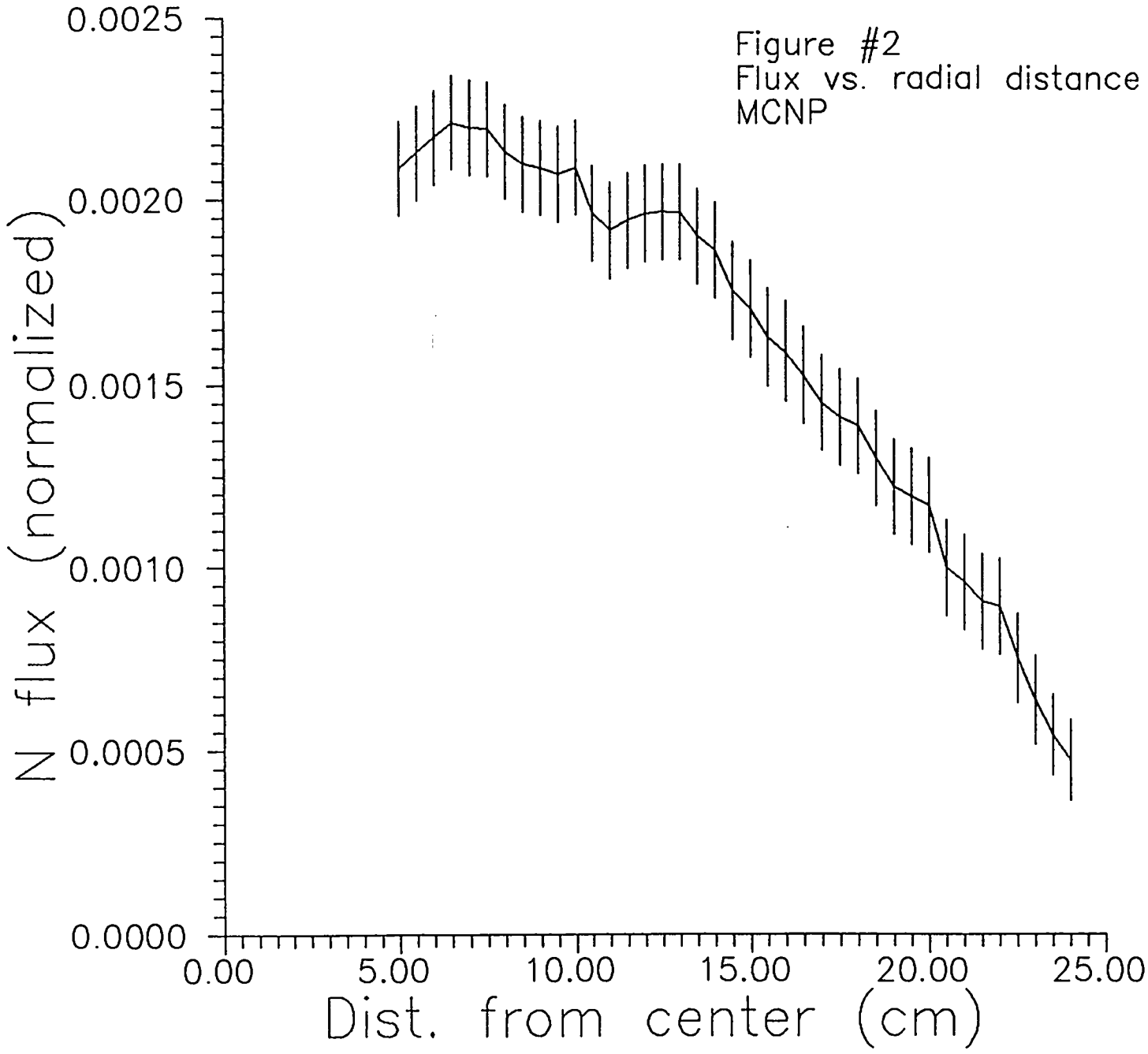


Figure #2
Flux vs. radial distance
MCNP

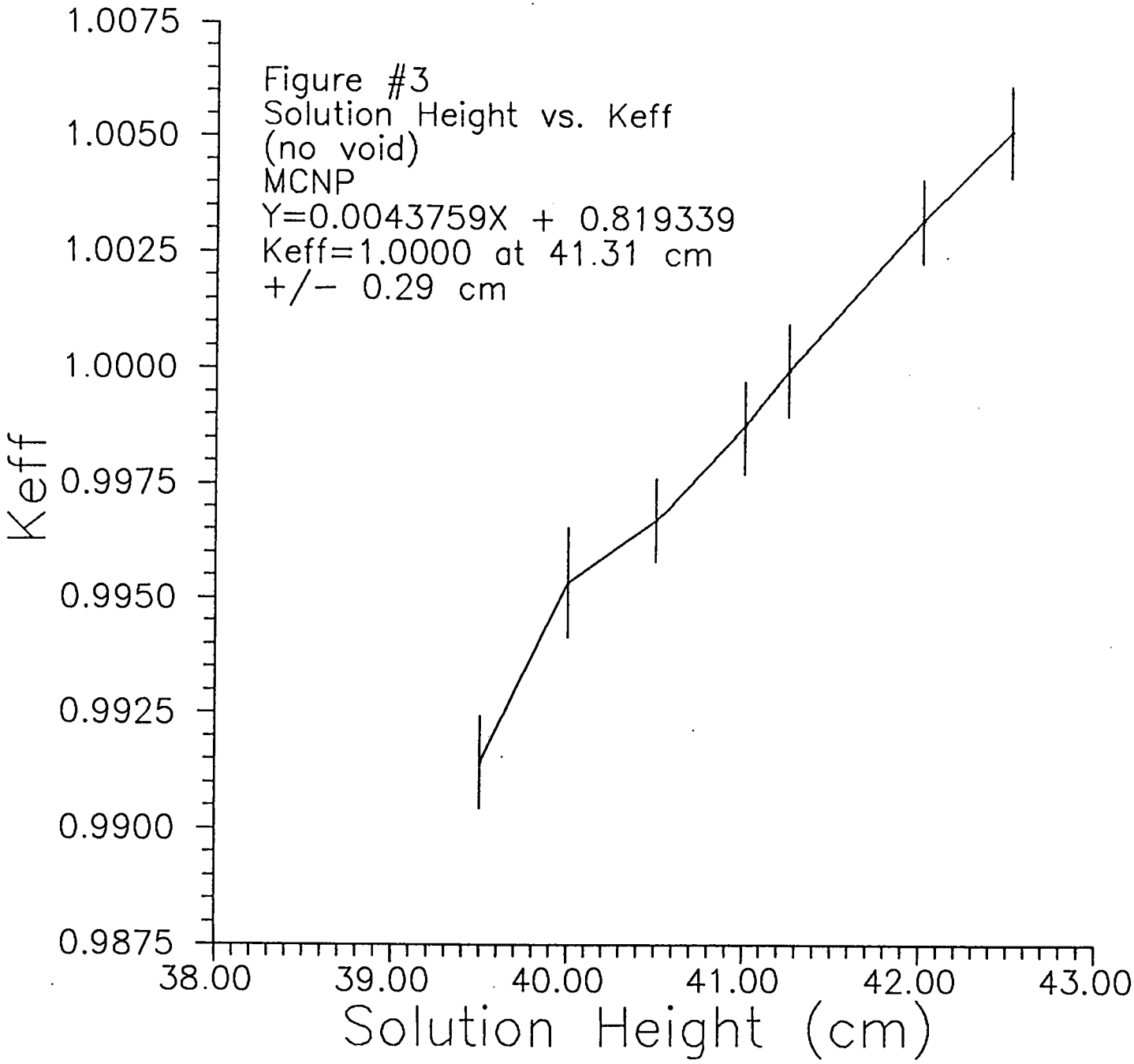


Figure #3
Solution Height vs. Keff
(no void)
MCNP
Y=0.0043759X + 0.819339
Keff=1.0000 at 41.31 cm
+/- 0.29 cm
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
0.9875
Keff
38.00
39.00
40.00
41.00
42.00
43.00
Solution Height (cm)

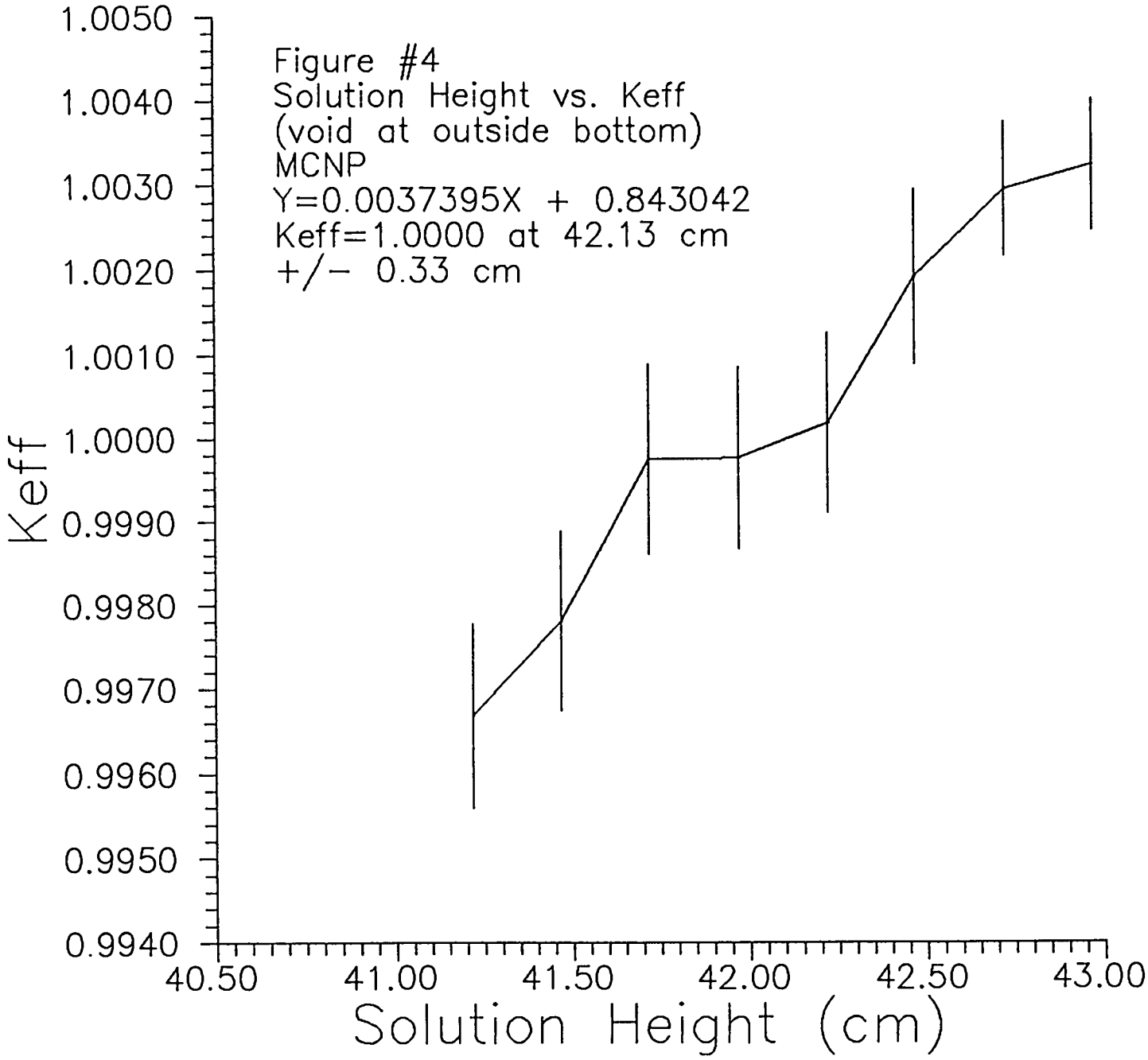


Figure #4
Solution Height vs. Keff
(void at outside bottom)
MCNP
Y=0.0037395X + 0.843042
Keff=1.0000 at 42.13 cm
+/- 0.33 cm
1.0050
1.0040
1.0030
1.0020
1.0010
1.0000
0.9990
0.9980
0.9970
0.9960
0.9950
0.9940
Keff
40.50
41.00
41.50
42.00
42.50
43.00
Solution Height (cm)

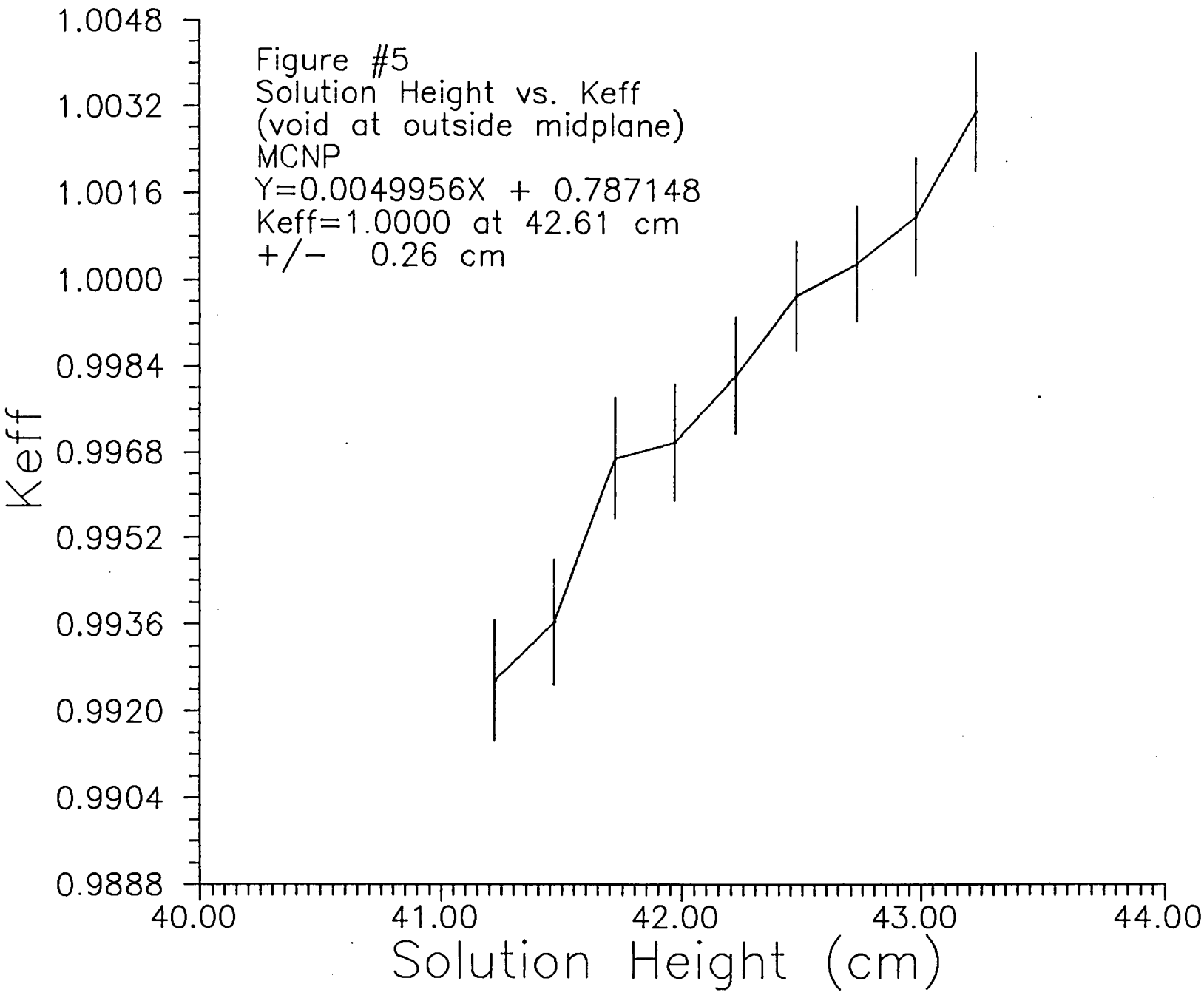


Figure #5
Solution Height vs. Keff
(void at outside midplane)
MCNP
Y=0.0049956X + 0.787148
Keff=1.0000 at 42.61 cm
+/- 0.26 cm
1.0048
1.0032
1.0016
1.0000
0.9984
0.9968
0.9952
0.9936
0.9920
0.9904
0.9888
Keff
40.00
41.00
42.00
43.00
44.00
Solution Height (cm)

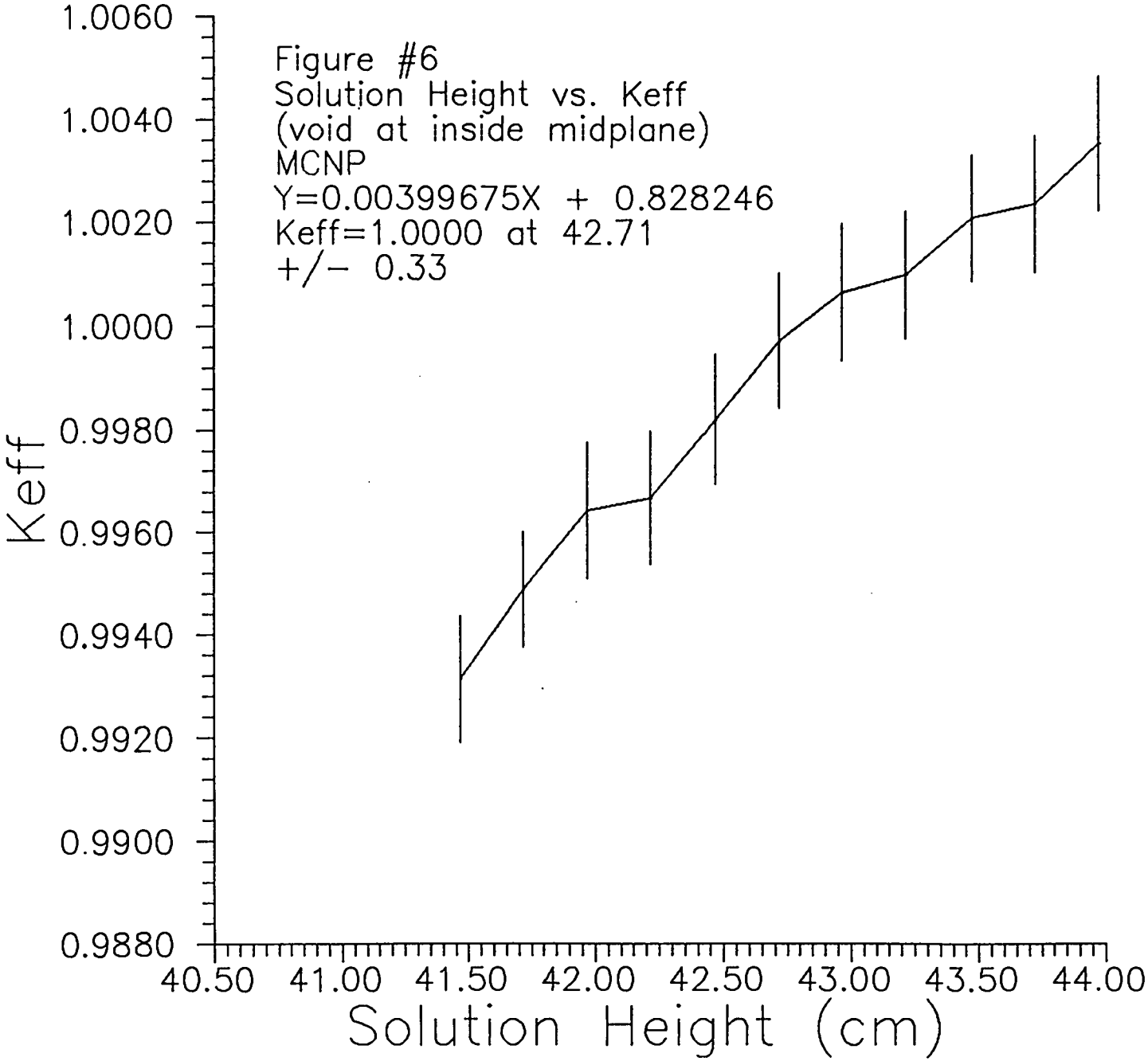


Figure #6
Solution Height vs. Keff
(void at inside midplane)
MCNP
Y=0.00399675X + 0.828246
Keff=1.0000 at 42.71
+/- 0.33
Keff
1.0060
1.0040
1.0020
1.0000
0.9980
0.9960
0.9940
0.9920
0.9900
0.9880
40.50
41.00
41.50
42.00
42.50
43.00
43.50
44.00
Solution Height (cm)

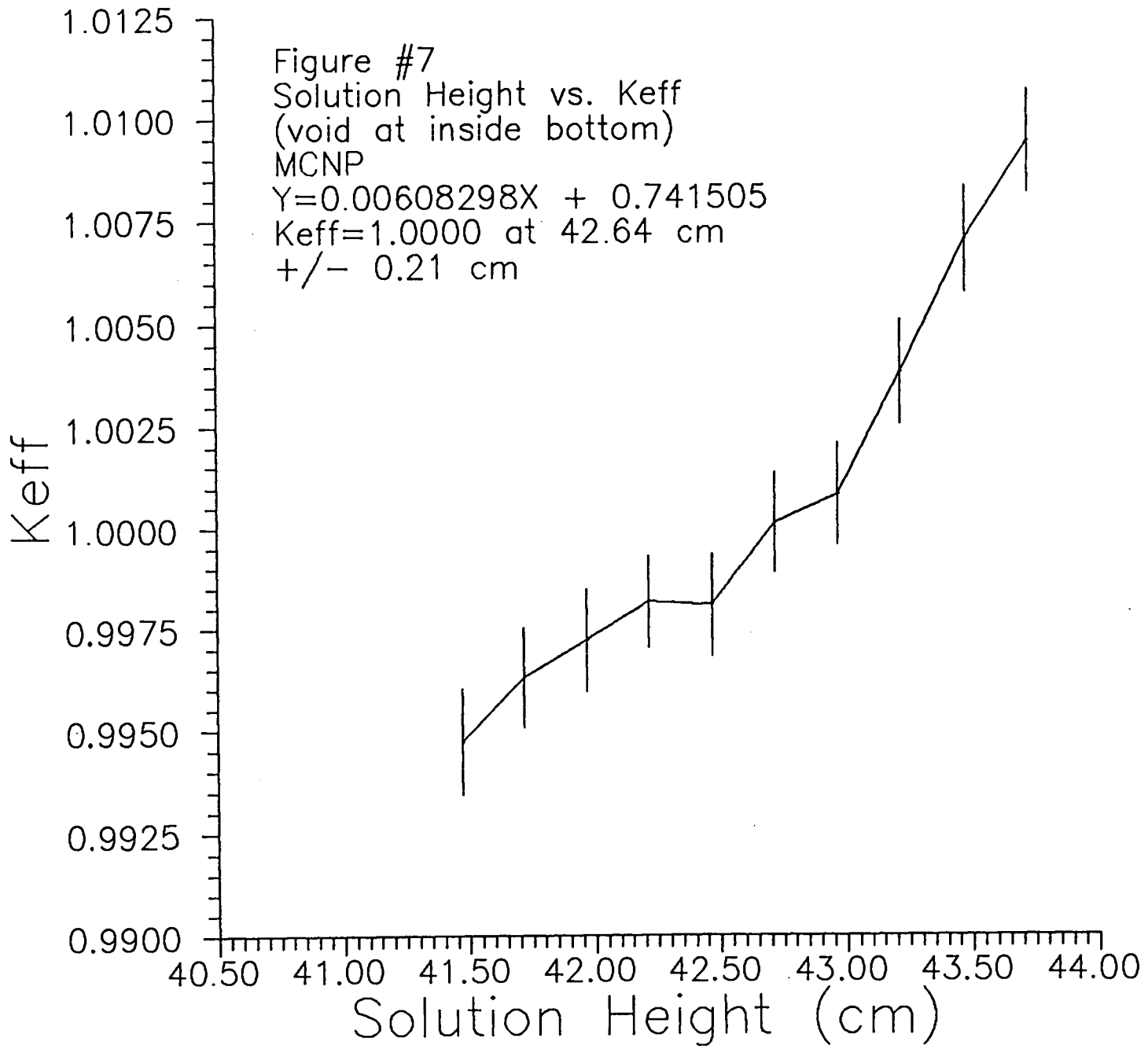


Figure #7
Solution Height vs. Keff
(void at inside bottom)
MCNP
Y=0.00608298X + 0.741505
Keff=1.0000 at 42.64 cm
+/- 0.21 cm
Keff
1.0125
1.0100
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
40.50
41.00
41.50
42.00
42.50
43.00
43.50
44.00
Solution Height (cm)

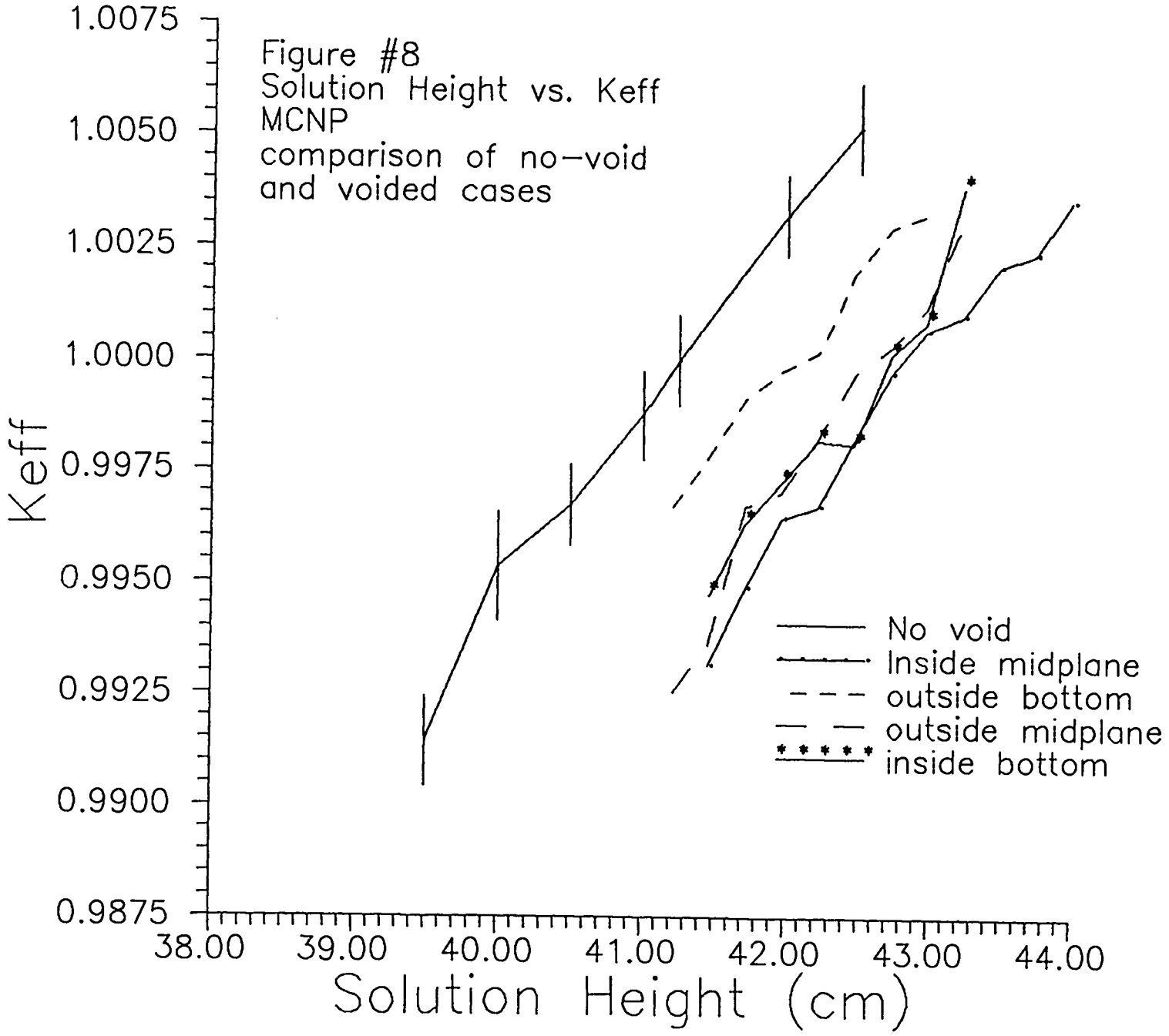


Figure #8
Solution Height vs. Keff
MCNP
comparison of no-void
and voided cases
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
0.9875
Keff
38.00
39.00
40.00
41.00
42.00
43.00
44.00
Solution Height (cm)
No void
Inside midplane
outside bottom
outside midplane
inside bottom

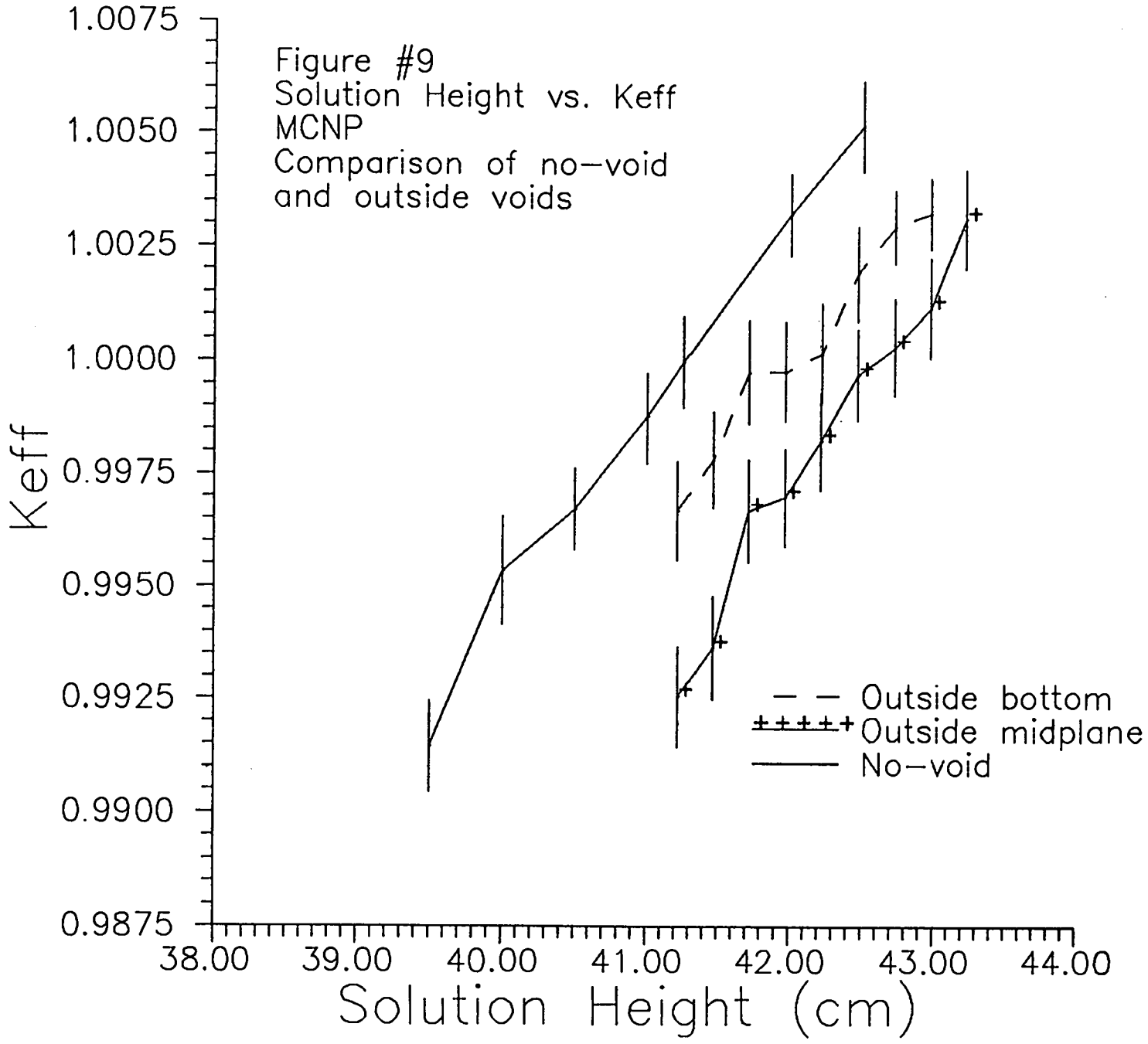


Figure #9
Solution Height vs. Keff
MCNP
Comparison of no-void
and outside voids
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
0.9875
Keff
38.00
39.00
40.00
41.00
42.00
43.00
44.00
Solution Height (cm)
Outside bottom
Outside midplane
No-void

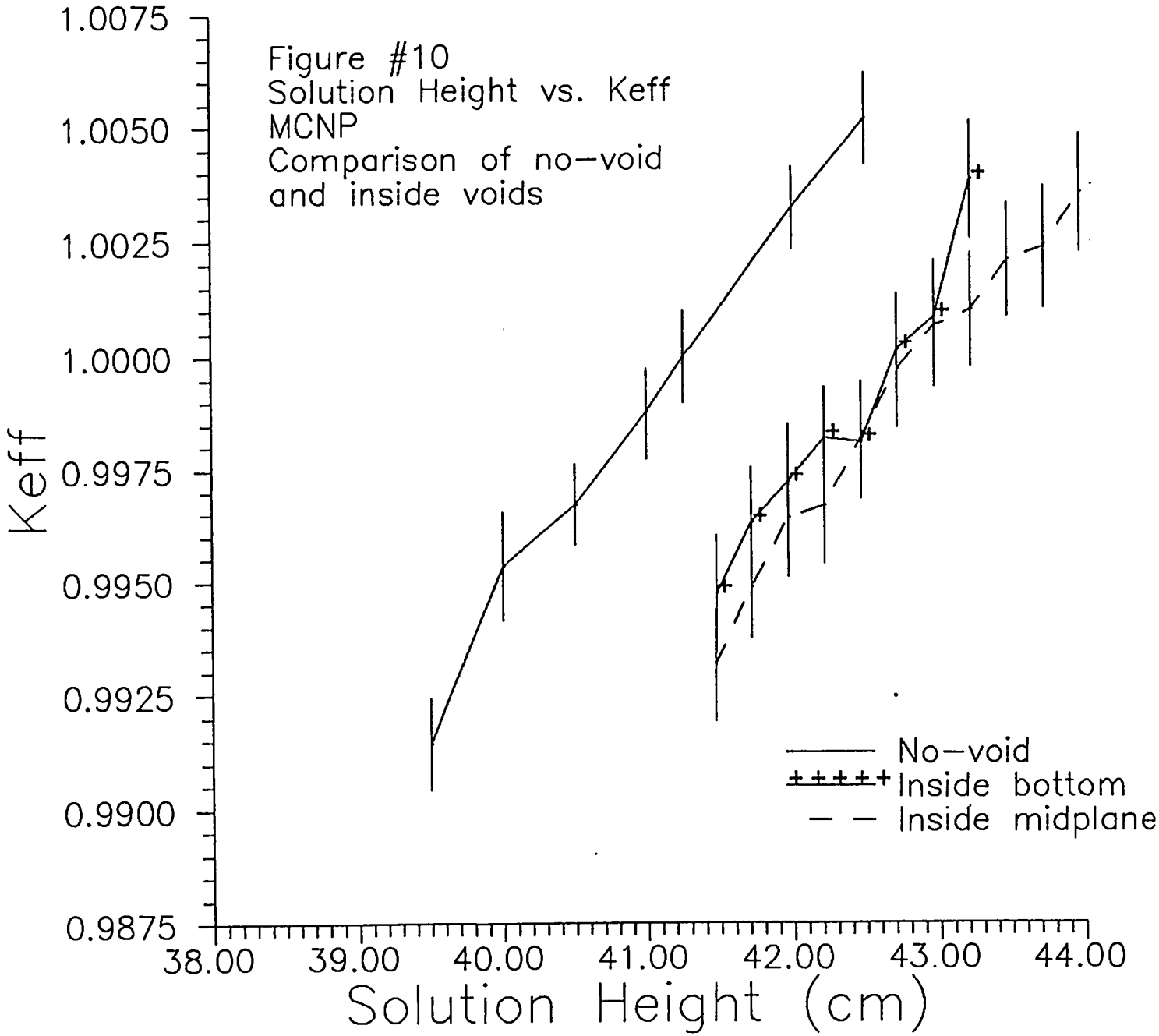


Figure #10
Solution Height vs. Keff
MCNP
Comparison of no-void
and inside voids
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
0.9875
Keff
38.00
39.00
40.00
41.00
42.00
43.00
44.00
Solution Height (cm)
No-void
Inside bottom
Inside midplane

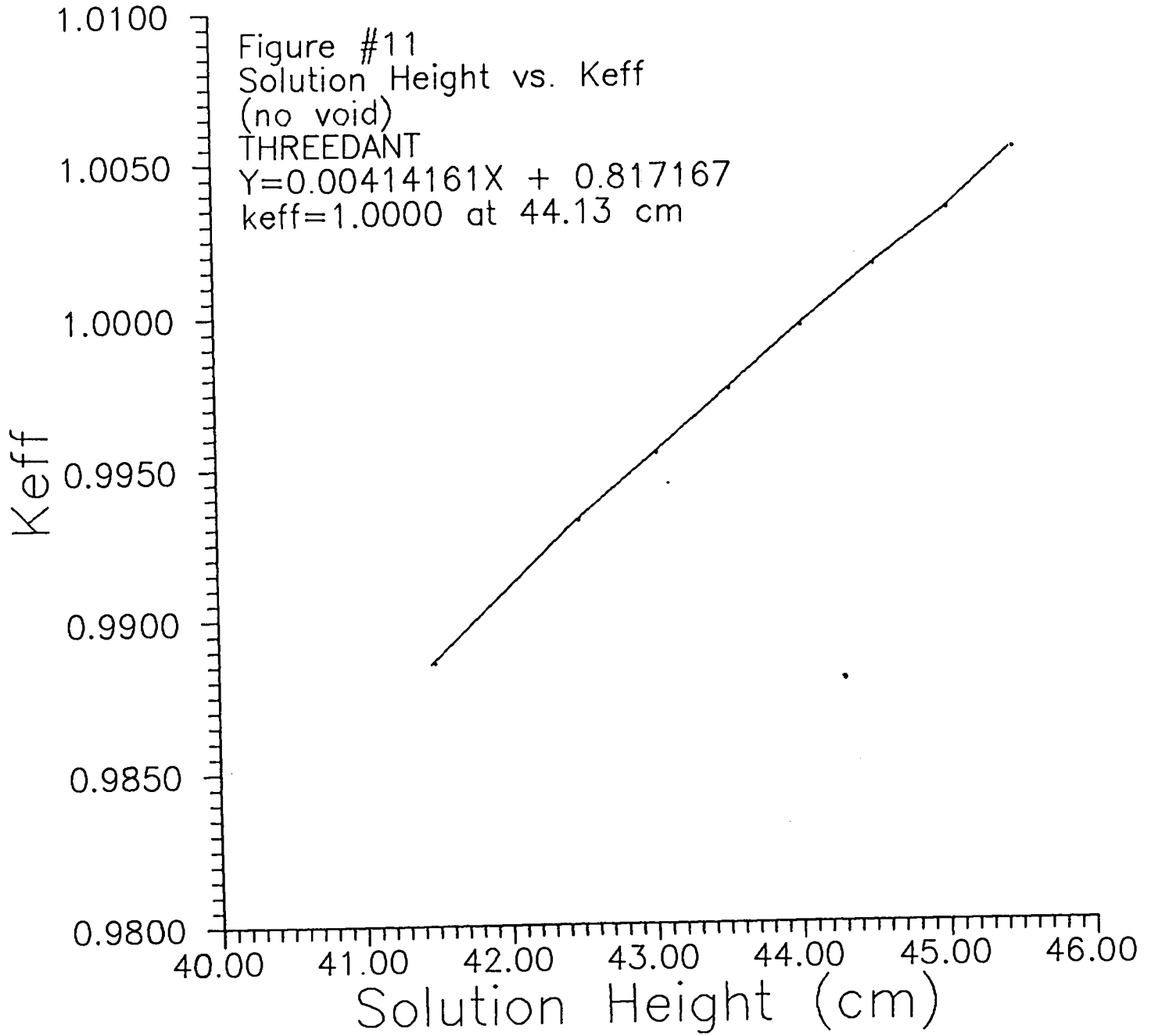


Figure #11
Solution Height vs. Keff
(no void)
THREEDANT
Y=0.00414161X + 0.817167
keff=1.0000 at 44.13 cm
1.0100
1.0050
1.0000
0.9950
0.9900
0.9850
0.9800
Keff
40.00
41.00
42.00
43.00
44.00
45.00
46.00
Solution Height (cm)

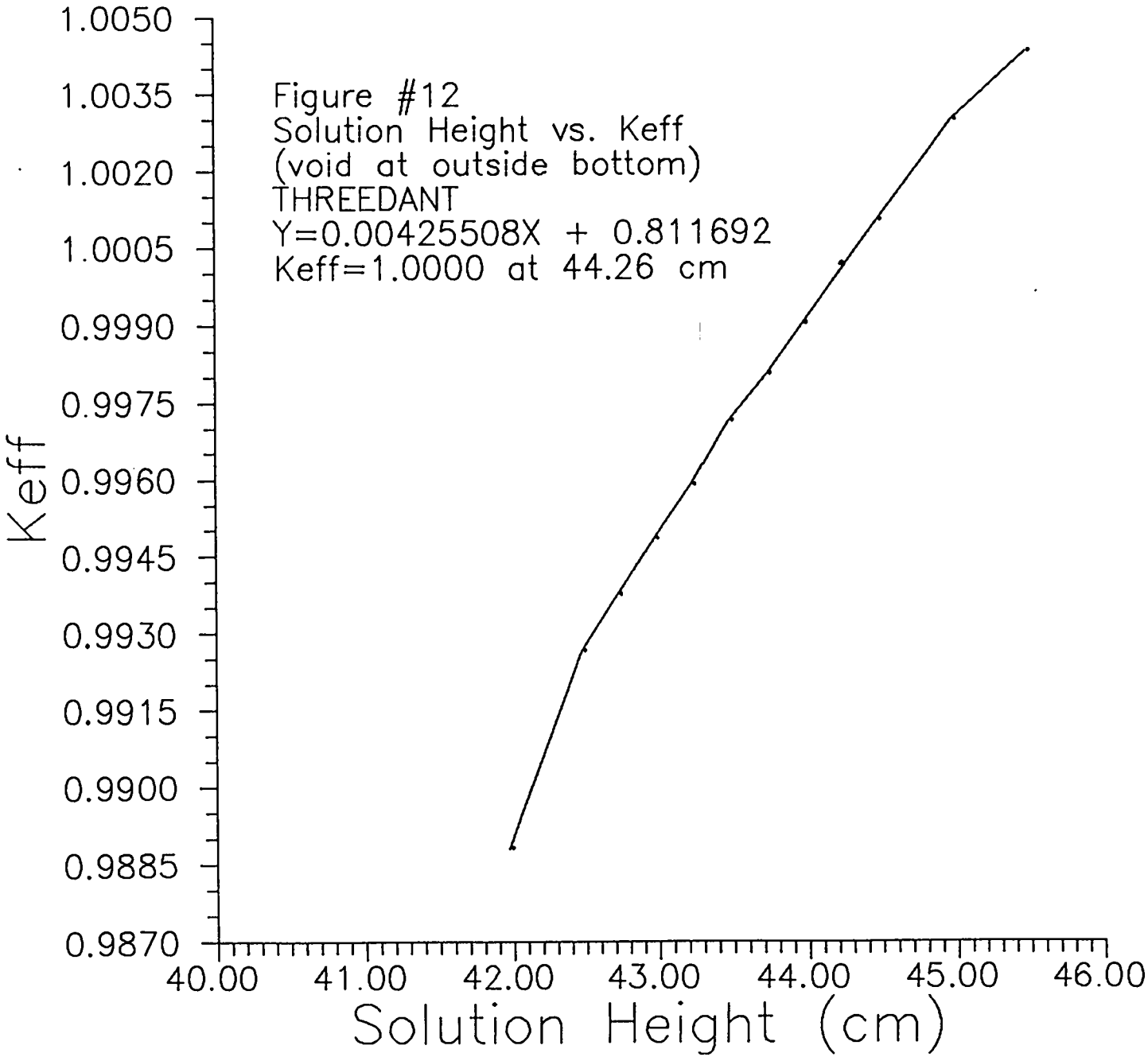


Figure #12
Solution Height vs. Keff
(void at outside bottom)
THREEDANT
Y=0.00425508X + 0.811692
Keff=1.0000 at 44.26 cm
Keff
1.0050
1.0035
1.0020
1.0005
0.9990
0.9975
0.9960
0.9945
0.9930
0.9915
0.9900
0.9885
0.9870
40.00
41.00
42.00
43.00
44.00
45.00
46.00
Solution Height (cm)

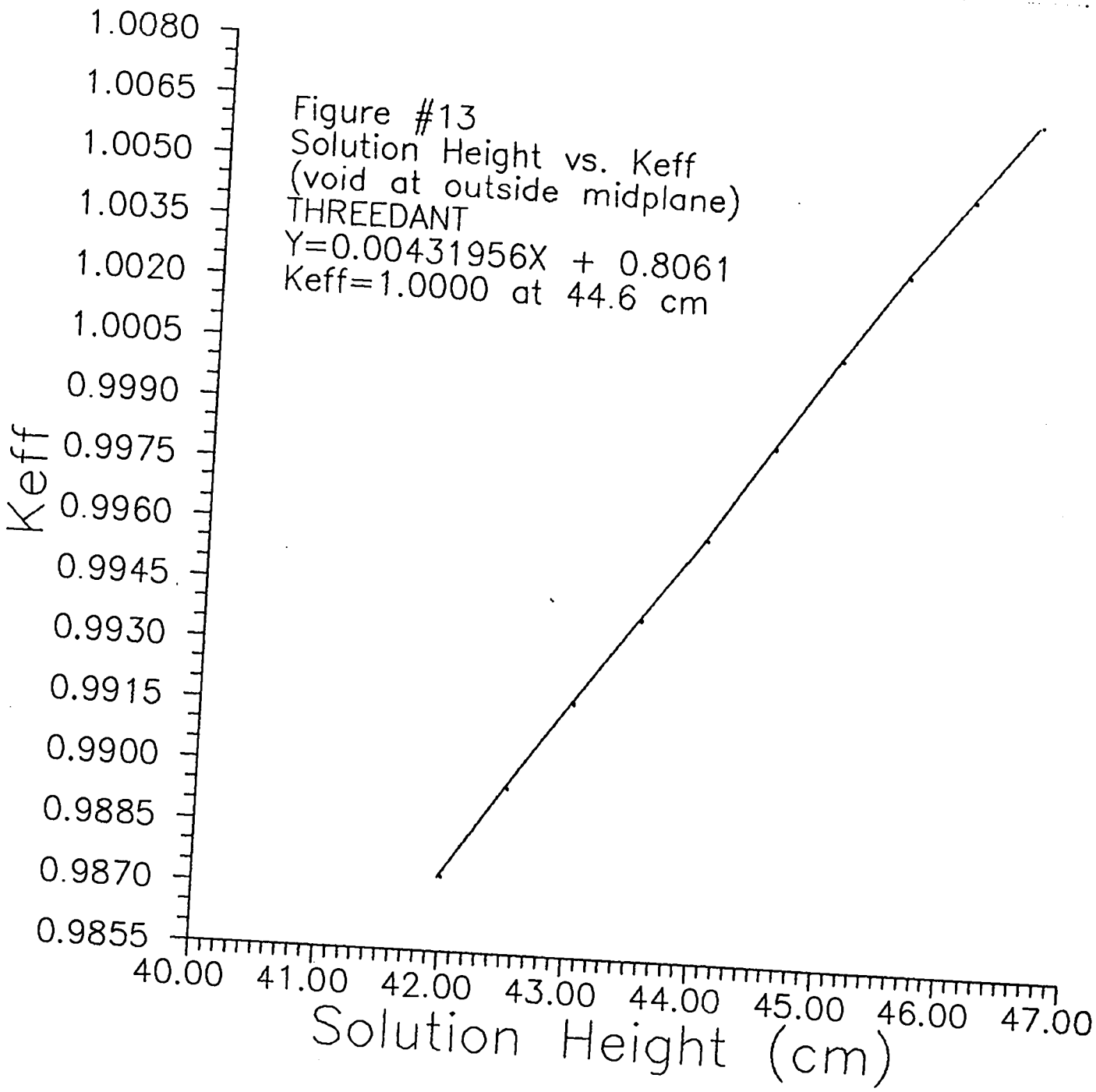


Figure #13
Solution Height vs. Keff
(void at outside midplane)
THREEDANT
Y=0.00431956X + 0.8061
Keff=1.0000 at 44.6 cm
Keff
1.0080
1.0065
1.0050
1.0035
1.0020
1.0005
0.9990
0.9975
0.9960
0.9945
0.9930
0.9915
0.9900
0.9885
0.9870
0.9855
40.00
41.00
42.00
43.00
44.00
45.00
46.00
47.00
Solution Height (cm)

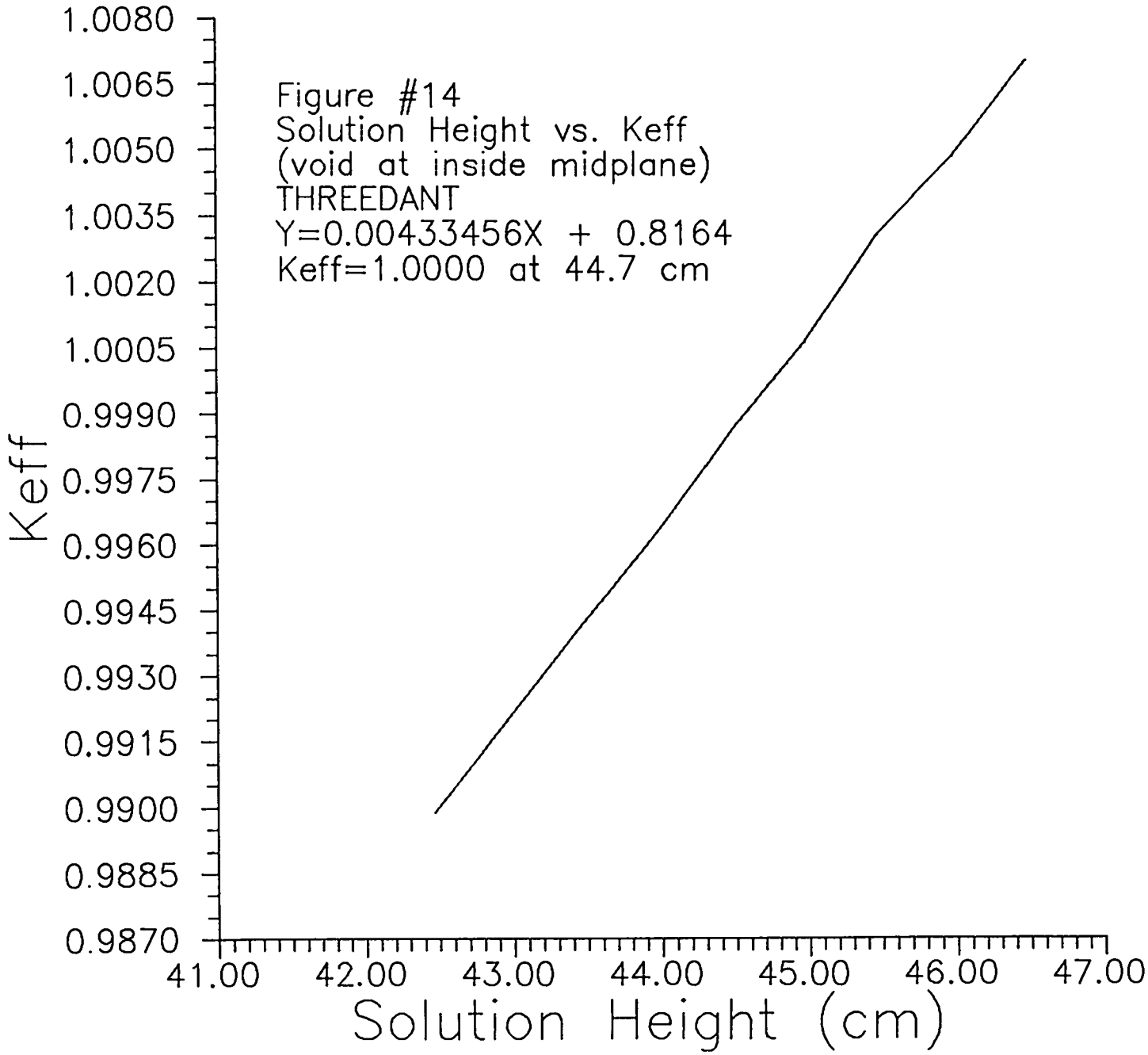


Figure #14
Solution Height vs. Keff
(void at inside midplane)
THREEDANT
Y=0.00433456X + 0.8164
Keff=1.0000 at 44.7 cm
Keff
1.0080
1.0065
1.0050
1.0035
1.0020
1.0005
0.9990
0.9975
0.9960
0.9945
0.9930
0.9915
0.9900
0.9885
0.9870
41.00
42.00
43.00
44.00
45.00
46.00
47.00
Solution Height (cm)

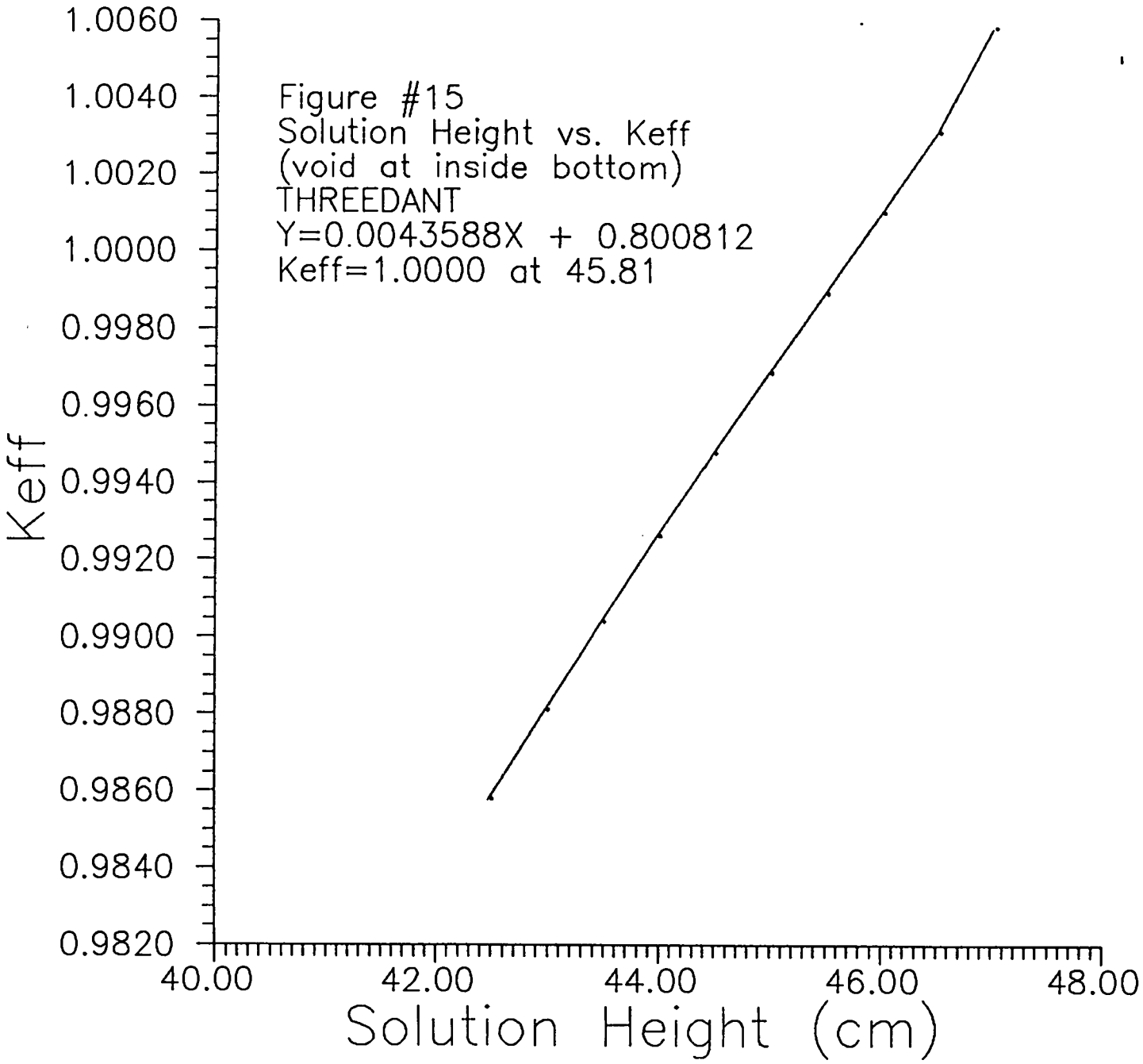


Figure #15
Solution Height vs. Keff
(void at inside bottom)
THREEDANT
Y=0.0043588X + 0.800812
Keff=1.0000 at 45.81
Keff
1.0060
1.0040
1.0020
1.0000
0.9980
0.9960
0.9940
0.9920
0.9900
0.9880
0.9860
0.9840
0.9820
40.00
42.00
44.00
46.00
48.00
Solution Height (cm)

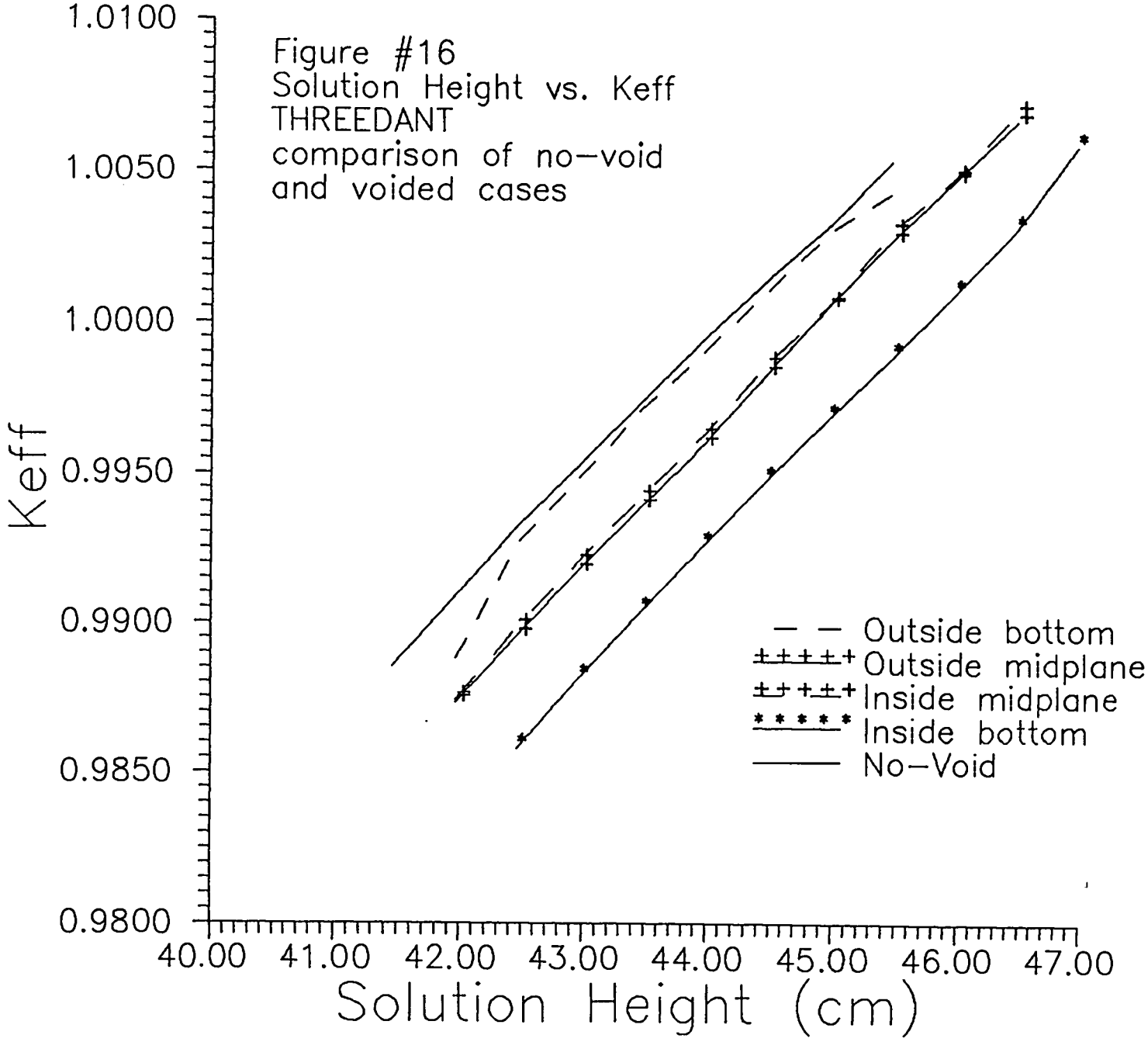


Figure #16
Solution Height vs. Keff
THREEDANT
comparison of no-void
and voided cases
1.0100
1.0050
1.0000
0.9950
0.9900
0.9850
0.9800
Keff
40.00
41.00
42.00
43.00
44.00
45.00
46.00
47.00
Solution Height (cm)
Outside bottom
Outside midplane
Inside midplane
Inside bottom
No-Void

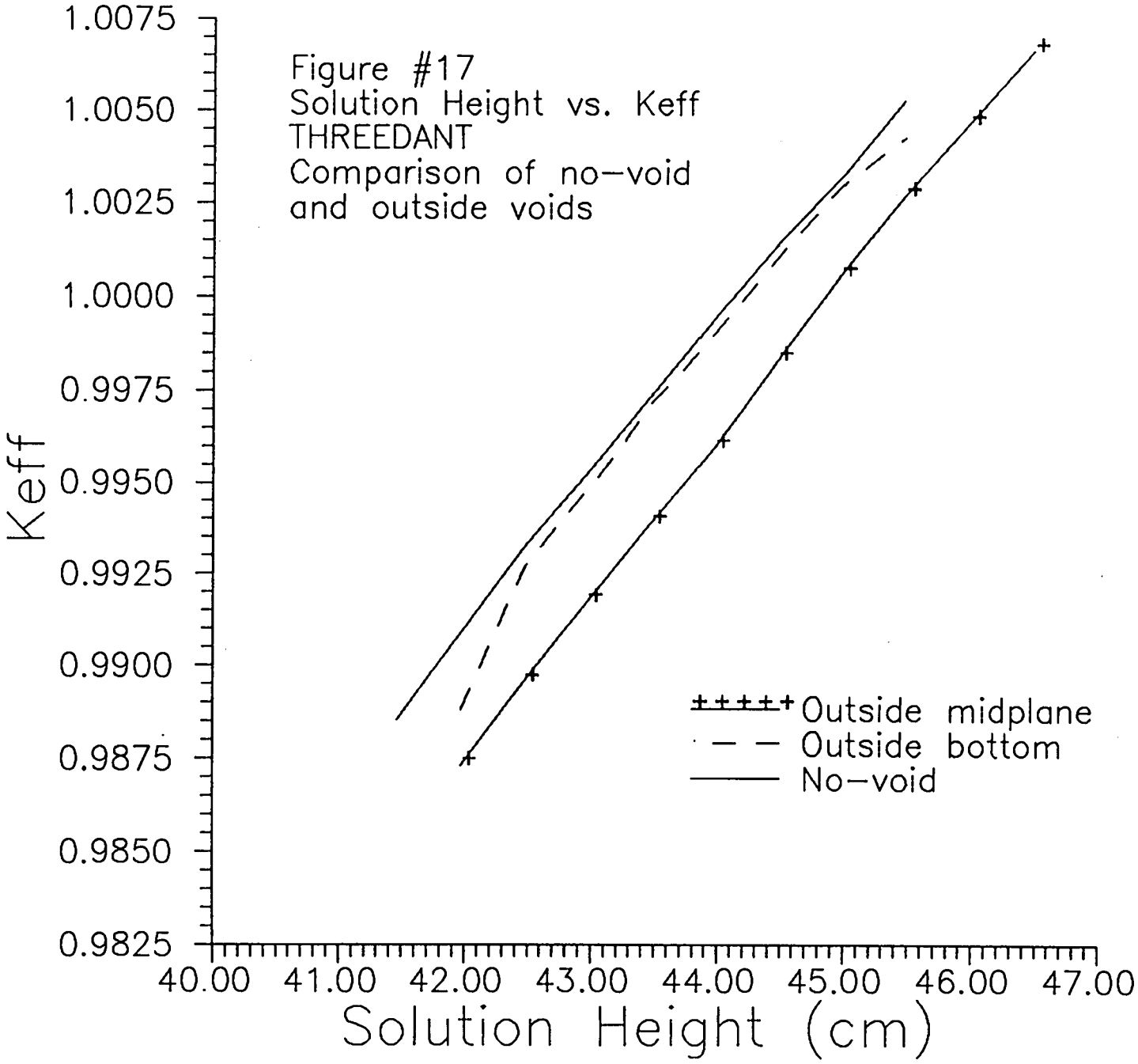


Figure #17
Solution Height vs. Keff
THREEDANT
Comparison of no-void
and outside voids
Keff
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
0.9875
0.9850
0.9825
40.00
41.00
42.00
43.00
44.00
45.00
46.00
47.00
Solution Height (cm)
Outside midplane
Outside bottom
No-void

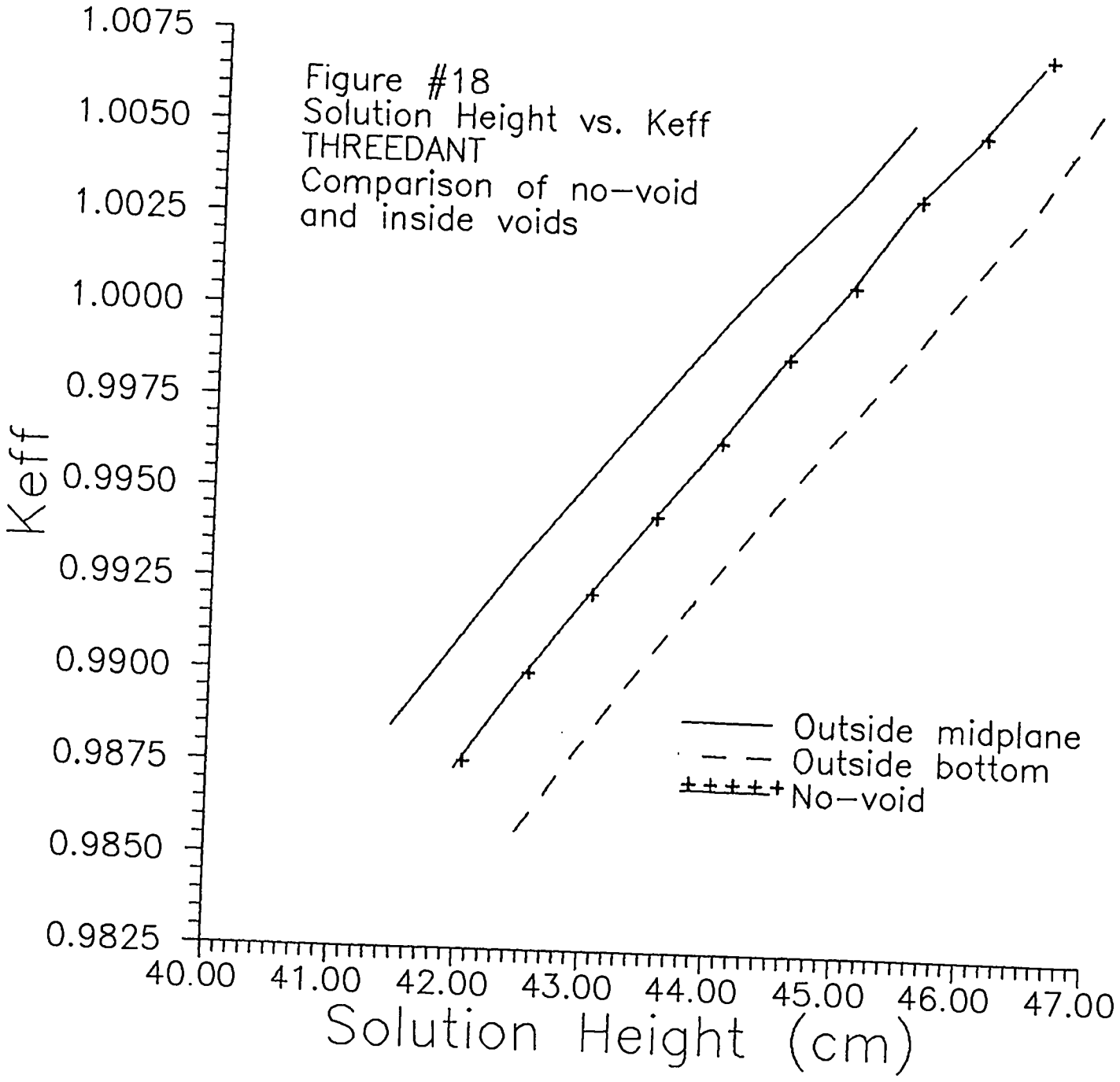
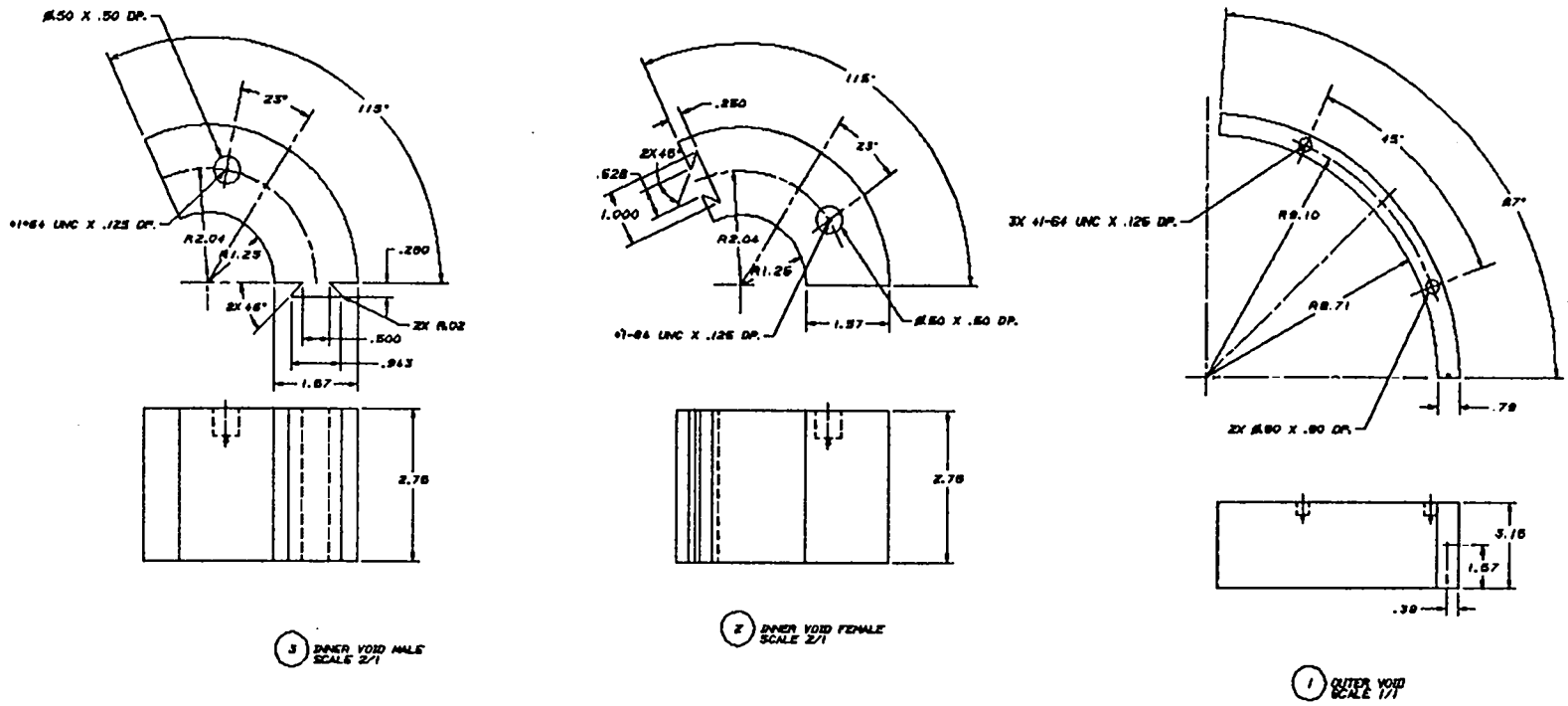


Figure #18
Solution Height vs. Keff
THREEDANT
Comparison of no-void
and inside voids
1.0075
1.0050
1.0025
1.0000
0.9975
0.9950
0.9925
0.9900
0.9875
0.9850
0.9825
Keff
40.00
41.00
42.00
43.00
44.00
45.00
46.00
47.00
Solution Height (cm)
Outside midplane
Outside bottom
No-void

Figure #19
(AUTOCAD drawing of void for experiment)



Appendix A
(MCNP input file)

```
1mcnp     version 4xe   ld=01/12/93                          06/21/93 13:35:58
 ************************************************************************************          probid =
   06/21/93 13:35:58
 inp=inbot outp=outib

    1-        Sheba II(complicated geometry)
    2-        c       using thermal and prompt neutrons
    3-        c       started history at pt out side of void
    4-        c       changing shape from sphere to part of a cylinder
    5-        c       using importance (splitting & roulette) to reduce variance
    6-        c       Void placed at inside bottom
    7-        c       Void thickness= 4 cm, ht=7 cm, arc length=230.211 degree
    8-        c       Void placed with vol equiv to 7.5cm radius sphere
    9-        c       void volume by 1767.144 cm^3
   10-        c       solution ht increased by 0.9661019948 cm
   11-        c      4 void templete
   12-        1      10 9.36069-2 (-102 2 -101 -103 104 9)     $ UO2F solution
   13-        2      20 -7.9     (-4 1 2 -10)     $ ss,127cm walls,4826cm dia,12192cm high
   14-        3      20 -7.9       (-4 5 -2 9)      $254cm ss tank bottom
   15-        4      20 -7.9       (-4 -43 10 9)    $254cm ss tank top
   16-        5      40 -2.7       (20 -21 25 -6)   $Al tank, 18,288cm dia, 254cm walls
   17-        6      40 -2.7       (-21 9 22 -25)   $254cm Al tank bottom
   18-        7      50 -1.12      (-62 63 -61)     $control rod material (mat 50)
   19-        8      20 -7.9       (2 -61 62 -59)   $rod cladding
   20-        9      0             (-7 -5 8)        $mt below rod, Below fluid ok be be void
   21-        10     40 -2.7       (-9 7 -5 8)      $169.73cm Al tube under tank
   22-        11     30 -2.2505 (11:15:-13:-17) (14 -12 18 -16 22 -6) $1524cm conc sle.
   23-        12     30 -2.2505    (14 -12 18 -16 19 -22 9)       $1524cm thick con. base
   24-        13     30 -2.2505    (14 -12 18 -16 23 -24)         $6096cm con. shield
   25-        14     0             (4:43:-5) (-20 -6 5) #7 #8     $upper void
   26-        15     0             (100)                          $outside world, Should be VOID
   27-        16     0             (-1 3 -10 9)          $void inside tank over fuel
   28-        17     0             (-26 27 -28)
   29-        18     20 -7.9       (26:-27:28) (-29 30 -31)       $ss scram tank
   30-        19     0             (-32 33 -34)                   $u-fl in 2nd dump tank
   31-        20     20  -7.9       (32:-33:34) (-35 36 -37)       $ss scram tank
   32-        21     20  -7.9       (38 -39 40 -41 42 -5 9)        $508cm ss support table
   33-        22     0  -100       (-14:12:-18:16:-23:24) #6 #9 #10 #12
   34-                             (20:6:-25) #11 #5              $outer void
   35-        23     20 -7.9       (38 -39 40 -41 44 -45 9)    $lower 508cm ss suppoprt
   36-        24     0             (-20 25 -5) (29:-30:31) (35:-36:37) #9 #10 #21 #23
   37-                             (49:-50:51) (55:-56:57) #29    $lower void
   38-        25     0             (-46 47 -48)                   $u-fl in 3rd dump tank
   39-        26     20 -7.9       (46:-47:48) (-49 50 -51)       $ss scram tank
   40-        27     0             (-52 53 -54)                   $u-fl in 4th dump tank
   41-        28     20 -7.9       (52:-53:54) (-55 56 -57)       $ss dump tank
   42-        29     0             (-20 25 -58 9)                 $Down Below the solution, can
   43-        30     20 -7.9       (7 -43 5 -9)                   $glory hole wall
   44-        31     70 100-100    (5 -43 -7 59)                  $wall void          SHOULD NOT
   45-        32     70 100-100    (-2 5 -59)                     $void below out rod  SHOULD NO
   46-        33     60   -1.60    (-62 2 -63)                    $GRAPHITE FILLER 5080cm
   47-        34     0             (61 -43 -59)              $void above out burst rod
   48-        c
   49-        c       void area @(r,theta,z) 23.13,0,2.27
   50-        35     70 100-100  (9 -102 103 -104 2 -101) $cylinder slice  @bottom cor.
   51-        c      70  100-100 (                  )  $cylinder slice @midplane cor.
   52-        c
   53-        39     10 9.36069-2  (102 -1 2 -101 -103 104)  $Area diag. from "35" void
   54-        40     10 9.36069-2  (101 -3 -1 102 -103 104)    $Area above cell 39, diag in x
   55-        41     10 9.36069-2  (101 -3 -1 102 -103 -104) $area above and next to void "35"
   56-        42     10 9.36069-2  (101 -3 -1 102 103 -104)  $area above void "35", good for g
   57-        43     10 9.36069-2  (101 -3 -1 102 103 104)   $area above and next to void "35"
   58-        44     10 9.36069-2  (101 -3 -102 9 -103 104)  $area inside cell 40
   59-        c
   60-        45     10 9.36069-2 (-102 2 -101 -103 -104 9)   $area insdie 48
   61-        46     10 9.36069-2 (102 2 -101 103 -104 -1)    $area outside void area "35" goo
   62-        47     10 9.36069-2 (-102 2 -101 103 104 9)     $area inside 49
   63-        48     10 9.36069-2 (102 -1 2 -101 -103 -104)   $area outside 45, next to void "
   64-        49     10 9.36069-2 (102 -1 2 -101 103 104)     $area outside 47, next to voide
   65-        50     10 9.36069-2 (101 -3 -102 9 -103 -104)   $area inside cell 41
   66-        51     10 9.36069-2 (101 -3 -102 9 103 -104)    $area inside cell 42
   67-        52     10 9.36069-2 (101 -3 -102 9 103 104)     $area inside cell43
```

```
68-
69-        1      cz 24.13     $i.r of main tank
70-        2      pz 1.27     $lower fluid height
71-        3      pz 42.7361019948 $upper fluid height (1.27+0.9661019948+40.5)
72-        4      cz 25.40    $o.r of main tank
73-        5      pz -1.27    $bottom of ss tank
74-        6      pz 130.73      $top of Al tank
75-        7      cz 2.54      $i.r of central thimble
76-        8      pz -171.0
77-        9      cz 3.175     $o.r of central thimble
78-        10     pz 126.44    $top of ss. vessel, bottom is s2
79-        11     px 95.
80-        12     px 105.24
81-        13     px -95.
82-        14     px -105.24
83-        15     py 95.
84-        16     py 105.24
85-        17     py -95.
86-        18     py -105.24
87-        19     pz -169.01
88-        20     cz 91.44      $i.r of Al tank
89-        21     cz 93.98      $o.r of Al tank
90-        22     pz -153.77
91-        23     pz 138.43
92-        24     pz 199.39
93-        25     pz -151.23
94-        26     1 c/x 20. -32. 10.16
95-        27     1 px -58.43
96-        28     1 px 58.43
97-        29     1 c/x 20. -32. 11.43
98-        30     1 px -59.67
99-        31     1 px 59.67
100-       32     1 c/x -20. -32. 10.16
101-       33     1 px -58.43
102-       34     1 px  58.43
103-       35     1 c/x -20. -32. 11.43
104-       36     1 px -59.68
105-       37     1 px 59.68
106-       38     px -50.
107-       39     px 50.
108-       40     py -50.
109-       41     py 50.
110-       42     pz -6.35
111-       43     pz 128.98
112-       44     pz -117.
113-       45     pz -111.92
114-       46     2 c/x 20. -80. 10.16
115-       47     2 px -28.42
116-       48     2 px 88.42
117-       49     2 c/x 20. -80. 11.43
118-       50     2 px -29.67
119-       51     2 px 89.67
120-       52     2 c/x -20. -80. 10.16
121-       53     2 px -28.43
122-       54     2 px 88.43
123-       55     2 c/x -20. -80. 11.43
124-       56     2 px -29.68
125-       57     2 px 89.68
126-       58     pz -146.43
127-       59     cz 2.2225     $444.5cm o.d. of rod
128-       61     pz 102.87     $top of rod in out pos.
129-       62     cz 2.143125   $id of rod cladding
130-       63     pz 52.07
131-       100    so 440.       $sphere that comprises outside world
132-       c       Beginning of the void treatment
133-       101     pz 8.27
134-       102     cz 7.175    $inside cylinder
135-       103     py 0       $0 degree plane
136-       104     p 17.1488853698 -21.169948443 0 37.973650912    $approx a 230.211 degree
137-
138-       *tr1  0. 0. 0. 15. 90. 75. 90. 0. 90. 105. 90. 15. 1
139-       *tr2  0. 0. 0. 15. 90. 105. 90. 0. 90. 75. 90. 15. 1
140-       mode n
141-       imp:n 1 13r 0 1 18r 3 1 1 1 2 1 1 1 2 1 2 2 1 1 1
142-       c       vol 11j 674847. 8j 18724.0 1j 18724. 1798160. 10j
143-       m10    92235.50c 1.319-4 92238.50c 2.499-3
144-              92236.51c 1.316-6
145-              1001.50c 5.354-2 8016.50c 3.210-2 9019.51c 5.334-3
146-       m20    26000.55c -6.950-1 24000.50c -1.9-1 28000.50c -9.5-2
147-              25055.51c -2.0-2
148-       m30     1001.50c -.004532 8016.50c -.512597 11023.51c -.011553
149-               12000.51c -.003866 13027.50c -.035548 14000.51c -.360364
150-               19000.51c -.014219 20000.51c -.043546 26000.55c -.013775
151-       m40     13027.50c 1.0
152-       m50     1001.50c 5.55-2 6000.50c 2.8164-2 5010.50c 3.74-3
153-               5010.50c 1.496-2
```

```
154-        m60     6000.50c 1.0
155-        m70     5010.50c 1
156-        c
157-        totnu no
158-        c
159-        c     thermal treatment
160-        c
161-        mt10 lwtr.01t
162-        c
163-        kcode 2000. 1.0 10 350
164-        c     ksrc 05.0 -5. 9.0 0. 5.01 16. -5. 5. 16. 0. -5. 30. 14. 14. 3.
165-        print
166-
```

Appendix B
(THREEDANT input/output file)

```
1  22222222222    ddddddddddd     aaaaaaaaa    aa        aa   tttttttttttt    ooooooooooo   yy       yy    ooooooooooo
  2222222222222   ddddddddddddd    aaaaaaaaaaa   aaa       ra   tttttttttttt   ooooooooooooo   yy     yy    ooooooooooooo
  22          22  dd          dd  aa         aa  aaaa      aa       tt        aa         aa    yy   yy     aa         aa
              22  dd          dd  aa         aa  aa aa     aa       tt        aa                 yy  yy     aa
              22  dd          dd  aa         aa  aa  aa    aa       tt        aa                  yyyy      aa
            22    dd          dd  aaaaaaaaaaaaa  aa   aa   aa       tt        ooooooooooooo       yy        ooooooooooooo
          22      dd          dd  aaaaaaaaaaaaa  aa    aa  aa       tt         ooooooooooooo      yy         ooooooooooooo
        22        dd          dd  aa         aa  aa     aa aa       tt                   aa       yy                   aa
      22          dd          dd  aa         aa  aa      aa aa       tt                   aa       yy                   aa
    22            dd          dd  aa         aa  aa       aaaa       tt        aa         aa       yy        aa         aa
  2222222222222   ddddddddddddd  aa         aa  aa        aaa       tt        ooooooooooooo       yy        ooooooooooooo
  2222222222222   ddddddddddddd  aa         aa  aa         aa       tt         ooooooooooo        yy         ooooooooooo


  rrrrrrrrrrrrr   ooooooooooooo   11             ooooooooooooo     aaaaaaaaa     ooooooooooo    ooooooooooooo
  rrrrrrrrrrrrr   ooooooooooooo   11             ooooooooooooo    aaaaaaaaaaa   ooooooooooooo   ooooooooooooo
  rr         rr   oo             11             oo             oa         aa   oo         oo   oo
  rr         rr   oo             11             oo             oa         aa   oo              oo
  rr         rr   oo             11             oo             oa         aa   oo              oo
  rrrrrrrrrrrrr   ooooooooo      11             ooooooooo      oaaaaaaaaaaaa   ooooooooooooo   ooooooooo
  rrrrrrrrrrrrr   ooooooooo      11             ooooooooo      oaaaaaaaaaaaa    ooooooooooooo   ooooooooo
  rr       rr     oo             11             oo             oa         aa              oo   oo
  rr        rr    oo             11             oo             oa         aa              oo   oo
  rr         rr   oo             11             oo             aa         aa   oo         oo   oo
  rr         rr   ooooooooooooo   1111111111111   ooooooooooooo   oo         aa   ooooooooooooo   ooooooooooooo
  rr         rr   ooooooooooooo   1212111111111   ooooooooooooo   oo         aa    ooooooooooo    ooooooooooooo


   22222222222                    33333333333      aaaaaaaaa
  2222222222222                  3333333333333    aaaaaaaaaaa
  22          22                 33          33   aa         aa
              22                             33   aa         aa
              22                             33   aa         aa
            22                            333   aaaaaaaaaaaaa
          22          .....                333   aaaaaaaaaaaaa
        22            .....                 33   aa         aa
      22              .....                 33   aa         aa
    22                .....       33        33   aa         aa
  2222222222222                  3333333333333   aa         aa
  2222222222222                   33333333333    aa         aa
1
1
*****************************************************************************************************************
*****************************************************************************************************************
*
*              generalized input mode2e run on  with solver version 05-24-93*product release 2.3m     machine jezabel
*
*****************************************************************************************************************
*                    ***************************************************************************************
*                    *                                                                                     *
*                    *                    ...listing of cards in the input stream...                       *
*                    *                                                                                     *
*                    *    1.      3          0                                                             *
*                    *    2. SHEBA-11 Critical reactor                                                     *
*                    *    3. Dialidw=6.35(3.175r)cm 1do=48.26(24.13r)cm                                    *
*                    *    4. ESOLN=44.5cm + .966101994E cm                                                 *
*                    *    5. /Solution is DO2F2 (pE=11                                                     *
*                    *    6. /Using nitrogen is piece of voids                                             *
*                    *    7. /Void placed at inside bottom of cylinder                                     *
*                    *    8. / Cross sections from standard relib (118 isos)                               *
*                    *    9. /**********BLOCK 1***********                                                 *
*                    *   10. igeom=r-r-t                                                                   *
*                    *   11. ngroup=16                                                                     *
*                    *   12. ien=8                                                                         *
*                    *   13. niso=118                                                                      *
*                    *   14. mt=5                                                                          *
*                    *   15. nrone=5                                                                       *
*                    *   16. im=6                                                                          *
*                    *   17. it=34                                                                         *
*                    *   18. jm=7                                                                          *
*                    *   19. jt=56                                                                         *
*                    *   20. km=2                                                                          *
*                    *   21. kt=13                                                                         *
*                    *   22. maxscm=1100000                                                                *
*                    *   23. maxlcm=4000000                                                                *
*                    *   24. t                                                                             *
*                    *   25. /***********Block 11************                                               *
*                    *   26. xmesh=0.0,2.143125,2.54,3.175,7.175,24.13,25.4                                *
*                    *   27. xinte=2,1,2,9,16,4                                                            *
*                    *   28. ymesh=0.0,2.54,9.54,48.006101,53.34,106.04,127.71,130.25                      *
*                    *   29. yinte=2,13,24,4,7,3,3                                                         *
*                    *   30. zmesh=0.0,3194,0.5                                                            *
*                    *   31. zinte=5,6                                                                     *
*                    *   32. zones=5,5,2,2,2,2/4,5,2,5,1,2/4,5,2,1,1,2/4,5,2,5,5,2/                        *
*                    *   33.       3,5,2,5,5,2/5,5,2,5,5,2/5,5,2,2,2,21                                    *
*                    *   34.       5,5,2,2,2,2/4,5,2,1,1,2/4,5,2,1,1,2/4,5,2,5,5,2/                        *
*                    *   35.       3,5,2,5,5,2/5,5,2,5,5,2/5,5,2,2,2,2                                     *
*                    *   36. t                                                                             *
*                    *   37. /***********BLOCK 111***************                                           *
*                    *   38. lib=brelib t                                                                  *
*                    *   39. /***********BLOCK IV***************                                           *
*                    *   40. matls=fuel, '238-6r' 1.74556e-3 '238+7r' 7.74695e-4                           *
*                    *   41.     '23511r' 4.18087e-5 '23512r' 9.12342e-5                                   *
*                    *   42.     'o16' 3.2378e-2 'f19' 5.36022e-3 'h' 5.4004e-2/                           *
*                    *   43.     steel, 'cr' 1.7384e-2 'ni' 7.6994e-3 'fe' 5.9205e-2/                      *
*                    *   44.     otrlrod, 'h' 5.55e-2 'c' 2.8164e-2 'b' 1.87e-2;                           *
*                    *   45.     follos, 'o' 8.03e-2/                                                      *
*                    *   46.     filler, 'n' 1.0e-9/                                                       *
*                    *   47. assign=matls                                                                  *
*                    *   48. t                                                                             *
*                    *   49. /************BLOCK V****************                                           *
*                    *   50. isvt=1 isct=1 ibr=0 ibt=0 ibb=0 spel=1e-4 ibfrnt=1 ibback=1  t                *
*                    *   51. /************BLOCK VI***************                                           *
*                    *   52. ptsd=1 znsd=0 t                                                               *
*                    *                                                                                     *
*                    ***************************************************************************************
1
*****************************************************************************************************************
*****************************************************************************************************************
*
*                                                  case title
*
*****************************************************************************************************************
*********************
*key start case input  *          )
```

```
*********************
*                                  3  nhead   number of title cards to follow
*                                  0  notty   0/1  no/yes  suppress on-line terminal output
*                                  0  nollst  0/1  no/yes  suppress input listing
*
*                    ***************************************************************
*                    *                                                             *
*                    * SHEBA-11 Critical reactor                                   *
*                    * Dia:idw=6.35(3.175r)cm ldo=48.26(24.13r)cm                  *
*                    * EFOLN=44.5cm * .9661019948 mm                               *
*                    *                                                             *
*                    ***************************************************************
*********************
*key end   block i read*
*********************
*************************************************************************************
1
*************************************************************************************
*************************************************************************************
*
*                                  ...block i - controls and dimensions...
*
*************************************************************************************
*
*
*                                  ...dimensions (array name = dimens)...
*
*                    15  igeom   14/15 x-y-z/ r-z-theta
*                    16  ngroup  number of energy groups
*                     8  iss     angular quadrature order
*                   118  niso    number of input isotopes (from isotrs, groups, or cards)
*                     9  mt      number of permanent materials
*                     9  nzone   number of zones
*                     6  im      number of coarse mesh r intervals
*                    34  it      number of fine mesh intervals
*                     7  jm      number of coarse mesh y intervals
*                    56  jt      number of fine mesh y intervals
*                     2  km      number of coarse mesh z intervals
*                    13  kt      number of fine mesh z intervals
*
*                                     ...storage...
*
*                                     maxicm= 6000000
*                                     maxscm= 1100000
*
*************************************************************************************
*************************
*key end   block ii read-geom*
*************************
*
*                    15  igeom    1/2/3/6/7/8/9/11/16
*************************
*key end   block iii read-rs *
*************************
1*************************************************************************************
*************************************************************************************
*
*                                  ...block iii - cross section library...
*
*************************************************************************************
*
*                                     ...library source...
*                                        lib=brslib
*
*
*                                     ...energy structure...
*
*   group     chi          vel        lower bound   upper bound   group     chi          vel        lower bound   upper bound
*   -----  ----------   ----------   ----------   ----------   -----  ----------   ----------   ----------   ----------
*     1   2.04000E-01  2.85000E+01  3.00000E+06  1.00000E+08     9   0.00000E+00  2.06000E-01  1.00000E+02  9.50000E+02
*     2   3.44000E+01  1.99000E+01  1.40000E+06  3.00000E+06    10   0.00000E+00  1.01000E-01  3.00000E+01  1.00000E+02
*     3   1.68000E-01  1.47000E+01  9.00000E+05  1.40000E+06    11   0.00000E+00  5.66000E-02  1.00000E+01  3.00000E+01
*     4   1.80000E-01  1.10000E+01  4.00000E+05  8.00000E+05    12   0.00000E+00  3.19000E-02  3.00000E+00  1.00000E+01
*     5   9.00000E-02  6.70000E+00  1.00000E+05  4.00000E+05    13   0.00000E+00  1.79000E-02  1.00000E+00  3.00000E+00
*     6   1.40000E+02  2.70000E+00  1.70000E+04  1.00000E+05    14   0.00000E+00  1.09000E-02  4.00000E-01  1.00000E+00
*     7   0.00000E+00  1.14000E+00  3.00000E+03  1.70000E+04    15   0.00000E+00  6.06000E-03  1.00000E-01  9.00000E-01
*     8   0.00000E+00  4.80000E-01  5.50000E+02  3.00000E+03    16   0.00000E+00  2.18000E-03  0.00000E+00  1.00000E-01
*
*                                  last neutron group(lng) is number  16
*
*
*                    0  halxs   -1/0/1 - adjust absorption/no/adjust self scatter to force rs balance
*
*                                     ...edit position names...
*
*                                     position edname
*                                     --------- -----
*                                         1   chi
*                                         2   nasigf
*                                         3   total
*                                         4   abs
*                                         5   n-fiss
*
*                                  ...isotope names and numbers from library...
*
*                    number   name      number   name      number   name      number   name      number   name
*                    -------  -------   -------  -------   -------  -------   -------  -------   -------  -------
*                         1   al            25   240-6         49   239-12        73   238-10        97   238-4r
*                         2   b             26   240-7         50   239-13        74   238-11        98   238-5r
*                         3   be            27   240-8         51   239-14        75   238-12        99   238-6r
*                         4   c             28   240-9         52   239-15        76   238-13       100   238-7r
*                         5   cd            29   240-10        53   239-16        77   238-14       101   ce
*                         6   cl            30   240-11        54   th            78   238-15       102   ce
*                         7   ge            31   240-12        55   o233          79   238-16       103   te
*                         8   fl9           32   240-13        56   233-1         80   rr           104   23511r
*                         9   fe            33   240-14        57   233-2         81   n            105   23512r
*                        10   h             34   240-15        58   233-3         92   nb           106   238-0
*                        11   k             35   240-16        59   233-4         83   235-yr       107   er
*                        12   li6           36   240-17        60   233-5         84   235-1r       108   d
*                        13   li7           37   240-18        61   232-6         85   235-2r       109   pb
*                        14   mo            38   239-1         62   233-7         86   235-3r       110   pu241
*                        15   na            39   239-2         63   233-8         87   235-4r       111   copper
*                        16   ei            40   239-3         64   233-9         88   235-5r       112   ti
*                        17   ol6           41   239-4         65   233-10        89   235-6r       113   mg
*                        18   pu239         42   239-5         66   233-11        90   235-7r       114   sulfur
*                        19   pu240         43   239-6         67   233-12        91   235-8r       115   v
*                        20   240-1         44   239-7         68   o239          92   235-9r       116   te-1
*                        21   240-2         45   239-8         69   u235          93   235-10r      117   si
*                        22   240-3         46   239-9         70   u238y         94   238-1r       118   ca
*                        23   240-4         47   239-10        71   238-4         95   238-2r
*                        24   240-5         48   239-11        72   238-9         96   238-3r
*************************
*key end   card libe read   *
*************************
*************************
*key end   block iv read-mate*
*************************
*
*
*
*************************************************************************************
*************************************************************************************
*************************************************************************************
*
*
*                                  ... mixing instructions ...
*************************************************************************************
*
*          mix      comp       density    comp       density etc.
```

```
*          ---      ----      ------    ----      -------
*
*     matls
*     ------
*
*       1. fuel      23E-6r   1.74556E-03, 23E-7r   7.74685E-04, 23511r   4.18087E-05, 23512r   9.12342E-05,
*                    o16      3.23780E-02, f19      5.36022E-03, h        5.40040E-02,
*       2. steel     cr       1.73840E-02, ni       7.69940E-03, fe       5.92050E-02,
*       3. ctrlrod   h        5.55000E-02, o        2.81440E-02, b        1.87000E-02,
*       4. follow    c        8.03000E-02,
*       5. filler    n        1.00000E-09,
*********************
*key start mir card xs *
*********************
*********************
*key end   six card xs *
*********************
*********************************************************************************************************
*******************************
*key end   block v read-solvr*
*******************************
*******************************
*key end   block vi read-edit*
*******************************
*********************
*key end   input module*
*********************
*
*
*********************************************************************************************************
*********************************************************************************************************
1                   this threedant problem ran on  with solver version 05-24-93beta---- release 2.3a     machine jezabel
*SEEBA-11 Critical reactor
*Dimtidw=6.35(3.175r)cm ldo=48.26(24.13r)cm
*ESOLN=44.5cm * .966101994E cm
*
*********************************************************************************************************
*
*                                        ...block v -- solver input...
*
*********************************************************************************************************
*          raw     ss
*         input  defaulted
*         -----  --------
*
*                                        ...required input(array name = solin)...
*
*         1         1      ievt   0/1/2/3/4 * type of calculation
*                                    0 inhomogeneous source
*                                    1 k-effective
*                                    2 alpha or time absorption search
*                                    3 concentration search
*                                    4 delta(i.e. dimension) search
*         1         1      iect   legendre order of scattering
*         0         0      ith    0/1 - direct/adjoint - mode of calculation (default=direct)
*         0         1      ibl    0/1/3 - left boundary condition
*                                    vacuum/reflective/white
*         0         0      ibr    0/1/3 - right boundary condition
*                                    vacuum/reflective/white
*         0         0      ibt    0/1/2/3 - top boundary condition
*                                    vacuum/reflective/periodic/white
*         0         0      ibb    0/1/2/3 - bottom boundary condition
*                                    vacuum/reflective/periodic/white
*         1         1      ibbk   0/1/2/3 - back boundary condition
*                                    vacuum/reflective/periodic/white
*         1         1      ibfr   0/1/2/3 - front boundary condition
*                                    vacuum/reflective/periodic/white
*
*
*                                        ...convergence controls(array name = iter)...
*
*     1.000E+04 1.000E-04  epsi   inner iteration convergence criterion (default=0.0001)
*         0         1      iitl   maximum number of inner iterations per group until fission source is near
*                                convergence, i.e. lambda is near convergence.(default=1)
*         0        30      iita   maximum number of inner iterations per group when close to fission source convergence
*                                (default calculated)
*         0        20      oite   maximum number of outer iterations (default=20)
*         0         0      itlim  iteration time limit (seconds)
*
*
*
*********************************************************************************************************
*********************************************************************************************************
1*********************************************************************************************************
*********************************************************************************************************
*
*                                    ...block v -- solver input (continued)...
*
*********************************************************************************************************
*          raw     ss
*         input  defaulted
*         -----  --------
*
*
*                                        ...miscellaneous parameters(array name = misc)...
*
*     0.000E+00 0.000E+00  norm   normalization factor
*
*         0         0      influx 0/1 no/yes - read input flux from file rtflux (atflux for adjoint)
*         0         0      insors 0/1 no/yes - read input source from file firerc
*         0         1      iqcad  -3/-2/1/2/3 - source of quadrature constants (default=1)
*                                 -3 encon file
*                                 -2 hybrid product set (triangular arrangement)
*                                  1 old twotran built-in set
*                                  2 product set (rectangular arrangement)
*                                  3 card input
*
*                                        ...output controls(array name = solout)...
*
*                       0  fluxp  0/1/2   none/isotropic/all moments - flux print
*                       0  xsectp 0/1/2   none/principal/all - macroscopic cross section print
*                       0  fisorp 0/1     no/yes - print final fission source rate
*                       0  sourcp 0/1/2/3 no/as read/normalized/both - print inhomogeneous source
*                       0  angp   0/1     no/yes - print angular fluxes
*                       0  rafluz 0/1     no/yes - write angular fluxes to file rafluxm or amfluxm(if ith=1)
*                       0  rmflux 0/1     no/yes * write flux moments to file rmflux
*                       0  balp   0/1     no/yes - print coarse mesh balances
*
*                                        ...parameters inferred from input arrays...
*
*                                 0  inchi  0/1/2 none/one chi/renewise chi
*                                 0  isdenx 0/1/n - none/r density vector/full matrix
*                                 0  isdeny 0/1 no/yes - use y density vector
*                                 0  iqan   source anisotropy
*                                 0  isorse number of source moments input
*                                 0  isorer number of sourcx moments input
*                                 0  isorey number of sourcy moments input
*                                 0  isorer number of sourcr moments input
*                                 0  isoref number of sourcf moments input
*                                 0  iql    -1/0/1/2 isotropic/none/all angles/vectors -left boundary source
*                                 0  iqr    +1/0/1/2 isotropic/none/all angles/vectors -right boundary source
*                                 0  iqt    -1/0/1/2 isotropic/none/all angles/vectors -top boundary source
*                                 0  iqb    +1/0/1/2 isotropic/none/all angles/vectors -bottom boundary source
*                                 0  iqf    -1/0/1/2 isotropic/none/all angles/vectors -front boundary source
*                                 0  iqk    +1/0/1/2 isotropic/none/all angles/vectors -back boundary source
*
*
*
*********************************************************************************************************
*********************************************************************************************************
1*********************************************************************************************************
```

```
*
*                              ...parameters from block 1...
*
*                        15  igeom   14/15  x-y-z/r-z-theta
*                        16  ngrup   number of energy groups
*                         8  ism     angular quadrature order
*                         9  mt      number of permanent materials
*                         5  nzone   number of zones
*                         6  im      number of coarse mesh x intervals
*                         7  jm      number of coarse mesh y intervals
*                         2  km      number of coarse mesh z intervals
*                        34  it      number of fine mesh x intervals
*                        56  jt      number of fine mesh y intervals
*                        13  kt      number of fine mesh z intervals
*
*
*
*
*                                 ...material assignments to zones...
*
*
*key start matls to zones   *
*****************************
*
*                                        zone      material
*                                      no. name    no. name
*
*                                       1 zone1     1 fuel
*                                       2 zone2     2 steel
*                                       3 zone3     3 strire
*                                       4 zone4     4 follow
*                                       5 zone5     5 filler
*
*
*
*key start storage scp *
*************************
*
*  scm storage summary...
*
*      total scm required for this problem          638557
*      maximum scm available (maxscm= )            1100000
*      scm required for transport                   639486
*      scm required for diffusion                   361777
*
*
*  lcm storage summary...
*
*      lcm selected for this problem                5367012
*      maximum lcm specified (maxlcm= )             6000000
*           storage required for all quantities  in core is      5367012
*
*           diffusion parameters are in core.  if o.k. to put in core, set maxlcm .ge.       5367012
*           flux moments      are in core.  if o.k. to put in core, set maxlcm .ge.       3623067
*           diffusion fluxes are in core.  if o.k. to put in core, set maxlcm .ge.       2509227
*           scalar fr fluxes are in core.  if o.k. to put in core, set maxlcm .ge.       2090277
*           storage required for all quantities  on disk is      522597
*
*
*
*    5367012 words lcm required lcmadd
*
*
*  core flow
*
*
*key start sn constants*
*************************
*
*  s n constants for groups  1 to 16
*                 mu              eta              xi              weight
*
*       1     0.19232747E+00  0.9622994SE+00  0.19232747E+00  0.14598559E-01
*       2     0.97735027E+00  0.79352178E+00  0.19232746E+00  0.11656904E-01
*       3     0.19232747E+00  0.79352178E+00  0.57735027E+00  0.11656904E-01
*       4     0.79352178E+00  0.57735027E+00  0.19232746E+00  0.11654904E-01
*       5     0.57735027E+00  0.57735027E+00  0.57735027E+00  0.11262900E-01
*       6     0.19232747E+00  0.57735027E+00  0.79352178E+00  0.11656904E-01
*       7     0.96229946E+00  0.19232747E+00  0.19232747E+00  0.14598559E-01
*       8     0.79352178E+00  0.19232747E+00  0.57735027E+00  0.11656904E-01
*       9     0.97735027E+00  0.19232747E+00  0.79352178E+00  0.11656904E-01
*      10     0.19232747E+00  0.19232747E+00  0.96229946E+00  0.14598559E-01
*
*                                  spherical harmonics for each octant and angle
*  octants     1               2               3               4               5               6               7               8
*    a
*    1 e
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  +1.923275E-01   1.923275E-01  +1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01
*      3  -9.622995E-01  -9.622995E-01   9.622995E-01   9.622995E-01  -9.622995E-01  -9.622995E-01   9.622995E-01   9.622995E-01
*      4  -1.923275E-01  -1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01
*    2 a
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01
*      3  -7.935218E-01  -7.935218E-01   7.935218E-01   7.935218E-01  -7.935218E-01  -7.935218E-01   7.935218E-01   7.935218E-01
*      4  +1.923275E-01  -1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01
*    3 a
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  +1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01
*      3  -7.935218E-01  -7.935218E-01   7.935218E-01   7.935218E-01  -7.935218E-01  -7.935218E-01   7.935218E-01   7.935218E-01
*      4  -5.773503E-01  -5.773503E-01  -5.773503E-01  -5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01
*    4 a
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  -7.935218E-01   7.935218E-01  -7.935218E-01   7.935218E-01  -7.935218E-01   7.935218E-01  -7.935218E-01   7.935218E-01
*      3  +5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01
*      4  -1.923275E-01  -1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01
*    5 a
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01
*      3  +5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01
*      4  -5.773503E-01  -5.773503E-01  -5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01
*    6 a
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01
*      3  +5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01
*      4  -7.935218E-01  -7.935218E-01  -7.935218E-01   7.935218E-01   7.935218E-01   7.935218E-01   7.935218E-01   7.935218E-01
*    7 e
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  +9.622995E-01   9.622995E-01  -9.622995E-01   9.622995E-01  -9.622995E-01   9.622995E-01  -9.622995E-01   9.622995E-01
*      3  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01
*      4  -1.923275E-01  -1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01   1.923275E-01
*    8 e
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  +7.935116E-01   7.935218E-01  -7.935218E-01   7.935218E-01  -7.935218E-01   7.935218E-01  +7.935218E-01   7.935218E-01
*      3  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01
*      4  -9.773503E-01  -5.773503E-01  -5.773503E-01  -5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01   5.773503E-01
*    9 a
*      1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*      2  +5.773503E+01   9.773503E-01  -5.773503E+01   5.773503E-01  -5.773503E-01   5.773503E-01  -5.773503E-01   5.773503E-01
*      3  +1.923275E-01  -1.923275E+01   1.923275E-01   1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01
```

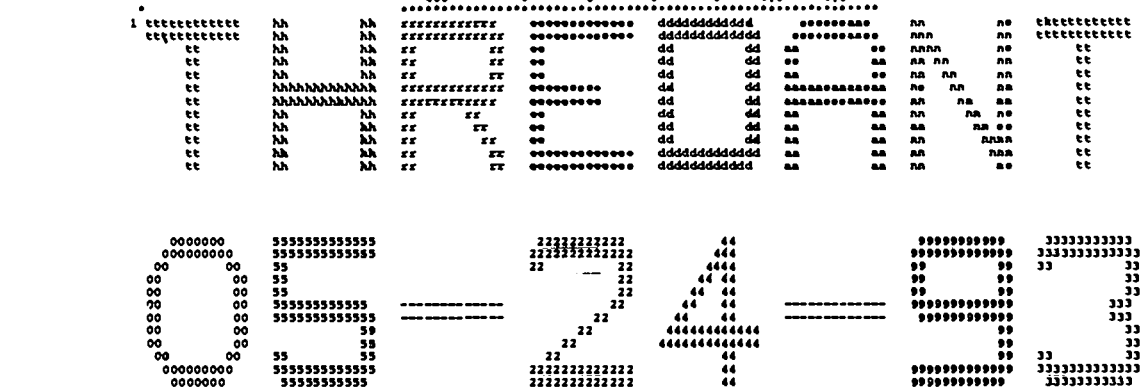
```
*    4  -7.935218E-01  -7.935218E-01  -7.935218E-01  -7.935218E-01   7.935218E-01   7.935218E-01   7.935218E-01   7.935218E-01
* 10 n
*    1   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00   1.000000E+00
*    2  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01  -1.923275E-01   1.923275E-01
*    3  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01  -1.923275E-01  -1.923275E-01   1.923275E-01   1.923275E-01
*    4  -9.622995E-01  -9.622995E-01  -9.622995E-01  -9.622995E-01   9.622995E-01   9.622995E-01   9.622995E-01   9.622995E-01
*
1*****************************material sep*****************************
.....................
*key etert seteriel sep*
.....................
* materiel map for k mesh intervale   1, to   5 and j mesh intervale  56, to   1, and i mesh intervale   1, to  34.
*
* 5 5 5 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
* 5 5 5 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
* 5 5 5 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
* 5 5 5 2 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 2 2 2 2 2 2
* 5 5 5 2 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 2 2 2 2 2 2
* 5 5 5 2 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 2 2 2 2 2 2
* 3 3
```

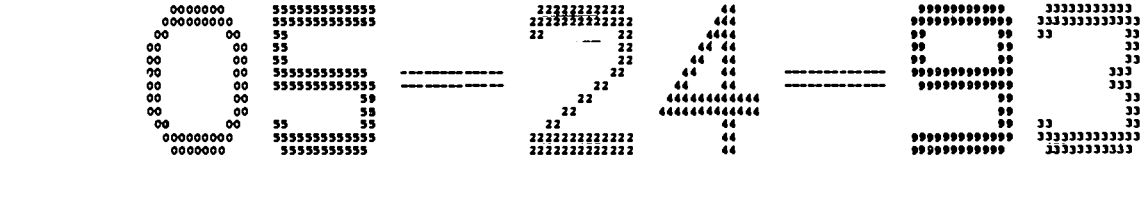
```
*   0  0.000E+00                          0.000E+00                          9.000E+00
*   1
*      2.143E+00       2   1.072E+00
*                                        2.540E+00       2   1.270E+00
*                                                                            3.194E-01       5   6.384E-02
*   2
*      2.590E+00       1   3.969E-01
*                                        9.540E+00      13   5.385E-01
*                                                                            5.000E-01       8   2.257E-02
*   3
*      3.175E+00       2   3.175E-01
*                                        4.801E+01      24   1.403E+00
*   4
*      7.175E+00       9   4.444E-01
*                                        5.334E+01       4   1.333E+00
*   5
*      2.413E+01      16   1.060E+00
*                                        1.060E+02       7   7.529E+00
*   4
*      2.540E+01       4   3.175E-01
*                                        1.277E+02       3   7.223E+00
*   7
*                                        1.302E+02       3   8.467E-01
*
*****************************************************************************************************
1
*****************************************************************************************************
*****************************************************************************************************
*
*                    ...cross section related data from file macrxs  000000011690 version  1 ...
*
*****************************************************************************************************
*
*
*  1 fuel      2 steel     3 strire    4 fellow    5 filler
*
*
*
*****************************************************************************************************
1
*****************************************************************************************************
*****************************************************************************************************
*
*                                  ...iteration controls and criteria...
*
*****************************************************************************************************
*
*
*                                        ***iteration criteria***
*
*                                           transport inners
*
*          criterion    quantity to test                          value     action taken if value exceeded
*          ---------    ----------------                          -----     ------------------------------
*             iitl  - inner iteration count until near lambda       1          terminates inners
*                     (i.e. fission source) convergence
*             iita  - inner iteration count when near lambda       30          terminates inners
*                     (i.e. fission source) convergence
*             epsi  - fractional ptwise flux change            1.00E-04        does another inner
*                     per inner
*
*                                          diffusion sub-outers
*
*          criterion    quantity to test                          value     action taken if value exceeded
*          ---------    ----------------                          -----     ------------------------------
*             sitmd - sub-outer iteration count                    40          terminates sub-outers
*             eps   - diffusion lambda-1.0 (see note below)    1.00E-04        does another sub-outer
*             eps   - fractional ptwise fission change         1.00E-04        does another sub-outer
*                     per sub-outer (see note below)
*
*             note: eps, when the problem is finally converged, will equal epsi, the value shown above, however,
*                   early in the iteration process, a larger value may be used to avoid unnecessary iterations.
*
*                                        final convergence criteria
*
*          criterion    quantity to test                          value     action taken if value exceeded
*          ---------    ----------------                          -----     ------------------------------
*             sita  - outer iteration count                        20          quits with error message
*             epsi  - transport lambda-1.0                     1.00E-04        does another outer
*
*****************************************************************************************************
*****************************************************************************************************
1
*****************************************************************************************************
*****************************************************************************************************
*
*                    ...flux and eigenvalue convergence as monitored by threadant...
*
*****************************************************************************************************
*****************************
*key start iteration monitor *
*****************************
*
*
*  cpu time outer       diffusion      k-eff                    max ptwise   max ptwise   inners
*   (sec)    no. inners sub-outers  eigenvalue   lambda-1       flux change  flux change converged
*   62.43     0
*1193.61     1      0        5      1.00206438  5.39279E-03   0.00000E+00  0.00000E+00  **no**
*3920.64     2     33        2      1.00621614  4.67099E-03   1.34000E+00  8.74907E-01  **no**
*6729.01     3     32        4      0.99882788 -6.48419E-03   1.83886E-01  6.46853E-02  **no**
*9347.47     4     32        2      0.99988774  7.92676E-05   2.23293E-01  1.98724E-02  **no**
* 12024.     5     32        3      0.99992633  3.74005E-05   1.84842E-01  8.63697E-03  **no**
* 14622.     6     32        3      0.99991790 -7.94837E-06   1.24028E-01  1.94196E-03  **no**
* 17020.     7     32        3      0.99991315 -4.43695E-06   1.80151E-02  1.30041E-03  **no**
* 19399.     8     32        3      0.99990515 -7.57677E-06   7.67103E-03  1.74833E-03  **no**
*
*     ------------------------------------------------------------------------
*
*              -- inner iteration summary for outer iteration no.   9 --
*
*                                   iter per max flux   at
*                              group  group   change   mesh
*                                1     9   0.68E-04   6, 46, 12
*                                2     6   0.94E-04  14, 56, 12
*                                3     5   0.73E-04  13, 56, 13
*                                4     6   0.67E-04  13, 56, 13
*                                5     5   0.75E-04  12, 56, 13
*                                6     6   0.88E-04  10, 47, 13
*                                7    19   0.84E-04   1, 52, 13
* **no accel. + diffusion poor  *  9    10   0.93E-04  34, 53, 13
*                                9     8   0.98E-04   1, 52, 13
*                               10    16   0.90E+04   1, 52, 13
*                               11    10   0.91E+04   1, 52, 13
*                               12    11   0.59E-04   5, 56,  5
* **no accel. + diffusion poor  * 13    10   0.70E+04   3, 46, 13
*                               14     6   0.91E+04   1, 51, 13
* **no accel. - diffusion poor  * 15    12   0.86E-04  24, 56, 13
*                               16    11   0.85E+04   2, 33,  5
*
*
*  cpu time outer       diffusion      k-eff                    max ptwise   max ptwise   inners
*   (sec)    no. inners sub-outers  eigenvalue   lambda-1       flux change  flux change converged
* 29247.     9    150        2      0.99990099 -4.07802E-06   9.82965E-05  1.52119E-06   yes
*
*                    **** some acceleration inhibited ****
*
*                 $99999 all convergence criteria satisfied 9$9$99
*
*  particle balance = -1.65536E+05     total inners all outers =  375
*
*****************************************************************************************************
1
```

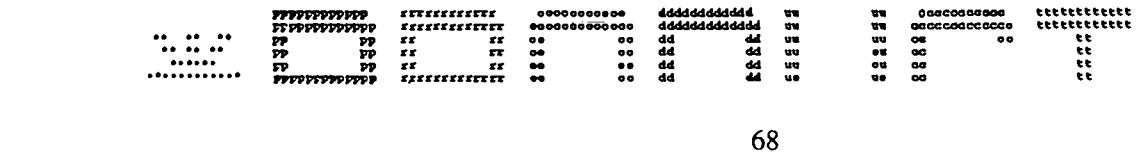
```
                                        ...group edit and balances upon converg-nce...

                        ...title---SHEBA-11 Critical reactor                                    ...

                                        ...system balance tables...(neutrons only)

*key start balance table     *

  gp          source     fission source          absorption          le scatter       self scatter       out scatter        net leakage
   1   0.0000000E+00     2.9368677E+03     7.5922914E+01     6.3666429E-12     8.7760250E+02     2.2168736E+03     3.4432864E+02
   2   0.0000000E+00     4.4464827E+03     6.4889312E+01     1.3032098E+03     2.6144444E+03     5.0099688E+03     6.7629977E+02
   3   0.0000000E+00     2.1715381E+03     1.1711702E+01     2.3175653E+03     1.9928162E+03     4.1918806E+03     3.2567694E+02
   4   0.0000000E+00     2.3266479E+03     1.6959939E+01     4.6305395E+03     4.3763173E+03     6.4973028E+03     4.4316340E+02
   5   0.0000000E+00     1.1633240E+03     2.0983811E+01     7.4288945E+03     7.7302563E+03     9.1603158E+03     4.1128902E+02
   6   0.0000000E+00     1.8096151E+02     3.6757727E+01     8.4964573E+03     8.5191038E+03     8.5782353E+03     2.4268208E+02
   7   0.0000000E+00     0.0000000E+00     4.6066335E+01     8.4934149E+03     9.0274141E+03     8.3072754E+03     1.4029564E+02
   8   0.0000000E+00     0.0000000E+00     9.0430598E+01     8.2505010E+03     7.3645555E+03     9.0300189E+03     1.3009571E+02
   9   0.0000000E+00     0.0000000E+00     2.5321836E+02     8.0729447E+03     7.1981129E+03     7.7116852E+03     1.0826456E+02
  10   0.0000000E+00     0.0000000E+00     3.3225194E+02     6.6698210E+03     5.6497666E+03     6.2644044E+03     7.1766904E+01
  11   0.0000000E+00     0.0000000E+00     2.7486303E+02     6.0956441E+03     5.9738737E+03     5.7584500E+03     4.2333842E+01
  12   0.0000000E+00     0.0000000E+00     4.6251840E+02     6.1700026E+03     5.1206341E+03     5.6461985E+03     6.1189822E+01
  13   0.0000000E+00     0.0000000E+00     8.0838558E+01     5.5386736E+03     2.6186824E+03     5.4039891E+03     5.3849277E+01
  14   0.0000000E+00     0.0000000E+00     1.1847353E+02     4.9307960E+03     2.8561930E+03     4.7703609E+03     4.1962469E+01
  15   0.0000000E+00     0.0000000E+00     7.7024339E+02     5.9829615E+03     2.2682916E+04     5.1844972E+03     9.8243185E+01
  16   0.0000000E+00     0.0000000E+00     6.9255769E+03     7.0490954E+03     1.6696558E+05     2.9230716E-09     1.2352771E+02
 tot   0.0000000E+00     1.2925822E+04     9.5826064E+03     9.1630321E+04     2.5356728E+05     9.1630363E+04     3.3449446E+03

  gp    right leakage horizontal leakage       top leakage     vertical leakage     front leakage     fr-back leakage   particle balance
   1   2.9411089E+02     2.9411089E+02     5.5065526E+00     5.0215198E+01     4.1063144E+04     4.1063144E+04     +9.6837171E-08
   2   5.7351387E+02     5.7351387E+02     1.1314389E+01     1.0279500E+02     9.0574773E+04     9.0574773E+04     -8.0748975E-05
   3   2.7049956E+02     2.7049856E+02     5.9968250E+00     5.5177936E+01     5.5036791E+04     5.5036791E+04     +3.6428071E-05
   4   3.6752453E+02     3.6752653E+02     9.1273335E+00     7.5636461E+01     4.0827142E+04     4.0827142E+04     +3.4642569E-08
   5   3.4122706E+02     3.4122706E+02     7.3796754E+00     7.0061097E+01     9.7357603E+04     8.7357603E+04     +3.0673997E-05
   6   2.1808406E+02     2.1809406E+02     4.4857945E+00     4.4597668E+01     3.7128542E+04     3.7129542E+04     +2.7965047E+05
   7   1.1898694E+02     1.1898694E+02     2.2107915E+00     2.0308677E+01     2.0297414E-05     2.0297414E-05     -1.3707021E-06
   8   1.1044314E+02     1.1043314E+02     2.1023138E+00     1.9632176E+01     3.7763764E-04     3.7763764E-04     +5.3628968E+06
   9   9.2815626E+01     9.2815626E+01     1.6942316E+00     1.5428797E+01     1.3967398E-04     1.3967398E-04     +1.7059950E-07
  10   6.1473618E+01     6.1473618E+01     1.1292036E+00     1.0293255E+01     3.0828276E-05     3.0828276E-05     -1.0756568E-07
  11   5.3460742E+01     5.3440742E+01     9.6148950E+01     8.8730361E+00     6.3356184E-05     6.3356184E-05     -1.2517498E-07
  12   5.2554960E+01     5.2554960E+01     9.1761528E-01     8.6346039E+00     5.8403672E-05     5.8403672E-05     -3.0455246E-07
  13   4.6542894E+01     4.6542894E+01     7.6315690E-01     7.3062954E+00     8.5195198E-05     8.5195198E-05     -4.1098165E-07
  14   3.6524275E+01     3.6524275E+01     5.5957437E-01     5.4382490E+00     1.4428266E-04     1.4428266E-04     -1.0421901E-07
  15   7.7889509E+01     7.7889509E+01     9.8153520E-01     1.0353208E+01     4.6797368E-04     4.6797368E-04     -3.7141143E-06
  16   1.1264066E+02     1.1264066E+02     9.3226893E-01     1.0886610E+01     4.1710906E-04     4.1710906E-04     -1.2683237E-06
 tot   2.8293134E+03     2.8293134E+03     5.5062758E+01     5.1562815E+02     5.3276019E-03     5.3276019E-03     -1.6553647E-05

1
 Multigrid work units...  Total=  10430.94 au,
       By group...
    1    408.75  2    568.11  3    520.82  4    501.67  5    501.84  6    479.85  7    730.50  8    582.40  9    618.40
   10    740.18 11    642.37 12    763.45 13    930.38 14    837.52 15    746.43 16    737.97

 Multigrid average convergence rate by group...
    1 0.8832  2 0.8574  3 0.9173  4 0.8916  5 0.9582  6 0.8257  7 0.7408  8 1.0758  9 0.7588
   10 0.7713 11 0.9120 12 0.8538 13 1.8563 14 0.9344 15 2.0374 16 0.9167

 timing info...tswep,tdse,trelx,tput3,tintrp=21420.50 6419.71 3446.05  562.93  394.85 seconds.

integral summary information
summary integral-k-eff      9.9990099E-01
integral-source-i              neutron  0.0000000E+00
integral-fission-i             neutron  1.2925822E+04
integral-absorption-i          neutron  9.5826064E+03
integral-in-scat-i             neutron  9.1630321E+04
integral-self-scat-i           neutron  2.5356728E+05
integral-out-scat-i            neutron  9.1630363E+04
integral-net lkage-i           neutron  3.3449468E+03
integral-right lkage-i         neutron  2.8293134E+03
integral-horizontal lkage-i    neutron  2.8293134E+03
integral-top lkage-i           neutron  5.5062758E+01
integral-vertical lkage-i      neutron  5.1562815E+02
integral-front lkage-i         neutron  5.3276019E-03
integral-fr-back lkage-i       neutron  5.3276019E-03
integral-particle bal-i        neutron -3.2033493E-04

                                        ...interface file rtflux written..

                                        ...interface file snoone written..


threedant iteration time, sins  4.8754E+02
1
                                edit run on  with solver version 05-24-93*product release 2.3e     machine jezabel
0
                                        ...edit output...

                                        ...block vi - edit specification data...

*key start edit output *


 cross section balancing (balxs.ne.0)
       or
 transport correction (trcorrdiag, cusaro, or bhs)
 will NOT be reflected in edits
```

```
                                   ...input control integers...

                1  pted      0/1     no/yes - point edits desired
                0  zned      0/1     no/yes - zone edits desired

                0  ejed      0/1     direct/adjoint edit(see rtflux/rtflux file)

                0  igrped    0/1/2/3 print totals only/print broad groups only/same as 1/print all groups and totals
                0  bywolp    0/1     no/yes * multiply point reaction rates by mesh volumes
                0  rofluz    0/1     no/yes - write the rzflux file (zone average flux file)
                0  rmnflx    0/1     no/yes - write the rmnflx file (zone average flux moments file)


                                   ...floating parameters...

      0.000000E+00  power     0/p     no/normalize all results, including flux files, to p megawatts
      2.100000E+02  mevper    mev per fission (default: 210 mev)


                                ...energy related edit information...

                  16  number of fine neutron groups
                   0  number of fine gamma groups
                  16  total number of fine groups
                  16  total number of broad groups


                                ...space related edit information...

                24752  number of points to edit
                    0  number of zones to edit
                    0  0/1  no/yes  density factors were input
```

```
                                        run highlights

*key start run highlights    *

                                  ***********************************
                                  *                                 *
                                  *    all modules are tentatively ok.   *
                                  *     interface file geodst written.   *
                                  * cross sections from cards via broilb.*
                                  *    interface mixing files written.  *
                                  *     interface file regmat written   *
                                  *    no files macrxs,enrodt written.  *
                                  * *left boundary condition overridden* *
                                  *     interface file eolinp written.   *
                                  *     interface file editit written.   *
                                  *       start solver execution.        *
                                  *  * some acceleration inhibitions *   *
                                  *     all convergence criteria met.    *
                                  *     interface file rtflux written.   *
                                  *     interface file enzone written.   *
                                  *          start edit execution.       *
                                  *            edits completed.          *
                                  *                                      *
                                  ***********************************

                                        storage and timing history

                                  ***************************************************************
                                  *          scm      scm      lcm      lcm      cpu      cycle   *
                                  * module   words    limit    words    limit   seconds  seconds  *
                                  * ------  ------   ------   ------   ------  -------  ------   *
                                  *    0        0        0        0        0  29257.9      0.0    *
                                  *  100    28871  1100000        0        0     24.5      0.0    *
                                  *  101        0        0        0        0     11.6      0.0    *
                                  *  102     1083  1100000       99  6000000      0.2      0.0    *
                                  *  103      439  1100000        0        0      0.2      0.0    *
                                  *  104     2755  1100000        0        0      0.3      0.0    *
                                  *  105        0        0        0        0      0.0      0.0    *
                                  *  106        0        0        0        0      0.0      0.0    *
                                  *  107     2495  1100000     8942  6000000      2.6      0.0    *
                                  *  108        0        0        0        0      0.1      0.0    *
                                  *  109    29094  1100000        0        0      0.2      0.0    *
                                  *  112        0        0        0        0      0.0      0.0    *
                                  *  200   638557  1100000  5367012  6000000  29227.8      0.0    *
                                  *  201        0        0        0        0     28.4      0.0    *
                                  *  202        0        0        0        0      8.5      0.0    *
                                  *  203     3767  1100000        0        0      0.7      0.0    *
                                  *  204        0        0        0        0      0.1      0.0    *
                                  *  205        0        0        0        0      9.2      0.0    *
                                  *  206        0        0        0        0  25657.3      0.0    *
                                  *  207        0        0        0        0   3517.2      0.0    *
                                  *  208        0        0        0        0      0.8      0.0    *
                                  *  210        0        0        0        0      0.4      0.0    *
                                  *  211        0        0        0        0      5.1      0.0    *
                                  *  300        0        0        0        0      5.6      0.0    *
                                  *  301   150958  1100000        1  6000000      1.9      0.0    *
                                  *  302        0        0        0        0      0.0      0.0    *
                                  *  400        0        0        0        0      0.0      0.0    *
                                  ***************************************************************
```







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