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FEASIBILITY OF MONITORING SUBCRITICALITY DURING FUELING OF THE ADVANCED NEUTRON SOURCE REACTOR USING THE ^{252}Cf-SOURCE-DRIVEN NOISE ANALYSIS METHOD

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Timothy Eugene Valentine

August 1992

DEDICATION

This thesis is dedicated to my wife

Jennifer S. Valentine;

to the rest of my family; and especially to my grandfather

Clarence C. Cox.

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ABSTRACT

Fueling of the Advanced Neutron Source (ANS) reactor is unique in that the core is composed of two annular fuel elements with different diameters, each of which is supercritical when moderated and infinitely reflected by heavy water. Therefore, there is a need for careful design and detailed criticality safety analysis of each step of the fueling process to ensure that a criticality during fueling is not a major safety issue. Further, there is a need to measure the subcriticality associated with the loading of the fuel elements into the reactor during the critical experiments program.

To maintain subcriticality of the fuel annuli, each fuel element will have material on the inner and outer radial surfaces to isolate the fissile material from the heavy water reflector as the fuel annuli are transferred into the reactor core. The ability of structural materials to decouple the annuli from the heavy water has been analyzed by using the KENO Va Monte Carlo code to determine whether they can be used as the isolation materials. With 25-mm-thick inner stainless steel isolators and outer aluminum isolators that are 127 mm thick for the upper fuel annuli and 57 mm thick for the lower fuel annuli in place, the effective neutron multiplication factors for the upper and lower fuel elements are 0.653 ± 0.002 and 0.769 ± 0.002 respectively. With only one of the isolators in place, the effective neutron multiplication factors for both the upper and lower fuel annuli are less than 0.95; therefore, if the isolators are independently supported, two mutually exclusive events must occur before a criticality event could occur.

A Monte Carlo calculation of the ^{252}Cf-source-driven noise analysis method has shown that it is feasible to measure the subcriticality of the fuel annulus/isolator assembly in the critical experiments program and, if appropriate, during the fueling of the ANS reactor. The calculated coherences have shown that a measurement of the ratio of spectral densities to a precision of 2% can be made in less than 11 minutes with the upper fuel annulus/isolator in the transfer shaft of the ANS reactor and with the source in the inner isolator and two ^{3}He counters on each side of the fuel annulus in the outer isolator assembly. The calculated auto power spectral densities, the cross power spectral densities, the coherences, and the ratio of spectral densities can be compared directly to the data obtained from future measurements. The subcriticality can also be obtained, thus verifying the fueling scenario of the ANS reactor.

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INTRODUCTION

1.0 Background

Fueling of the Advanced Neutron Source (ANS) reactor[1] is unique in that the core is composed of two annular fuel elements with different diameters, each of which is supercritical when moderated and infinitely reflected by heavy water. The neutron multiplication factors for the upper and lower fuel annuli in infinite heavy water are ~1.2 and ~1.1 respectively. These neutron multiplication factors produce the need for careful design and detailed criticality safety analysis of each step of the fueling process to ensure that criticality during fueling is not a major safety issue. Therefore, there is a need for a mechanism that can maintain the subcriticality of the fuel elements in heavy water. There may be a need to monitor subcriticality during the initial fuel loading of the ANS reactor, and there certainly is a need to measure the subcriticality associated with loading the fuel elements into the reactor during the critical experiments program.

To maintain subcriticality, each fuel element will have material on the inner and outer radial surfaces to isolate the fissile material from the heavy water moderator and reflector as the fuel annuli are transferred into the reactor core. Neutron absorbers are used to maintain subcriticality of fissile materials in many situations. However, if neutron absorbers are used as a criticality control mechanism, the presence of the neutron absorber in the isolator must be periodically verifiable as per U. S. Department of Energy Order 5480.5; therefore, the use of structural materials as the isolators makes the verification process simpler (it could be visual). The use of structural materials as isolators also minimizes the chance of mechanical damage during fueling. The scope of this isolator analysis is limited to neutronic calculations only. Other considerations such as decay heat have not yet been evaluated. The purpose of this work is to develop a fueling concept for the ANS reactor and investigate the applicability of monitoring the subcriticality during the critical experiments verifying the concept for fueling the ANS reactor, and if appropriate, during initial loading of the ANS reactor.

The count rate method has often been used to monitor initial fuel loading of a reactor. As the fuel elements are placed in the reactor core, the count rates provide an indication of the relative change in the reactivity during the fuel loading process. The count rate (CR) can be expressed as

$$CR=\frac{\epsilon g^{*}S}{\nu(1-k)/k}\,, \tag{1.1}$$

where S is the integral source strength over the system; ϵ is the detection efficiency in counts per fission; ν is the average number of prompt neutrons per fission; k is the effective neutron multiplication factor; and g^{*}, which is related to the source effectiveness, is defined as

$$g^{*}=\frac{\int S(r)\,I_s(r)\,dr\int P(r)\,dr}{\int S(r)\,dr\int P(r)\,I(r)\,dr}\,, \tag{1.2}$$

where P(r) is the induced fission density distribution; S(r) is the source distribution; I(r) is the importance of induced fission neutrons for producing fission; and $I_s(r)$ is the importance of source neutrons for producing fission. These parameters are defined as follows:

$$I(r) = \int \chi(r,E)\, \phi^{+}(r,E)\, dE, \tag{1.3}$$

$$P(r) = \int \Sigma_f(r,E)\, \phi(r,E)\, dE, \tag{1.4}$$

$$I_s(r) = \int \chi_s(r,E)\, \phi^{+}(r,E)\, dE, \tag{1.5}$$

where $\chi(r,E)$ is the energy distribution of the fission neutrons; $\chi_s(r,E)$ is the energy distribution of source neutrons; $\Sigma_f(r,E)$ is the macroscopic fission cross section; $\phi(r,E)$ is the neutron flux; and $\phi^{+}(r,E)$ is the static adjoint flux. However, since the count rate method is very dependent on detection efficiency and effective source strength, the count rate method in most cases does not provide a useful technique to estimate the reactivity of the system as fuel is being placed in the reactor core. It has been used basically as a qualitative method rather than a quantitative method for initial fuel loading. In many cases the changes in the count rate during the loading of a reactor are more related to changes in the source strength and detector efficiencies rather than to changes in the reactivity of the system. Figure 1.1[2] is an illustration of this effect in the approach to critical inverse count rate curves for the initial loading of the Phénix reactor. As can be seen in Fig. 1.1, the inverse count rate was not very sensitive to changes in k even though k was increasing for addition of fuel elements 19 through 41. During this stage of the fuel loading process, the reactivity was not being monitored because source-detector effects were obscuring the reactivity changes. Therefore, for these elements, the extrapolations of inverse count rate to

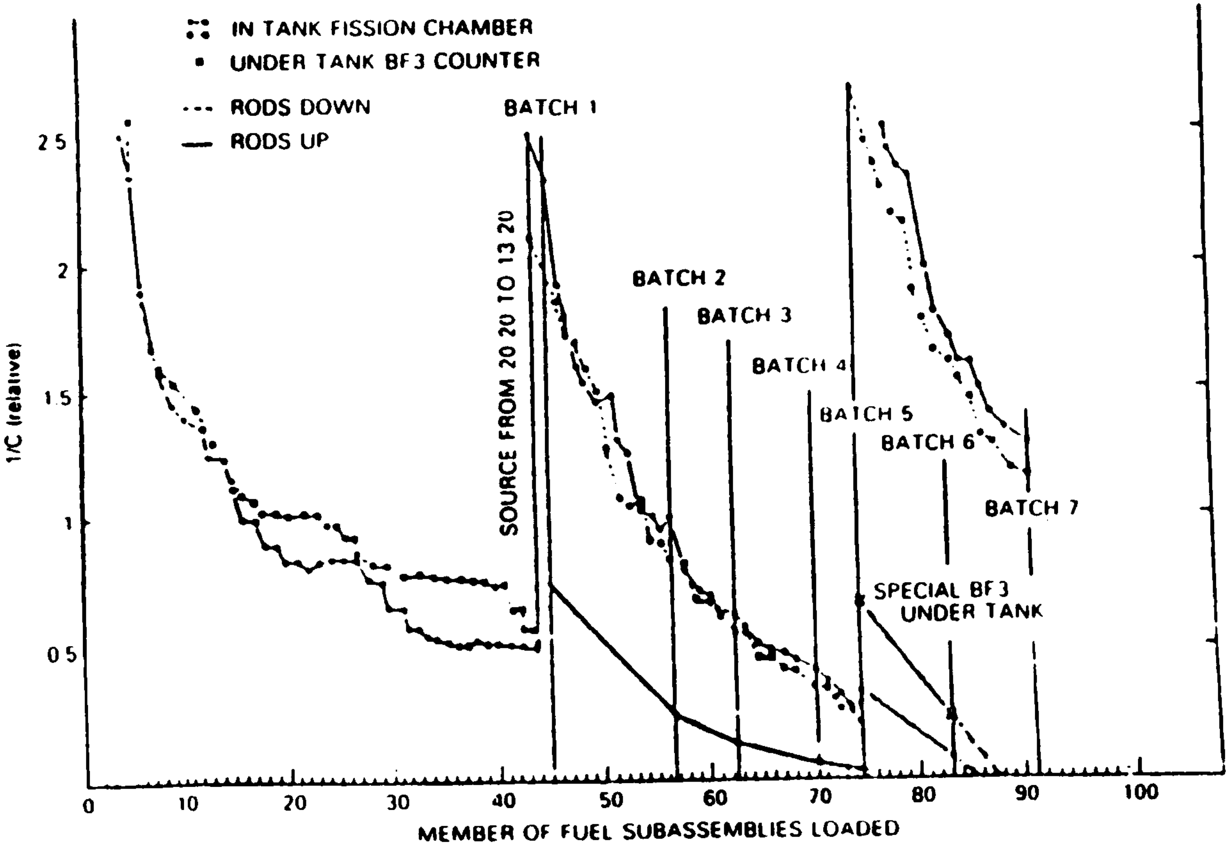


Figure 1.1 Critical Approach Inverse Count Rate Curves for the Initial Loading of the Phénix Reactor[2]

delayed criticality were meaningless. What this meant was that the loading proceeded essentially without monitoring k. The modified neutron source multiplication method has been used to determine the reactivity by using the following relationship

$$\frac{(1-k)}{k} = \frac{A\epsilon S\beta_c}{CR\epsilon_c S_c}, \qquad (1.6)$$

where subscript c refers to the values of the parameters near delayed criticality and A is a calibration factor obtained at delayed criticality or a known reactivity slightly subcritical.[3] This requires a reference measurement near critical to be performed prior to the initial fueling of the reactor which is not practical. Due to the difficulties that may be encountered with the count rate method, an alternate method to monitor fuel loading of the ANS reactor has been investigated by using the Monte Carlo code KENO-NR[4].

The ^{252}Cf-source-driven noise analysis method has been applied in many applications: quality assurance and verification for new reactor fuel elements[5], initial fuel loading of reactors[2], and spent reactor fuel storage[6]. Besides these applications, this method has been used to analyze a wide variety of subcritical systems: uranium metal systems[7], interacting tank systems[8], plutonium solution systems[9], and a dynamic uranium solution system.[10] This technique has been successfully used to monitor k from 0.3 to 0.999. The measured ratio of spectral densities from the ^{252}Cf measurement does not depend on detection efficiency or source intensity, but the ratio does depend on other parameters for only the subcritical state of interest that vary slightly or in many cases almost linearly with reactivity. The subcritical parameters can be either measured or obtained from measurements of others.[2] The ^{252}Cf measurement requires the use of a source that is contained within detector #1 to initiate the fission process and two neutron detectors (#2 and #3) to measure fission chains initiated by neutrons from the spontaneous fission of the ^{252}Cf source. The ratio of spectral densities is related to reactivity in the following manner.

$$\frac{1-k}{k}=\frac{C_1R(\omega)}{1-C_2R(\omega)}, \qquad (1.7)$$

$$R(\omega)=\frac{G_{12}^{*}(\omega)G_{13}(\omega)}{G_{11}(\omega)G_{23}(\omega)}, \qquad (1.8)$$

where k is the effective multiplication factor of the fissile assembly, C_1 and C_2 are constants dependent on other subcritical parameters of the system and the effect of the detector on the subsequent detection of the fission chain population, $R(\omega)$ is the ratio of spectral densities, G_{12}^{*} is the complex conjugate of the cross power spectral density of the source detector #1 and the neutron detector #2, G_{13} is the cross power spectral density of the source detector #1 and the neutron detector #3, G_{11} is the auto power spectral density of the source detector, and G_{23} is the cross power spectral density of the two neutron detectors. Mihalczo and Blakeman[2] have shown that the ^{252}Cf-source-driven noise analysis method is more linear with (1-k)/k and more useful to predict initial delayed criticality. Figure 1.2[2] presents the normalized results obtained from an experiment in which a 550-mm-diameter tank was filled with a uranyl fluoride solution. The data presented in Fig. 1.2 show that the ratio of spectral densities is linear with the solution height, whereas the inverse count rate

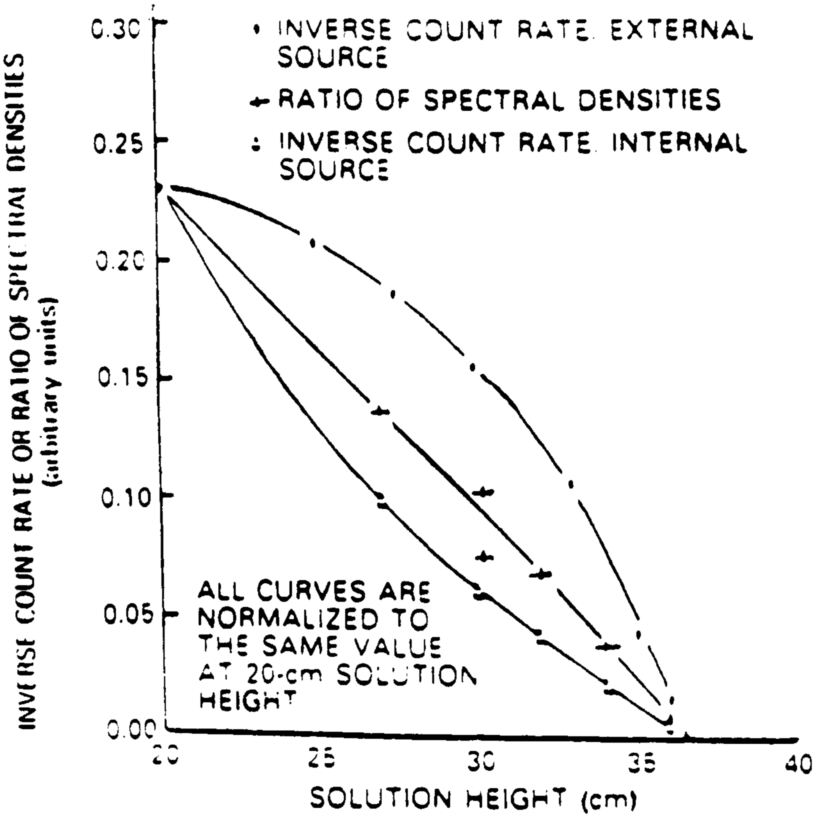


Figure 1.2 Ratio of Spectral Densities and Inverse Count Rate as a Function of Solution Height[2]

curves tend to either overpredict or underpredict initial delayed criticality early in the loading. This demonstrates that the ^{252}Cf measurement is a better method of monitoring the changing reactivity of a system as fuel is added.

For a reactor like the ANS, this method would not be sensitive to the (γ,n) neutrons in the heavy water since single particle events cannot contribute directly to the coherence between detectors. The use of the ^{252}Cf-source-driven noise analysis method offers advantages for fueling and evaluation of the fueling process in the critical experiments program because the measured ratio of spectral densities does not depend on detection efficiency or source intensity and the method provides a direct indication of the reactivity of the fuel-isolator assembly during the fueling process. In addition, some other noise parameters vary with higher powers of $(1-k)/k$ and thus are much more sensitive to changes in k.

1.1 Organization

In order to obtain an understanding of the complexity involved in the fueling of the ANS reactor, a description of the ANS reactor is presented in Chap. 2. Details concerning the fuel annuli, the fueling structure, and the size and location of the various components contained in the reactor are provided. The purpose of Chap. 3 is to define some basic noise related measured quantities, provide a general description of the ^{252}Cf-source-driven noise analysis (CSDNA) measurement, provide a description of a more general theory of the method based on the Monte Carlo code KENO-NR[4] used to interpret the CSDNA measurements, and provide a description of the point kinetics representation of the power spectral densities of the CSDNA method. Chapter 4 contains a description of a proposed fueling scenario for the ANS reactor. The results of the isolator analysis are presented in Chap. 5. Neutronic calculations for the fuel annuli with various combinations of isolators and neutronic calculations for the fuel-isolator assemblies in different positions in the fueling structure are contained in Chap. 5. The results of the CSDNA simulations are provided in Chap. 6. The most subcritical positions of the fuel-isolator assemblies in the fueling area are analyzed by the CSDNA calculations. Conclusions and recommendations are presented from the results of the criticality safety and the noise analysis evaluations in Chap. 7. The appendices give additional details of this work. Appendix A contains sample input files for the KENO Va[11] models of the upper and lower fuel elements of the ANS reactor. For completeness, details about the effect of light water on the criticality of the fuel annuli are presented in Appendix B, where the results of a previous analysis of the subcriticality of the fuel annuli in light water and the change in the multiplication factor of the reactor core with light water ingress into the heavy water reflector and coolant are given. The results of an analysis of submerging the fuel elements in various levels of heavy water are presented in Appendix C. Appendix D contains detailed results of the CSDNA calculations of the upper fuel annulus/isolator assembly with black detectors, and Appendix E contains detailed results of the CSDNA calculations of the lower fuel annulus/isolator assembly with black detectors. The black detectors are discussed in detail in the appendices.

CHAPTER 2

DESCRIPTION OF THE ADVANCED NEUTRON SOURCE REACTOR

2.0 Background

The ANS reactor is presently in the conceptual design stages. Although the details have not been finalized, conceptual design has been completed. The reactor is being designed as a user experimental facility for neutron research. There are numerous facilities available in the reactor for neutron scattering analysis, materials irradiation, isotope production, materials analysis, and nuclear science studies. The reactor is designed to achieve a high flux in the reflector tank in order to perform unprecedented neutron scattering studies. The peak thermal neutron flux in the reflector is $7.4(10^{19})$ n/(m^2 s). The isotope production facilities and the materials irradiation facilities are designed to be at least as good as those available at the High Flux Isotope Reactor (HFIR). Figure 2.1[1] is a conceptual design of the reactor assembly displaying the internal components of the reactor. There are two annular fuel elements that comprise the reactor core. There are three hafnium control rods that are located in the inner region of the annular fuel elements. The control rods are to be driven upward from the bottom of the reactor to the top of the reflector vessel to facilitate the ease of removal and loading of the fuel elements. The core pressure boundary tube (CPBT) separates the core flow from the heavy water reflector. This allows the large heavy water reflector region to have a low pressure relative to the pressure of the core region. There are eight shutdown rods that are

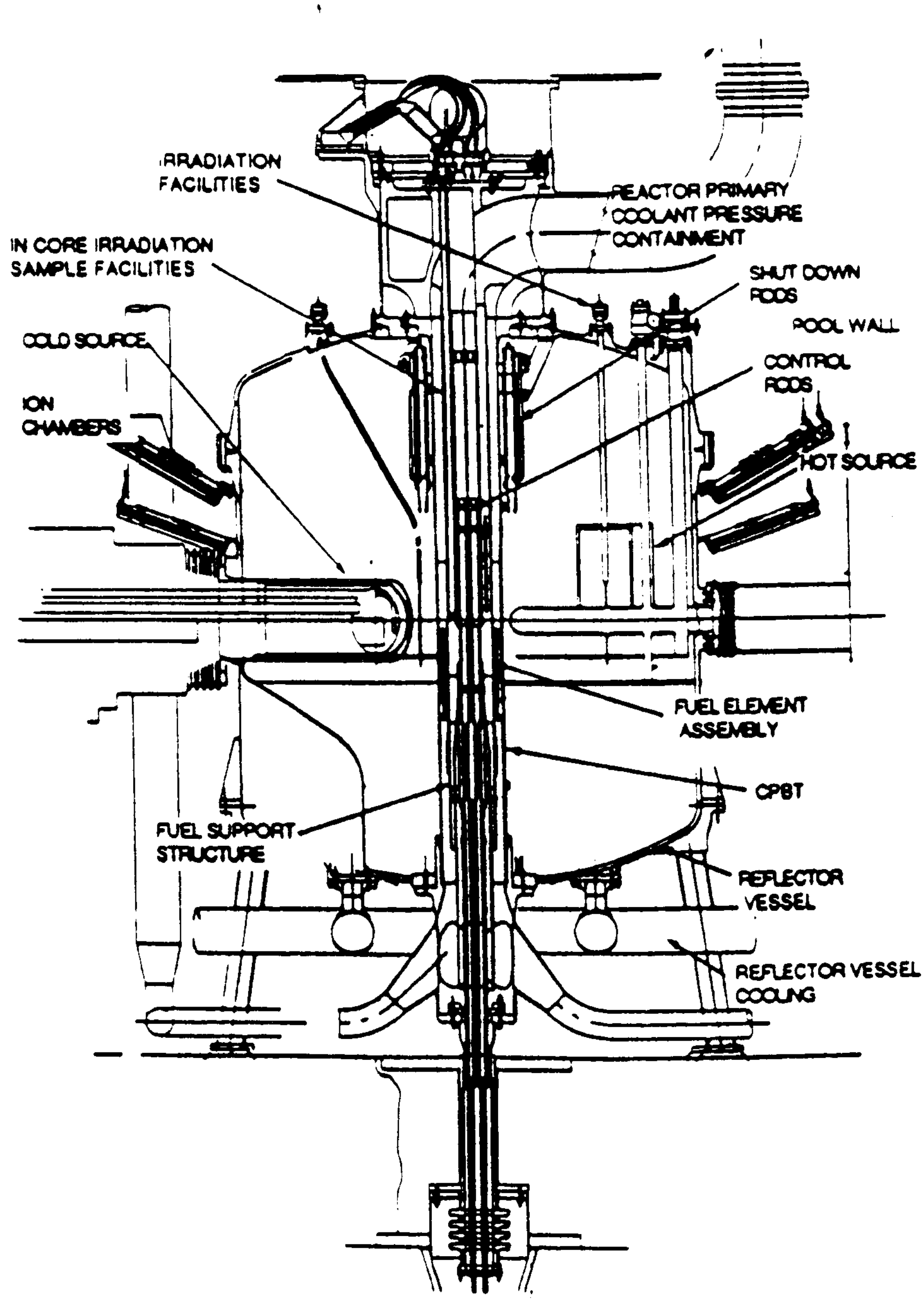


Figure 2.1 Internal Components of the Advanced Neutron Source Reactor[1]

located outside the core pressure boundary tube in the reflector. The shutdown rods move down from the top of the reactor vessel, where they are located during reactor operation, to the midplane of the reactor core to affect the shutdown of the reactor.

2.1 Annular Fuel Elements

The ANS core is composed of two annular fuel elements. The elements are comprised of involute fuel plates that are approximately 1.2 mm thick and spaced 1.2 mm apart. Figure 2.2[11] is a diagram of the involute fuel plates for the upper fuel element. There are 432 fuel plates in the upper fuel annulus and 252 fuel plates in the lower fuel annulus. There is a total of about 16 kg of ^{235}U in both fuel annuli. The plates contain a highly enriched uranium silicide composite (U_3Si_2) whose thickness varies radially. Figure 2.3[11] illustrates the typical radial variation of the uranium silicide thickness in the involute fuel plates. Uranium silicide is used as the fuel because the thermodynamic properties of the silicide are preferable over other uranium compounds. The distribution of the uranium silicide varies axially and radially as shown schematically in Fig. 2.4[11]. In order to accurately model the variations of the fuel density in the annuli, detailed models of the annuli must be made to achieve a proper representation of the varying material in the fuel annuli. The volume fractions of the fuel, coolant, and cladding in the core are 0.3, 0.5, and 0.2, respectively. The fuel elements are designed such that one element is located above the other in the reactor core as shown if Fig. 2.5[11]. With this design, a high

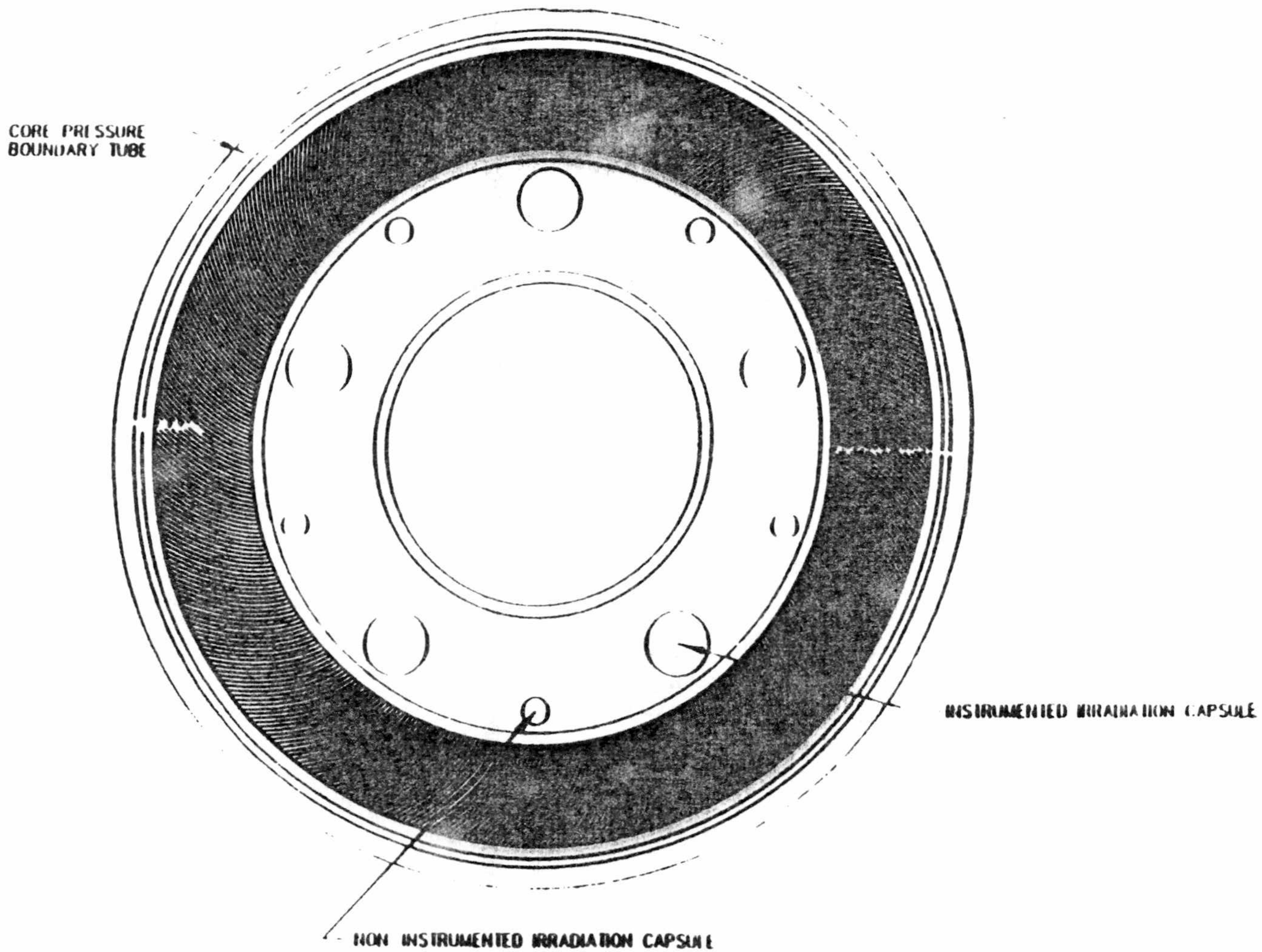


Figure 2.2 Involute Fuel Plate Design for the Upper Fuel Element[12]

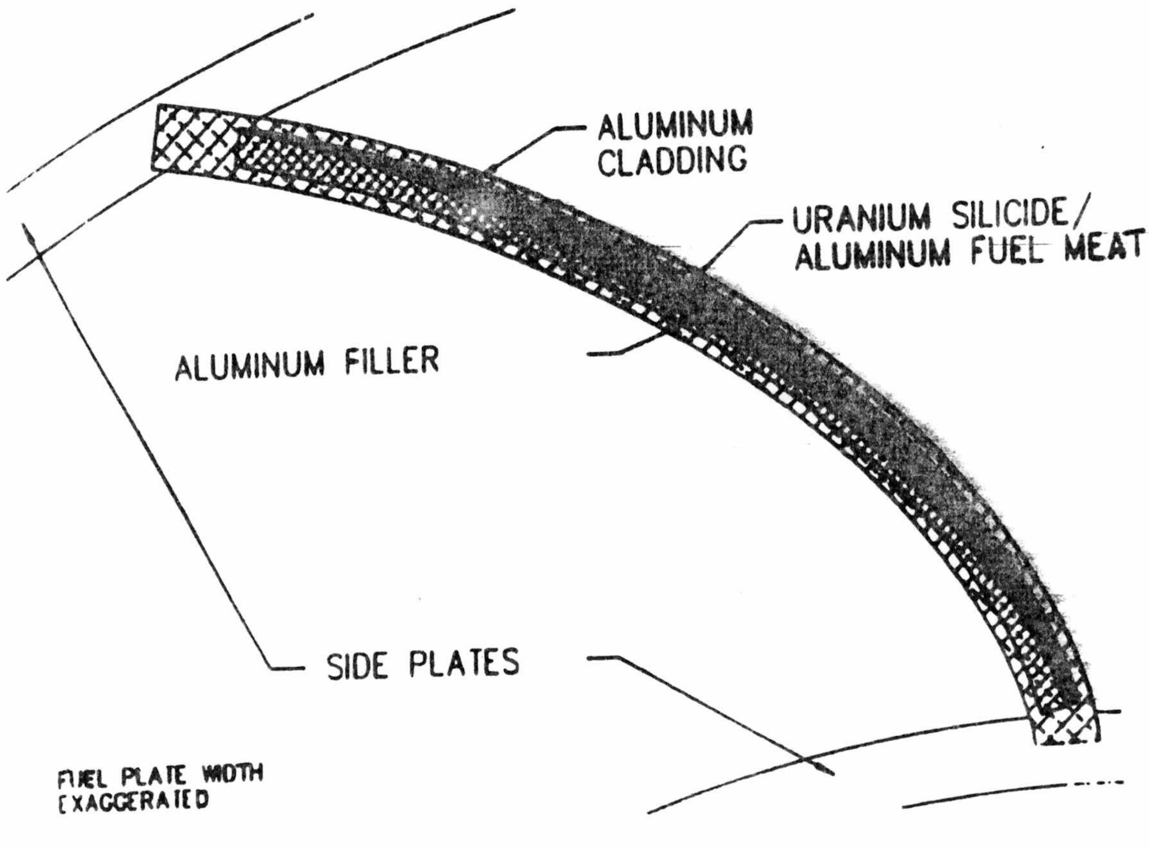


Figure 2.3 Typical U_3Si_2 Variation in the Involute Fuel Plates[12]

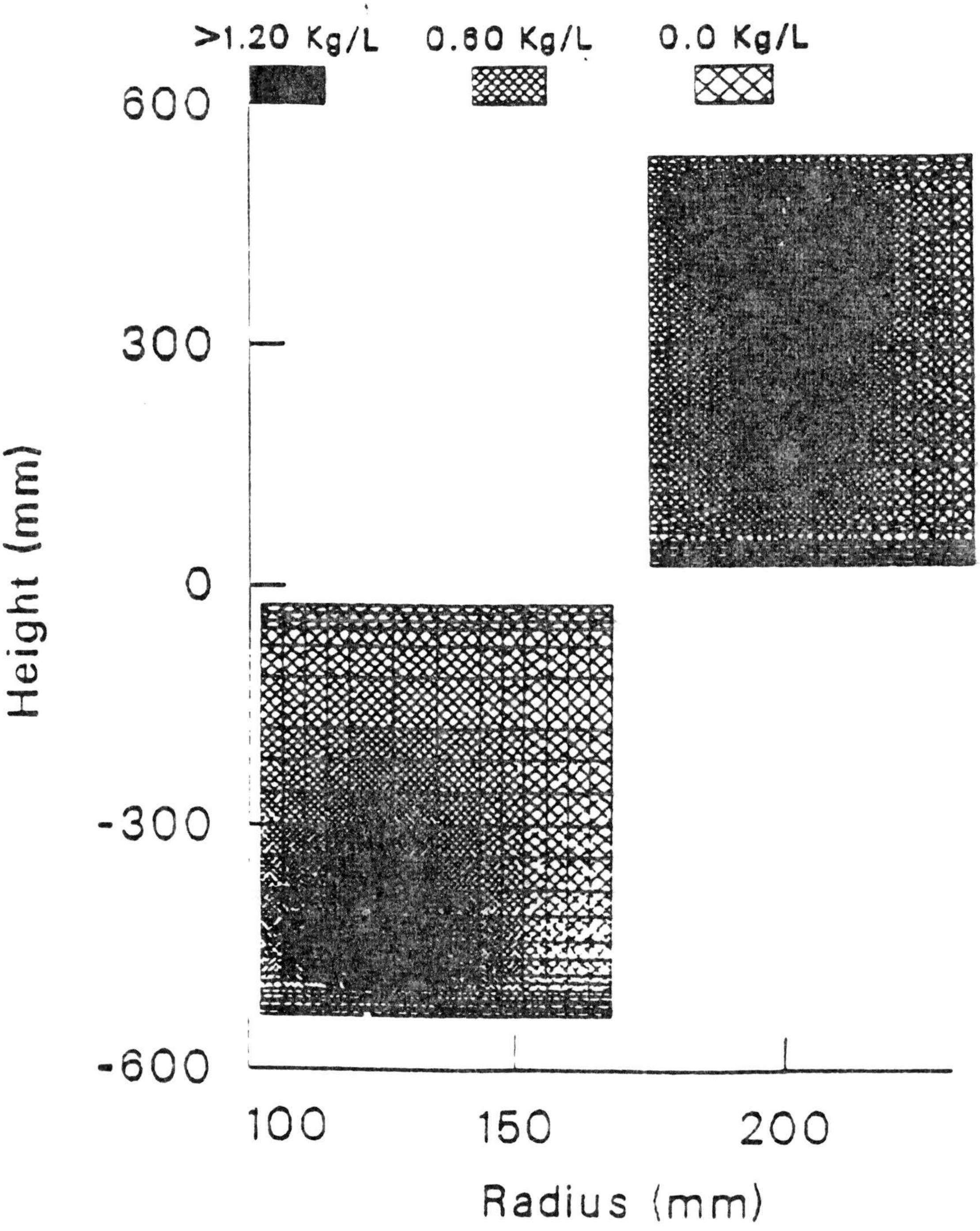


Figure 2.4 ^{235}U Density Variations in the Fuel Annuli[12]

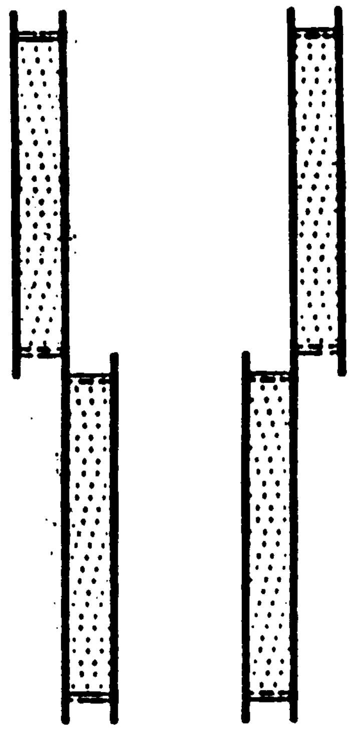


Figure 2.5 Fuel Annuli Positioning[12]

flux in a large volume of the reflector is achievable. Figure 2.6 is a schematic that shows the dimensions of the upper fuel element, and Fig. 2.7 is a schematic that shows the dimensions of the lower fuel element.

2.2 Reactor Structures

There are many structures that are contained within the reactor building. Figure 2.8[1] provides a plan view of the reactor facility. The reflector vessel is centered in the reactor building, has a 3.5-m diameter and is approximately 4.3 m high. The reflector vessel is filled with heavy water. A 1.3-m-thick pool of light water surrounds the reflector vessel on the sides and is contained within the reactor building by a biological shield. Irradiation facilities are located within the core pressure boundary tube and in the reflector vessel as shown in Fig. 2.1. There are three hafnium control rods located within the inner regions of the fuel annuli. Figure 2.9 is a cross section view of the control rods. The control rods have a 1.2-m long hafnium section that extends the length of both the upper and lower fuel annuli in the fully inserted position. There are eight hafnium safety rods located outside the core pressure boundary tubes in the heavy water reflector. These safety rods are positioned near the top of the reflector vessel during normal operation and are inserted into the reactor core for fueling. There are eight beam tubes located in the reflector vessel as shown in Fig. 2.10[11]. These beam tubes are used to perform neutron scattering studies. There are two cold neutron sources and one hot neutron source located in the reflector vessel. The cold sources are used to obtain very low

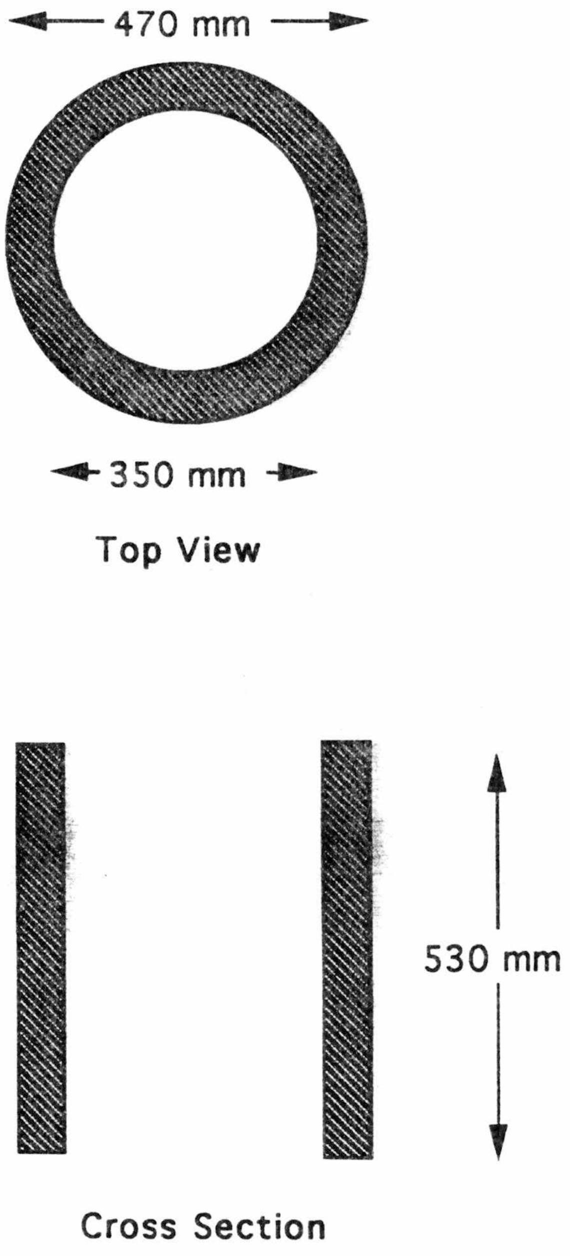


Figure 2.6 Upper Fuel Element Dimensions

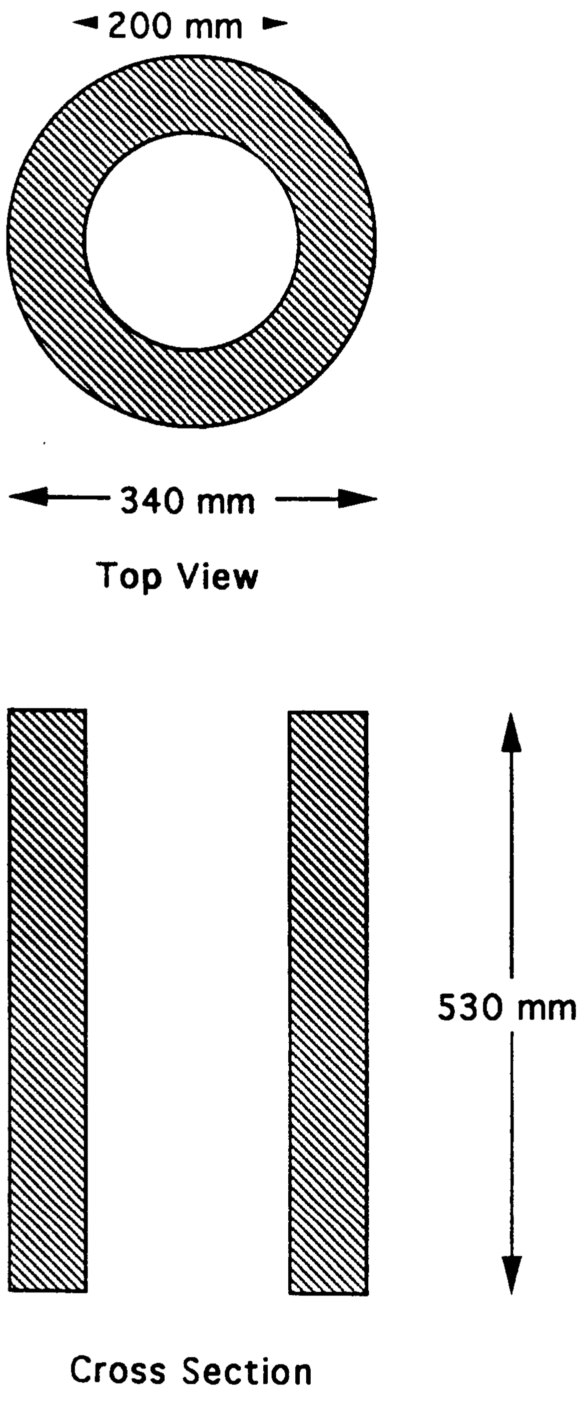


Figure 2.7 Lower Fuel Element Dimensions

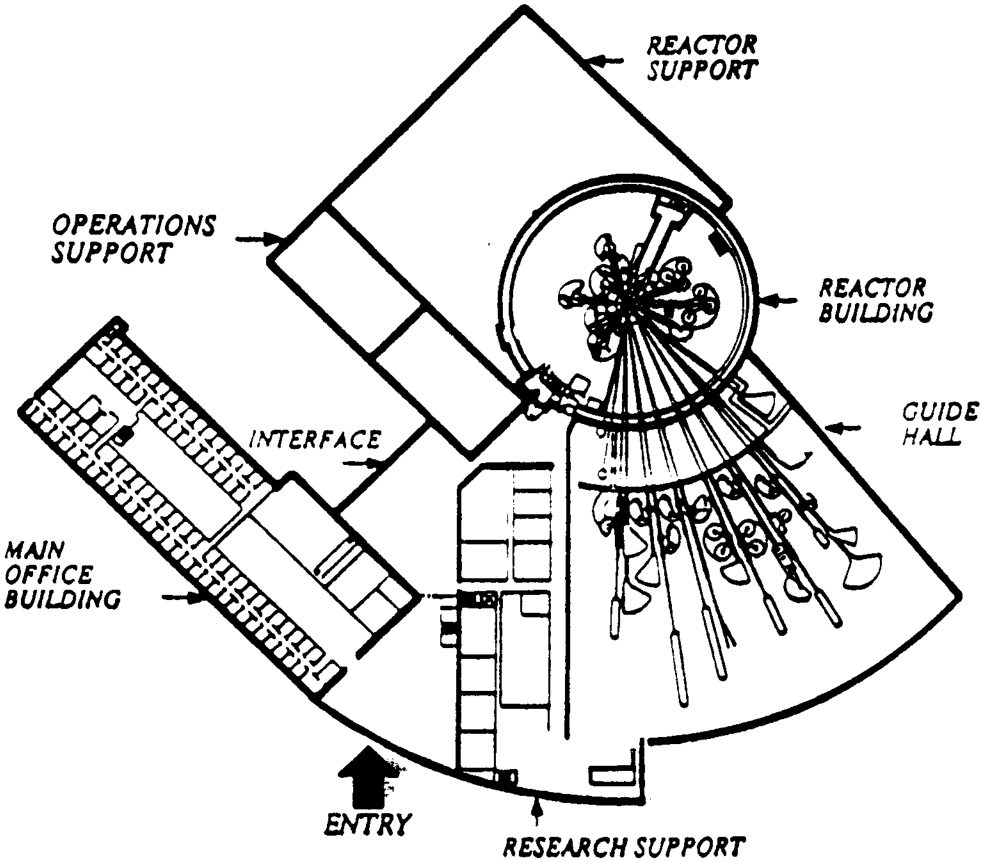


Figure 2.8 Conceptual Plan View of Advanced Neutron Source Reactor Facility[1]

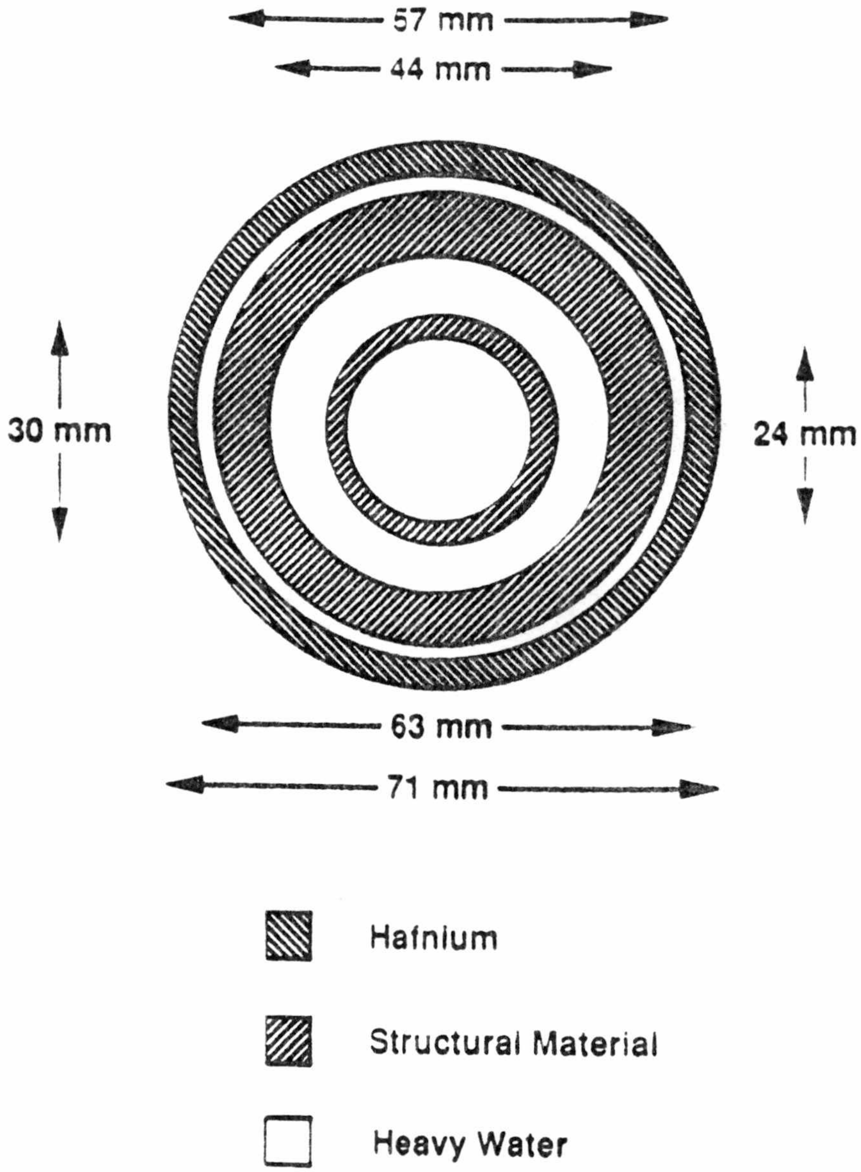


Figure 2.9 Radial Cross Section of Inner Control Rods

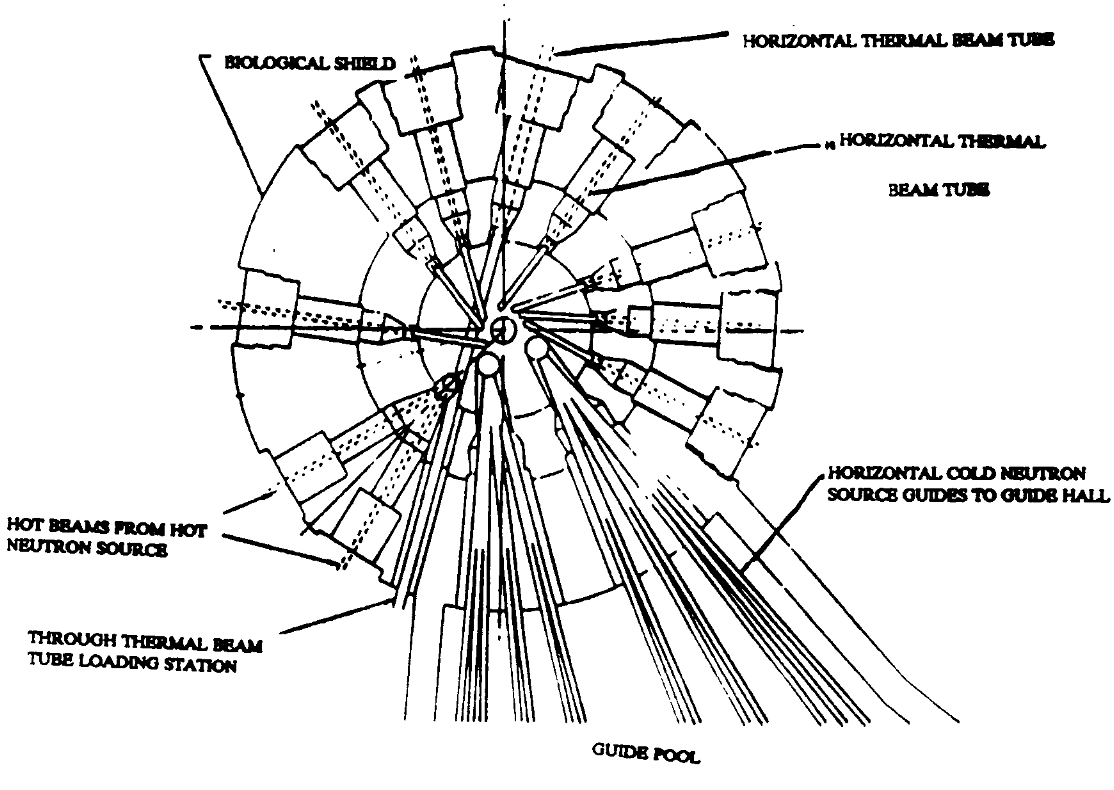


Figure 2.10 Location of Beam Tubes, Cold Neutron Sources, and Hot Neutron Sources in the ANS Reactor[12]

velocity neutrons (1 m/s) in a deuterium medium while the hot source will provide neutrons with a high velocity relative to those from the cold sources. Figure 2.10 depicts the location of the two cold sources and the hot source relative to the location of the eight beam tubes.

2.3 Fueling Structure

The conceptual fueling structure consists of a transfer shaft located above the reflector tank that leads to the interim fuel storage canal where the fuel elements are loaded. Figure 2.11[1] presents a schematic of the fueling structures. The fresh fuel elements are brought through the top of the interim fuel storage canal and into the transfer shaft. The fuel elements are finally lowered down the 1.43-m-diameter transfer shaft and into the reactor core. After the spent fuel elements are removed from the reactor core, they are transferred through the transfer shaft above the reflector vessel and are placed in the interim fuel storage canal until the decay heat is reduced to acceptable levels. After some time, the spent fuel annuli are moved from the storage area into the light water pool for long term storage or removal.

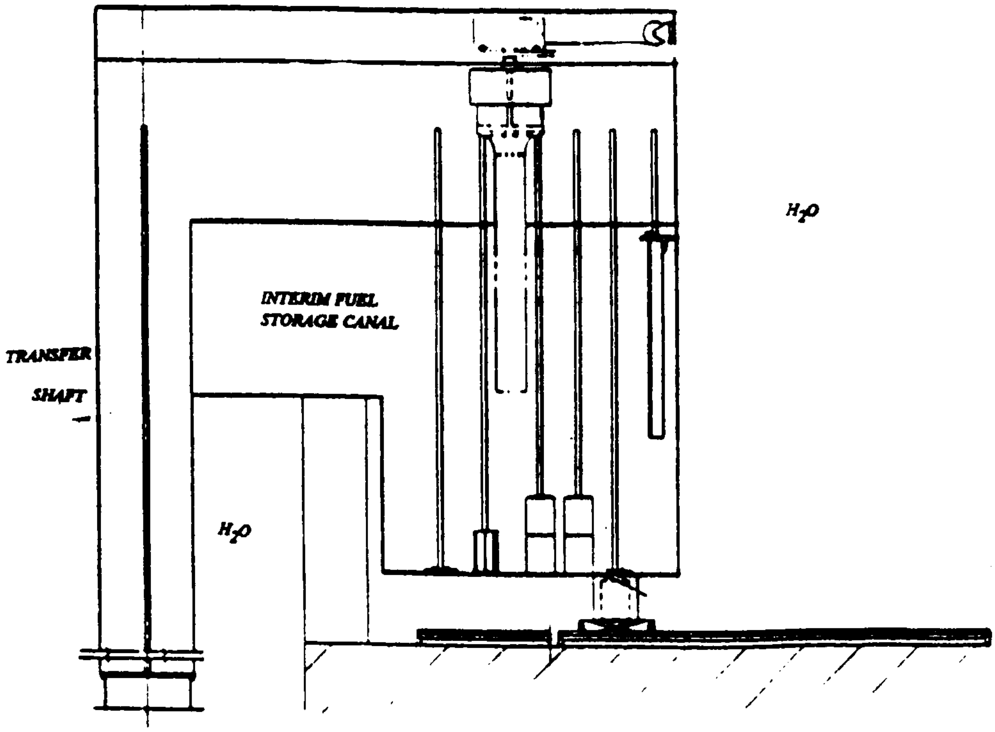


Figure 2.11 Side View of Fueling Structure Located Above Reactor Reflector Vessel[1]

CHAPTER 3

^{252}Cf-SOURCE-DRIVEN NOISE ANALYSIS (CSDNA) METHOD

3.0 Background

The CSDNA method is a measurement technique that was developed by Mihalczo and Pare[13] to determine the subcriticality of a fissile assembly. The method is preferable over other measurements used to determine the subcriticality of a fissile assembly because the ratio of spectral densities for the ^{252}Cf measurement does not depend on detection efficiency or source intensity and does not require a measurement near delayed criticality. An ionization chamber (detector 1) that contains the ^{252}Cf spontaneous fission source is placed near the fissile assembly and initiates the fission chain multiplication process. Two neutron detectors (detectors 2 and 3) are placed near the fissile assembly to detect the neutrons from the fission chains initiated by the ^{252}Cf source as shown in Fig. 3.1. Typically, the source detector is placed near the geometrical center of the fissile assembly, and the two neutron detectors are placed symmetrically around the system. The auto power spectral densities (APSDs) and the cross power spectral densities (CPSDs) of the detector responses are determined and combined to form a ratio that is proportional to the reactivity of the fissile assembly. In this chapter, some basic noise analysis quantities are defined. The measurement of these quantities and the KENO-NR calculation of the measurement are described. The methods to determine the neutron multiplication factor are also discussed in this chapter. To intuitively understand how the various

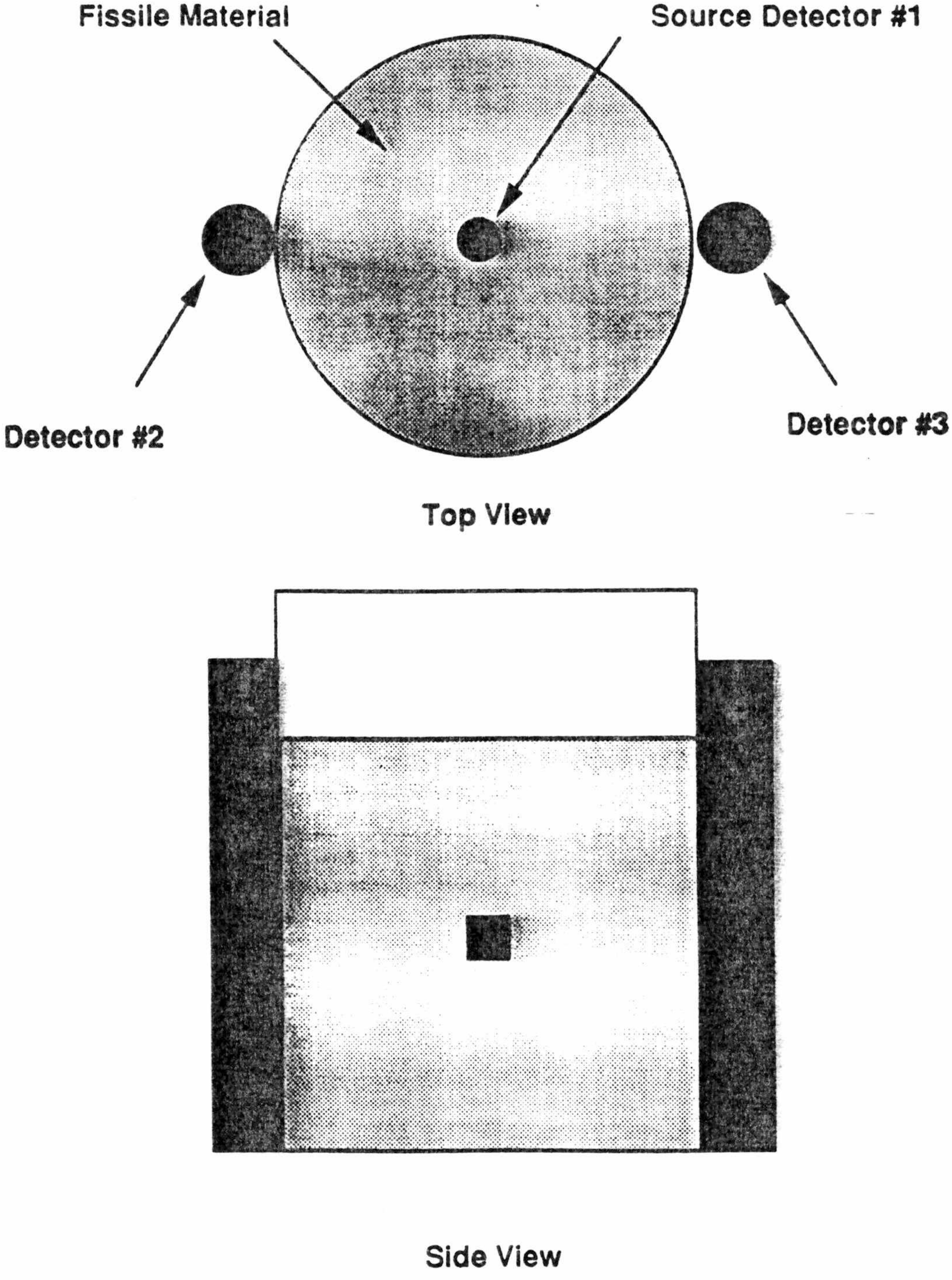


Figure 3.1 Source and Detector Locations for Typical CSDNA Measurement

noise measured quantities are related to the reactor physics parameters of the system, the expressions for APSDs, CPSDs, and the ratio of spectral densities are defined in terms of the modified point kinetics model.[3]

3.1 Noise Related Measured Quantities

The auto power and cross power spectral densities are determined by taking the Fourier transform of the auto and cross correlation functions of the detector responses respectively. The auto correlation function is defined as

$$\varphi_{xx}=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}x(t)x(t+\tau)dt, \tag{3.1}$$

where x(t) can be the detector response. The auto correlation function of a variable is the measure of the similar information contained in the variable at time t and the information contained in the variable at time $t+\tau$. The APSD is defined as

$$G_{xx}(\omega)=\int_{-\infty}^{\infty}\varphi_{xx}(\tau)e^{-j\omega\tau}d\tau. \tag{3.2}$$

The cross correlation function between two signals is defined as

$$\varphi_{xy}(\tau)=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}x(t)y(t+\tau)dt. \tag{3.3}$$

The cross correlation function is a measure of the similar information contained in one signal at time t and the other signal at time $t+\tau$. The CPSD is defined as

$$G_{xy}(\omega)=\int_{-\infty}^{\infty}\varphi_{xy}(\tau)e^{-j\omega\tau}d\tau. \tag{3.4}$$

The coherence between two signals is the measure of the degree to which signal depends on the other signal and is the fraction of information that is common to both signals. The coherences between the detector responses are defined as

$$\gamma_{12}^2(\omega)=\frac{|G_{12}(\omega)|^2}{G_{11}(\omega)G_{22}(\omega)}, \tag{3.5}$$

$$\gamma_{13}^2(\omega)=\frac{|G_{13}(\omega)|^2}{G_{11}(\omega)G_{33}(\omega)}, \tag{3.6}$$

$$\gamma_{23}^2(\omega)=\frac{|G_{23}(\omega)|^2}{G_{22}(\omega)G_{33}(\omega)}. \tag{3.7}$$

The following ratio of coherences, which is equivalent to the magnitude of the ratio of spectral densities, can be used to determine the reactivity of a fissile assembly

$$R(\omega)=\sqrt{\frac{\gamma_{12}^2(\omega)\gamma_{13}^2(\omega)}{\gamma_{23}^2(\omega)}}. \tag{3.8}$$

Expressing the ratio in the form of coherences, the variance of the ratio can be determined by using the variances of the coherences. Since the coherences are real variables, the estimation of the variance in the ratio is easier than using the variances of the ratio of spectral densities since some of the CPSDs are complex. The true coherence between two signals is

$$\gamma^2 = \frac{S/N}{1+S/N}, \tag{3.9}$$

where S/N is the signal to noise ratio. King[14] has shown that the measured coherence satisfies the relation

$$\hat{\gamma}^2 = \gamma^2 + \frac{(1-\gamma^2)^2}{n}, \tag{3.10}$$

where n is the number of data blocks and γ^2 is the true coherence for all cases except for n=1 and γ^2 is neither 0 or 1. The measured standard deviation was shown by King[14] to be

$$\sigma_{\hat{\gamma}^2} = \frac{\hat{\gamma}^2(1-\gamma^2)}{\sqrt{(1+n\gamma^2/2)}}. \tag{3.11}$$

The bias, $\hat{\gamma}^2 - \gamma^2$, diminishes as 1/n; therefore, the coherences can be used to estimate the amount of data needed for the measured coherence to converge to the true coherence. The bias is known precisely and can be removed from the data. For the purpose of error analysis, King[14] has shown that treating the coherences as independent quantities is valid. The relative error of the ratio is expressed as

$$\epsilon_R = \frac{\sigma_R^2}{R} = \frac{[\epsilon^2_{\hat{\gamma}^2_{12}} + \epsilon^2_{\hat{\gamma}^2_{13}} + \epsilon^2_{\hat{\gamma}^2_{23}}]^{1/2}}{2}, \tag{3.12}$$

where

$$\epsilon_{\gamma^2} \approx \frac{\sigma_{\gamma^2}}{\gamma^2} = \frac{(1-\gamma^2)}{\sqrt{1+n\gamma^2/2}}. \tag{3.13}$$

3.2 ^{252}Cf-Source-Driven Noise Analysis Measurement

The CSDNA measurement employs three detectors. One detector contains the ^{252}Cf source that initiates the fission chains in the fissile assembly. This detector emits a pulse each time a spontaneous fission of ^{252}Cf occurs but is not very sensitive to neutrons from the assembly. The other two detectors are used to detect neutrons from fission in the assembly. To eliminate noise and small pulses from background radiation, the detector signals are sent through discriminators. The signal pulses from the discriminator are input into a circuit that converts them into voltage pulses that have a constant area and a frequency spectrum defined by an adjustable RC time constant. The signals are then passed through a low pass filter, which eliminates the upper frequency components that are greater than half the sampling rate. This prevents aliasing from occurring during the discrete Fourier processing of the signal.[4] The filtered signal is digitized repeatedly by an analog-to-digital converter to provide an integer value proportional to the voltage of the signal. The digitized data are divided into segments, called data blocks, of typically 512 or 1024 points, and the computer does a discrete Fourier transform operation on each block. By using the Fourier transformed data for the three detectors, the APSDs and CPSDs are calculated for each data block by complex multiplication of the transformed data. The block data are then averaged with previous data to obtain the average APSDs and CPSDs. The average APSDs and CPSDs are used to calculate the coherences and the ratio of spectral densities.

3.3 KENO-NR[4] Simulation of the CSDNA Measurement

KENO-NR is an analog Monte Carlo code that calculates the CSDNA method. Given the source location, the neutron detector locations, and the description of the fissile assembly, KENO-NR calculates the CSDNA method by initiating fissions in the source detector and tracking the progeny produced from the induced fissions. The neutrons are tracked until the multiplication process has stopped and the detector responses are tallied. The source detector and the positions of the neutron detectors are specified in the input file used by KENO-NR. Figure 3.2[4] is the program flow chart for KENO-NR. The code processes the information obtained in the input data file. After processing the geometry and mixture information, an outer loop is started in which the number of source fissions is determined for each generation. The source neutrons and their progeny are then tracked. Figure 3.3[4] is the flow chart for generating fission neutron information. The code records the time of the fissions started by the ^{252}Cf spontaneous fission source and the number of neutrons emitted by the fission event. The code then tracks the fission chains initiated by the ^{252}Cf source. Figure 3.4[4] is a diagram of the tracking procedure used in KENO-NR. If a neutron enters the detection media that comprise one of the neutron detectors and has an interaction, the event may be a detection if the interaction corresponds to the type of detector present (e.g., capture event for a capture detector). Depending on the type of neutron detector, the neutron can be removed or allowed to have more interactions. The time when a neutron is detected

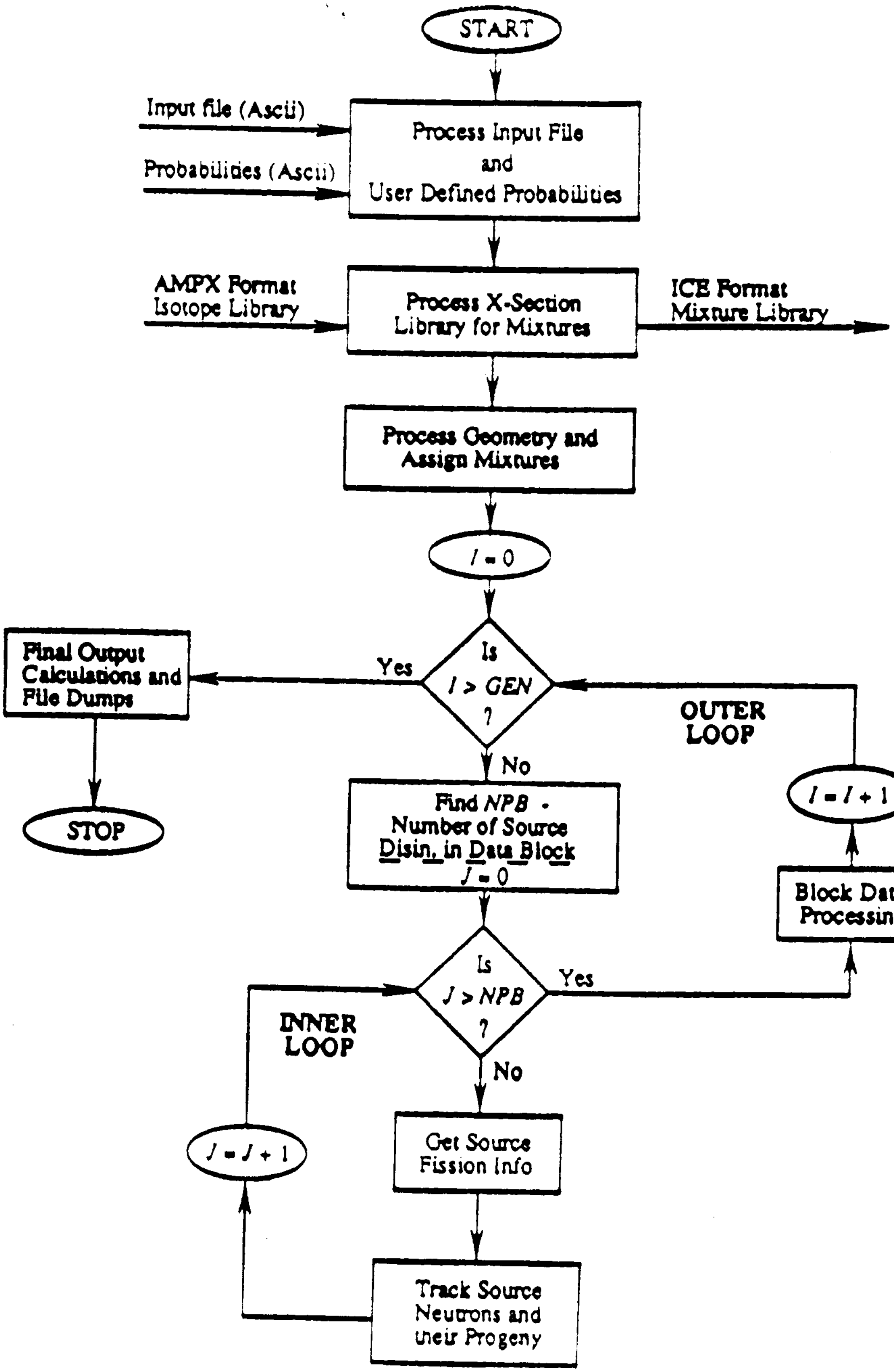


Figure 3.2 KENO-NR Flow Chart[4]

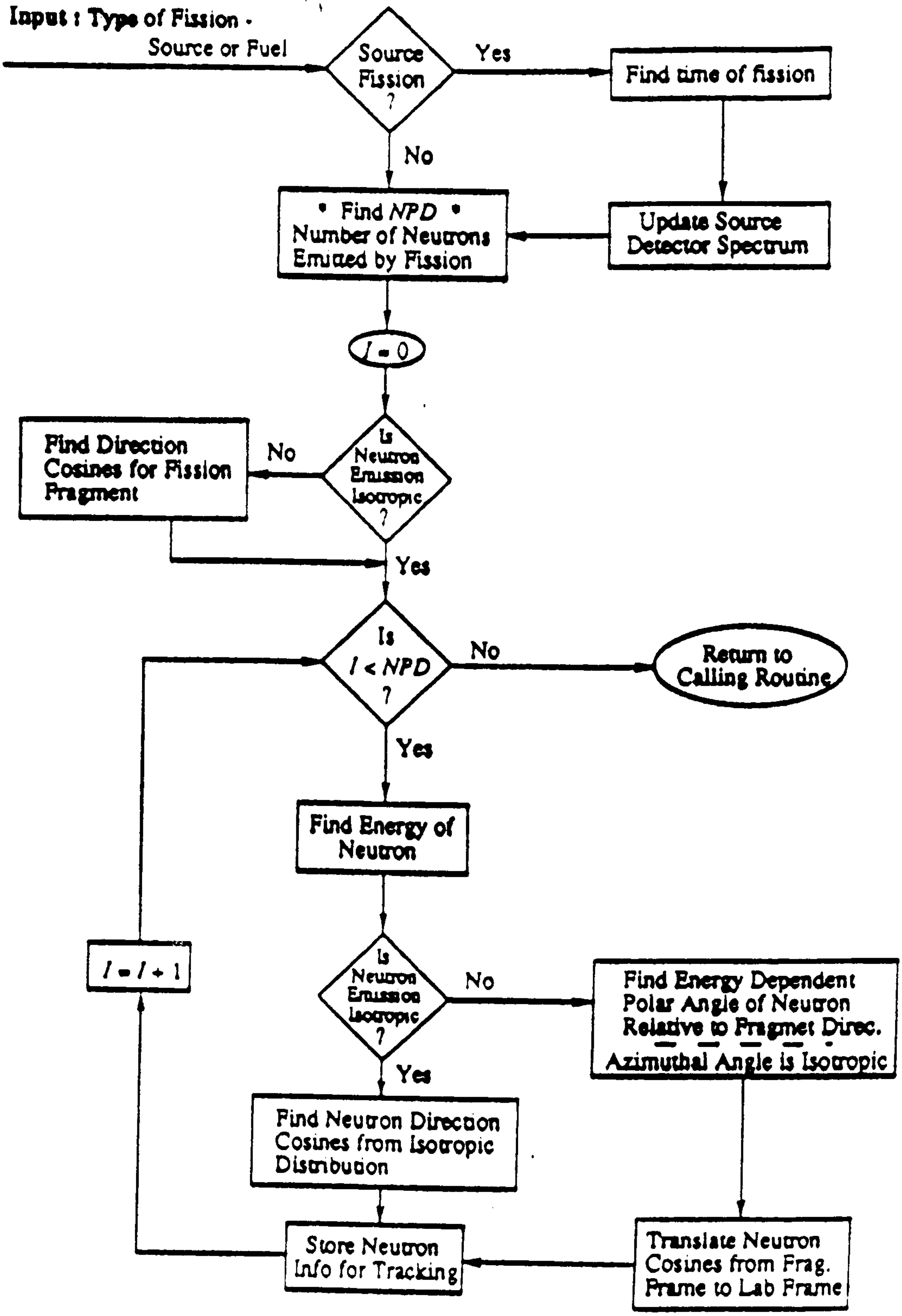


Figure 3.3 Flow Chart for Generating Fission Neutron Information[4]

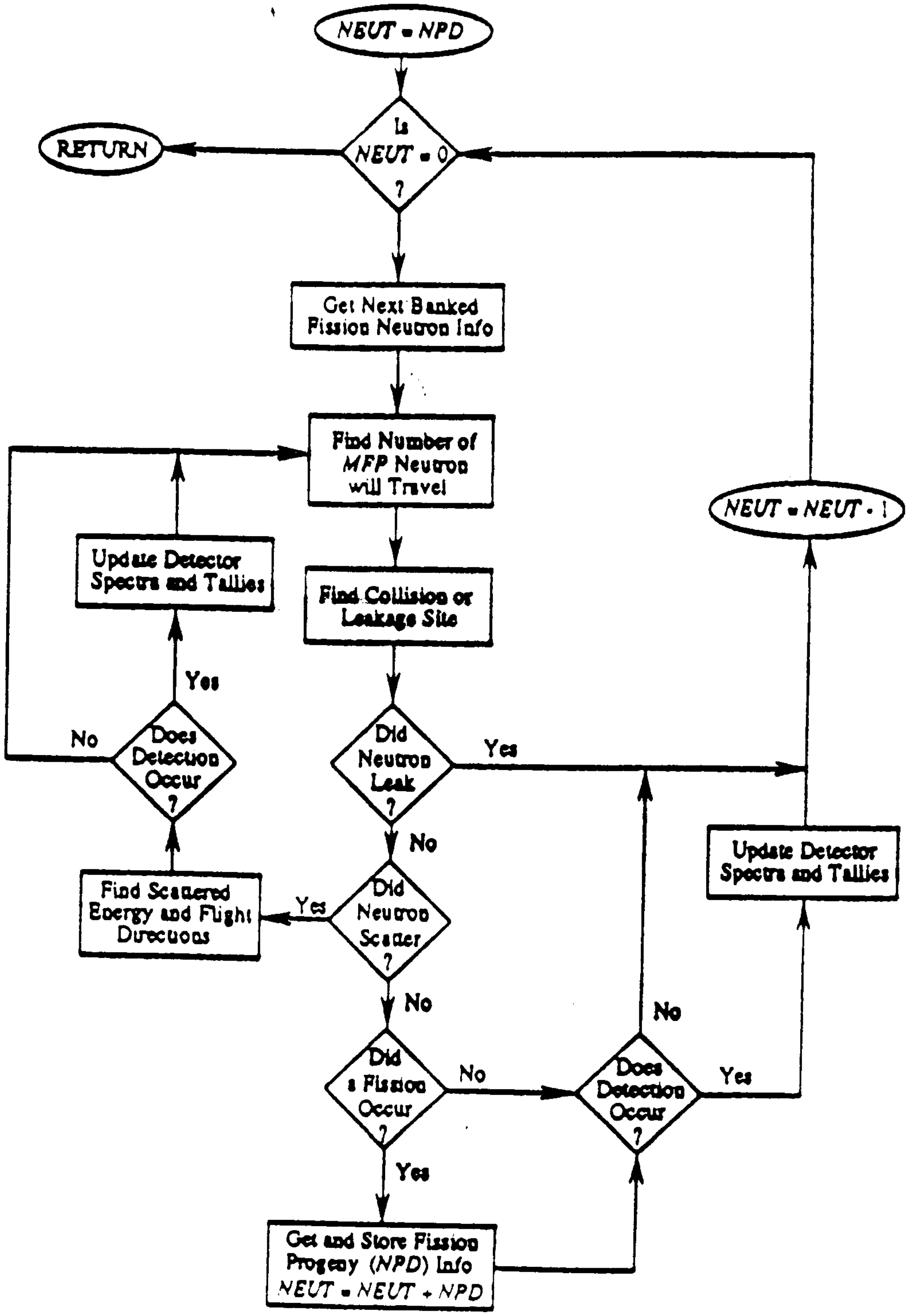


Figure 3.4 Flow Chart for Neutron Tracking[4]

is determined by adding its birth time from the ^{252}Cf fission that initiated the fission chain to the time it spent in the system before detection. The time series of pulses at each detector are obtained for each fission chain. The time series of detector pulses are superimposed with a source fission rate to produce the complete sequence of pulses at each detector. The detector responses are then discretely sampled for a given number of points with a given frequency. The sampling rate determines the width of each time bin in the data block. The number of data blocks and the sampling rate are specified in the KENO-NR input file. Data blocks are segments of data that are typically 512 or 1024 points. By recording the detection events and the times of the detection events, the power spectrum of the detector responses can be determined. The APSDs and the CPSDs are determined for the various detectors and are used in evaluating the ratio of spectral densities for the fissile assembly. Figure 3.5[4] is the flow diagram for computing the ratio of spectral densities. The bin averaged mean is subtracted from the detector signals. These data may then be passed through a spectral window to correct for errors due to the finite length of the sampled data. The discrete Fourier transform of the digitized data from the detectors is then computed. The various APSDs and CPSDs can then be determined.[4]

KENO-NR calculates the spectral data for the ^{252}Cf measurement. KENO-NR does not incorporate delayed neutrons. The delayed neutrons only affect the low frequency, less than 1 Hz, of the spectral data; therefore, they do not affect the interpretation of the spectral data above 1 Hz. The effective neutron multiplication

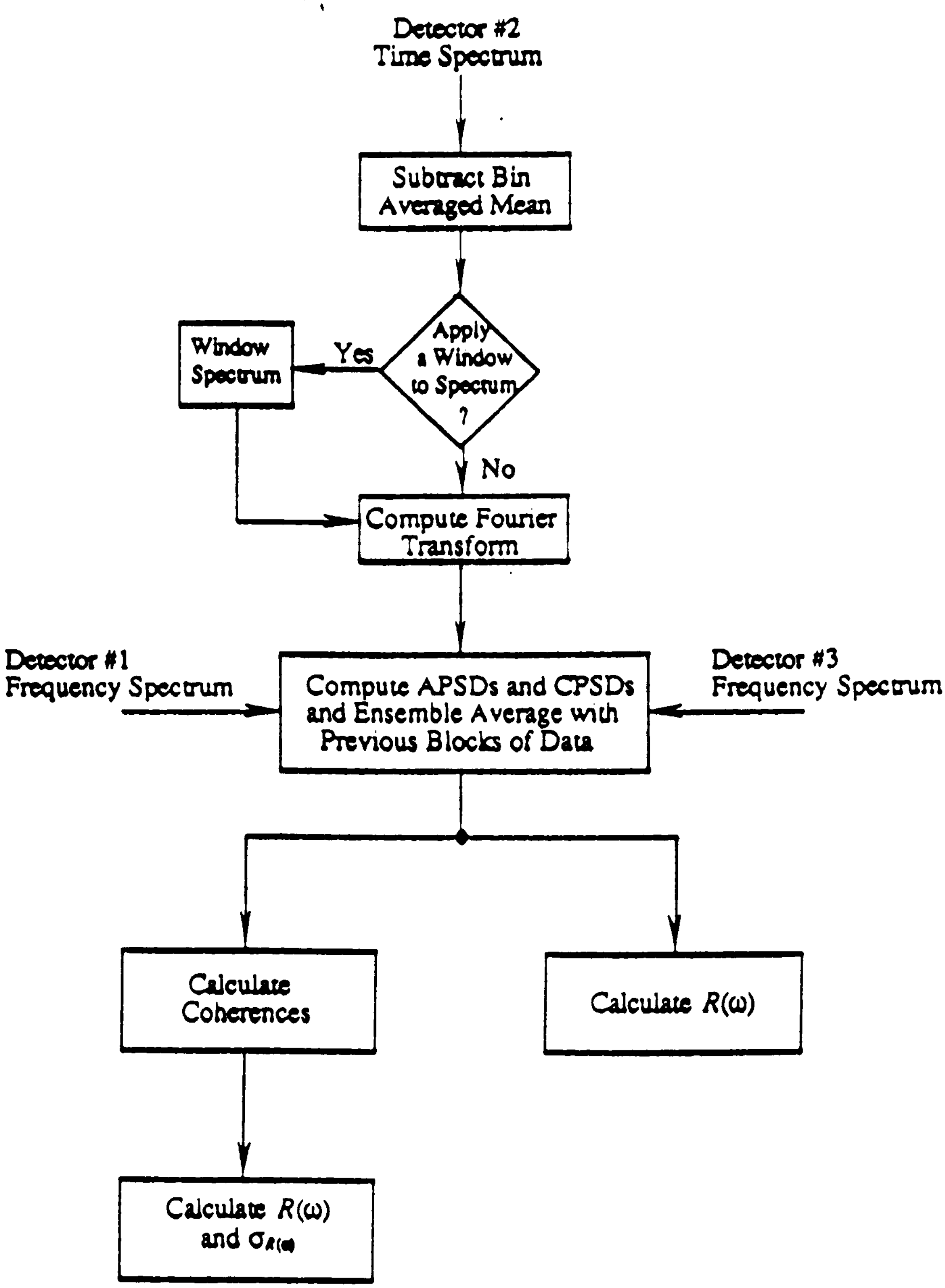


Figure 3.5 Flow Chart for Computing the Ratio of Spectral Densities[4]

factor can be determined from the spectral data by using a point kinetics model for the transfer function of the fissile system. The spectral data obtained from the code can be compared directly to the spectral data obtained from measurements performed using the CSDNA method. If the power spectral densities and the coherences obtained from the KENO-NR calculations agree with those obtained from the CSDNA measurements, the KENO-NR model and the cross section data used for the calculations are representative of the actual system. This validates KENO-NR and the cross sections used in the calculations by direct calculation of measured data. Therefore, the model and cross section data set can be used to calculate k using KENO-AK. This is the most general approach in obtaining the multiplication factor for a system because the point kinetics interpretation of the spectral data no longer needs to be applied and can be replaced by the more general Monte Carlo method.

KENO-AK uses the analog tracking subroutines of KENO-NR to perform a distributed fission source k calculation. KENO-AK tracks the individual fission chains until the chains die. The major difference between KENO-AK and KENO-NR is the treatment of the source. The source specified in the KENO-AK input file provides an initial guess for the fission distribution. Neutron information is generated for the source fission sites. The neutrons and their progeny are tracked until the fission chain dies. The induced fissions are the first generation fissions. These fission sites provide the source distribution for the next iteration. This process is repeated for many generations. An average k is calculated using the previous generations until k converges. Figure 3.6[4] is the flow chart for KENO-AK.[4]

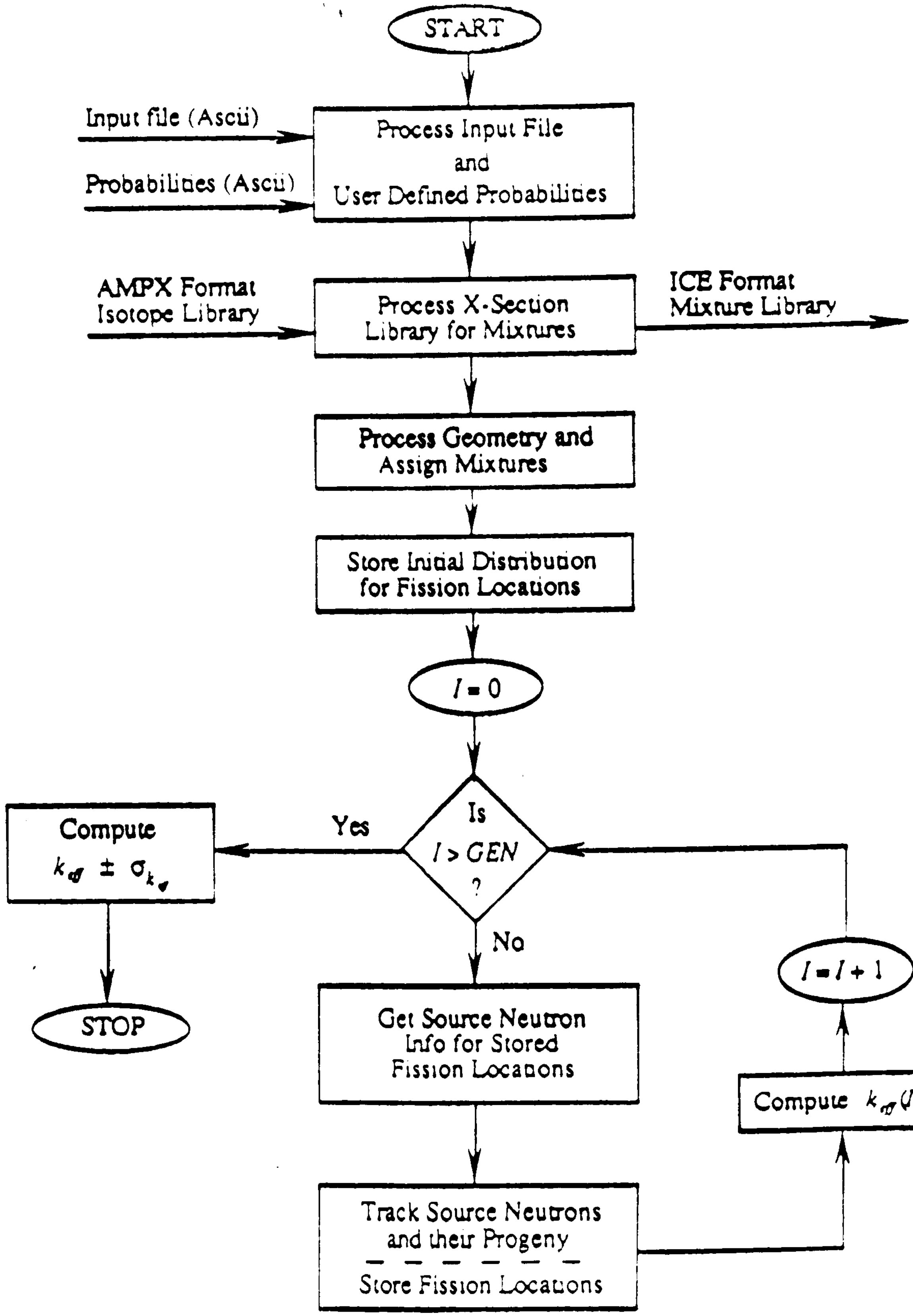


Figure 3.6 KENO-AK Flow Chart[4]

3.4 Point Kinetics Representation of Spectral Data

In cases where point kinetics is applicable, it can be used to obtain the neutron multiplication factor from the measurement of R(ω). The point kinetics model is simple and can aid in understanding the measurement. The APSDs and the CPSDs of the detector responses can be determined by using a block diagram of the process. Figure 3.7[4] is a block diagram that is used to determine the PSDs of detectors. The APSDs are defined as follows:

$$G_{11}(\omega)=2|h_1(\omega)|^2[\frac{31}{2}F_c q_\alpha^2+F_c q_c^2], \tag{3.14}$$

$$G_{22}(\omega)=2|h_2(\omega)|^2[W_2 F q_2^2+\frac{W_2^2\bar{q}_2^2}{\bar{\nu}_p^2}|H_s(\omega)|^2 G_s], \tag{3.15}$$

$$G_{33}(\omega)=2|h_3(\omega)|^2[W_3 F q_3^2+\frac{W_3^2\bar{q}_3^2}{\bar{\nu}_p^2}|H_s(\omega)|^2 G_s], \tag{3.16}$$

where $h_1(\omega)$, $h_2(\omega)$, and $h_3(\omega)$ are the transfer functions of the electronic components of the detection systems; q_c is the average charge released in detector #1 per ^{252}Cf spontaneous fission; q_α is the average charge released in detector #1 per ^{252}Cf α-decay; q_2 and q_3 are the charges released per interaction in detectors #2 and #3; W_2 and W_3 are the detection efficiencies of the detectors #2 and #3 in counts per reactor fission; F_c is the ^{252}Cf spontaneous fission rate; F is the fission rate of the fissile assembly; υ_p is the number of prompt neutrons per induced fission; $H_s(\omega)$ is the

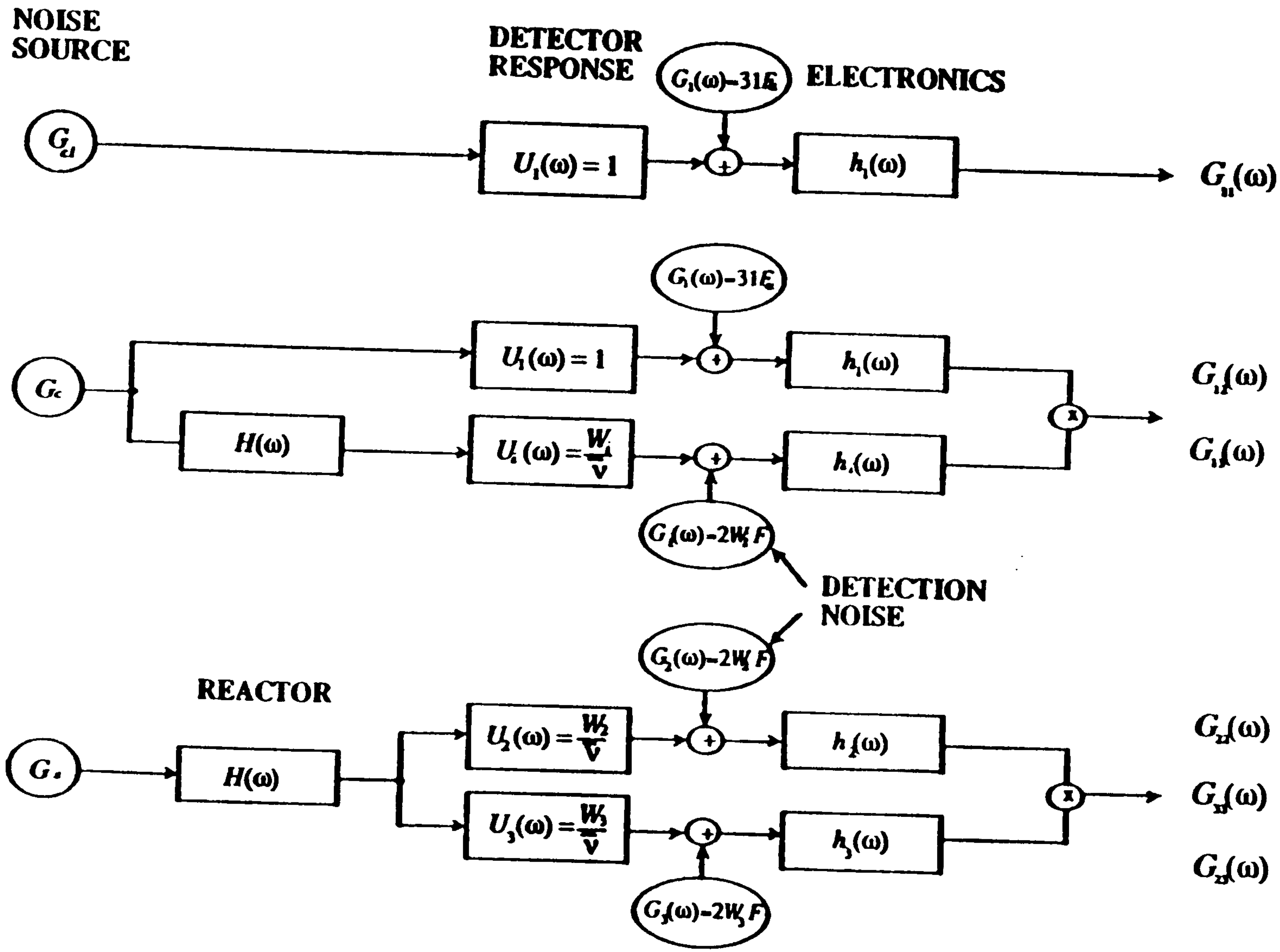


Figure 3.7 Block Diagram for Determining PSDs of CSDNA Method[4]

reactor transfer function; and G_s is the PSD of the reactor noise-equivalent source. The PSD of the reactor noise-equivalent source for scattering detectors is

$$G_s=2v_p^2XFR\ [1+\frac{V}{XR}+\frac{F_cI_c\ v_c^2}{FI\ XR\bar{v}_p^2}], \tag{3.17}$$

$$X=\frac{v_p(v_p-1)}{v_p^2}, \tag{3.18}$$

$$V=\frac{(2\beta-\rho)}{(1-\beta)\bar{v}_p}, \tag{3.19}$$

where χ is the Diven factor, R is a spatial correction factor, I is the average importance of a neutron from the fission of the fissile assembly, I_c is the average importance of a neutron from ^{252}Cf fission, υ_c is the average number of prompt neutrons per ^{252}Cf fission, β is the effective total delayed neutron fraction, and ρ is the reactivity of the fissile assembly. If the absorption in the detector significantly affects the detection, the $(2\beta-\rho)$ term in Eq. (3.19) is replaced by $+\rho$. The detector effects can be important only in systems that have low multiplication factors and where the fission rate of the fissile system is comparable to the fission rate of the spontaneous ^{252}Cf source. The reactor transfer function which relates the source events to the prompt neutron production rate is

$$H_s(\omega)=\frac{1}{j\omega\Lambda+(\beta-\rho)}, \tag{3.20}$$

where Λ is the prompt neutron generation time. The CPSDs for this model are

$$G_{12}(\omega)=2h_1^*(\omega)h_2(\omega)\bar{q}_c\frac{W_2\bar{q}_2}{\bar{\nu}_p}H_s(\omega)\bar{\nu}_c\frac{F_cI_c}{I}, \tag{3.21}$$

$$G_{13}(\omega)=2h_1^*(\omega)h_3(\omega)\bar{q}_c\frac{W_3\bar{q}_3}{\bar{\nu}_p}H_s(\omega)\bar{\nu}_c\frac{F_cI_c}{I}, \tag{3.22}$$

$$G_{23}(\omega)=h_2^*(\omega)h_3(\omega)\frac{W_2\bar{q}_2}{\bar{\nu}_p}\frac{W_3\bar{q}_3}{\bar{\nu}_p}|H_s(\omega)|^2G_s, \tag{3.23}$$

where * denotes complex conjugate. The ratio of spectral densities is defined as

$$R(\omega)=\frac{G_{12}^*(\omega)G_{13}(\omega)}{G_{11}(\omega)G_{23}(\omega)}. \tag{3.24}$$

Reactivity can be defined as the source emission rate divided by the production rate of the fissile assembly. By using this definition, reactivity is

$$-\rho=\frac{F_cI_c\bar{\nu}_c+F_iI_i\bar{\nu}_i}{FI\bar{\nu}}, \tag{3.25}$$

where υ is the average number of neutrons per reactor fission. The ratio of spectral densities for systems that are slightly subcritical can be written as

$$R(\omega)=\frac{\bar{\nu}_c}{\bar{\nu}}\frac{I_c}{I}\frac{1}{RX'}\frac{(1-k)}{k}, \tag{3.26}$$

where X' is X times the term in brackets in Eq. (3.17). When the multiplying system is far subcritical, the ratio of spectral densities is of the form

$$\frac{1-k}{k}=\frac{C_1R(\omega)}{1-C_2R(\omega)}, \tag{3.27}$$

where

$$C_1=\frac{XR\nu I(1-\beta)}{\bar{\nu}_c I_c}+\frac{2\beta I}{\bar{\nu} I_c}, \tag{3.28}$$

$$C_2=\frac{\overline{\nu_c^2}}{\bar{\nu}_c^2}+\frac{I}{\bar{\nu}_c I_c}. \tag{3.29}$$

If the detectors affect the subsequent fission chain population or subsequent detection probability, the expressions for C_1 and C_2 become

$$C_1=\frac{RX\bar{\nu}I}{\bar{\nu}_c I_c}, \tag{3.30}$$

$$C_2=X_cR_c. \tag{3.31}$$

For heavy water reflected systems where kinetic distortion is significant, an additional factor must be introduced which divides the R(ω) in the numerator of Eq. (3.27). This factor corrects for the use of static adjoint fluxes where dynamic adjoint fluxes are more appropriate. Equations (3.26) and (3.27) do not depend on detection efficiency or source strength. However, the ratio of spectral densities does depend on subcritical parameters that must be determined from other measurements or calculated. For pulse mode operation, the alpha pulses are discriminated and the reactivity determination does not depend on the properties of the ^{252}Cf detection system. References 4 and 14 provide details about the derivation of the PSDs and coherence presented above. For certain source-detector locations, the point kinetics representation is not applicable. Although the CSDNA measurement preferentially samples the long fission chains which comprise the fundamental mode of the flux, there are instances where the detector locations tend to sample the higher modes of the flux. This results in inappropriate multiplication factors determined by the point kinetics interpretation since the model is not applicable.[14]

CHAPTER 4

FUELING SEQUENCE

A concept for fueling the ANS reactor is as follows. Each fuel element with its inner and outer isolators is placed into the interim fuel storage canal and then moved to the top of a long, 1.43-m-diameter pipe above the reactor core. This pipe is referred to as the transfer shaft. The fuel annulus/isolator assembly moves down the transfer shaft to the top of the reflector vessel (Fig. 2.11). The lower element is inserted first. Because of mechanical interference with the control rods, the inner isolator of the lower annulus is removed as the fuel element is lowered into the reactor tank around the control rods. When the element has been lowered around the control rods and is in its proper position, the outer isolator is removed through the transfer shaft. The upper fuel annulus/isolator assembly follows the same route except that at the top of the reactor tank, the outer isolator is removed because the diameter of this isolator is larger than that of the core pressure boundary tube. This element with its inner isolator is lowered into its core position around the control rods, and the inner isolator is removed. These operations are performed with the safety rods that are located in the reflector region inserted adjacent to the fuel annuli. For removal of the fuel elements after operation, the procedure is reversed, except that the spent fuel remains in the interim fuel storage canal until the decay heat reduces to a level where the element can be moved to the light water pool.

CHAPTER 5

ISOLATOR ANALYSIS

5.0 Background

To ensure that a criticality event cannot occur with the fuel annulus/isolator assembly in heavy water, the effective neutron multiplication factor (k) of the fuel annulus/isolator assembly is designed to be less than 0.95. Each individual isolator is capable of maintaining k below the subcritical limit of 0.95. Structural materials are used as the isolating materials to avoid the need to verify the presence of a neutron poison in the isolator. Figure 5.1 is a diagram of the fuel annulus/isolator assembly. The isolators are spaced 6.4 mm from the fuel annuli. The top plate of the outer isolator does not completely cover the fuel annulus. There are vacant regions in the top of the outer isolator over the fuel annulus so that the heavy water flow and heat removal is not restricted by the outer isolator.

The determination of the effective neutron multiplication factors for the various fuel/isolator configurations in an infinite amount of heavy water is performed by using KENO Va.[11] KENO Va has been used to calculate the criticality of highly enriched uranium systems reflected by heavy water.[12] Multi-region models of the ANS fuel elements are derived from VENTURE[15] models of the fuel elements.[16] The VENTURE model is a volume weighted model that averages the fuel and moderator in each zone to obtain a set of material number densities that are representative of the involute fuel plates that comprise the ANS fuel element. The

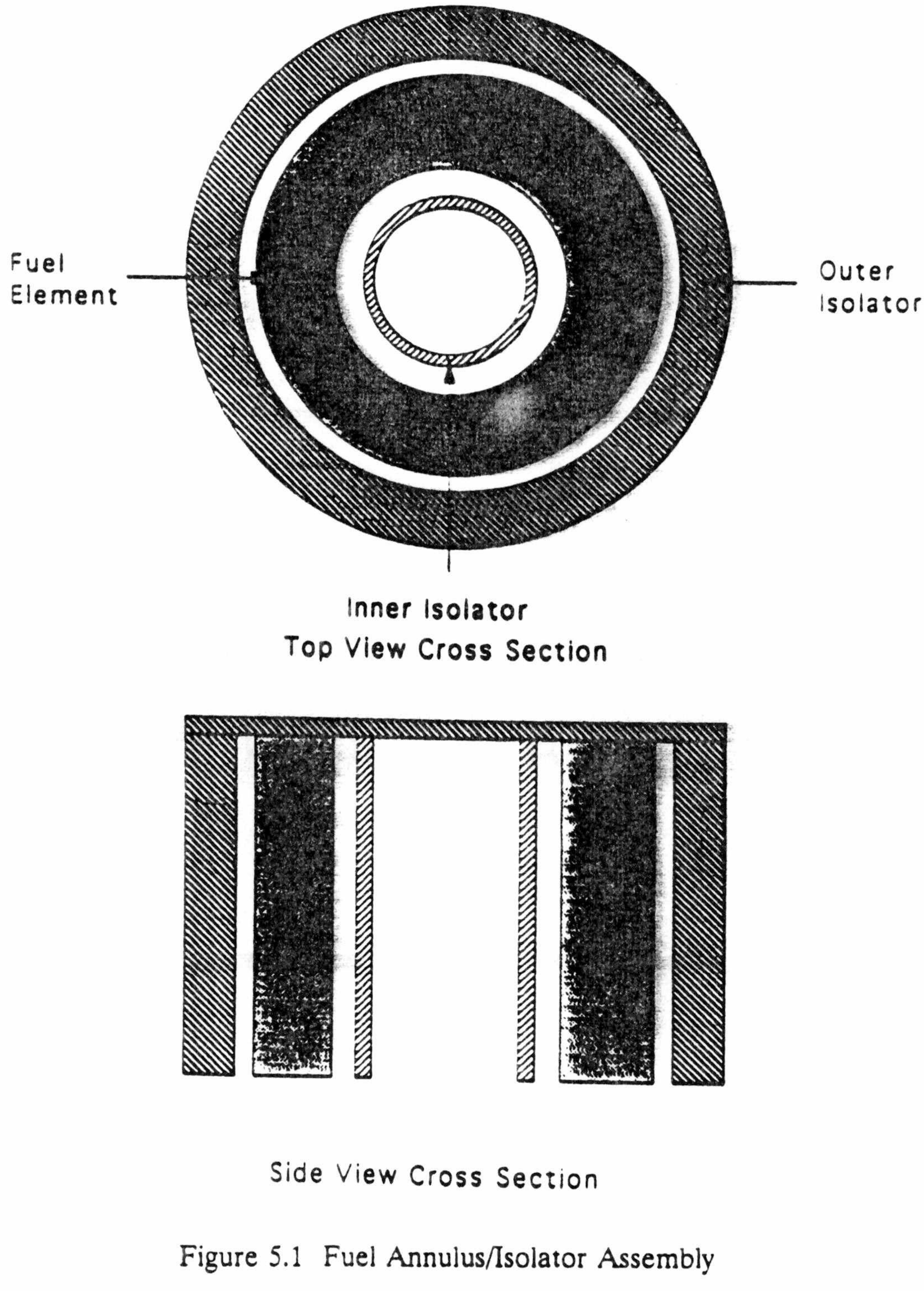


Figure 5.1 Fuel Annulus/Isolator Assembly

models of the fuel elements have 25 axial zones and 13 radial zones as shown in Fig. 2.4. Appendix A contains the KENO Va input files that describe the details about the zone sizes for the upper and lower fuel elements. A 26-group, neutron cross section library, which is a broad-group, general purpose cross section library, is used in the KENO Va model.[17] The 26-group library was developed from a ENDF/B-V cross section data set that consists of 99 fine groups. The KENO Va calculations were performed on Unix workstations (SUN SparcStation) in approximately 10 hours for each case analyzed.

5.1 Multiplication Factors for Fuel Elements with Isolators

To determine the proper isolating material for the inside of the fuel element and the proper isolator for the outside of the fuel element, the calculations are performed with the fuel annulus in the center of a heavy water reflector. The reflector is modeled as a 6-m-high and 4.0-m-wide and-thick region of heavy water to obtain a conservative estimate of the neutron multiplication factors of the fuel annulus/isolator assembly. The neutron multiplication factors for the fuel annuli change less than 1% when more heavy water is added radially or axially. The inner isolator that is used in the calculations is stainless steel 304. The outer isolator is aluminum. The outer isolator is 127-mm-thick aluminum, and the inner isolator is 25.4-mm-thick stainless steel for the upper fuel element. With either isolator present, the k value is below 0.95. With both isolators present, the neutron multiplication factor for the upper fuel element is 0.653 ± 0.002. Table 5.1 contains the results of the analysis of the isolators for the upper fuel element. These k values are conservative because the amount of heavy water moderator and reflector used in the calculations is greater than the amount of heavy water present in the fueling structures.

Table 5.1 Multiplication Factors for the Upper Fuel Element with Isolation Materials in D_2O Reflector		
Inner Isolator	Isolator	k
25.4-mm SS	none	0.933 ± 0.003
none	127-mm Al	0.945 ± 0.002
25.4-mm SS	127-mm Al	0.653 ± 0.002

Table 5.2 provides the results of the analysis of the absorbers for the lower fuel element. The outer isolator is 57.2-mm-thick aluminum, and the inner isolator is 25.4-mm-thick stainless steel 304 for the lower fuel element. With both isolators present, the neutron multiplication factor for the lower fuel element is 0.769 ± 0.002. These k values are also conservative since the amount of heavy water moderator and reflector used in the calculations is greater than the amount of heavy water present in the fueling structures.

Table 5.2 Multiplication Factors for the Lower Fuel Element with Isolation Materials in D_2O Reflector		
Inner Isolator	Outer Isolator	k
25.4-mm SS	none	0.936 ± 0.004
none	57.2-mm Al	0.948 ± 0.002
25.4-mm SS	57.2-mm Al	0.769 ± 0.002

These Monte Carlo calculations have shown that the use of appropriate structural materials to maintain subcriticality of the upper and lower fuel annuli reflected by heavy water will be adequate for fueling the ANS reactor. Thus, with both isolators present and supported independently so that two mutually exclusive isolator losses must occur, the probability of a criticality event is very acceptable.

5.2 Multiplication Factors for Fuel Annulus/Isolator Assemblies with Detectors

The presence of the neutron absorbing ^3He detectors for monitoring the subcriticality also have an effect on k; therefore, the criticality calculations need to be reevaluated to account for the effects of the detectors on the criticality of the fuel annulus/isolator assembly. Figure 5.2 is a diagram of the detectors' positions in the isolators. The detectors have a 51-mm diameter and are the length of the fuel annuli. There are two important positions in the fueling process where k should be measured. The first is the interim fuel storage canal where the fuel annuli are surrounded by a 5-m-high, 3-m-thick region of heavy water. The second is in the center of the transfer shaft. As shown in Fig. 2.11, the transfer shaft is surrounded by light water;

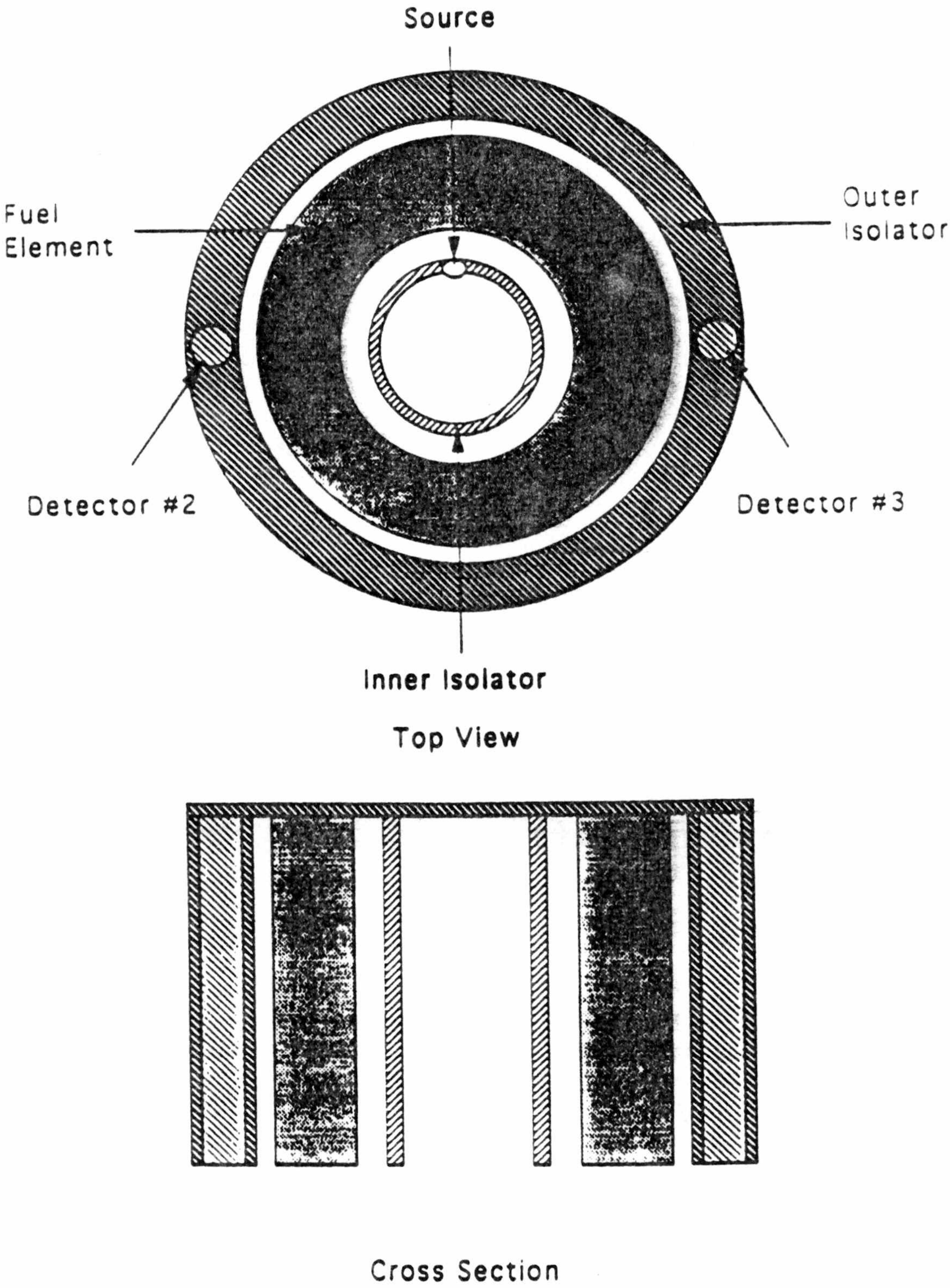


Figure 5.2 Source and Detector Locations in Fuel Annulus/Isolator Assembly

therefore, k is evaluated in this position to determine the criticality of the fuel annulus/isolator in the center of the transfer shaft. The transfer shaft is modeled as a 5-m-high, 1.43-m-diameter tank of heavy water with a 0.15-m-thick region of light water surrounding the heavy water. Tables 5.3 and 5.4 present the results of criticality evaluations of the fuel annulus/isolator assemblies with detectors in the interim fuel storage canal and in the transfer shaft respectively. The upper fuel annulus/isolator assembly has k values of 0.619 ± 0.001 and 0.583 ± 0.001 in the interim fuel storage canal and in the transfer shaft respectively. The lower fuel annulus/isolator assembly has k values of 0.723 ± 0.002 and 0.675 ± 0.002 in the interim fuel storage canal and in the transfer shaft respectively. The addition of the detectors reduce k about 5% for each fuel annulus/isolator assembly.

Table 5.3 Multiplication Factors of the Fuel Annuli with Isolation Materials and Detectors in the Interim Fuel Storage Canal

Fuel Annuli	k
Upper	0.619 ± 0.001
Lower	0.723 ± 0.002

Table 5.4 Multiplication Factors of the Fuel Annuli with Isolation Materials and Detectors in the Transfer Shaft

Fuel Annuli	k
Upper	0.583 ± 0.001
Lower	0.675 ± 0.002

CHAPTER 6

^{252}Cf-SOURCE DRIVEN NOISE ANALYSIS RESULTS

6.0 Background

The purpose of this chapter is to determine the ability of the CSDNA method in monitoring the subcriticality of the ANS fuel annuli. This method can be used to monitor changes in k for each fuel annulus with both isolators with the fuel annulus/isolator assembly in the center of the transfer shaft and in the center of the interim fuel storage canal in the critical experiments program and, if appropriate, in the initial loading of the ANS reactor. The Monte Carlo code KENO-NR that calculates the CSDNA spectral data is used in the study. The calculated APSDs, CPSDs, and ratio of spectral densities can be compared directly to the spectral data from future CSDNA measurements of the ANS fuel annuli in the critical experiments program. The use of KENO-NR for performing the CSDNA simulation of the ANS fuel annuli is justified since the code is a variation of KENO Va which is used for highly enriched uranium systems that are reflected by heavy water.[12] The tracking routines and the cross section processing of KENO-NR are those of KENO Va.

The quantities of interest from the CSDNA measurement are the APSDs, CPSDs, coherences, and the ratio of spectral densities. The magnitude of the APSD of the source detector is related to the fission rate of the ^{252}Cf spontaneous fission source. The magnitudes of the APSDs of the neutron detectors 2 and 3 are related to the count rates of the detectors. The CPSDs are useful because they establish the relationship between two simultaneous measured signals. The CPSD can provide insight into the relationship between the input and output of a system or the degree to which two outputs of a system depend on one another. The CPSDs can be used to estimate the transfer function between the input and output of a system. The coherence functions are used to estimate the causality between two signals. The low frequency coherence between source and either of the neutron detectors is inversely proportional to the square of the reactivity and can be used to estimate the amount of data needed for the calculation to converge. The lower frequency coherence between the two neutron detectors is inversely proportional to the reactivity to the fourth power at low values of k and is also used to determine the amount of data needed for the simulation to converge.[18]

The CSDNA calculations for the fuel elements are performed with the fuel assembly located in the center of the interim fuel storage canal and in the center of the transfer shaft. As mentioned in Chap. 5, the interim fuel storage canal is modeled as a 5-m-high, 3-m-thick heavy water pool. The transfer shaft is modeled as a 5-m-high, 1.43-m-diameter tank of heavy water with a 0.15-m-thick region of light water surrounding the heavy water. Figure 5.2 provides an illustration of the fuel annulus/isolator assembly that is used in the KENO-NR calculations. Detector #1 is the fission chamber containing the ^{252}Cf spontaneous fission source. Detectors #2 and #3 are ^{3}He proportional detectors used to detect neutrons that escape from the fuel element. The ^{3}He detectors are 530 mm long and have a 50-mm diameter. There are two types of detectors used in the CSDNA calculations, capture and black detectors. The capture detector and the response of the capture detector represents the actual ^{3}He detector. The black detectors, which have the same physical dimensions of the capture detectors, are used to decrease the computational time needed to perform the CSDNA calculations. Black detectors score any neutron that enters the detection media as a count and then the neutron is killed. The black detectors have higher efficiencies than the capture detectors; therefore, the calculation times for the black detectors will be orders of magnitude less than the calculation time for the capture detectors. For some subcritical systems, the black detectors affect the multiplication of the system. Thus, the APSDs, CPSDs, coherences, and the ratio of spectral densities must be scaled appropriately to represent the actual ^{3}He detector responses. This can be accomplished by normalizing the APSDs, CPSDs, coherences, and the ratio of spectral densities to the values obtained by using the capture detectors. The KENO-NR calculations were performed in 1000 hours for the fuel annulus/isolator assembly with capture detectors and in 50 hours for the fuel annulus/isolator assembly with black detectors to achieve less than 1% bias difference between the measured coherence and the true coherence. The bias can be subtracted from the coherences since it is precisely known.

6.1 Upper Fuel Element CSDNA Analysis

Since the upper fuel annulus/isolator assembly is the most subcritical assembly, the CSDNA calculations were performed using the capture and black detectors. The black detectors will have higher break frequencies than the capture detectors because the neutron absorption of the black detectors is higher than those of the capture detectors. Since the detector configuration is symmetric, the APSDs, CPSDs, coherences, and ratio of spectral densities between the source and the neutron detectors are presented only for the detector combination 12 and are equivalent to those for detector combination 13. The auto power spectral densities as a function of frequency for the assembly with capture detectors in the transfer shaft and in the interim fuel storage canal are shown in Figs. 6.1 and 6.2, respectively. The low frequency values of the auto power spectral densities for the fuel annulus/isolator assembly in the transfer shaft and in the interim fuel storage canal are presented in Tables 6.1 and 6.2. The low frequency value of the APSD of the source detector is equivalent to the ^{252}Cf fissions per data block. The APSD of the source detector is flat because the randomness of the ^{252}Cf fissions can be represented as white noise. The low frequency values of the APSDs of the neutron detectors are in units of detector counts per data block. The APSD of the neutron detector is not flat for all frequencies. This results because the transfer function of the fissile system is approximately a first order lag as shown in Eq. (3.20). The flat portion of the APSD and the roll off represents the neutron fluctuations within the system while the higher frequency constant component is associated with detection noise. For low efficiency detectors, the detection noise component increases. This causes difficulties in estimating the break frequency of the APSD.[19]

The CPSD between the source detector and the neutron detector is a complex quantity while the CPSD between the neutron detectors is a real quantity using the modified point kinetics representations of the CPSDs if the detectors are located symmetrically. Figures 6.3 and 6.4 are the real and imaginary components of the

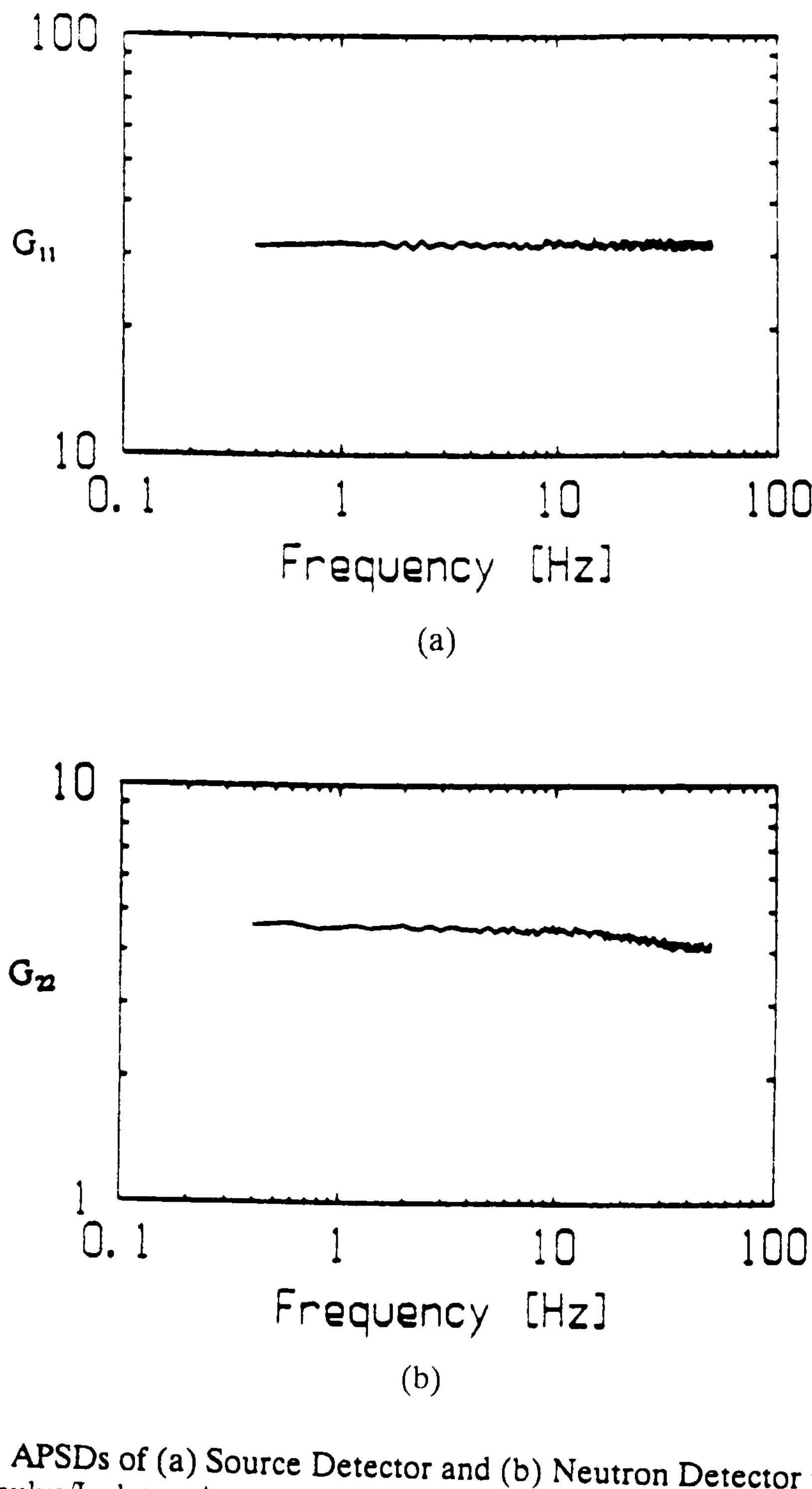
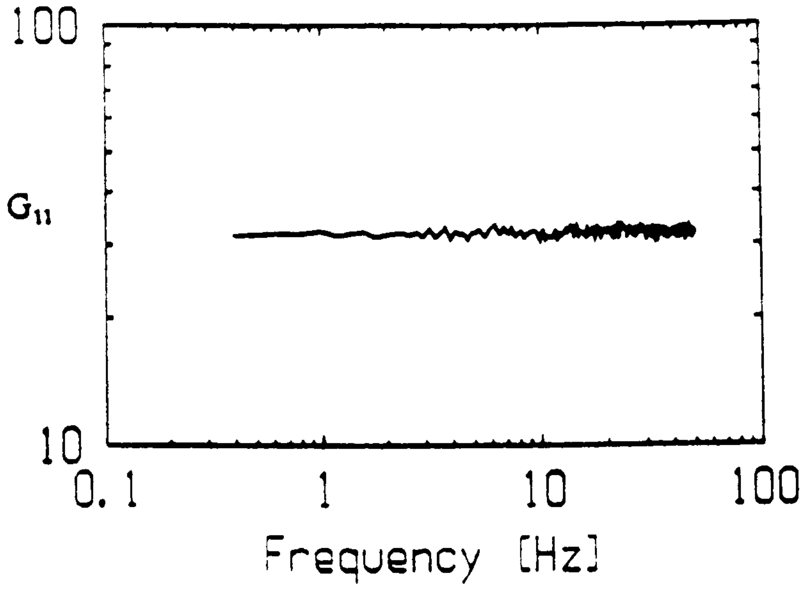
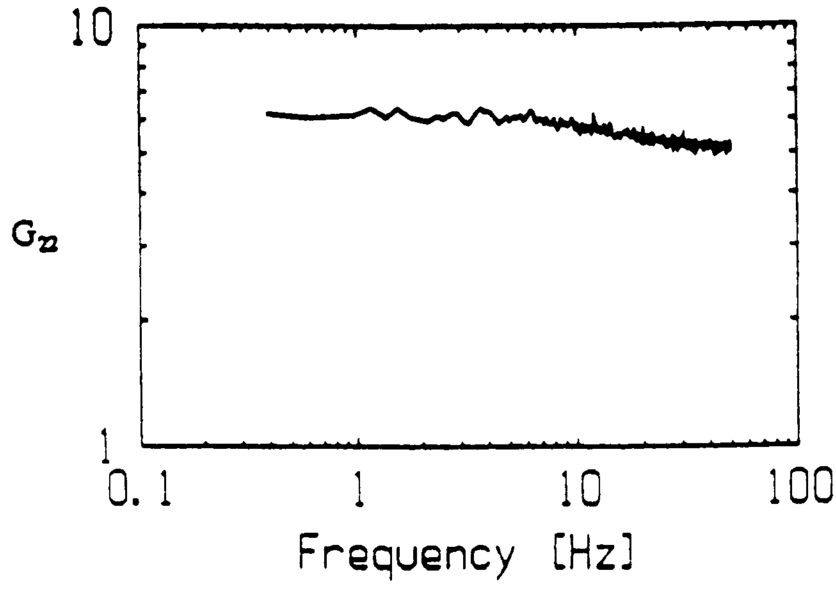


Figure 6.1 APSDs of (a) Source Detector and (b) Neutron Detector for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Transfer Shaft.



(a)



(b)

Figure 6.2 APSDs of (a) Source Detector and (b) Neutron Detector for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Interim Fuel Storage Canal.

Table 6.1 Low Frequency APSDs for the Upper Fuel Annulus/Isolator Assembly in the Transfer Shaft		
Detector Type	G_{11} Counts/Block	G_{22} Counts/Block
Capture	32	5
Black	32	21

Table 6.2 Low Frequency APSDs for the Upper Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal		
Detector Type	G_{11} Counts/Block	G_{22} Counts/Block
Capture	32	6
Black	32	25

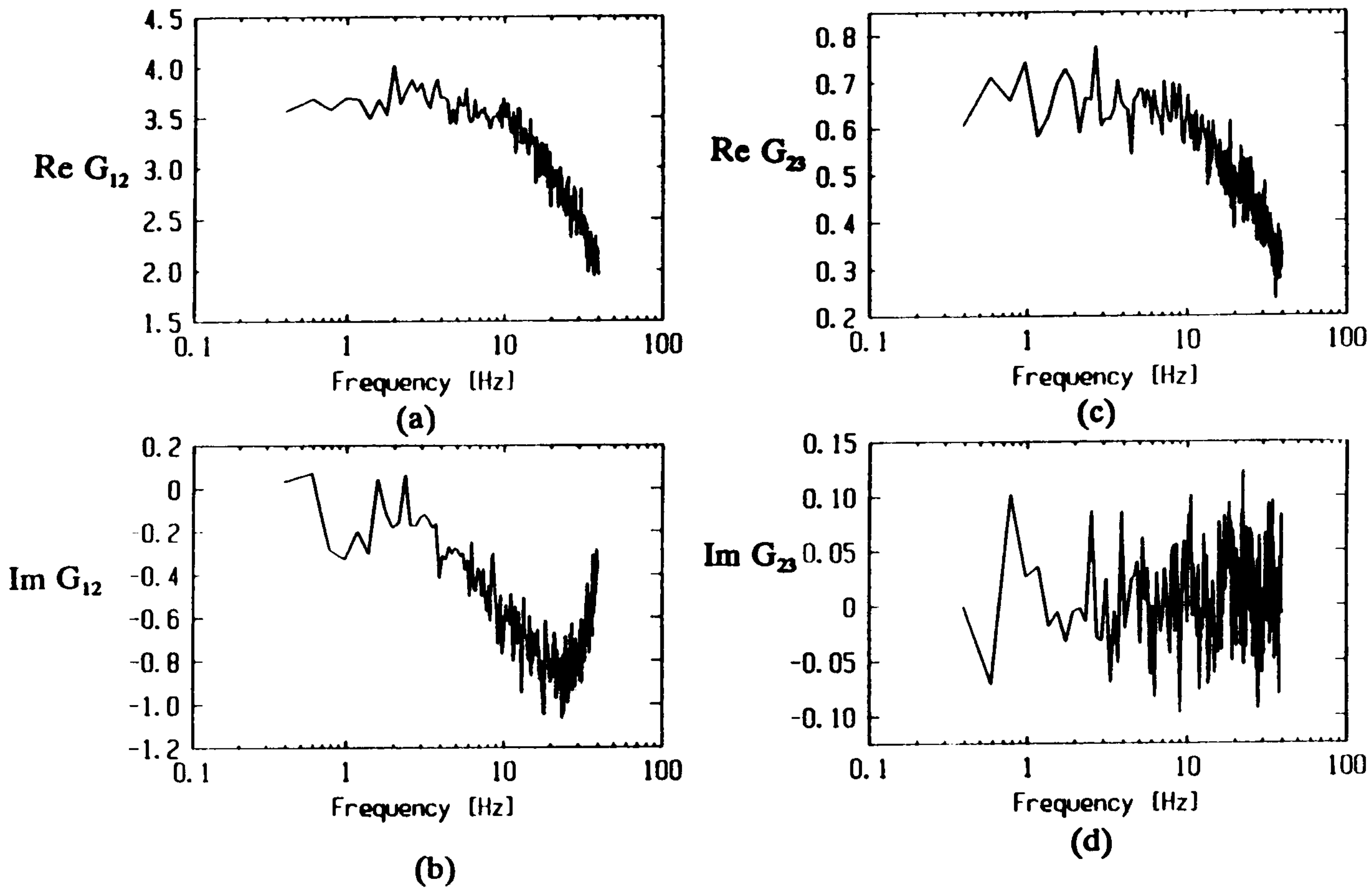


Figure 6.3 (a) Real CPSD Between Source Detector and Neutron Detector, (b) Imaginary CPSD Between Source Detector and Neutron Detector, (c) Real CPSD Between Neutron Detectors, and (d) Imaginary CPSD Between Neutron Detectors for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Transfer Shaft.

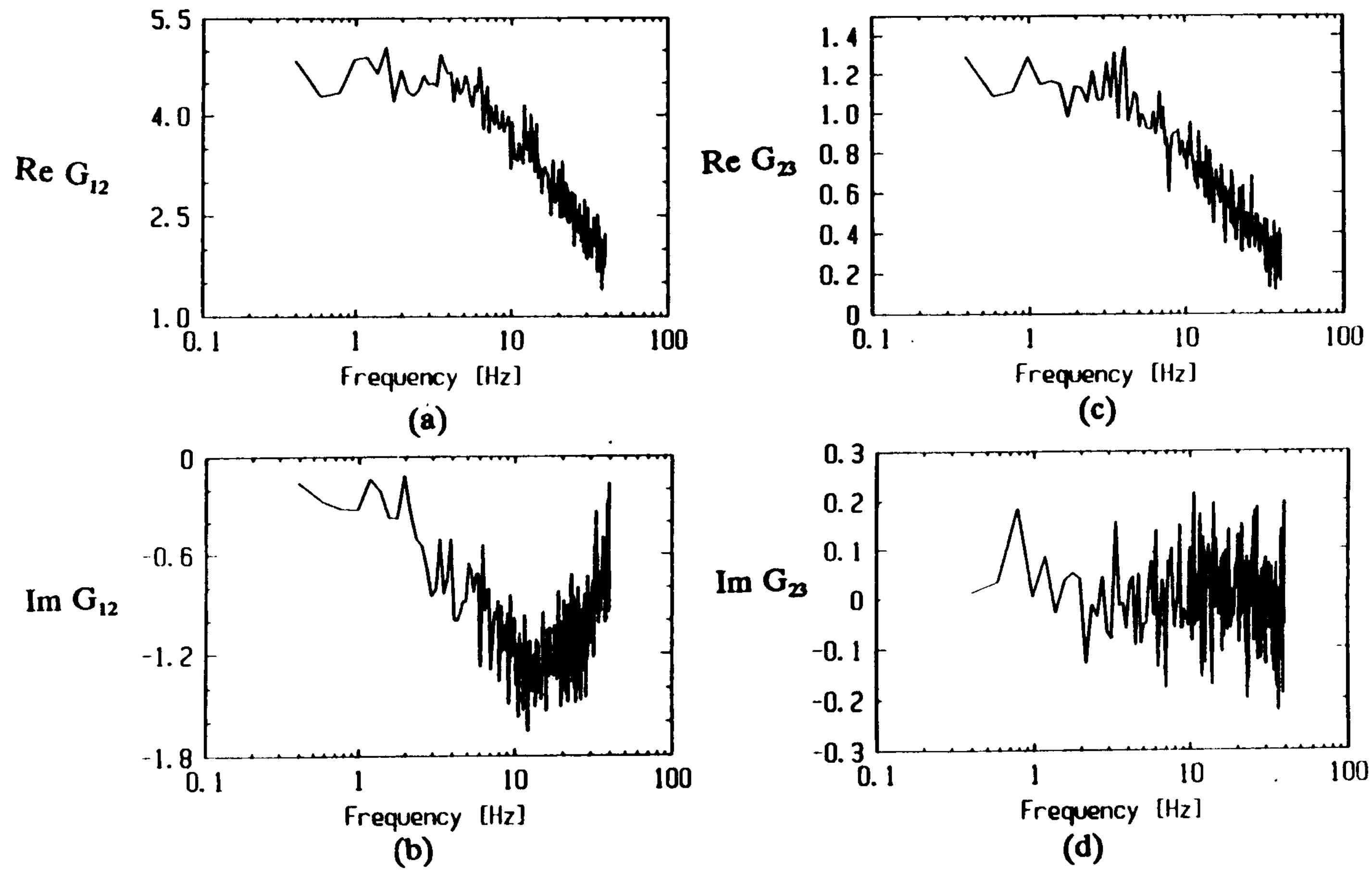
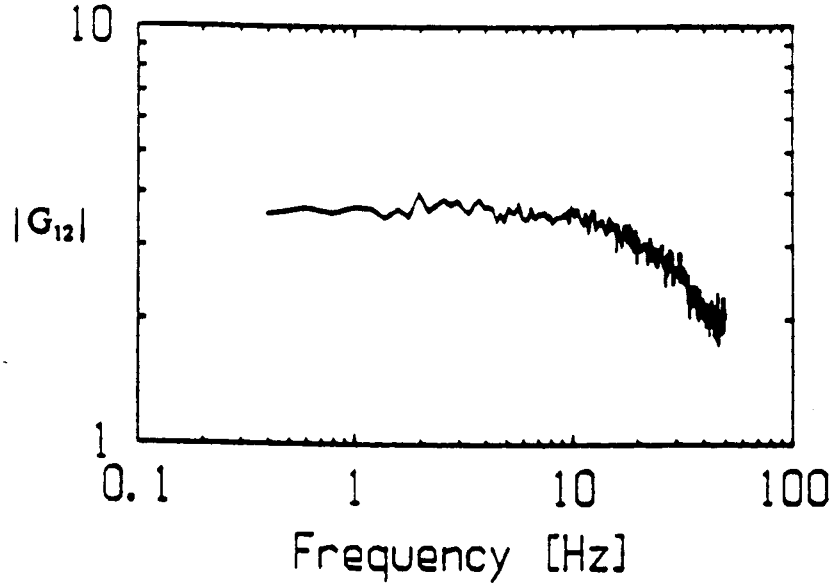
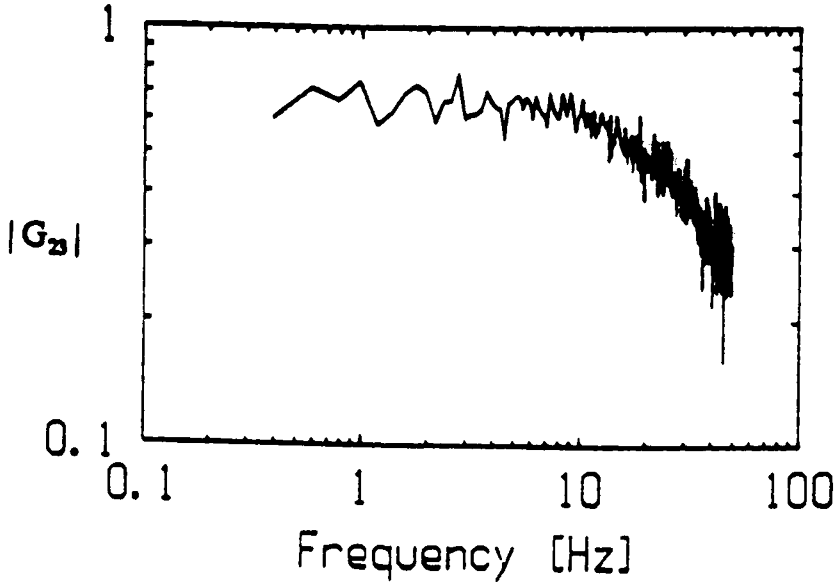


Figure 6.4 (a) Real CPSD Between Source Detector and Neutron Detector, (b) Imaginary CPSD Between Source Detector and Neutron Detector, (c) Real CPSD Between Neutron Detectors, and (d) Imaginary CPSD Between Neutron Detectors for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Interim Fuel Storage Canal.

CPSDs for the fuel annulus/isolator assembly with capture detectors in the transfer shaft and in the interim fuel storage canal respectively. The break frequency of the CPSD can be related to the reactivity of the fissile system. Since the fuel annulus/isolator assembly in the transfer shaft is farther subcritical than the same assembly in the interim fuel storage canal, the break frequency of the CPSD is higher with the assembly in the transfer shaft. This results because the fission chains become smaller as the system becomes more subcritical. The imaginary parts of the CPSDs between the source detector and a neutron detector are negative because the transfer function of the fissile system has a negative imaginary part. The imaginary component of the CPSDs between the two neutron detectors is zero for the cases analyzed, thus suggesting that the point kinetics model may be applicable in interpreting the data. Figures 6.5 and 6.6 are the magnitudes of the cross power spectral densities of the fuel annulus/isolator assembly with capture detectors in the transfer shaft and in the interim fuel storage canal, respectively. The CPSD between the source detector and the neutron detector decreases one decade per decade while the CPSD between the two neutron detectors decreases two decades per decade. The cross power spectral densities are in units of detected counts per block. Tables 6.3 and 6.4 contain the low frequency values of the magnitudes of the CPSDs for the assembly in the transfer shaft and in the interim fuel storage canal respectively. The magnitude of the CPSDs is lower than the magnitude of the APSDs because the CPSD is a measure of correlated information shared between two signals while the APSD is the measure of correlated information shared between a signal at time t and

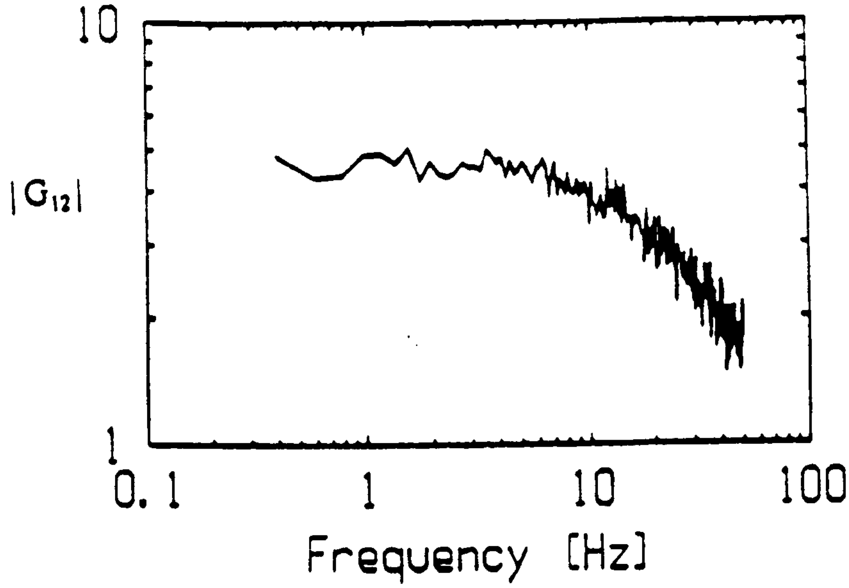


(a)

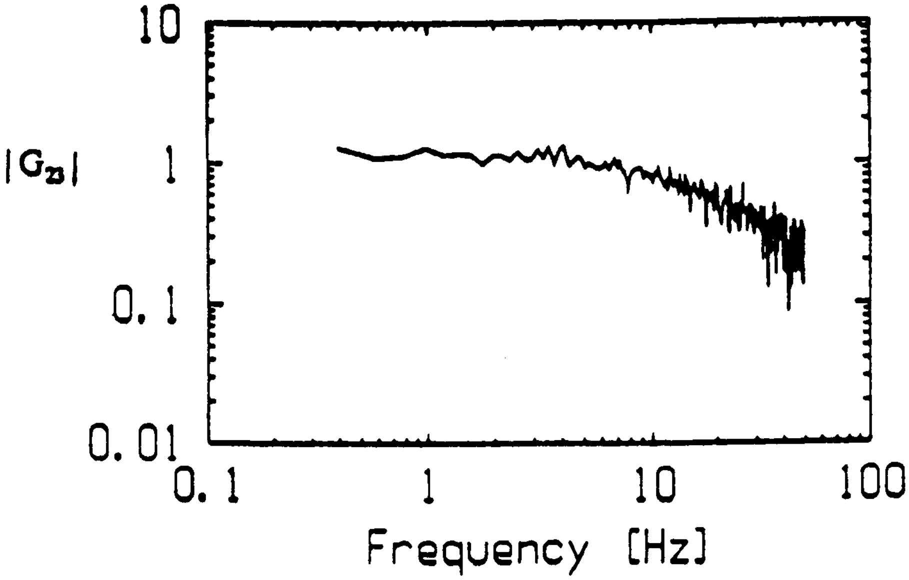


(b)

Figure 6.5 Magnitude of CPSDs Between (a) Source and Neutron Detector and (b) Two Neutron Detectors for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Transfer Shaft.



(a)



(b)

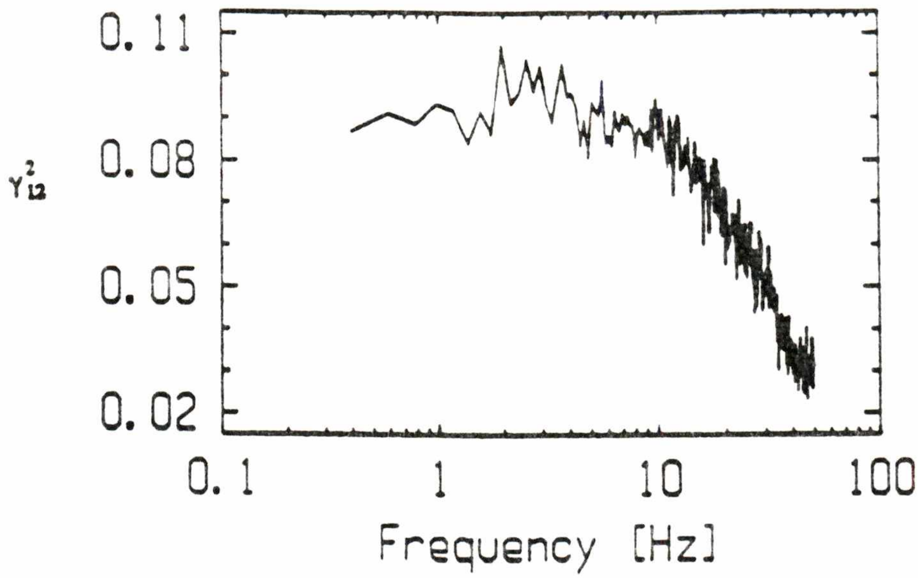
Figure 6.6 Magnitude of CPSDs Between (a) Source and Neutron Detector and (b) Two Neutron Detectors for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Interim Fuel Storage Canal.

Table 6.3 Low Frequency Magnitudes of CPSDs for the Upper Fuel Annulus/Isolator Assembly in the Transfer Shaft		
Detector Type	$\lvert G_{12} \rvert$ Counts/Block	$\lvert G_{23} \rvert$ Counts/Block
Capture	3.4	0.7
Black	10	7.0

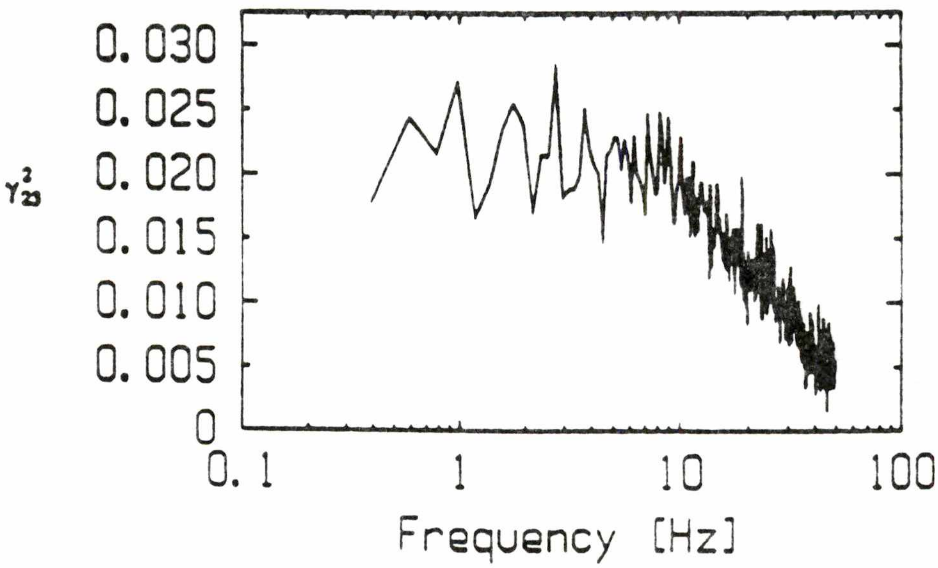
Table 6.4 Low Frequency Magnitudes of CPSDs for the Upper Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal		
Detector Type	$\lvert G_{12} \rvert$ Counts/Block	$\lvert G_{23} \rvert$ Counts/Block
Capture	4.4	1.0
Black	13	9.0

itself at time $t+\tau$. The CPSDs between the source detector and the neutron detector are higher than the CPSDs between the two neutron detectors because more correlated information is shared between the source detector and the neutron detector. The normalization of the APSDs and CPSDs is arbitrary since the ratio of the spectral densities is the quantity related to subcriticality.

Figures 6.7 and 6.8 are plots of the coherences as a function of frequency for the capture detectors in the transfer shaft and in the interim fuel storage canal respectively. Tables 6.5 and 6.6 contain the low frequency values of the coherences for the capture and black detectors in the transfer shaft and in the interim fuel storage canal respectively. The low frequency value of the coherence can be used to estimate the measurement time required for the ratio of spectral densities to converge. As mentioned in Chap. 3, the bias is used to determine the amount of data needed for the measured coherence to converge to the true coherence. The bias diminishes as 1/n where n is the number of data blocks data used in the estimate. For large values of n, the measured coherence approaches the true coherence. To determine the amount of data needed to be within a certain percentage of the true coherence, the inverse of the measured coherence times the desired percentage of error in the coherence determines the number of data blocks required. The time of measurement is determined by multiplying the number of data blocks by the number of points per data block and dividing this quantity by the sampling rate. The number of data blocks needed for the measured coherence to converge within 10% of the true coherence is estimated to be around 500 blocks. Sampling 512 points per block



(a)



(b)

Figure 6.7 Coherences Between (a) Source and Neutron Detector and (b) Two Neutron Detectors for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Transfer Shaft.

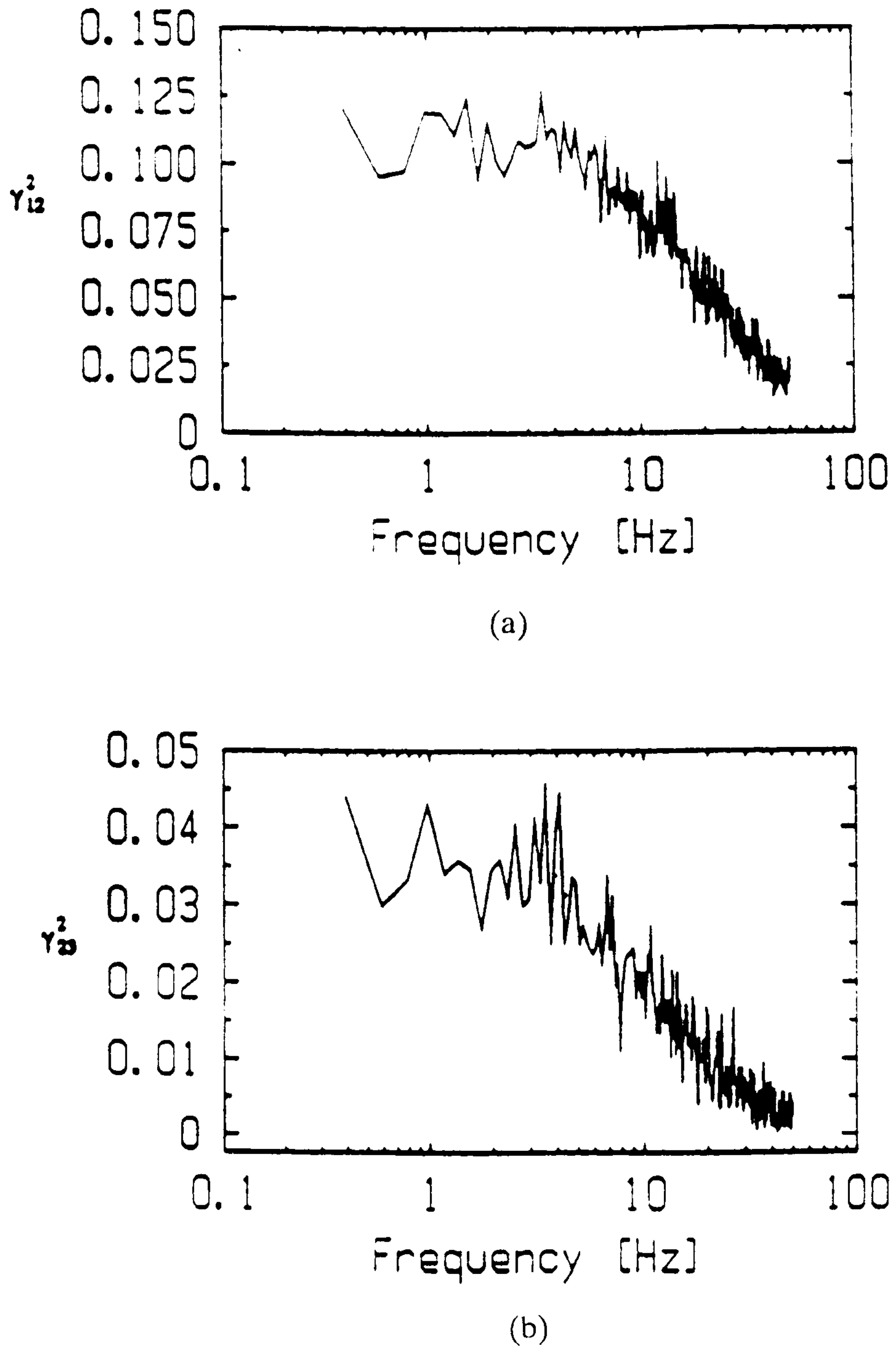


Figure 6.8 Coherences Between (a) Source and Neutron Detector and (b) Two Neutron Detectors for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Interim Fuel Storage Canal.

Table 6.5 Low Frequency Coherences for the Upper Fuel Annulus/Isolator Assembly in the Transfer Shaft		
Detector Type	γ_{12}^2	γ_{23}^2
Capture	0.09	0.02
Black	0.20	0.09

Table 6.6 Low Frequency Coherences for the Upper Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal		
Detector Type	γ_{12}^2	γ_{23}^2
Capture	0.11	0.04
Black	0.21	0.11

at a rate of 100 points per second would result in a measurement time of approximately 43 minutes to a precision of 2% in the ratio of spectral densities, with the coherence between detectors measured to 3% and that between the source and detectors to 2%. If two ^{3}He counters are utilized on each side of the fuel element, then the coherence between counters on opposite sides would increase a factor of four above that calculated for one counter since this coherence depends on the product of the detector efficiencies. The coherence between the source and detector would increase by a factor of 2 over that for one counter. Thus, using two detectors on each side of the fuel element, the measurement could be performed in less than 11 minutes to a precision of 2% in the ratio of spectral densities, with the coherences between detectors measured to 3% and that between the source and detectors to 2%. For locations during the fueling process with higher neutron multiplication factors, such as the interim fuel storage canal, the measurement times are shorter. Utilizing two ^{3}He counters on each side of the fuel element in the interim fuel storage canal, the measurement could be performed in approximately 5 minutes to a precision of 3% in the ratio of spectral densities, with the coherence between detectors and between the source and detectors measured to 3%.

The ratio of spectral densities as a function of frequency for the fuel annulus/isolator assembly with capture detectors are presented in Fig. 6.9 with the assembly in the transfer shaft and in Fig. 6.10 with the assembly in the interim fuel storage canal. The low frequency value of the ratio of spectral densities is presented in Tables 6.7 and 6.8 for the assembly in the transfer shaft and in the interim fuel

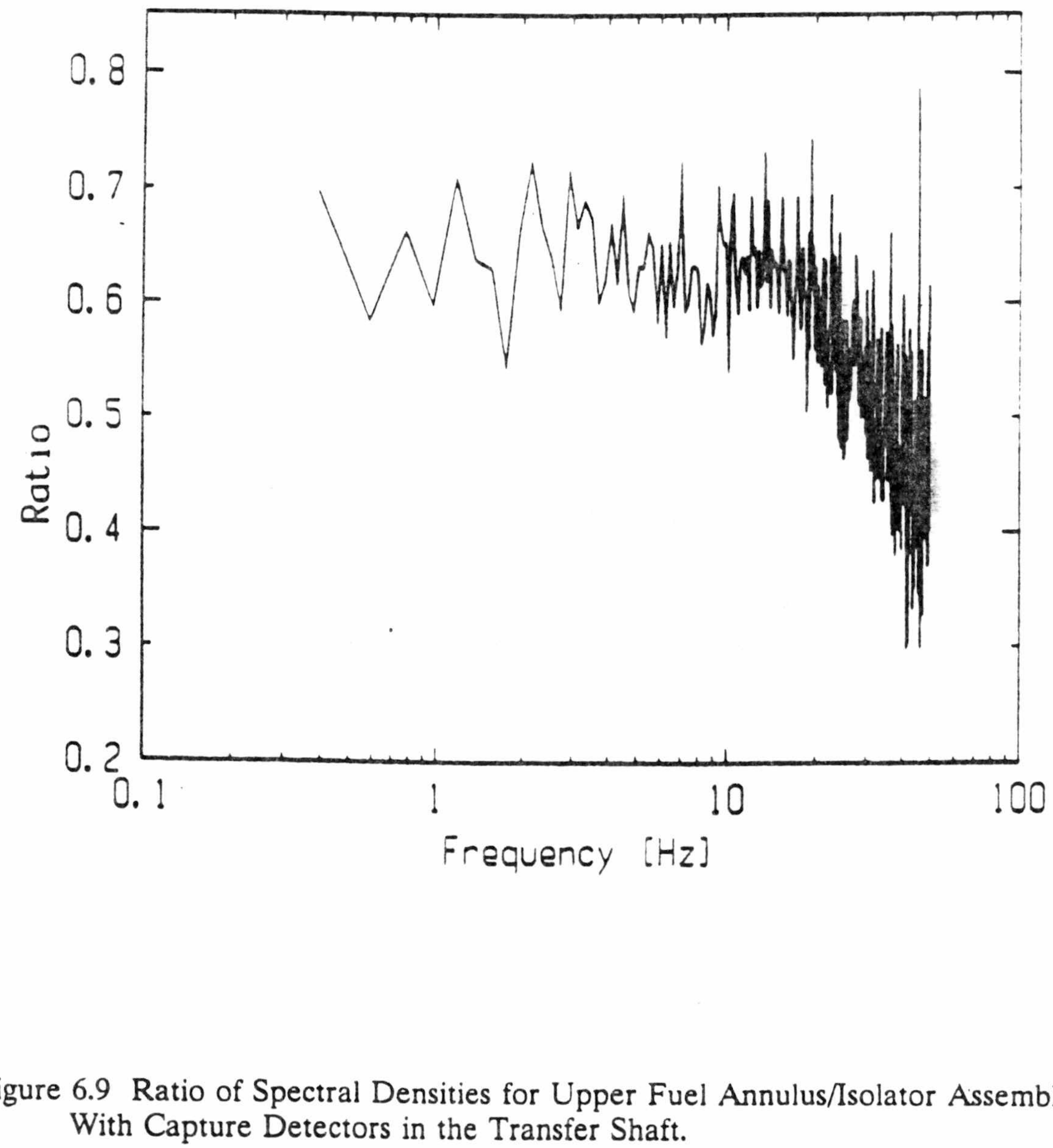


Figure 6.9 Ratio of Spectral Densities for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Transfer Shaft.

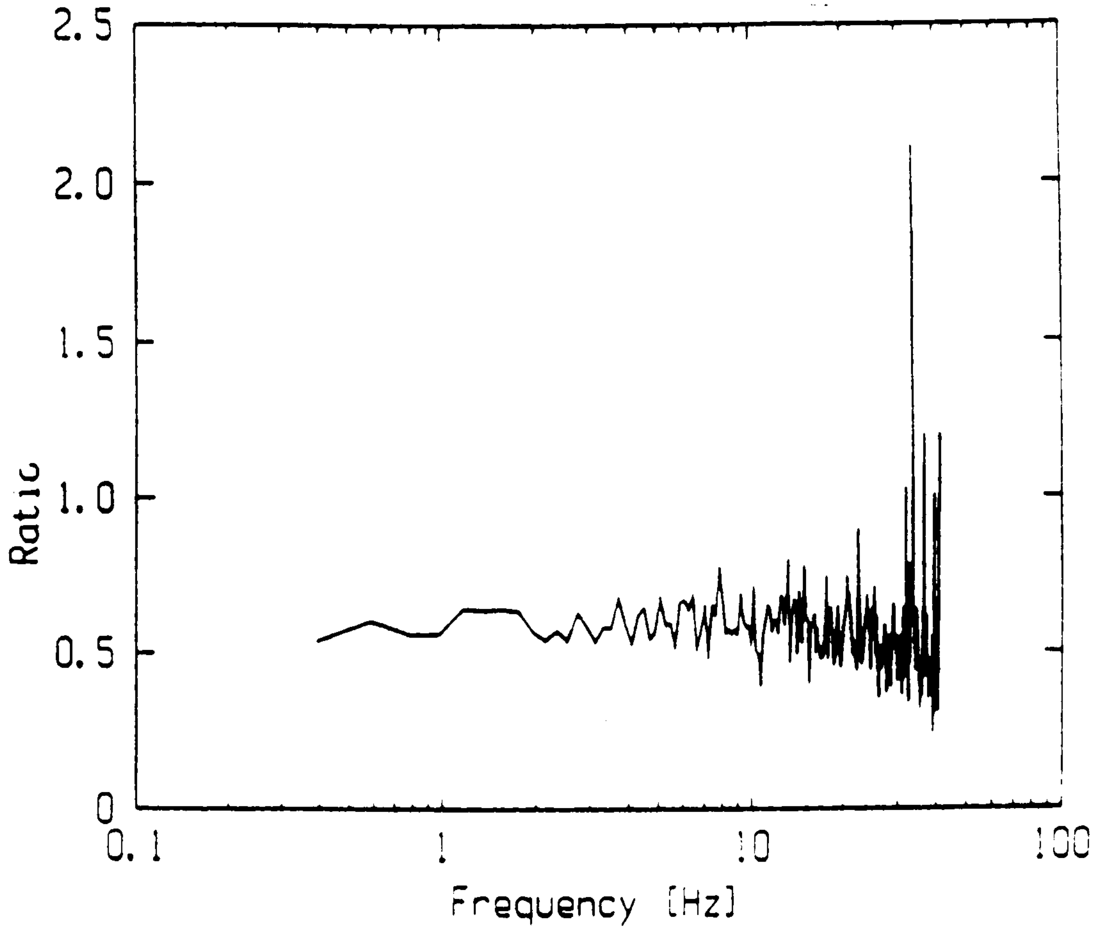


Figure 6.10 Ratio of Spectral Densities for Upper Fuel Annulus/Isolator Assembly With Capture Detectors in the Interim Fuel Storage Canal.

Table 6.7 Low Frequency Value of Ratio of Spectral Densities for the Upper Fuel Annulus/Isolator Assembly in the Transfer Shaft

Detector Type	Ratio of Spectral Densities
Capture	0.646 ± 0.010
Black	0.661 ± 0.004

Table 6.8 Low Frequency Value of Ratio of Spectral Densities for the Upper Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal

Detector Type	Ratio of Spectral Densities
Capture	0.588 ± 0.010
Black	0.628 ± 0.004

storage canal respectively. The low frequency value of the ratio of spectral densities is used to estimate the reactivity of the system. The ratio of spectral densities decreases as the multiplication factor of the system increases. Therefore, the low frequency value of the ratio of spectral densities for the assembly in the transfer shaft is greater than the low frequency value of the ratio of spectral densities for the same assembly in the interim fuel storage canal.

Appendix D contains a discussion about the CSDNA analysis of the upper fuel annulus/isolator assembly with the black detectors in both the transfer shaft and in the interim fuel storage canal. The coherences, APSDs, CPSDs, and the ratio of spectral densities for the black detectors are discussed in Appendix D.

6.2 Lower Fuel Element CSDNA Analysis

Since the lower fuel element is very similar to the upper fuel element, the calculations were performed using only the black detectors to reduce computational time. The detectors have the approximately the same affect on the multiplication factor for both of the fuel annulus/isolator assemblies. The ^{3}He detectors reduce the multiplication factor by approximately 5% for both the upper and lower fuel annulus/isolator assemblies. The APSDs, CPSDs, coherences, and the ratios of spectral densities for the black detectors can be scaled appropriately by using normalization factors obtained from the comparison of the various detector types for the upper fuel annulus/isolator analysis to represent the ^{3}He detectors. The low frequency values of the auto power spectral densities are presented in Table 6.9 for the assembly in the transfer shaft and in Table 6.10 for the assembly in the interim

Table 6.9 Low Frequency APSDs for the Lower Fuel Annulus/Isolator Assembly in the Transfer Shaft		
Detector Type	G_{11} Counts/Block	G_{22} Counts/Block
Black	32	65

Table 6.10 Low Frequency APSDs for the Lower Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal		
Detector Type	G_{11} Counts/Block	G_{22} Counts/Block
Black	32	80

fuel storage canal. Likewise, Tables 6.11 and 6.12 present the low frequency values of the magnitudes of the cross power spectral densities of the fuel annulus/isolator assembly in the transfer shaft and in the interim fuel storage canal respectively. Tables 6.13 and 6.14 contain the low frequency values of the coherences for the lower fuel annulus/isolator assembly in the transfer shaft and in the interim fuel storage canal respectively. Since the lower fuel annulus/isolator assembly has a slightly higher neutron multiplication factor than that of the upper fuel element, the measurement times for the lower fuel annulus/isolator assembly will be shorter. The low frequency values of the ratios of spectral densities are given in Tables 6.15 and 6.16 for the assembly in the transfer shaft and in the interim fuel storage canal respectively. Normalizing the black detector results is appropriate because the black detectors affect the multiplication of the fuel annulus/isolator assembly in the same manner as the capture detectors. Appendix E contains more details about the results of the calculations. APSDs, CPSDs, coherences, and the ratio of spectral densities are plotted in Appendix E.

Table 6.11 Low Frequency Magnitudes of CPSDs for the Lower Fuel Annulus/Isolator Assembly in the Transfer Shaft		
Detector Type	$\lvert G_{12} \rvert$ Counts/Block	$\lvert G_{23} \rvert$ Counts/Block
Black	25	30

Table 6.12 Low Frequency Magnitudes of CPSDs for the Lower Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal		
Detector Type	$\lvert G_{12} \rvert$ Counts/Block	$\lvert G_{23} \rvert$ Counts/Block
Black	30	40

Table 6.13 Low Frequency Coherences for the Lower Fuel Annulus/Isolator Assembly in the Transfer Shaft		
Detector Type	γ_{12}^2	γ_{23}^2
Black	0.33	0.25

Table 6.14 Low Frequency Coherences for the Lower Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal		
Detector Type	γ_{12}^2	γ_{23}^2
Black	0.34	0.29

Table 6.15 Low Frequency Value of Ratio of Spectral Densities for the Lower Fuel Annulus/Isolator Assembly in the Transfer Shaft	
Detector Type	Ratio of Spectral Densities
Black	0.674 ± 0.002

Table 6.16 Low Frequency Value of Ratio of Spectral Densities for the Lower Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal	
Detector Type	Ratio of Spectral Densities
Black	0.637 ± 0.002

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.0 Summary

Fueling of the ANS reactor is unique in that the core is composed of two annular fuel elements with different diameters, each of which is supercritical when moderated and infinitely reflected by heavy water. The neutron multiplication factors for the upper and lower fresh fuel annuli in infinite heavy water are approximately 1.2 and 1.1 respectively. These neutron multiplication factors produce the need for careful design and detailed criticality safety analysis of each step of the fueling process to ensure that criticality during fueling is not a major safety issue. To maintain subcriticality, the fuel annuli will have materials on the inner and outer radial surfaces to isolate the fissile material from the heavy water reflector. The KENO Va Monte Carlo analysis, using a 26-group ENDF/B-V cross section library, has shown that aluminum can be used as the outer isolator and stainless steel can be used as the inner isolator. With either the inner isolator or the outer isolator present, each fuel element is subcritical and the effective neutron multiplication factor remains below 0.95 for both the upper and lower fuel annuli. For the upper fuel annulus, the inner isolator is 25.4-mm-thick stainless steel and the outer isolator is 127-mm-thick aluminum. The inner isolator is 25.4-mm-thick stainless steel and the outer isolator is 57.2-mm-thick aluminum for the lower fuel annulus. With both the inner isolator and the outer isolator present, the upper and lower fuel elements have calculated k values of 0.653 ± 0.002 and 0.769 ± 0.002, respectively. These results were obtained by placing the fuel annulus/isolator assembly in a 6-m-high and 4-m-wide and -thick region of heavy water in order to obtain a conservative estimate of the neutron multiplication factors. Structural materials are used as the isolators instead of neutron poisons because the verification of the difficulties involved in verifying the presence of neutron poisons in the isolator. These calculations have demonstrated a viable concept for safely fueling the ANS reactor which will be verified in the critical experiments program.

The calculations of the ^{252}Cf-source-driven noise analysis method have shown that the CSDNA measurements are practical in that they can be performed in a short time. The coherences have shown that a measurement of the ratio of spectral densities to a precision of 2% can be made in less than 11 minutes with the upper fuel annulus/isolator assembly in the transfer shaft and with two ^{3}He counters on each side of the fuel annulus/isolator assembly with the source located in the inner isolator. For locations where the multiplication factor is higher, the measurement can be made in less time. Utilizing two ^{3}He counters on each side of the upper fuel annulus/isolator assembly in the interim fuel storage canal, the measurement could be performed in approximately 5 minutes to a precision of 3% in the ratio of spectral densities. With the upper fuel annulus/isolator assembly in the transfer shaft, the low frequency ratio of spectral densities is 0.646 ± 0.010 using the capture detectors. The ratio of spectral densities is 0.588 ± 0.009 using the capture detectors with the upper fuel annulus/isolator assembly in the interim fuel storage canal. These values can be compared to the results that will be obtained in the critical experiments program.

The importance of the calculations is that the calculated APSDs, CPSDs, coherences, and the ratio of spectral densities can be compared directly to the spectral data obtained from future measurements in the critical experiments program verifying the fueling scenario of the ANS reactor regardless of the applicability of the modified point kinetics theory. This allows the Monte Carlo method to replace the modified point kinetics theory. If the KENO-NR model and the group cross section data sets calculate the measured data accurately, then the effective multiplication factor can be estimated using KENO-AK. The Monte Carlo calculations of the CSDNA method can be performed in a reasonable time using UNIX work stations (SUN SparcStations). The measured coherences can be determined to within 10% of the true coherence using 50 hours of the computation time, thus showing that the Monte Carlo calculations of the CSDNA method are feasible for the fueling of the ANS reactor. The calculations have shown that it is feasible to perform the CSDNA measurement in the critical experiments program to verify the fueling process for the ANS reactor and, if appropriate, in the initial loading of the reactor.

7.1 Recommendations for Future Work

A more detailed analysis of the isolation materials needs to be performed to take into consideration factors such as the effect of decay heat on the materials. An analysis of spent fuel annulus/isolator assemblies with varying burnups would determine the feasibility of using the CSDNA measurement to measure the subcriticality of spent fuel annuli and to determine to what extent the CSDNA method may be applied. To test the sensitivity of the results to changes in neutron cross sections, additional cross section data sets need to be developed for the ANS reactor. The final recommendation would be to perform the actual measurement to validate the spectral data results obtained from the CSDNA calculations in order to verify the subcriticality of the ANS fuel annuli in the fueling scenario.

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APPENDICES

APPENDIX A

KENO Va FUEL ANNULI MODELS

The models of the annular fuel elements have 25 axial zones and 13 radial zones as shown in Fig. 2.4. Figures A.1 and A.2 contain a listing of the input files for the upper and lower fuel annulus/isolator assemblies respectively. The mixture data presented in the input files describe the fuel gradients in the axial and radial directions. There are 39 geometry units that are used to described the fuel annuli. The first 12 geometry units are the detector units that are inserted as holes in the outer isolator. Units 13 through 37 describe the axial variations of the fuel elements. The radial variations are described as concentric cylinders in each axial unit. Units 38 and 39 are used to describe the amount of reflector below and above the fuel annulus/isolator assembly. These data files can also be used in the KENO-NR code with slight modification to the parameter data and by adding an extra data block. A 26-group neutron cross section library is used in the calculations. There are 6 thermal energy groups, 12 intermediate energy groups, and 6 fast energy groups.

```
~/library/ansa2cmod
ANS REFUELING MODEL: 1" Stainless Steel, 5" Al
READ PARAM
  TME=900.0 TBA=15.0 NPG=500 NSK=5 GEN=500 LIB=34 TRK=NO RUN=YES
  NB8=1800
END PARAM
READ MIXT  SCT=2 EPS=1
MIX=1
1002    6.65600-02 8016   3.32800-02
MIX=2
13027   6.02374-02
MIX=3
24000   1.74300-02 25055 1.73500-03 26000 5.93600-02 28000 7.72100-03
MIX=4
13027   6.02374-02
MIX=5
13027   6.02374-02
MIX=6
492235 6.03260-04 92238 4.48343-05 13027 2.85978-02 14000 4.38103-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=7
492235 6.11333-04 92238 4.54343-05 13027 2.85774-02 14000 4.43966-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=8
492235 6.18013-04 92238 4.59307-05 13027 2.85605-02 14000 4.48816-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=9
492235 6.22586-04 92238 4.62706-05 13027 2.85490-02 14000 4.52138-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=10
492235 6.18444-04 92238 4.59628-05 13027 2.85594-02 14000 4.49130-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=11
492235 6.05329-04 92238 4.49881-05 13027 2.85926-02 14000 4.39605-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=12
492235 5.92318-04 92238 4.40211-05 13027 2.86254-02 14000 4.30156-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=13
492235 5.82654-04 92238 4.33029-05 13027 2.86498-02 14000 4.23138-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=14
492235 5.72611-04 92238 4.25564-05 13027 2.86752-02 14000 4.15844-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=15
492235 5.62676-04 92238 4.18181-05 13027 2.87003-02 14000 4.08630-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=16
492235 5.52898-04 92238 4.10914-05 13027 2.87249-02 14000 4.01528-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=17
492235 5.43306-04 92238 4.03785-05 13027 2.87492-02 14000 3.94563-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=18
```

Figure A.1 KENO Va Input File For Upper Annulus/Isolator Assembly

```
492235 6.14331-04 92238 4.56571-05 13027 2.85698-02 14000 4.46142-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=19
492235 6.31107-04 92238 4.69039-05 13027 2.85275-02 14000 4.58326-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=20
492235 6.14240-04 92238 4.56503-05 13027 2.85701-02 14000 4.46077-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=21
492235 6.01501-04 92238 4.47035-05 13027 2.86022-02 14000 4.36825-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=22
492235 5.88288-04 92238 4.37215-05 13027 2.86356-02 14000 4.27229-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=23
492235 5.75236-04 92238 4.27515-05 13027 2.86685-02 14000 4.17751-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=24
492235 5.62114-04 92238 4.17763-05 13027 2.87017-02 14000 4.08221-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=25
492235 5.48886-04 92238 4.07932-05 13027 2.87351-02 14000 3.98615-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=26
192235 6.33667-04 92238 4.70941-05 13027 2.85210-02 14000 4.60185-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=27
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=28
392235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=29
492235 6.02193-04 92238 4.47550-05 13027 2.86005-02 14000 4.37328-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=30
492235 5.86212-04 92238 4.35673-05 13027 2.86408-02 14000 4.25722-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=31
492235 5.70035-04 92238 4.23650-05 13027 2.86817-02 14000 4.13974-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=32
492235 5.53845-04 92238 4.11618-05 13027 2.87226-02 14000 4.02216-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=33
192235 6.43586-04 92238 4.78313-05 13027 2.84960-02 14000 4.67389-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=34
192235 6.63768-04 92238 4.93312-05 13027 2.84450-02 14000 4.82045-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.1 (continued)

```
26000   6.65000-05 25055 1.04100-05
MIX=35
492235 6.14431-04 92238 4.56645-05 13027 2.85696-02 14000 4.46215-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=36
492235 5.95801-04 92238 4.42799-05 13027 2.86166-02 14000 4.32685-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=37
492235 5.77067-04 92238 4.28877-05 13027 2.86639-02 14000 4.19081-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=38
492235 5.58463-04 92238 4.15049-05 13027 2.87109-02 14000 4.05569-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=39
192235 6.53036-04 92238 4.85336-05 13027 2.84721-02 14000 4.74251-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=40
192235 6.75814-04 92238 5.02265-05 13027 2.84146-02 14000 4.90793-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=41
292235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=42
492235 6.25108-04 92238 4.64581-05 13027 2.85426-02 14000 4.53969-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=43
492235 6.04189-04 92238 4.49033-05 13027 2.85954-02 14000 4.38777-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=44
492235 5.83363-04 92238 4.33555-05 13027 2.86480-02 14000 4.23653-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=45
492235 5.62769-04 92238 4.18250-05 13027 2.87000-02 14000 4.08697-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=46
192235 6.61645-04 92238 4.91734-05 13027 2.84504-02 14000 4.80503-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=47
492235 6.33564-04 92238 4.70865-05 13027 2.85213-02 14000 4.60110-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=48
492235 6.10745-04 92238 4.53905-05 13027 2.85789-02 14000 4.43538-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=49
492235 5.88556-04 92238 4.37415-05 13027 2.86349-02 14000 4.27424-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=50
492235 5.66650-04 92238 4.21134-05 13027 2.86902-02 14000 4.11515-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=51
```

Figure A.1 (continued)

```
492235 6.73149-04 92238 5.00284-05 13027 2.84213-02 14000 4.88858-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=52
492235 6.44406-04 92238 4.78923-05 13027 2.84939-02 14000 4.67984-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=53
492235 6.19076-04 92238 4.60097-05 13027 2.85579-02 14000 4.49588-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=54
492235 5.94968-04 92238 4.42180-05 13027 2.86187-02 14000 4.32080-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=55
492235 5.71362-04 92238 4.24636-05 13027 2.86783-02 14000 4.14938-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=56
492235 6.86826-04 92238 5.10449-05 13027 2.83868-02 14000 4.98790-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=57
492235 6.57203-04 92238 4.88434-05 13027 2.84616-02 14000 4.77278-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=58
492235 6.28257-04 92238 4.66921-05 13027 2.85347-02 14000 4.56256-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=59
492235 6.01983-04 92238 4.47394-05 13027 2.86010-02 14000 4.37175-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=60
492235 5.76575-04 92238 4.28510-05 13027 2.86652-02 14000 4.18723-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=61
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=62
492235 6.69723-04 92238 4.97738-05 13027 2.84300-02 14000 4.86369-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=63
492235 6.36966-04 92238 4.73393-05 13027 2.85127-02 14000 4.62581-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=64
492235 6.07200-04 92238 4.51271-05 13027 2.85878-02 14000 4.40964-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=65
492235 5.80100-04 92238 4.31130-05 13027 2.86563-02 14000 4.21283-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=66
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=67
492235 6.79099-04 92238 5.04706-05 13027 2.84063-02 14000 4.93178-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.1 (continued)

```
26000   6.65000-05 25055 1.04100-05
MIX=68
492235 6.43399-04 92238 4.78174-05 13027 2.84964-02 14000 4.67253-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=69
492235 6.11162-04 92238 4.54216-05 13027 2.85778-02 14000 4.43841-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=70
492235 5.82022-04 92238 4.32559-05 13027 2.86514-02 14000 4.22679-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=71
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=72
492235 6.82542-04 92238 5.07265-05 13027 2.83976-02 14000 4.95679-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=73
492235 6.44451-04 92238 4.78956-05 13027 2.84938-02 14000 4.68016-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=74
492235 6.09843-04 92238 4.53235-05 13027 2.85812-02 14000 4.42883-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=75
492235 5.78886-04 92238 4.30228-05 13027 2.86593-02 14000 4.20401-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=76
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=77
492235 6.77722-04 92238 5.03683-05 13027 2.84098-02 14000 4.92179-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=78
492235 6.37632-04 92238 4.73888-05 13027 2.85110-02 14000 4.63064-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=79
492235 6.00841-04 92238 4.46545-05 13027 2.86039-02 14000 4.36346-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=80
492235 5.68833-04 92238 4.22756-05 13027 2.86847-02 14000 4.13100-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=81
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=82
492235 6.64254-04 92238 4.93674-05 13027 2.84438-02 14000 4.82398-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=83
492235 6.23156-04 92238 4.63129-05 13027 2.85475-02 14000 4.52551-04
24000   1.25000-05 1002   3.32800-02  8016 1.66400-02
26000   6.65000-05 25055 1.04100-05
MIX=84
```

Figure A.1 (continued)

```
492235 5.85629-04 92238 4.35240-05 13027 2.86423-02 14000 4.25299-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=85
492235 5.53146-04 92238 4.11098-05 13027 2.87243-02 14000 4.01708-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=86
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=87
492235 6.42658-04 92238 4.77623-05 13027 2.84983-02 14000 4.66714-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=88
492235 6.01343-04 92238 4.46918-05 13027 2.86026-02 14000 4.36711-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=89
492235 5.64581-04 92238 4.19597-05 13027 2.86954-02 14000 4.10013-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=90
492235 5.32556-04 92238 3.95796-05 13027 2.87763-02 14000 3.86755-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=91
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=92
492235 6.18983-04 92238 4.60028-05 13027 2.85581-02 14000 4.49521-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=93
492235 5.78428-04 92238 4.29888-05 13027 2.86605-02 14000 4.20069-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=94
492235 5.42094-04 92238 4.02885-05 13027 2.87522-02 14000 3.93682-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=95
492235 5.10161-04 92238 3.79152-05 13027 2.88328-02 14000 3.70492-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=96
492235 5.92429-04 92238 4.40293-05 13027 2.86251-02 14000 4.30237-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=97
492235 5.53112-04 92238 4.11073-05 13027 2.87244-02 14000 4.01684-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=98
492235 5.17594-04 92238 3.84676-05 13027 2.88141-02 14000 3.75890-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=99
492235 4.86402-04 92238 3.61494-05 13027 2.88928-02 14000 3.53237-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=100
492235 5.64346-04 92238 4.19422-05 13027 2.86960-02 14000 4.09842-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.1 (continued)

```
26000  6.65000-05 25055 1.04100-05
MIX=101
492235 5.25950-04 92238 3.90886-05 13027 2.87930-02 14000 3.81958-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=102
492235 4.91377-04 92238 3.65191-05 13027 2.88803-02 14000 3.56850-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=103
492235 4.61043-04 92238 3.42648-05 13027 2.89569-02 14000 3.34821-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=104
392235 6.36813-04 92238 4.73279-05 13027 2.85131-02 14000 4.62469-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=105
492235 5.17879-04 92238 3.84888-05 13027 2.88134-02 14000 3.76097-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=106
492235 4.82252-04 92238 3.58410-05 13027 2.89033-02 14000 3.50223-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=107
492235 4.50365-04 92238 3.34711-05 13027 2.89838-02 14000 3.27066-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=108
492235 4.22472-04 92238 3.13981-05 13027 2.90543-02 14000 3.06810-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=109
392235 5.96605-04 92238 4.43397-05 13027 2.86146-02 14000 4.33269-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=110
392235 5.54392-04 92238 4.12024-05 13027 2.87212-02 14000 4.02614-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=111
492235 4.51044-04 92238 3.35216-05 13027 2.89821-02 14000 3.27560-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=112
492235 4.21640-04 92238 3.13363-05 13027 2.90564-02 14000 3.06206-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=113
492235 3.95166-04 92238 2.93687-05 13027 2.91232-02 14000 2.86979-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=114
492235 3.71793-04 92238 2.76316-05 13027 2.91822-02 14000 2.70005-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=115
492235 5.52729-04 92238 4.10788-05 13027 2.87254-02 14000 4.01406-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=116
492235 5.74745-04 92238 4.27151-05 13027 2.86698-02 14000 4.17394-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=117
```

Figure A.1 (continued)

```
392235 5.62555-04 92238 4.18091-05 13027 2.87006-02 14000 4.08541-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=118
392235 5.13405-04 92238 3.81562-05 13027 2.88247-02 14000 3.72847-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=119
392235 4.81195-04 92238 3.57624-05 13027 2.89060-02 14000 3.49456-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=120
492235 3.94261-04 92238 2.93014-05 13027 2.91255-02 14000 2.86322-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=121
492235 3.71600-04 92238 2.76173-05 13027 2.91827-02 14000 2.69865-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=122
492235 3.51004-04 92238 2.60866-05 13027 2.92347-02 14000 2.54908-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=123
492235 3.32642-04 92238 2.47219-05 13027 2.92811-02 14000 2.41573-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=124
192235 4.91530-04 92238 3.65305-05 13027 2.88799-02 14000 3.56961-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=125
192235 5.06828-04 92238 3.76675-05 13027 2.88413-02 14000 3.68071-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=126
192235 5.16256-04 92238 3.83681-05 13027 2.88175-02 14000 3.74918-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=127
192235 5.20229-04 92238 3.86634-05 13027 2.88074-02 14000 3.77803-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=128
292235 5.78626-04 92238 4.30035-05 13027 2.86600-02 14000 4.20213-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=129
292235 5.48274-04 92238 4.07477-05 13027 2.87366-02 14000 3.98170-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=130
392235 5.01009-04 92238 3.72350-05 13027 2.88560-02 14000 3.63845-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=131
392235 4.62719-04 92238 3.43893-05 13027 2.89526-02 14000 3.36038-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=132
392235 4.37182-04 92238 3.24914-05 13027 2.90171-02 14000 3.17492-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=133
492235 3.60822-04 92238 2.68163-05 13027 2.92099-02 14000 2.62038-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.1 (continued)

```
26000  6.65000-05 25055 1.04100-05
MIX=134
492235 3.42465-04 92238 2.54520-05 13027 2.92563-02 14000 2.48707-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=135
492235 3.25482-04 92238 2.41898-05 13027 2.92991-02 14000 2.36373-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=136
492235 3.10033-04 92238 2.30416-05 13027 2.93382-02 14000 2.25153-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=137
192235 4.48610-04 92238 3.33407-05 13027 2.89883-02 14000 3.25792-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=138
192235 4.59254-04 92238 3.41318-05 13027 2.89614-02 14000 3.33522-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=139
192235 4.65242-04 92238 3.45768-05 13027 2.89463-02 14000 3.37870-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=140
192235 4.67080-04 92238 3.47134-05 13027 2.89416-02 14000 3.39205-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=141
392235 5.18739-04 92238 3.85527-05 13027 2.88112-02 14000 3.76721-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=142
392235 4.93560-04 92238 3.66814-05 13027 2.88748-02 14000 3.58435-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=143
392235 4.56877-04 92238 3.39551-05 13027 2.89674-02 14000 3.31796-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=144
392235 4.26784-04 92238 3.17186-05 13027 2.90434-02 14000 3.09941-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=145
392235 4.06266-04 92238 3.01937-05 13027 2.90952-02 14000 2.95040-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=146
492235 3.37544-04 92238 2.50862-05 13027 2.92687-02 14000 2.45133-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=147
492235 3.22078-04 92238 2.39368-05 13027 2.93077-02 14000 2.33901-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=148
492235 3.07515-04 92238 2.28545-05 13027 2.93445-02 14000 2.23325-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=149
492235 2.94095-04 92238 2.18572-05 13027 2.93784-02 14000 2.13579-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=150
```

Figure A.1 (continued)

```
492235 3.98379-04 92238 2.96076-05 13027 2.91151-02 14000 2.89313-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=151
492235 4.04114-04 92238 3.00338-05 13027 2.91006-02 14000 2.93478-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=152
492235 4.06445-04 92238 3.02070-05 13027 2.90947-02 14000 2.95170-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=153
492235 4.05902-04 92238 3.01666-05 13027 2.90961-02 14000 2.94776-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=154
492235 3.98482-04 92238 2.96152-05 13027 2.91148-02 14000 2.89387-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=155
492235 3.81859-04 92238 2.83798-05 13027 2.91568-02 14000 2.77316-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=156
492235 3.59195-04 92238 2.66954-05 13027 2.92140-02 14000 2.60857-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=157
492235 3.40459-04 92238 2.53029-05 13027 2.92613-02 14000 2.47250-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=158
492235 3.27474-04 92238 2.43378-05 13027 2.92941-02 14000 2.37820-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=159
492235 3.14386-04 92238 2.33652-05 13027 2.93272-02 14000 2.28315-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=160
492235 3.01755-04 92238 2.24264-05 13027 2.93591-02 14000 2.19142-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=161
492235 2.89513-04 92238 2.15166-05 13027 2.93900-02 14000 2.10251-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=162
492235 2.77873-04 92238 2.06515-05 13027 2.94194-02 14000 2.01798-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=163
1002   6.65600-02  8016  3.32800-02
MIX=164
13027  5.95711-02 26000 3.32300-04   25055 5.20500-05   14000 3.47000-04
24000  6.25000-05
MIX=165
5011   1.93950-03  5010  4.81840-04   1002  3.32800-02  14000 1.73000-04
8016   1.66400-02  13027 2.97800-02   25055 2.60000-05  26000 1.66000-04
24000  3.12000-05
MIX=166
13027  6.02374-02
MIX=167
13027  6.02374-02
MIX=168
5010   1.1198-04
```

Figure A.1 (continued)

```
MIX=169
5010    1.1198-04
MIX=170
492235 6.23842-04 92238 4.63640-05 13027 2.85458-02 14000 4.53050-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=171
492235 6.27553-04 92238 4.66398-05 13027 2.85364-02 14000 4.55745-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=172
492235 6.39024-04 92238 4.74922-05 13027 2.85075-02 14000 4.64075-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=173
492235 6.47395-04 92238 4.81144-05 13027 2.84863-02 14000 4.70154-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=174
492235 6.51633-04 92238 4.84294-05 13027 2.84756-02 14000 4.73232-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=175
492235 6.47087-04 92238 4.80915-05 13027 2.84871-02 14000 4.69931-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=176
192235 6.51042-04 92238 4.83854-05 13027 2.84771-02 14000 4.72803-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=177
192235 6.66767-04 92238 4.95541-05 13027 2.84374-02 14000 4.84223-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=178
192235 6.78863-04 92238 5.04531-05 13027 2.84069-02 14000 4.93007-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=179
392235 6.88219-04 92238 5.11485-05 13027 2.83833-02 14000 4.99802-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=180
192235 6.82704-04 92238 5.07386-05 13027 2.83972-02 14000 4.95797-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=181
192235 6.86715-04 92238 5.10367-05 13027 2.83871-02 14000 4.98710-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=182
392235 6.90055-04 92238 5.12849-05 13027 2.83786-02 14000 5.01135-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=183
392235 6.87421-04 92238 5.10891-05 13027 2.83853-02 14000 4.99222-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=184
192235 6.48329-04 92238 4.81838-05 13027 2.84840-02 14000 4.70833-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=185
192235 6.79825-04 92238 5.05246-05 13027 2.84045-02 14000 4.93706-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
```

Figure A.1 (continued)

```
MIX=186
392235 6.61971-04 92238 4.91977-05 13027 2.84495-02 14000 4.80740-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=187
192235 5.90328-04 92238 4.38732-05 13027 2.86304-02 14000 4.28711-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=188
192235 5.98108-04 92238 4.44514-05 13027 2.86108-02 14000 4.34361-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=189
292235 6.62920-04 92238 4.92682-05 13027 2.84471-02 14000 4.81429-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=190
292235 6.24283-04 92238 4.63967-05 13027 2.85447-02 14000 4.53370-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
END MIXT
READ GEOM
UNIT 1
CYLINDER  168  1  2.38125    0.5    0.0
CYLINDER  166  1  2.54       0.5    0.0
UNIT 2
CYLINDER  169  1  2.38125    0.5    0.0
CYLINDER  167  1  2.54       0.5    0.0
UNIT 3
CYLINDER  168  1  2.38125    1.0    0.0
CYLINDER  166  1  2.54       1.0    0.0
UNIT 4
CYLINDER  169  1  2.38125    1.0    0.0
CYLINDER  167  1  2.54       1.0    0.0
UNIT 5
CYLINDER  168  1  2.38125    2.0    0.0
CYLINDER  166  1  2.54       2.0    0.0
UNIT 6
CYLINDER  169  1  2.38125    2.0    0.0
CYLINDER  167  1  2.54       2.0    0.0
UNIT 7
CYLINDER  168  1  2.38125    3.175  0.0
CYLINDER  166  1  2.54       3.175  0.0
UNIT 8
CYLINDER  169  1  2.38125    3.175  0.0
CYLINDER  167  1  2.54       3.175  0.0
UNIT 9
CYLINDER  168  1  2.38125    4.0    0.0
CYLINDER  166  1  2.54       4.0    0.0
UNIT 10
CYLINDER  169  1  2.38125    4.0    0.0
CYLINDER  167  1  2.54       4.0    0.0
UNIT 11
CYLINDER  168  1  2.38125    6.35   0.0
CYLINDER  166  1  2.54       6.35   0.0
UNIT 12
CYLINDER  169  1  2.38125    6.35   0.0
CYLINDER  167  1  2.54       6.35   0.0
UNIT 13
CYLINDER  163  1  14.325     1.0     0.0
CYLINDER    3  1  14.865     1.0     0.0
CYLINDER  163  1  17.50      1.0     0.0
CYLINDER  165  1  18.50      1.0     0.0
CYLINDER  163  1  24.135     1.0     0.0
CYLINDER    2  1  16.335     1.0     0.0
HOLE        8     0.485      0.0     0.0
```

Figure A.1 (continued)

```
HOLE          4      -30.485    0.0       0.0
CUBOID        1   1   4P150.00  1.0       0.0
CUBOID        0   1   4P150.00  1.0       0.0
UNIT 14
CYLINDER    163   1   14.325    0.5       0.0
CYLINDER      3   1   16.865    0.5       0.0
CYLINDER    163   1   17.50     0.5       0.0
CYLINDER      6   1   17.875    0.5       0.0
CYLINDER      7   1   18.25     0.5       0.0
CYLINDER      8   1   18.625    0.5       0.0
CYLINDER      9   1   19.00     0.5       0.0
CYLINDER    170   1   19.75     0.5       0.0
CYLINDER     10   1   20.50     0.5       0.0
CYLINDER     11   1   21.25     0.5       0.0
CYLINDER     12   1   21.625    0.5       0.0
CYLINDER     13   1   22.00     0.5       0.0
CYLINDER     14   1   22.375    0.5       0.0
CYLINDER     15   1   22.75     0.5       0.0
CYLINDER     16   1   23.125    0.5       0.0
CYLINDER     17   1   23.50     0.5       0.0
CYLINDER    163   1   24.135    0.5       0.0
CYLINDER      2   1   36.835    0.5       0.0
HOLE          1       30.485    0.0       0.0
HOLE          2      -30.485    0.0       0.0
CUBOID        1   1   4P150.00  0.5       0.0
CUBOID        0   1   4P150.00  0.5       0.0
UNIT 15
CYLINDER    163   1   14.325    0.5       0.0
CYLINDER      3   1   16.865    0.5       0.0
CYLINDER    163   1   17.50     0.5       0.0
CYLINDER     18   1   17.875    0.5       0.0
CYLINDER    171   1   18.25     0.5       0.0
CYLINDER    172   1   18.625    0.5       0.0
CYLINDER    173   1   19.00     0.5       0.0
CYLINDER    174   1   19.75     0.5       0.0
CYLINDER    175   1   20.50     0.5       0.0
CYLINDER     19   1   21.25     0.5       0.0
CYLINDER     20   1   21.625    0.5       0.0
CYLINDER     21   1   22.00     0.5       0.0
CYLINDER     22   1   22.375    0.5       0.0
CYLINDER     23   1   22.75     0.5       0.0
CYLINDER     24   1   23.125    0.5       0.0
CYLINDER     25   1   23.50     0.5       0.0
CYLINDER    163   1   24.135    0.5       0.0
CYLINDER      2   1   36.835    0.5       0.0
HOLE          1       30.485    0.0       0.0
HOLE          2      -30.485    0.0       0.0
CUBOID        1   1   4P150.00  0.5       0.0
CUBOID        0   1   4P150.00  0.5       0.0
UNIT 16
CYLINDER    163   1   14.325    0.5       0.0
CYLINDER      3   1   16.865    0.5       0.0
CYLINDER    163   1   17.50     0.5       0.0
CYLINDER     26   1   17.875    0.5       0.0
CYLINDER    176   1   18.25     0.5       0.0
CYLINDER    177   1   18.625    0.5       0.0
CYLINDER    178   1   19.00     0.5       0.0
CYLINDER     27   1   21.625    0.5       0.0
CYLINDER    179   1   22.00     0.5       0.0
CYLINDER     29   1   22.375    0.5       0.0
CYLINDER     30   1   22.75     0.5       0.0
CYLINDER     31   1   23.125    0.5       0.0
CYLINDER     32   1   23.50     0.5       0.0
CYLINDER    163   1   24.135    0.5       0.0
CYLINDER      2   1   36.835    0.5       0.0
HOLE          1       30.485    0.0       0.0
```

Figure A.1 (continued)

```
HOLE          2     -30.485    0.0      0.0
CUBOID        1  1  4P150.00   0.5      0.0
CUBOID        0  1  4P150.00   0.5      0.0
UNIT 17
CYLINDER    163  1  14.325     0.5      0.0
CYLINDER      3  1  16.865     0.5      0.0
CYLINDER    163  1  17.50      0.5      0.0
CYLINDER     33  1  17.875     0.5      0.0
CYLINDER     34  1  18.25      0.5      0.0
CYLINDER    180  1  18.625     0.5      0.0
CYLINDER     27  1  19.00      0.5      0.0
CYLINDER     28  1  22.00      0.5      0.0
CYLINDER     35  1  22.375     0.5      0.0
CYLINDER     36  1  22.75      0.5      0.0
CYLINDER     37  1  23.125     0.5      0.0
CYLINDER     38  1  23.50      0.5      0.0
CYLINDER    163  1  24.135     0.5      0.0
CYLINDER      2  1  36.835     0.5      0.0
HOLE          1      30.485    0.0      0.0
HOLE          2     -30.485    0.0      0.0
CUBOID        1  1  4P150.00   0.5      0.0
CUBOID        0  1  4P150.00   0.5      0.0
UNIT 18
CYLINDER    163  1  14.325     0.5      0.0
CYLINDER      3  1  16.865     0.5      0.0
CYLINDER    163  1  17.50      0.5      0.0
CYLINDER     39  1  17.875     0.5      0.0
CYLINDER     40  1  18.25      0.5      0.0
CYLINDER     27  1  19.00      0.5      0.0
CYLINDER     41  1  20.50      0.5      0.0
CYLINDER     28  1  22.00      0.5      0.0
CYLINDER     42  1  22.375     0.5      0.0
CYLINDER     43  1  22.75      0.5      0.0
CYLINDER     44  1  23.125     0.5      0.0
CYLINDER     45  1  23.50      0.5      0.0
CYLINDER    163  1  24.135     0.5      0.0
CYLINDER      2  1  36.835     0.5      0.0
HOLE          1      30.485    0.0      0.0
HOLE          2     -30.485    0.0      0.0
CUBOID        1  1  4P150.00   0.5      0.0
CUBOID        0  1  4P150.00   0.5      0.0
UNIT 19
CYLINDER    163  1  14.325     0.5      0.0
CYLINDER      3  1  16.865     0.5      0.0
CYLINDER    163  1  17.50      0.5      0.0
CYLINDER     46  1  17.875     0.5      0.0
CYLINDER    181  1  18.25      0.5      0.0
CYLINDER     27  1  19.00      0.5      0.0
CYLINDER     41  1  20.50      0.5      0.0
CYLINDER     28  1  22.00      0.5      0.0
CYLINDER     47  1  22.375     0.5      0.0
CYLINDER     48  1  22.75      0.5      0.0
CYLINDER     49  1  23.125     0.5      0.0
CYLINDER     50  1  23.50      0.5      0.0
CYLINDER    163  1  24.135     0.5      0.0
CYLINDER      2  1  36.835     0.5      0.0
HOLE          1      30.485    0.0      0.0
HOLE          2     -30.485    0.0      0.0
CUBOID        1  1  4P150.00   0.5      0.0
CUBOID        0  1  4P150.00   0.5      0.0
UNIT 20
CYLINDER    163  1  14.325     1.0      0.0
CYLINDER      3  1  16.865     1.0      0.0
CYLINDER    163  1  17.50      1.0      0.0
CYLINDER     51  1  17.375     1.0      0.0
CYLINDER     27  1  19.00      1.0      0.0
```

Figure A.1 (continued)

```
CYLINDER   41  1  20.50     1.0      0.0
CYLINDER   28  1  22.00     1.0      0.0
CYLINDER   52  1  22.375    1.0      0.0
CYLINDER   53  1  22.75     1.0      0.0
CYLINDER   54  1  23.125    1.0      0.0
CYLINDER   55  1  23.50     1.0      0.0
CYLINDER  163  1  24.135    1.0      0.0
CYLINDER    2  1  36.835    1.0      0.0
HOLE        3     30.485    0.0      0.0
HOLE        4    -30.485    0.0      0.0
CUBOID      1  1  4P150.00  1.0      0.0
CUBOID      0  1  4P150.00  1.0      0.0
UNIT 21
CYLINDER  163  1  14.325    1.0      0.0
CYLINDER    3  1  16.865    1.0      0.0
CYLINDER  163  1  17.50     1.0      0.0
CYLINDER   56  1  17.875    1.0      0.0
CYLINDER   27  1  19.00     1.0      0.0
CYLINDER   41  1  20.50     1.0      0.0
CYLINDER   28  1  22.00     1.0      0.0
CYLINDER   57  1  22.375    1.0      0.0
CYLINDER   58  1  22.75     1.0      0.0
CYLINDER   59  1  23.125    1.0      0.0
CYLINDER   60  1  23.50     1.0      0.0
CYLINDER  163  1  24.135    1.0      0.0
CYLINDER    2  1  36.835    1.0      0.0
HOLE        3     30.485    0.0      0.0
HOLE        4    -30.485    0.0      0.0
CUBOID      1  1  4P150.00  1.0      0.0
CUBOID      0  1  4P150.00  1.0      0.0
UNIT 22
CYLINDER  163  1  14.325    2.0      0.0
CYLINDER    3  1  16.865    2.0      0.0
CYLINDER  163  1  17.50     2.0      0.0
CYLINDER   61  1  17.875    2.0      0.0
CYLINDER   27  1  19.00     2.0      0.0
CYLINDER   41  1  20.50     2.0      0.0
CYLINDER   28  1  22.00     2.0      0.0
CYLINDER   62  1  22.375    2.0      0.0
CYLINDER   63  1  22.75     2.0      0.0
CYLINDER   64  1  23.125    2.0      0.0
CYLINDER   65  1  23.50     2.0      0.0
CYLINDER  163  1  24.135    2.0      0.0
CYLINDER    2  1  36.835    2.0      0.0
HOLE        5     30.485    0.0      0.0
HOLE        6    -30.485    0.0      0.0
CUBOID      1  1  4P150.00  2.0      0.0
CUBOID      0  1  4P150.00  2.0      0.0
UNIT 23
CYLINDER  163  1  14.325    2.0      0.0
CYLINDER    3  1  16.865    2.0      0.0
CYLINDER  163  1  17.50     2.0      0.0
CYLINDER   66  1  17.875    2.0      0.0
CYLINDER   27  1  19.00     2.0      0.0
CYLINDER   41  1  20.50     2.0      0.0
CYLINDER   28  1  22.00     2.0      0.0
CYLINDER   67  1  22.375    2.0      0.0
CYLINDER   68  1  22.75     2.0      0.0
CYLINDER   69  1  23.125    2.0      0.0
CYLINDER   70  1  23.50     2.0      0.0
CYLINDER  163  1  24.135    2.0      0.0
CYLINDER    2  1  36.835    2.0      0.0
HOLE        5     30.485    0.0      0.0
HOLE        6    -30.485    0.0      0.0
CUBOID      1  1  4P150.00  2.0      0.0
CUBOID      0  1  4P150.00  2.0      0.0
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Figure A.1 (continued)

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UNIT 24
CYLINDER  163  1  14.325     3.175    0.0
CYLINDER    3  1  16.865     3.175    0.0
CYLINDER  163  1  17.50      3.175    0.0
CYLINDER   71  1  17.375     3.175    0.0
CYLINDER   27  1  19.00      3.175    0.0
CYLINDER   41  1  20.50      3.175    0.0
CYLINDER   28  1  22.00      3.175    0.0
CYLINDER   72  1  22.375     3.175    0.0
CYLINDER   73  1  22.75      3.175    0.0
CYLINDER   74  1  23.125     3.175    0.0
CYLINDER   75  1  23.50      3.175    0.0
CYLINDER  163  1  24.135     3.175    0.0
CYLINDER    2  1  36.835     3.175    0.0
HOLE        7     30.485     0.0      0.0
HOLE        8    -30.485     0.0      0.0
CUBOID      1  1  4P150.00   3.175    0.0
CUBOID      0  1  4P150.00   3.175    0.0
UNIT 25
CYLINDER  163  1  14.325     3.175    0.0
CYLINDER    3  1  16.865     3.175    0.0
CYLINDER  163  1  17.50      3.175    0.0
CYLINDER   76  1  17.875     3.175    0.0
CYLINDER   27  1  19.00      3.175    0.0
CYLINDER   41  1  20.50      3.175    0.0
CYLINDER   28  1  22.00      3.175    0.0
CYLINDER   77  1  22.375     3.175    0.0
CYLINDER   78  1  22.75      3.175    0.0
CYLINDER   79  1  23.125     3.175    0.0
CYLINDER   80  1  23.50      3.175    0.0
CYLINDER  163  1  24.135     3.175    0.0
CYLINDER    2  1  36.835     3.175    0.0
HOLE        7     30.485     0.0      0.0
HOLE        8    -30.485     0.0      0.0
CUBOID      1  1  4P150.00   3.175    0.0
CUBOID      0  1  4P150.00   3.175    0.0
UNIT 26
CYLINDER  163  1  14.325     4.0      0.0
CYLINDER    3  1  16.865     4.0      0.0
CYLINDER  163  1  17.50      4.0      0.0
CYLINDER   81  1  17.875     4.0      0.0
CYLINDER   27  1  19.00      4.0      0.0
CYLINDER   41  1  20.50      4.0      0.0
CYLINDER   28  1  22.00      4.0      0.0
CYLINDER   82  1  22.375     4.0      0.0
CYLINDER   83  1  22.75      4.0      0.0
CYLINDER   84  1  23.125     4.0      0.0
CYLINDER   85  1  23.50      4.0      0.0
CYLINDER  163  1  24.135     4.0      0.0
CYLINDER    2  1  36.835     4.0      0.0
HOLE        9     30.485     0.0      0.0
HOLE       10    -30.485     0.0      0.0
CUBOID      1  1  4P150.00   4.0      0.0
CUBOID      0  1  4P150.00   4.0      0.0
UNIT 27
CYLINDER  163  1  14.325     4.0      0.0
CYLINDER    3  1  16.865     4.0      0.0
CYLINDER  163  1  17.50      4.0      0.0
CYLINDER   86  1  17.875     4.0      0.0
CYLINDER   27  1  19.00      4.0      0.0
CYLINDER   41  1  20.50      4.0      0.0
CYLINDER   28  1  22.00      4.0      0.0
CYLINDER   87  1  22.375     4.0      0.0
CYLINDER   88  1  22.75      4.0      0.0
CYLINDER   89  1  23.125     4.0      0.0
CYLINDER   90  1  23.50      4.0      0.0
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Figure A.1 (continued)

```
CYLINDER  163  1  24.135     4.0       0.0
CYLINDER    2  1  36.835     4.0       0.0
HOLE        9     30.485     0.0       0.0
HOLE       10    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   4.0       0.0
CUBOID      0  1  4P150.00   4.0       0.0
UNIT 28
CYLINDER  163  1  14.325     4.0       0.0
CYLINDER    3  1  16.865     4.0       0.0
CYLINDER  163  1  17.50      4.0       0.0
CYLINDER   91  1  17.875     4.0       0.0
CYLINDER   27  1  19.00      4.0       0.0
CYLINDER   41  1  20.50      4.0       0.0
CYLINDER   28  1  22.00      4.0       0.0
CYLINDER   92  1  22.375     4.0       0.0
CYLINDER   93  1  22.75      4.0       0.0
CYLINDER   94  1  23.125     4.0       0.0
CYLINDER   95  1  23.50      4.0       0.0
CYLINDER  163  1  24.135     4.0       0.0
CYLINDER    2  1  36.835     4.0       0.0
HOLE        9     30.485     0.0       0.0
HOLE       10    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   4.0       0.0
CUBOID      0  1  4P150.00   4.0       0.0
UNIT 29
CYLINDER  163  1  14.325     4.0       0.0
CYLINDER    3  1  16.865     4.0       0.0
CYLINDER  163  1  17.50      4.0       0.0
CYLINDER   27  1  19.00      4.0       0.0
CYLINDER   41  1  20.50      4.0       0.0
CYLINDER   28  1  22.00      4.0       0.0
CYLINDER   96  1  22.375     4.0       0.0
CYLINDER   97  1  22.75      4.0       0.0
CYLINDER   98  1  23.125     4.0       0.0
CYLINDER   99  1  23.50      4.0       0.0
CYLINDER  163  1  24.135     4.0       0.0
CYLINDER    2  1  36.835     4.0       0.0
HOLE        9     30.485     0.0       0.0
HOLE       10    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   4.0       0.0
CUBOID      0  1  4P150.00   4.0       0.0
UNIT 30
CYLINDER  163  1  14.325     4.0       0.0
CYLINDER    3  1  16.865     4.0       0.0
CYLINDER  163  1  17.50      4.0       0.0
CYLINDER   27  1  19.00      4.0       0.0
CYLINDER   41  1  20.50      4.0       0.0
CYLINDER   28  1  21.625     4.0       0.0
CYLINDER  182  1  22.00      4.0       0.0
CYLINDER  100  1  22.375     4.0       0.0
CYLINDER  101  1  22.75      4.0       0.0
CYLINDER  102  1  23.125     4.0       0.0
CYLINDER  103  1  23.50      4.0       0.0
CYLINDER  163  1  24.135     4.0       0.0
CYLINDER    2  1  36.835     4.0       0.0
HOLE        9     30.485     0.0       0.0
HOLE       10    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   4.0       0.0
CUBOID      0  1  4P150.00   4.0       0.0
UNIT 31
CYLINDER  163  1  14.325     6.35      0.0
CYLINDER    3  1  16.865     6.35      0.0
CYLINDER  163  1  17.50      6.35      0.0
CYLINDER   27  1  19.00      6.35      0.0
CYLINDER   41  1  20.50      6.35      0.0
CYLINDER   28  1  21.25      6.35      0.0
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Figure A.1 (continued)

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CYLINDER  103  1  21.625     6.35      0.0
CYLINDER  104  1  22.00      6.35      0.0
CYLINDER  105  1  22.375     6.35      0.0
CYLINDER  106  1  22.75      6.35      0.0
CYLINDER  107  1  23.125     6.35      0.0
CYLINDER  108  1  23.50      6.35      0.0
CYLINDER  163  1  24.135     6.35      0.0
CYLINDER    2  1  36.835     6.35      0.0
HOLE       11     30.485     0.0       0.0
HOLE       12    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   6.35      0.0
CUBOID      0  1  4P150.00   6.35      0.0
UNIT 32
CYLINDER  163  1  14.325     4.0       0.0
CYLINDER    3  1  16.865     4.0       0.0
CYLINDER  163  1  17.50      4.0       0.0
CYLINDER  184  1  18.25      4.0       0.0
CYLINDER  185  1  18.625     4.0       0.0
CYLINDER   27  1  19.00      4.0       0.0
CYLINDER   41  1  20.50      4.0       0.0
CYLINDER  186  1  21.25      4.0       0.0
CYLINDER  109  1  21.625     4.0       0.0
CYLINDER  110  1  22.00      4.0       0.0
CYLINDER  111  1  22.375     4.0       0.0
CYLINDER  112  1  22.75      4.0       0.0
CYLINDER  113  1  23.125     4.0       0.0
CYLINDER  114  1  23.50      4.0       0.0
CYLINDER  163  1  24.135     4.0       0.0
CYLINDER    2  1  36.835     4.0       0.0
HOLE        9     30.485     0.0       0.0
HOLE       10    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   4.0       0.0
CUBOID      0  1  4P150.00   4.0       0.0
UNIT 33
CYLINDER  163  1  14.325     2.0       0.0
CYLINDER    3  1  16.865     2.0       0.0
CYLINDER  163  1  17.50      2.0       0.0
CYLINDER  115  1  17.875     2.0       0.0
CYLINDER  116  1  18.25      2.0       0.0
CYLINDER  187  1  18.625     2.0       0.0
CYLINDER  188  1  19.00      2.0       0.0
CYLINDER  189  1  19.75      2.0       0.0
CYLINDER  190  1  20.50      2.0       0.0
CYLINDER  117  1  21.25      2.0       0.0
CYLINDER  118  1  21.625     2.0       0.0
CYLINDER  119  1  22.00      2.0       0.0
CYLINDER  120  1  22.375     2.0       0.0
CYLINDER  121  1  22.75      2.0       0.0
CYLINDER  122  1  23.125     2.0       0.0
CYLINDER  123  1  23.50      2.0       0.0
CYLINDER  163  1  24.135     2.0       0.0
CYLINDER    2  1  36.835     2.0       0.0
HOLE        5     30.485     0.0       0.0
HOLE        6    -30.485     0.0       0.0
CUBOID      1  1  4P150.00   2.0       0.0
CUBOID      0  1  4P150.00   2.0       0.0
UNIT 34
CYLINDER  163  1  14.325     1.0       0.0
CYLINDER    3  1  16.865     1.0       0.0
CYLINDER  163  1  17.50      1.0       0.0
CYLINDER  124  1  17.875     1.0       0.0
CYLINDER  125  1  18.25      1.0       0.0
CYLINDER  126  1  18.625     1.0       0.0
CYLINDER  127  1  19.00      1.0       0.0
CYLINDER  128  1  19.75      1.0       0.0
CYLINDER  129  1  20.50      1.0       0.0
```

Figure A.1 (continued)

```
CYLINDER  130  1  21.25      1.0    0.0
CYLINDER  131  1  21.625     1.0    0.0
CYLINDER  132  1  22.00      1.0    0.0
CYLINDER  133  1  22.375     1.0    0.0
CYLINDER  134  1  22.75      1.0    0.0
CYLINDER  135  1  23.125     1.0    0.0
CYLINDER  136  1  23.50      1.0    0.0
CYLINDER  163  1  24.135     1.0    0.0
CYLINDER    2  1  36.835     1.0    0.0
HOLE        3     30.485     0.0    0.0
HOLE        4    -30.485     0.0    0.0
CUBOID      1  1  4P150.00   1.0    0.0
CUBOID      0  1  4P150.00   1.0    0.0
UNIT 35
CYLINDER  163  1  14.325     1.0    0.0
CYLINDER    3  1  16.865     1.0    0.0
CYLINDER  163  1  17.50      1.0    0.0
CYLINDER  137  1  17.875     1.0    0.0
CYLINDER  138  1  18.25      1.0    0.0
CYLINDER  139  1  18.625     1.0    0.0
CYLINDER  140  1  19.00      1.0    0.0
CYLINDER  141  1  19.75      1.0    0.0
CYLINDER  142  1  20.50      1.0    0.0
CYLINDER  143  1  21.25      1.0    0.0
CYLINDER  144  1  21.625     1.0    0.0
CYLINDER  145  1  22.00      1.0    0.0
CYLINDER  146  1  22.375     1.0    0.0
CYLINDER  147  1  22.75      1.0    0.0
CYLINDER  148  1  23.125     1.0    0.0
CYLINDER  149  1  23.50      1.0    0.0
CYLINDER  163  1  24.135     1.0    0.0
CYLINDER    2  1  36.835     1.0    0.0
HOLE        3     30.485     0.0    0.0
HOLE        4    -30.485     0.0    0.0
CUBOID      1  1  4P150.00   1.0    0.0
CUBOID      0  1  4P150.00   1.0    0.0
UNIT 36
CYLINDER  163  1  14.325     1.0    0.0
CYLINDER    3  1  16.865     1.0    0.0
CYLINDER  163  1  17.50      1.0    0.0
CYLINDER  150  1  17.875     1.0    0.0
CYLINDER  151  1  18.25      1.0    0.0
CYLINDER  152  1  18.625     1.0    0.0
CYLINDER  153  1  19.00      1.0    0.0
CYLINDER  154  1  19.75      1.0    0.0
CYLINDER  155  1  20.50      1.0    0.0
CYLINDER  156  1  21.25      1.0    0.0
CYLINDER  157  1  21.625     1.0    0.0
CYLINDER  158  1  22.00      1.0    0.0
CYLINDER  159  1  22.375     1.0    0.0
CYLINDER  160  1  22.75      1.0    0.0
CYLINDER  161  1  23.125     1.0    0.0
CYLINDER  162  1  23.50      1.0    0.0
CYLINDER  163  1  24.135     1.0    0.0
CYLINDER    5  1  36.835     1.0    0.0
HOLE        3     30.485     0.0    0.0
HOLE        4    -30.485     0.0    0.0
CUBOID      1  1  4P150.00   1.0    0.0
CUBOID      0  1  4P150.00   1.0    0.0
UNIT 37
CYLINDER  163  1  14.325     1.0    0.0
CYLINDER    3  1  16.865     1.0    0.0
CYLINDER  163  1  17.50      1.0    0.0
CYLINDER  165  1  23.50      1.0    0.0
CYLINDER  163  1  24.135     1.0    0.0
CYLINDER    4  1  36.835     1.0    0.0
HOLE        3     30.485     0.0    0.0
HOLE        4    -30.485     0.0    0.0
CUBOID      1  1  4P150.00   1.0    0.0
CUBOID      0  1  4P150.00   1.0    0.0
UNIT 38
CUBOID      1  1  4P150.00   200.00  0.0
CUBOID      0  1  4P150.00   200.00  0.0
UNIT 39
CYLINDER    5  1  36.835       2.54  0.0
CYLINDER    1  1  150.00     200.00  0.0
CUBOID      0  1  4P150.00   200.00  0.0
END GEOM
READ ARRAY
  ARA=1 NUX=1 NUY=1 NUZ=27 FILL 38 13 14
  15 16 17 18 19 20 21 22 23 24 25 26 27
  28 29 30 31 32 33 34 35 36 37 39 END FILL
END ARRAY
END DATA
END
```

Figure A.1 (continued)

```
~/library/ansa2cmod
ANS REFUELING MODEL: 1" Stainless Steel, 2 1/4" Al
READ PARAM
  TME=900.0 TBA=15.0 NPG=500 NSK=5 GEN=500 LIB=34 TRK=NO RUN=YES
  NB8=1800
END PARAM
READ MIXT  SCT=2 EPS=1
MIX=1
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=2
492235 6.51910-04 92238 4.84499-05 13027 2.84749-02 14000 4.73433-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=3
492235 6.35669-04 92238 4.72429-05 13027 2.85160-02 14000 4.61639-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=4
492235 6.19189-04 92238 4.60182-05 13027 2.85576-02 14000 4.49671-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=5
492235 6.02475-04 92238 4.47759-05 13027 2.85998-02 14000 4.37532-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=6
492235 6.76478-04 92238 5.02759-05 13027 2.84129-02 14000 4.91276-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=7
492235 6.54706-04 92238 4.86578-05 13027 2.84679-02 14000 4.75464-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=8
492235 6.32829-04 92238 4.70318-05 13027 2.85231-02 14000 4.59576-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=9
492235 6.10563-04 92238 4.53771-05 13027 2.85793-02 14000 4.43406-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=10
192235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=11
392235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=12
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=13
492235 6.69870-04 92238 4.97848-05 13027 2.84296-02 14000 4.86477-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=14
492235 6.43465-04 92238 4.78224-05 13027 2.84963-02 14000 4.67301-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=15
492235 6.17337-04 92238 4.58805-05 13027 2.85622-02 14000 4.48325-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.2 KENO Va Input File For Lower Annulus/Isolator Assembly

```
26000  6.65000-05 25055 1.04100-05
MIX=16
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=17
492235 6.82445-04 92238 5.07193-05 13027 2.83979-02 14000 4.95608-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=18
492235 6.52418-04 92238 4.84877-05 13027 2.84737-02 14000 4.73802-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=19
492235 6.23184-04 92238 4.63151-05 13027 2.85475-02 14000 4.52572-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=20
292235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=21
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=22
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=23
492235 6.60114-04 92238 4.90597-05 13027 2.84542-02 14000 4.79391-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=24
492235 6.28254-04 92238 4.66918-05 13027 2.85347-02 14000 4.56254-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=25
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=26
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=27
492235 6.66112-04 92238 4.95054-05 13027 2.84391-02 14000 4.83747-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=28
492235 6.32165-04 92238 4.69825-05 13027 2.85248-02 14000 4.59094-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=29
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=30
492235 6.72469-04 92238 4.99779-05 13027 2.84230-02 14000 4.88363-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=31
492235 6.36117-04 92238 4.72763-05 13027 2.85148-02 14000 4.61964-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=32
```

Figure A.2 (continued)

```
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=33
492235 6.77813-04 92238 5.03751-05 13027 2.84095-02 14000 4.92245-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=34
492235 6.38841-04 92238 4.74787-05 13027 2.85079-02 14000 4.63942-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=35
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=36
492235 6.76211-04 92238 5.02560-05 13027 2.84136-02 14000 4.91081-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=37
492235 6.35828-04 92238 4.72547-05 13027 2.85156-02 14000 4.61754-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=38
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=39
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=40
492235 6.64457-04 92238 4.93825-05 13027 2.84433-02 14000 4.82545-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=41
492235 6.24363-04 92238 4.64027-05 13027 2.85445-02 14000 4.53428-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=42
492235 6.91180-04 92238 5.13685-05 13027 2.83758-02 14000 5.01952-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=43
492235 6.79431-04 92238 5.04953-05 13027 2.84055-02 14000 4.93420-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=44
492235 6.38913-04 92238 4.74840-05 13027 2.85078-02 14000 4.63994-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=45
492235 6.00833-04 92238 4.46539-05 13027 2.86039-02 14000 4.36340-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=46
492235 6.77168-04 92238 5.03271-05 13027 2.84112-02 14000 4.91776-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=47
492235 6.36933-04 92238 4.73368-05 13027 2.85128-02 14000 4.62556-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=48
492235 6.00348-04 92238 4.46179-05 13027 2.86051-02 14000 4.35988-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.2 (continued)

```
26000  6.65000-05 25055 1.04100-05
MIX=49
492235 5.65927-04 92238 4.20597-05 13027 2.86920-02 14000 4.10990-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=50
492235 6.21619-04 92238 4.61987-05 13027 2.85514-02 14000 4.51435-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=51
492235 5.87121-04 92238 4.36348-05 13027 2.86385-02 14000 4.26382-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=52
492235 5.55009-04 92238 4.12482-05 13027 2.87196-02 14000 4.03061-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=53
492235 5.24746-04 92238 3.89991-05 13027 2.87960-02 14000 3.81084-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=54
492235 6.61722-04 92238 4.91792-05 13027 2.84502-02 14000 4.80559-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=55
492235 5.59064-04 92238 4.15496-05 13027 2.87094-02 14000 4.06006-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=56
492235 5.30764-04 92238 3.94464-05 13027 2.87808-02 14000 3.85454-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=57
492235 5.05151-04 92238 3.75428-05 13027 2.88455-02 14000 3.66854-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=58
492235 4.79849-04 92238 3.56624-05 13027 2.89094-02 14000 3.48479-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=59
492235 6.14302-04 92238 4.56549-05 13027 2.85699-02 14000 4.46122-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=60
492235 6.19655-04 92238 4.60528-05 13027 2.85564-02 14000 4.50009-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=61
492235 5.86858-04 92238 4.36153-05 13027 2.86392-02 14000 4.26191-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=62
492235 5.00508-04 92238 3.71978-05 13027 2.88572-02 14000 3.63482-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=63
492235 4.76989-04 92238 3.54498-05 13027 2.89166-02 14000 3.46401-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=64
492235 4.55020-04 92238 3.38171-05 13027 2.89721-02 14000 3.30447-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=65
```

Figure A.2 (continued)

```
492235 4.34303-04 92238 3.22774-05 13027 2.90244-02 14000 3.15402-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=66
192235 5.28939-04 92238 3.93107-05 13027 2.87854-02 14000 3.84128-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=67
192235 5.48460-04 92238 4.07615-05 13027 2.87361-02 14000 3.98305-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=68
192235 5.64119-04 92238 4.19253-05 13027 2.86966-02 14000 4.09677-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=69
192235 5.74873-04 92238 4.27246-05 13027 2.86695-02 14000 4.17487-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=70
292235 6.13933-04 92238 4.56275-05 13027 2.85708-02 14000 4.45853-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=71
392235 5.72067-04 92238 4.25160-05 13027 2.86765-02 14000 4.15449-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=72
392235 5.35641-04 92238 3.98089-05 13027 2.87685-02 14000 3.88996-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=73
392235 5.11575-04 92238 3.80202-05 13027 2.88293-02 14000 3.71518-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=74
492235 4.40815-04 92238 3.27614-05 13027 2.90079-02 14000 3.20131-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=75
492235 4.23102-04 92238 3.14449-05 13027 2.90527-02 14000 3.07267-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=76
492235 4.06335-04 92238 3.01988-05 13027 2.90950-02 14000 2.95091-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=77
492235 3.90442-04 92238 2.90177-05 13027 2.91351-02 14000 2.83549-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=78
192235 4.47145-04 92238 3.32318-05 13027 2.89920-02 14000 3.24728-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=79
192235 4.58507-04 92238 3.40762-05 13027 2.89633-02 14000 3.32979-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=80
192235 4.67418-04 92238 3.47385-05 13027 2.89408-02 14000 3.39451-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=81
192235 4.73473-04 92238 3.51885-05 13027 2.89255-02 14000 3.43848-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.2 (continued)

```
26000  6.65000-05 25055 1.04100-05
MIX=82
292235 5.20671-04 92238 3.86962-05 13027 2.88063-02 14000 3.78124-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=83
292235 5.08011-04 92238 3.77554-05 13027 2.88383-02 14000 3.68930-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=84
392235 4.81363-04 92238 3.57749-05 13027 2.89056-02 14000 3.49578-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=85
392235 4.57609-04 92238 3.40095-05 13027 2.89655-02 14000 3.32327-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=86
392235 4.41225-04 92238 3.27918-05 13027 2.90069-02 14000 3.20429-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=87
492235 3.84657-04 92238 2.85877-05 13027 2.91497-02 14000 2.79347-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=88
492235 3.72120-04 92238 2.76560-05 13027 2.91814-02 14000 2.70243-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=89
492235 3.60065-04 92238 2.67600-05 13027 2.92118-02 14000 2.61488-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=90
492235 3.48488-04 92238 2.58996-05 13027 2.92411-02 14000 2.53081-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=91
192235 3.60047-04 92238 2.67587-05 13027 2.92119-02 14000 2.61475-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=92
192235 3.66168-04 92238 2.72136-05 13027 2.91964-02 14000 2.65921-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=93
192235 3.70904-04 92238 2.75656-05 13027 2.91845-02 14000 2.69360-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=94
192235 3.74104-04 92238 2.78034-05 13027 2.91764-02 14000 2.71684-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=95
292235 4.10454-04 92238 3.05049-05 13027 2.90846-02 14000 2.98082-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=96
292235 4.03846-04 92238 3.00138-05 13027 2.91013-02 14000 2.93283-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=97
392235 3.89054-04 92238 2.89145-05 13027 2.91386-02 14000 2.82540-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=98
```

Figure A.2 (continued)

```
392235 3.75362-04 92238 2.78969-05 13027 2.91732-02 14000 2.72597-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=99
392235 3.65427-04 92238 2.71585-05 13027 2.91983-02 14000 2.65382-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=100
492235 3.22586-04 92238 2.39746-05 13027 2.93065-02 14000 2.34270-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=101
492235 3.14569-04 92238 2.33788-05 13027 2.93267-02 14000 2.28448-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=102
492235 3.06796-04 92238 2.28011-05 13027 2.93463-02 14000 2.22803-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=103
492235 2.99292-04 92238 2.22434-05 13027 2.93653-02 14000 2.17354-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=104
192235 2.90077-04 92238 2.15585-05 13027 2.93885-02 14000 2.10661-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=105
192235 2.93858-04 92238 2.18395-05 13027 2.93790-02 14000 2.13407-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=106
192235 2.96832-04 92238 2.20606-05 13027 2.93715-02 14000 2.15567-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=107
192235 2.98973-04 92238 2.22197-05 13027 2.93661-02 14000 2.17122-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=108
292235 3.27800-04 92238 2.43621-05 13027 2.92933-02 14000 2.38057-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=109
292235 3.25061-04 92238 2.41586-05 13027 2.93002-02 14000 2.36068-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=110
392235 3.17255-04 92238 2.35784-05 13027 2.93199-02 14000 2.30398-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=111
392235 3.09607-04 92238 2.30100-05 13027 2.93392-02 14000 2.24844-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=112
392235 3.03757-04 92238 2.25752-05 13027 2.93540-02 14000 2.20596-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=113
492235 2.70748-04 92238 2.01220-05 13027 2.94373-02 14000 1.96624-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=114
492235 2.65723-04 92238 1.97485-05 13027 2.94500-02 14000 1.92975-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
```

Figure A.2 (continued)

```
26000  6.65000-05 25055 1.04100-05
MIX=115
492235 2.60699-04 92238 1.93751-05 13027 2.94627-02 14000 1.89326-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=116
492235 2.55764-04 92238 1.90084-05 13027 2.94752-02 14000 1.85742-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=117
192235 2.54143-04 92238 1.88879-05 13027 2.94793-02 14000 1.84565-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=118
192235 2.57182-04 92238 1.91138-05 13027 2.94716-02 14000 1.86772-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=119
192235 2.59715-04 92238 1.93020-05 13027 2.94652-02 14000 1.88611-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=120
192235 2.61673-04 92238 1.94475-05 13027 2.94603-02 14000 1.90034-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=121
292235 2.87126-04 92238 2.13392-05 13027 2.93960-02 14000 2.08518-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=122
292235 2.86209-04 92238 2.12710-05 13027 2.93983-02 14000 2.07852-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=123
392235 2.81482-04 92238 2.09197-05 13027 2.94102-02 14000 2.04419-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=124
392235 2.76505-04 92238 2.05499-05 13027 2.94228-02 14000 2.00805-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=125
392235 2.72485-04 92238 2.02511-05 13027 2.94330-02 14000 1.97885-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=126
492235 2.43902-04 92238 1.81268-05 13027 2.95051-02 14000 1.77128-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=127
492235 2.40230-04 92238 1.78539-05 13027 2.95144-02 14000 1.74461-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=128
492235 2.36477-04 92238 1.75750-05 13027 2.95239-02 14000 1.71736-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=129
492235 2.32727-04 92238 1.72962-05 13027 2.95333-02 14000 1.69012-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=130
192235 2.36879-04 92238 1.76049-05 13027 2.95229-02 14000 1.72028-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=131
```

Figure A.2 (continued)

```
192235 2.39597-04 92238 1.78069-05 13027 2.95160-02 14000 1.74001-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=132
192235 2.41946-04 92238 1.79814-05 13027 2.95101-02 14000 1.75707-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=133
192235 2.43862-04 92238 1.81238-05 13027 2.95052-02 14000 1.77099-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=134
292235 2.67962-04 92238 1.99150-05 13027 2.94444-02 14000 1.94601-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=135
292235 2.67980-04 92238 1.99162-05 13027 2.94443-02 14000 1.94613-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=136
392235 2.64701-04 92238 1.96726-05 13027 2.94526-02 14000 1.92232-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=137
392235 2.60976-04 92238 1.93957-05 13027 2.94620-02 14000 1.89527-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=138
392235 2.57820-04 92238 1.91612-05 13027 2.94700-02 14000 1.87235-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=139
492235 2.31139-04 92238 1.71783-05 13027 2.95373-02 14000 1.67859-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=140
492235 2.28130-04 92238 1.69547-05 13027 2.95449-02 14000 1.65674-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=141
492235 2.24988-04 92238 1.67211-05 13027 2.95529-02 14000 1.63392-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=142
492235 2.21796-04 92238 1.64839-05 13027 2.95609-02 14000 1.61074-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=143
192235 2.25538-04 92238 1.67620-05 13027 2.95515-02 14000 1.63791-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=144
192235 2.28033-04 92238 1.69474-05 13027 2.95452-02 14000 1.65603-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=145
192235 2.30234-04 92238 1.71110-05 13027 2.95396-02 14000 1.67201-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=146
192235 2.32081-04 92238 1.72482-05 13027 2.95350-02 14000 1.68543-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=147
392235 2.54986-04 92238 1.89506-05 13027 2.94771-02 14000 1.85177-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
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Figure A.2 (continued)

```
26000  6.65000-05 25055 1.04100-05
MIX=148
392235 2.55597-04 92238 1.89959-05 13027 2.94756-02 14000 1.85621-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=149
392235 2.53652-04 92238 1.88514-05 13027 2.94805-02 14000 1.84208-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=150
392235 2.50811-04 92238 1.86403-05 13027 2.94877-02 14000 1.82145-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=151
392235 2.48272-04 92238 1.84516-05 13027 2.94941-02 14000 1.80301-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=152
492235 2.22753-04 92238 1.65550-05 13027 2.95585-02 14000 1.61769-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=153
492235 2.20213-04 92238 1.63662-05 13027 2.95649-02 14000 1.59924-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=154
492235 2.17505-04 92238 1.61650-05 13027 2.95718-02 14000 1.57958-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=155
492235 2.14707-04 92238 1.59571-05 13027 2.95788-02 14000 1.55926-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=156
492235 2.11610-04 92238 1.57269-05 13027 2.95867-02 14000 1.53677-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=157
492235 2.13754-04 92238 1.58862-05 13027 2.95812-02 14000 1.55233-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=158
492235 2.15637-04 92238 1.60261-05 13027 2.95765-02 14000 1.56601-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=159
492235 2.17251-04 92238 1.61461-05 13027 2.95724-02 14000 1.57773-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=160
492235 2.18801-04 92238 1.62613-05 13027 2.95685-02 14000 1.58899-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=161
492235 2.19660-04 92238 1.63251-05 13027 2.95663-02 14000 1.59523-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=162
492235 2.18937-04 92238 1.62714-05 13027 2.95682-02 14000 1.58997-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=163
492235 2.17485-04 92238 1.61635-05 13027 2.95718-02 14000 1.57943-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=164
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Figure A.2 (continued)

```
492235 2.16062-04 92238 1.60577-05 13027 2.95754-02 14000 1.56910-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=165
492235 2.14294-04 92238 1.59263-05 13027 2.95799-02 14000 1.55626-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=166
492235 2.12304-04 92238 1.57784-05 13027 2.95849-02 14000 1.54180-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=167
492235 2.10092-04 92238 1.56140-05 13027 2.95905-02 14000 1.52574-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=168
492235 2.07720-04 92238 1.54377-05 13027 2.95965-02 14000 1.50851-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=169
1002   6.65600-02 8016  3.32800-02
MIX=170
13027  5.59711-02 26000 3.32300-04 25055 5.20500-05 14000 3.47000-04
24000  6.25000-05
MIX=171
5011   1.93950-03  5010  4.81840-04   1002  3.32800-02  14000 1.73000-04
8016   1.66400-02  13027 2.97800-02   25055 2.60000-05  26000 1.66000-04
24000  3.12000-05
MIX=172
5010   1.11980-04
MIX=173
5010   1.11980-04
MIX=174
492235 6.86234-04 92238 5.10009-05 13027 2.83883-02 14000 4.98360-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=175
492235 6.68009-04 92238 4.96465-05 13027 2.84343-02 14000 4.85125-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=176
192235 6.42568-04 92238 4.77557-05 13027 2.84985-02 14000 4.66649-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=177
192235 6.65108-04 92238 4.94308-05 13027 2.84416-02 14000 4.83018-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=178
192235 6.80243-04 92238 5.05557-05 13027 2.84034-02 14000 4.94010-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=179
392235 6.69261-04 92238 4.97395-05 13027 2.84311-02 14000 4.86034-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=180
292235 6.33685-04 92238 4.70954-05 13027 2.85210-02 14000 4.60198-04
24000  1.25000-05 1002  3.32800-02  8016 1.66400-02
26000  6.65000-05 25055 1.04100-05
MIX=181
13027  6.02374-02
MIX=182
24000  1.74300-02 25055 1.73500-03 26000 5.93600-02 28000 7.72100-03
END MIXT
READ GEOM
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Figure A.2 (continued)

```
UNIT 1
CYLINDER  172  1  2.38125   0.5    0.0
CYLINDER  181  1  2.54      0.5    0.0
UNIT 2
CYLINDER  173  1  2.38125   0.5    0.0
CYLINDER  181  1  2.54      0.5    0.0
UNIT 3
CYLINDER  172  1  2.38125   1.0    0.0
CYLINDER  181  1  2.54      1.0    0.0
UNIT 4
CYLINDER  173  1  2.38125   1.0    0.0
CYLINDER  181  1  2.54      1.0    0.0
UNIT 5
CYLINDER  172  1  2.38125   2.0    0.0
CYLINDER  181  1  2.54      2.0    0.0
UNIT 6
CYLINDER  173  1  2.38125   2.0    0.0
CYLINDER  181  1  2.54      2.0    0.0
UNIT 7
CYLINDER  172  1  2.38125   3.175  0.0
CYLINDER  181  1  2.54      3.175  0.0
UNIT 8
CYLINDER  173  1  2.38125   3.175  0.0
CYLINDER  181  1  2.54      3.175  0.0
UNIT 9
CYLINDER  172  1  2.38125   4.0    0.0
CYLINDER  181  1  2.54      4.0    0.0
UNIT 10
CYLINDER  173  1  2.38125   4.0    0.0
CYLINDER  181  1  2.54      4.0    0.0
UNIT 11
CYLINDER  172  1  2.38125   6.35   0.0
CYLINDER  181  1  2.54      6.35   0.0
UNIT 12
CYLINDER  173  1  2.38125   6.35   0.0
CYLINDER  181  1  2.54      6.35   0.0
UNIT 13
CYLINDER  169  1  7.025     1.0     0.0
CYLINDER  182  1  9.565     1.0     0.0
CYLINDER  169  1  10.20     1.0     0.0
CYLINDER  171  1  16.80     1.0     0.0
CYLINDER  169  1  17.435    1.0     0.0
CYLINDER  181  1  23.15     1.0     0.0
HOLE        3     20.2925   0.0     0.0
HOLE        4    -20.2925   0.0     0.0
CUBOID    169  1  4P150.00  1.0     0.0
CUBOID      0  1  4P150.00  1.0     0.0
UNIT 14
CYLINDER  169  1  7.025     0.5     0.0
CYLINDER  182  1  9.565     0.5     0.0
CYLINDER  169  1  10.20     0.5     0.0
CYLINDER  174  1  10.6125   0.5     0.0
CYLINDER    1  1  14.7375   0.5     0.0
CYLINDER  175  1  15.15     0.5     0.0
CYLINDER    2  1  15.5625   0.5     0.0
CYLINDER    3  1  15.975    0.5     0.0
CYLINDER    4  1  16.3875   0.5     0.0
CYLINDER    5  1  16.80     0.5     0.0
CYLINDER  169  1  17.435    0.5     0.0
CYLINDER  181  1  23.15     0.5     0.0
HOLE        1     20.2925   0.0     0.0
HOLE        2    -20.2925   0.0     0.0
CUBOID    169  1  4P150.00  0.5     0.0
CUBOID      0  1  4P150.00  0.5     0.0
UNIT 15
CYLINDER  169  1  7.025     0.5     0.0
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Figure A.2 (continued)

```
CYLINDER  182  1  9.565      0.5    0.0
CYLINDER  169  1  10.20      0.5    0.0
CYLINDER    1  1  15.15      0.5    0.0
CYLINDER    6  1  15.5625    0.5    0.0
CYLINDER    7  1  15.975     0.5    0.0
CYLINDER    8  1  16.3875    0.5    0.0
CYLINDER    9  1  16.80      0.5    0.0
CYLINDER  169  1  17.435     0.5    0.0
CYLINDER  181  1  23.15      0.5    0.0
HOLE        1     20.2925    0.0    0.0
HOLE        2    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   0.5    0.0
CUBOID      0  1  4P150.00   0.5    0.0
UNIT 16
CYLINDER  169  1  7.025      0.5    0.0
CYLINDER  182  1  9.565      0.5    0.0
CYLINDER  169  1  10.20      0.5    0.0
CYLINDER   10  1  11.85      0.5    0.0
CYLINDER   11  1  15.15      0.5    0.0
CYLINDER   12  1  15.5625    0.5    0.0
CYLINDER   13  1  15.975     0.5    0.0
CYLINDER   14  1  16.3875    0.5    0.0
CYLINDER   15  1  16.80      0.5    0.0
CYLINDER  169  1  17.435     0.5    0.0
CYLINDER  181  1  23.15      0.5    0.0
HOLE        1     20.2925    0.0    0.0
HOLE        2    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   0.5    0.0
CUBOID      0  1  4P150.00   0.5    0.0
UNIT 17
CYLINDER  169  1  7.025      0.5    0.0
CYLINDER  182  1  9.565      0.5    0.0
CYLINDER  169  1  10.20      0.5    0.0
CYLINDER   10  1  11.85      0.5    0.0
CYLINDER   11  1  15.15      0.5    0.0
CYLINDER   16  1  15.5625    0.5    0.0
CYLINDER   17  1  15.975     0.5    0.0
CYLINDER   18  1  16.3875    0.5    0.0
CYLINDER   19  1  16.80      0.5    0.0
CYLINDER  169  1  17.435     0.5    0.0
CYLINDER  181  1  23.15      0.5    0.0
HOLE        1     20.2925    0.0    0.0
HOLE        2    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   0.5    0.0
CUBOID      0  1  4P150.00   0.5    0.0
UNIT 18
CYLINDER  169  1  7.025      0.5    0.0
CYLINDER  182  1  9.565      0.5    0.0
CYLINDER  169  1  10.20      0.5    0.0
CYLINDER   10  1  11.85      0.5    0.0
CYLINDER   20  1  13.50      0.5    0.0
CYLINDER   11  1  15.15      0.5    0.0
CYLINDER   21  1  15.5625    0.5    0.0
CYLINDER   22  1  15.975     0.5    0.0
CYLINDER   23  1  16.3875    0.5    0.0
CYLINDER   24  1  16.80      0.5    0.0
CYLINDER  169  1  17.435     0.5    0.0
CYLINDER  181  1  23.15      0.5    0.0
HOLE        1     20.2925    0.0    0.0
HOLE        2    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   0.5    0.0
CUBOID      0  1  4P150.00   0.5    0.0
UNIT 19
CYLINDER  169  1  7.025      0.5    0.0
CYLINDER  182  1  9.565      0.5    0.0
CYLINDER  169  1  10.20      0.5    0.0
```

Figure A.2 (continued)

```
CYLINDER  10  1  11.85     0.5   0.0
CYLINDER  20  1  13.50     0.5   0.0
CYLINDER  11  1  15.15     0.5   0.0
CYLINDER  25  1  15.5625   0.5   0.0
CYLINDER  26  1  15.975    0.5   0.0
CYLINDER  27  1  16.3875   0.5   0.0
CYLINDER  28  1  16.80     0.5   0.0
CYLINDER 169  1  17.435    0.5   0.0
CYLINDER 181  1  23.15     0.5   0.0
HOLE       1     20.2925   0.0   0.0
HOLE       2    -20.2925   0.0   0.0
CUBOID   169  1  4P150.00  0.5   0.0
CUBOID     0  1  4P150.00  0.5   0.0
UNIT 20
CYLINDER 169  1  7.025     1.0   0.0
CYLINDER 182  1  9.565     1.0   0.0
CYLINDER 169  1  10.20     1.0   0.0
CYLINDER  10  1  11.85     1.0   0.0
CYLINDER  20  1  13.50     1.0   0.0
CYLINDER  11  1  15.15     1.0   0.0
CYLINDER   1  1  15.5625   1.0   0.0
CYLINDER  29  1  15.975    1.0   0.0
CYLINDER  30  1  16.3875   1.0   0.0
CYLINDER  31  1  16.80     1.0   0.0
CYLINDER 169  1  17.435    1.0   0.0
CYLINDER 181  1  23.15     1.0   0.0
HOLE       3     20.2925   0.0   0.0
HOLE       4    -20.2925   0.0   0.0
CUBOID   169  1  4P150.00  1.0   0.0
CUBOID     0  1  4P150.00  1.0   0.0
UNIT 21
CYLINDER 169  1  7.025     1.0   0.0
CYLINDER 182  1  9.565     1.0   0.0
CYLINDER 169  1  10.20     1.0   0.0
CYLINDER  10  1  11.85     1.0   0.0
CYLINDER  20  1  13.50     1.0   0.0
CYLINDER  11  1  15.15     1.0   0.0
CYLINDER   1  1  15.5625   1.0   0.0
CYLINDER  32  1  15.975    1.0   0.0
CYLINDER  33  1  16.3875   1.0   0.0
CYLINDER  34  1  16.80     1.0   0.0
CYLINDER 169  1  17.435    1.0   0.0
CYLINDER 181  1  23.15     1.0   0.0
HOLE       3     20.2925   0.0   0.0
HOLE       4    -20.2925   0.0   0.0
CUBOID   169  1  4P150.00  1.0   0.0
CUBOID     0  1  4P150.00  1.0   0.0
UNIT 22
CYLINDER 169  1  7.025     2.0   0.0
CYLINDER 182  1  9.565     2.0   0.0
CYLINDER 169  1  10.20     2.0   0.0
CYLINDER  10  1  11.85     2.0   0.0
CYLINDER  20  1  13.50     2.0   0.0
CYLINDER  11  1  15.15     2.0   0.0
CYLINDER   1  1  15.5625   2.0   0.0
CYLINDER  35  1  15.975    2.0   0.0
CYLINDER  36  1  16.3875   2.0   0.0
CYLINDER  37  1  16.80     2.0   0.0
CYLINDER 169  1  17.435    2.0   0.0
CYLINDER 181  1  23.15     2.0   0.0
HOLE       5     20.2925   0.0   0.0
HOLE       6    -20.2925   0.0   0.0
CUBOID   169  1  4P150.00  2.0   0.0
CUBOID     0  1  4P150.00  2.0   0.0
UNIT 23
CYLINDER 169  1  7.025     2.0   0.0
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Figure A.2 (continued)

```
CYLINDER  182  1   9.565      2.0     0.0
CYLINDER  169  1  10.20       2.0     0.0
CYLINDER   10  1  11.85       2.0     0.0
CYLINDER   20  1  13.50       2.0     0.0
CYLINDER   11  1  15.15       2.0     0.0
CYLINDER   38  1  15.5625     2.0     0.0
CYLINDER   39  1  15.975      2.0     0.0
CYLINDER   40  1  16.3875     2.0     0.0
CYLINDER   41  1  16.80       2.0     0.0
CYLINDER  169  1  17.435      2.0     0.0
CYLINDER  181  1  23.15       2.0     0.0
HOLE        5     20.2925     0.0     0.0
HOLE        6    -20.2925     0.0     0.0
CUBOID    169  1  4P150.00    2.0     0.0
CUBOID      0  1  4P150.00    2.0     0.0
UNIT 24
CYLINDER  169  1   7.025      3.175   0.0
CYLINDER  182  1   9.565      3.175   0.0
CYLINDER  169  1  10.20       3.175   0.0
CYLINDER   10  1  11.85       3.175   0.0
CYLINDER   20  1  13.50       3.175   0.0
CYLINDER   11  1  15.15       3.175   0.0
CYLINDER   42  1  15.5625     3.175   0.0
CYLINDER   43  1  15.975      3.175   0.0
CYLINDER   44  1  16.3875     3.175   0.0
CYLINDER   45  1  16.80       3.175   0.0
CYLINDER  169  1  17.435      3.175   0.0
CYLINDER  181  1  23.15       3.175   0.0
HOLE        7     20.2925     0.0     0.0
HOLE        8    -20.2925     0.0     0.0
CUBOID    169  1  4P150.00    3.175   0.0
CUBOID      0  1  4P150.00    3.175   0.0
UNIT 25
CYLINDER  169  1   7.025      3.175   0.0
CYLINDER  182  1   9.565      3.175   0.0
CYLINDER  169  1  10.20       3.175   0.0
CYLINDER   10  1  11.85       3.175   0.0
CYLINDER   20  1  13.50       3.175   0.0
CYLINDER   11  1  15.15       3.175   0.0
CYLINDER   46  1  15.5625     3.175   0.0
CYLINDER   47  1  15.975      3.175   0.0
CYLINDER   48  1  16.3875     3.175   0.0
CYLINDER   49  1  16.80       3.175   0.0
CYLINDER  169  1  17.435      3.175   0.0
CYLINDER  181  1  23.15       3.175   0.0
HOLE        7     20.2925     0.0     0.0
HOLE        9    -20.2925     0.0     0.0
CUBOID    169  1  4P150.00    3.175   0.0
CUBOID      0  1  4P150.00    3.175   0.0
UNIT 26
CYLINDER  169  1   7.025      4.0     0.0
CYLINDER  182  1   9.565      4.0     0.0
CYLINDER  169  1  10.20       4.0     0.0
CYLINDER   10  1  11.85       4.0     0.0
CYLINDER   20  1  13.50       4.0     0.0
CYLINDER   11  1  15.15       4.0     0.0
CYLINDER   50  1  15.5625     4.0     0.0
CYLINDER   51  1  15.975      4.0     0.0
CYLINDER   52  1  16.3875     4.0     0.0
CYLINDER   53  1  16.80       4.0     0.0
CYLINDER  169  1  17.435      4.0     0.0
CYLINDER  181  1  23.15       4.0     0.0
HOLE        9     20.2925     0.0     0.0
HOLE       10    -20.2925     0.0     0.0
CUBOID    169  1  4P150.00    4.0     0.0
CUBOID      0  1  4P150.00    4.0     0.0
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Figure A.2 (continued)

```
UNIT 27
CYLINDER  169  1  7.025     4.0    0.0
CYLINDER  182  1  9.565     4.0    0.0
CYLINDER  169  1  10.20     4.0    0.0
CYLINDER   10  1  11.85     4.0    0.0
CYLINDER   20  1  13.50     4.0    0.0
CYLINDER   11  1  14.7375   4.0    0.0
CYLINDER   54  1  15.15     4.0    0.0
CYLINDER   55  1  15.5625   4.0    0.0
CYLINDER   56  1  15.975    4.0    0.0
CYLINDER   57  1  16.3875   4.0    0.0
CYLINDER   58  1  16.80     4.0    0.0
CYLINDER  169  1  17.435    4.0    0.0
CYLINDER  181  1  23.15     4.0    0.0
HOLE        9     20.2925   0.0    0.0
HOLE       10    -20.2925   0.0    0.0
CUBOID    169  1  4P150.00  4.0    0.0
CUBOID      0  1  4P150.00  4.0    0.0
UNIT 28
CYLINDER  169  1  7.025     4.0    0.0
CYLINDER  182  1  9.565     4.0    0.0
CYLINDER  169  1  10.20     4.0    0.0
CYLINDER   59  1  10.6125   4.0    0.0
CYLINDER  176  1  11.05     4.0    0.0
CYLINDER  177  1  11.4375   4.0    0.0
CYLINDER  178  1  11.85     4.0    0.0
CYLINDER   20  1  13.50     4.0    0.0
CYLINDER  179  1  14.325    4.0    0.0
CYLINDER   60  1  14.7375   4.0    0.0
CYLINDER   61  1  15.15     4.0    0.0
CYLINDER   62  1  15.5625   4.0    0.0
CYLINDER   63  1  15.975    4.0    0.0
CYLINDER   64  1  16.3875   4.0    0.0
CYLINDER   65  1  16.80     4.0    0.0
CYLINDER  169  1  17.435    4.0    0.0
CYLINDER  181  1  23.15     4.0    0.0
HOLE        9     20.2925   0.0    0.0
HOLE       10    -20.2925   0.0    0.0
CUBOID    169  1  4P150.00  4.0    0.0
CUBOID      0  1  4P150.00  4.0    0.0
UNIT 29
CYLINDER  169  1  7.025     4.0    0.0
CYLINDER  182  1  9.565     4.0    0.0
CYLINDER  169  1  10.20     4.0    0.0
CYLINDER   66  1  10.6125   4.0    0.0
CYLINDER   67  1  11.025    4.0    0.0
CYLINDER   68  1  11.4375   4.0    0.0
CYLINDER   69  1  11.85     4.0    0.0
CYLINDER  180  1  12.675    4.0    0.0
CYLINDER   70  1  13.50     4.0    0.0
CYLINDER   71  1  14.325    4.0    0.0
CYLINDER   72  1  14.7375   4.0    0.0
CYLINDER   73  1  15.15     4.0    0.0
CYLINDER   74  1  15.5625   4.0    0.0
CYLINDER   75  1  15.975    4.0    0.0
CYLINDER   76  1  16.3875   4.0    0.0
CYLINDER   77  1  16.80     4.0    0.0
CYLINDER  169  1  17.435    4.0    0.0
CYLINDER  181  1  23.15     4.0    0.0
HOLE        9     20.2925   0.0    0.0
HOLE       10    -20.2925   0.0    0.0
CUBOID    169  1  4P150.00  4.0    0.0
CUBOID      0  1  4P150.00  4.0    0.0
UNIT 30
CYLINDER  169  1  7.025     4.0    0.0
CYLINDER  182  1  9.565     4.0    0.0
```

Figure A.2 (continued)

```
CYLINDER  169  1  10.20      4.0    0.0
CYLINDER   78  1  10.6125    4.0    0.0
CYLINDER   79  1  11.025     4.0    0.0
CYLINDER   80  1  11.4375    4.0    0.0
CYLINDER   81  1  11.85      4.0    0.0
CYLINDER   82  1  12.675     4.0    0.0
CYLINDER   83  1  13.50      4.0    0.0
CYLINDER   84  1  14.325     4.0    0.0
CYLINDER   85  1  14.7375    4.0    0.0
CYLINDER   86  1  15.15      4.0    0.0
CYLINDER   87  1  15.5625    4.0    0.0
CYLINDER   88  1  15.975     4.0    0.0
CYLINDER   89  1  16.3875    4.0    0.0
CYLINDER   90  1  16.80      4.0    0.0
CYLINDER  169  1  17.435     4.0    0.0
CYLINDER  181  1  23.15      4.0    0.0
HOLE        9     20.2925    0.0    0.0
HOLE       10    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   4.0    0.0
CUBOID      0  1  4P150.00   4.0    0.0
UNIT 31
CYLINDER  169  1  7.025      6.35   0.0
CYLINDER  182  1  9.565      6.35   0.0
CYLINDER  169  1  10.20      6.35   0.0
CYLINDER   91  1  10.6125    6.35   0.0
CYLINDER   92  1  11.025     6.35   0.0
CYLINDER   93  1  11.4375    6.35   0.0
CYLINDER   94  1  11.85      6.35   0.0
CYLINDER   95  1  12.675     6.35   0.0
CYLINDER   96  1  13.50      6.35   0.0
CYLINDER   97  1  14.325     6.35   0.0
CYLINDER   98  1  14.7375    6.35   0.0
CYLINDER   99  1  15.15      6.35   0.0
CYLINDER  100  1  15.5625    6.35   0.0
CYLINDER  101  1  15.975     6.35   0.0
CYLINDER  102  1  16.3875    6.35   0.0
CYLINDER  103  1  16.80      6.35   0.0
CYLINDER  169  1  17.435     6.35   0.0
CYLINDER  181  1  23.15      6.35   0.0
HOLE       11     20.2925    0.0    0.0
HOLE       12    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   6.35   0.0
CUBOID      0  1  4P150.00   6.35   0.0
UNIT 32
CYLINDER  169  1  7.025      4.0    0.0
CYLINDER  182  1  9.565      4.0    0.0
CYLINDER  169  1  10.20      4.0    0.0
CYLINDER  104  1  10.6125    4.0    0.0
CYLINDER  105  1  11.025     4.0    0.0
CYLINDER  106  1  11.4375    4.0    0.0
CYLINDER  107  1  11.85      4.0    0.0
CYLINDER  108  1  12.675     4.0    0.0
CYLINDER  109  1  13.50      4.0    0.0
CYLINDER  110  1  14.325     4.0    0.0
CYLINDER  111  1  14.7375    4.0    0.0
CYLINDER  112  1  15.15      4.0    0.0
CYLINDER  113  1  15.5625    4.0    0.0
CYLINDER  114  1  15.975     4.0    0.0
CYLINDER  115  1  16.3875    4.0    0.0
CYLINDER  116  1  16.80      4.0    0.0
CYLINDER  169  1  17.435     4.0    0.0
CYLINDER  181  1  23.15      4.0    0.0
HOLE        9     20.2925    0.0    0.0
HOLE       10    -20.2925    0.0    0.0
CUBOID    169  1  4P150.00   4.0    0.0
CUBOID      0  1  4P150.00   4.0    0.0
```

Figure A.2 (continued)

```
UNIT 33
CYLINDER 169  1  7.025      2.0     0.0
CYLINDER 182  1  9.565      2.0     0.0
CYLINDER 169  1  10.20      2.0     0.0
CYLINDER 117  1  10.6125    2.0     0.0
CYLINDER 118  1  11.025     2.0     0.0
CYLINDER 119  1  11.4375    2.0     0.0
CYLINDER 120  1  11.85      2.0     0.0
CYLINDER 121  1  12.675     2.0     0.0
CYLINDER 122  1  13.50      2.0     0.0
CYLINDER 123  1  14.325     2.0     0.0
CYLINDER 124  1  14.7375    2.0     0.0
CYLINDER 125  1  15.15      2.0     0.0
CYLINDER 126  1  15.5625    2.0     0.0
CYLINDER 127  1  15.975     2.0     0.0
CYLINDER 128  1  16.3875    2.0     0.0
CYLINDER 129  1  16.80      2.0     0.0
CYLINDER 169  1  17.435     2.0     0.0
CYLINDER 181  1  23.15      2.0     0.0
HOLE       5     20.2925    0.0     0.0
HOLE       6    -20.2925    0.0     0.0
CUBOID   169  1  4P150.00   2.0     0.0
CUBOID     0  1  4P150.00   2.0     0.0
UNIT 34
CYLINDER 169  1  7.025      1.0     0.0
CYLINDER 182  1  9.565      1.0     0.0
CYLINDER 169  1  10.20      1.0     0.0
CYLINDER 130  1  10.6125    1.0     0.0
CYLINDER 131  1  11.025     1.0     0.0
CYLINDER 132  1  11.4375    1.0     0.0
CYLINDER 133  1  11.85      1.0     0.0
CYLINDER 134  1  12.675     1.0     0.0
CYLINDER 135  1  13.50      1.0     0.0
CYLINDER 136  1  14.325     1.0     0.0
CYLINDER 137  1  14.7375    1.0     0.0
CYLINDER 138  1  15.15      1.0     0.0
CYLINDER 139  1  15.5625    1.0     0.0
CYLINDER 140  1  15.975     1.0     0.0
CYLINDER 141  1  16.3875    1.0     0.0
CYLINDER 142  1  16.80      1.0     0.0
CYLINDER 169  1  17.435     1.0     0.0
CYLINDER 181  1  23.15      1.0     0.0
HOLE       3     20.2925    0.0     0.0
HOLE       4    -20.2925    0.0     0.0
CUBOID   169  1  4P150.00   1.0     0.0
CUBOID     0  1  4P150.00   1.0     0.0
UNIT 35
CYLINDER 169  1  7.025      1.0     0.0
CYLINDER 182  1  9.565      1.0     0.0
CYLINDER 169  1  10.20      1.0     0.0
CYLINDER 143  1  10.6125    1.0     0.0
CYLINDER 144  1  11.025     1.0     0.0
CYLINDER 145  1  11.4375    1.0     0.0
CYLINDER 146  1  11.85      1.0     0.0
CYLINDER 147  1  12.675     1.0     0.0
CYLINDER 148  1  13.50      1.0     0.0
CYLINDER 149  1  14.325     1.0     0.0
CYLINDER 150  1  14.7375    1.0     0.0
CYLINDER 151  1  15.15      1.0     0.0
CYLINDER 152  1  15.5625    1.0     0.0
CYLINDER 153  1  15.975     1.0     0.0
CYLINDER 154  1  16.3875    1.0     0.0
CYLINDER 155  1  16.80      1.0     0.0
CYLINDER 169  1  17.435     1.0     0.0
CYLINDER 181  1  23.15      1.0     0.0
HOLE       3     20.2925    0.0     0.0
HOLE       4    -20.2925    0.0     0.0
CUBOID   169  1  4P150.00   1.0     0.0
CUBOID     0  1  4P150.00   1.0     0.0
UNIT 36
CYLINDER 169  1  7.025      1.0     0.0
CYLINDER 182  1  9.565      1.0     0.0
CYLINDER 169  1  10.20      1.0     0.0
CYLINDER 156  1  10.6125    1.0     0.0
CYLINDER 157  1  11.025     1.0     0.0
CYLINDER 158  1  11.4375    1.0     0.0
CYLINDER 159  1  11.85      1.0     0.0
CYLINDER 160  1  12.675     1.0     0.0
CYLINDER 161  1  13.50      1.0     0.0
CYLINDER 162  1  14.325     1.0     0.0
CYLINDER 163  1  14.7375    1.0     0.0
CYLINDER 164  1  15.15      1.0     0.0
CYLINDER 165  1  15.5625    1.0     0.0
CYLINDER 166  1  15.975     1.0     0.0
CYLINDER 167  1  16.3875    1.0     0.0
CYLINDER 168  1  16.80      1.0     0.0
CYLINDER 169  1  17.435     1.0     0.0
CYLINDER 181  1  23.15      1.0     0.0
HOLE       3     20.2925    0.0     0.0
HOLE       4    -20.2925    0.0     0.0
CUBOID   169  1  4P150.00   1.0     0.0
CUBOID     0  1  4P150.00   1.0     0.0
UNIT 37
CYLINDER 169  1  7.025      1.0     0.0
CYLINDER 182  1  9.565      1.0     0.0
CYLINDER 169  1  10.20      1.0     0.0
CYLINDER 171  1  16.80      1.0     0.0
CYLINDER 169  1  17.435     1.0     0.0
CYLINDER 181  1  23.15      1.0     0.0
HOLE       3     20.2925    0.0     0.0
HOLE       4    -20.2925    0.0     0.0
CUBOID   169  1  4P150.00   1.0     0.0
CUBOID     0  1  4P150.00   1.0     0.0
UNIT 38
CUBOID   169  1  4P150.00   200.00  0.0
CUBOID     0  1  4P150.00   200.00  0.0
UNIT 39
CYLINDER 181  1  23.15      2.54    0.0
CUBOID   169  1  4P150.00   200.00  0.0
CUBOID     0  1  4P150.00   200.00  0.0
END GEOM
READ ARRAY
  ARA=1 NUX=1 NUY=1 NUZ=27 FILL 38 13 14 15 16 17
  18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
  33 34 35 36 37 39 END FILL
END ARRAY
END DATA
END
```

Figure A.2 (continued)

APPENDIX B

CRITICALITY OF THE FUEL ANNULI IN LIGHT WATER

The fuel annuli are subcritical when moderated and reflected by light water. The neutron multiplication factors for the upper and lower fuel elements in infinite light water are 0.806 ± 0.005 and 0.839 ± 0.005 respectively.[12] Figure B.1 is the response of the neutron multiplication factor (eigenvalue) of the ANS reactor to light water ingress in the reflector region and in the core pressure boundary tube.[12]

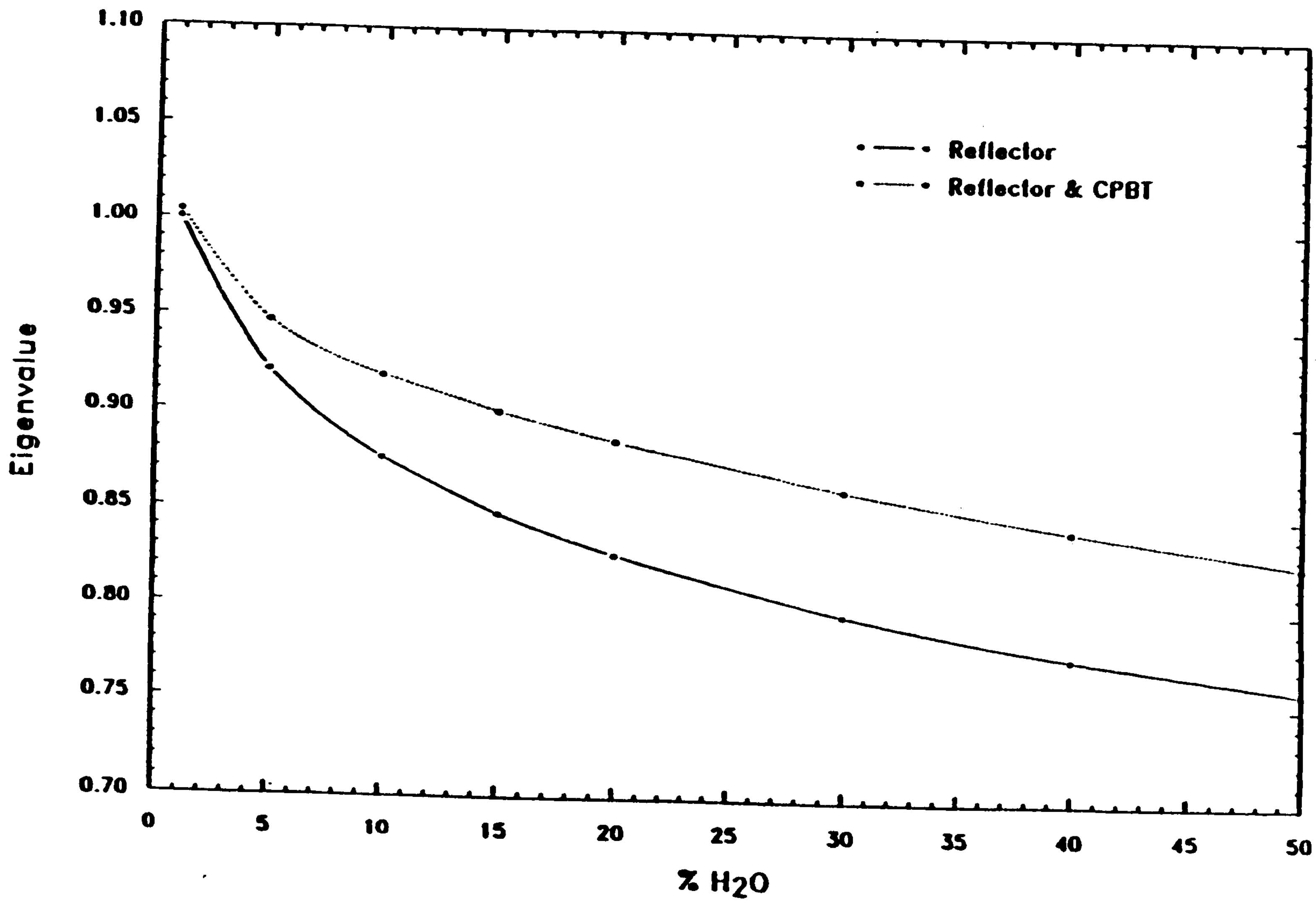

Figure B.1 Effect of Light Water Ingress in the reflector (solid line) and in reflector and core pressure boundary tube (dashed line) on the neutron multiplicatoin of the reactor core.

APPENDIX C

CRITICALITY OF FUEL ANNULI IN VARIOUS LEVELS OF D_2O

The criticality of the fuel annuli is affected by the level of heavy water that the fuel elements are submerged. Table C.1 presents the effective neutron multiplication factors for various heavy water levels from 100 mm to the top of the fuel elements with no bottom reflector of heavy water. The diameter of the heavy water is 3.3-m. This measurement should be one of the basic physics benchmarks obtained in the critical experiments program.

Table C.1 Neutron Multiplication Factors for Fuel Annuli in Various Levels of Heavy Water

Level of Heavy Water	k of Upper Element	k of Lower Element
100 mm	0.063 ± 0.001	0.063 ± 0.001
200 mm	0.236 ± 0.001	0.232 ± 0.001
300 mm	0.493 ± 0.001	0.485 ± 0.001
400 mm	0.715 ± 0.002	0.661 ± 0.002
500 mm	0.864 ± 0.002	0.781 ± 0.002

If a 1-m heavy water reflector is below the fuel annuli with the level of heavy water at 500 mm, the multiplication factors for the upper and lower fuel elements are 1.056 ± 0.002 and 0.964 ± 0.002, respectively. These multiplication factors indicate that careful design considerations must be made when the fuel elements are in the presence of heavy water. The critical experiments program could also determine the level of heavy water for criticality with a bottom reflector of heavy water.

APPENDIX D

CSDNA RESULTS FOR UPPER FUEL ANNULUS/ISOLATOR ASSEMBLY WITH BLACK DETECTORS

Black detectors are fictitious detectors that are used to decrease the amount of calculation time needed for the results of the KENO-NR code to converge. Black detectors score any neutron that enters the detection media as a count and then the neutron is lost. This greatly increases the detection efficiency of the black detector; therefore, the calculation time is decreased significantly. The frequency content of the CPSDs is higher because more high energy neutrons are detected using the high efficiency black detectors. The coherences and PSDs for the fuel annulus/isolator assembly in the transfer shaft are shown in Fig. D.1. The low frequency values of the coherences and PSDs are greater than those for the capture detector because the coherences and PSDs are a function of detection efficiency. Figure D.2 is a plot of the ratio of spectral densities as a function of frequency for the fuel annulus/isolator assembly in the transfer shaft. The low frequency value of the ratio of spectral densities is higher than that obtained with the capture detectors because the black detectors absorb more neutrons than the capture detectors; therefore, the multiplication factor of the fuel annulus/isolator assembly is lower. Although the efficiency of the black detector is much higher than that of the capture detector, the black detector behaves in the same manner as the capture detector. Scaling the ratio of spectral densities obtained from the black detectors to match those obtained from the capture detectors would produce accurate results since the neutron absorption

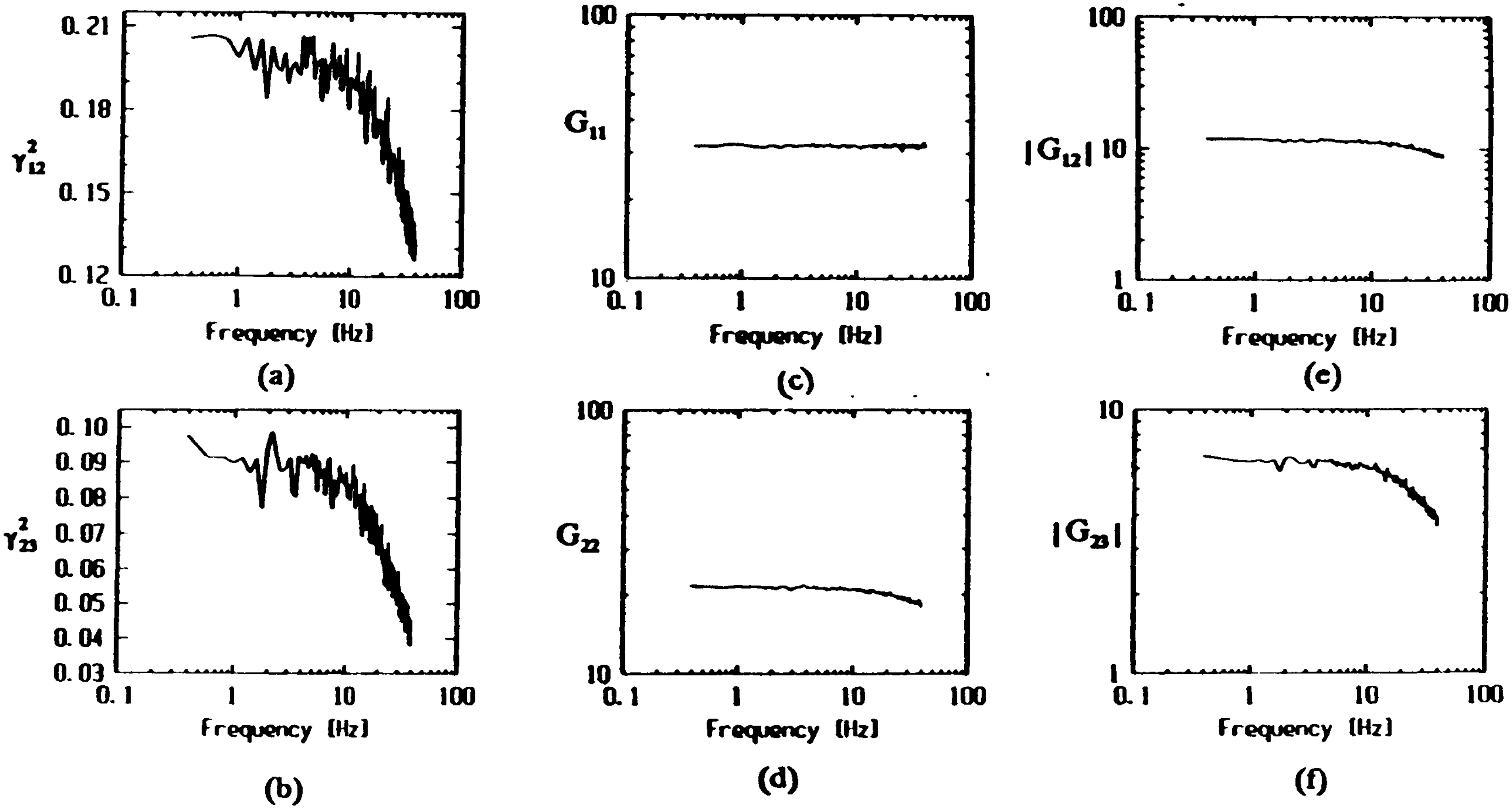

Figure D.1 (a) Coherence Between Source and Detector, (b) Coherence Between Detectors, (c) APSD of Source, (d) APSD of Detector, (e) CPSD Between Source and Detector, and (f) CPSD Between Detectors with Fuel Annulus/Isolator Assembly in the Transfer Shaft with Black Detectors

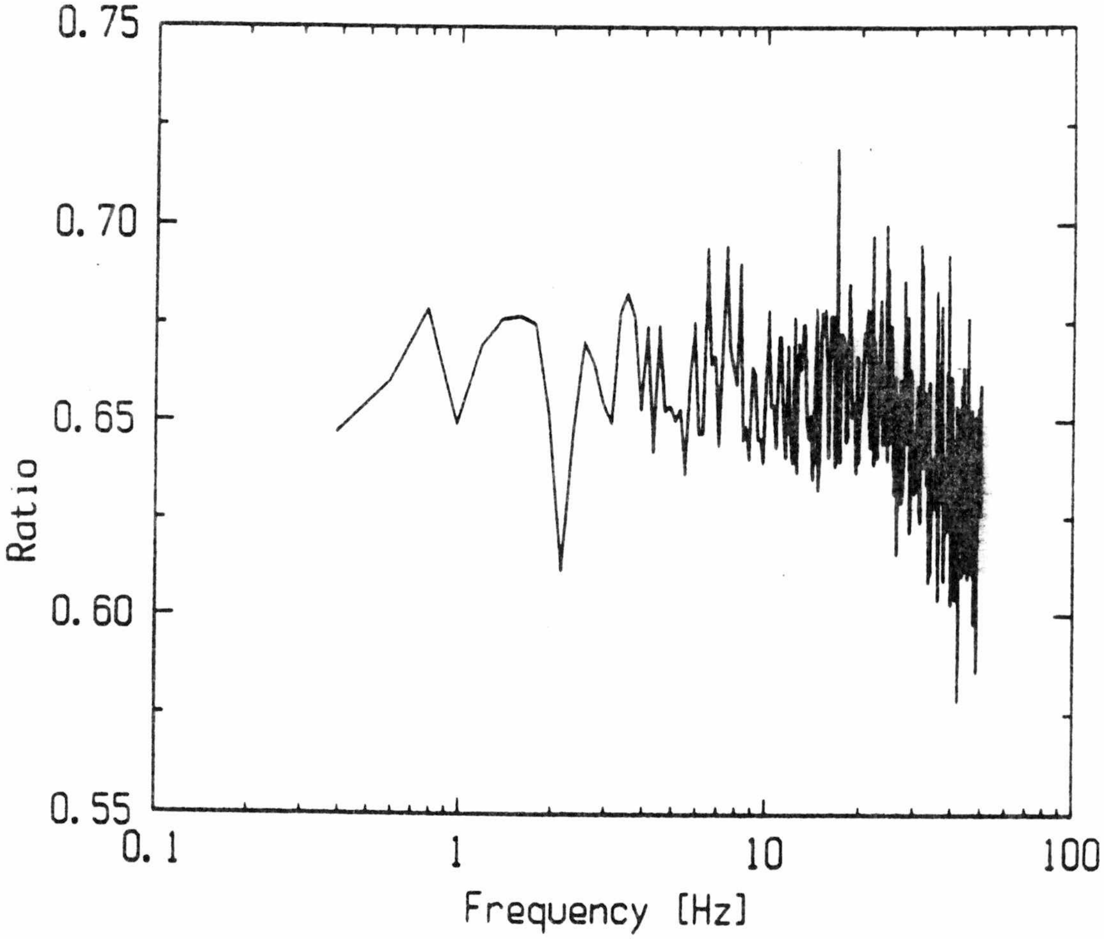

Figure D.2 Ratio of Spectral Densities for Fuel Annulus/Isolator Assembly in the Transfer Shaft with Black Detectors properties of the neutron detectors are similar to those of the capture detectors. The low frequency values of the coherences and PSDs for the fuel annulus/isolator assembly in the interim fuel storage canal are shown in Fig. D.3. The ratio of spectral densities for the fuel annulus/isolator assembly in the interim fuel storage canal are shown in Fig. D.4. The results obtained with the fuel annulus/isolator assembly with black detectors in the interim fuel storage canal are similar to those obtained with the same assembly in the transfer shaft.

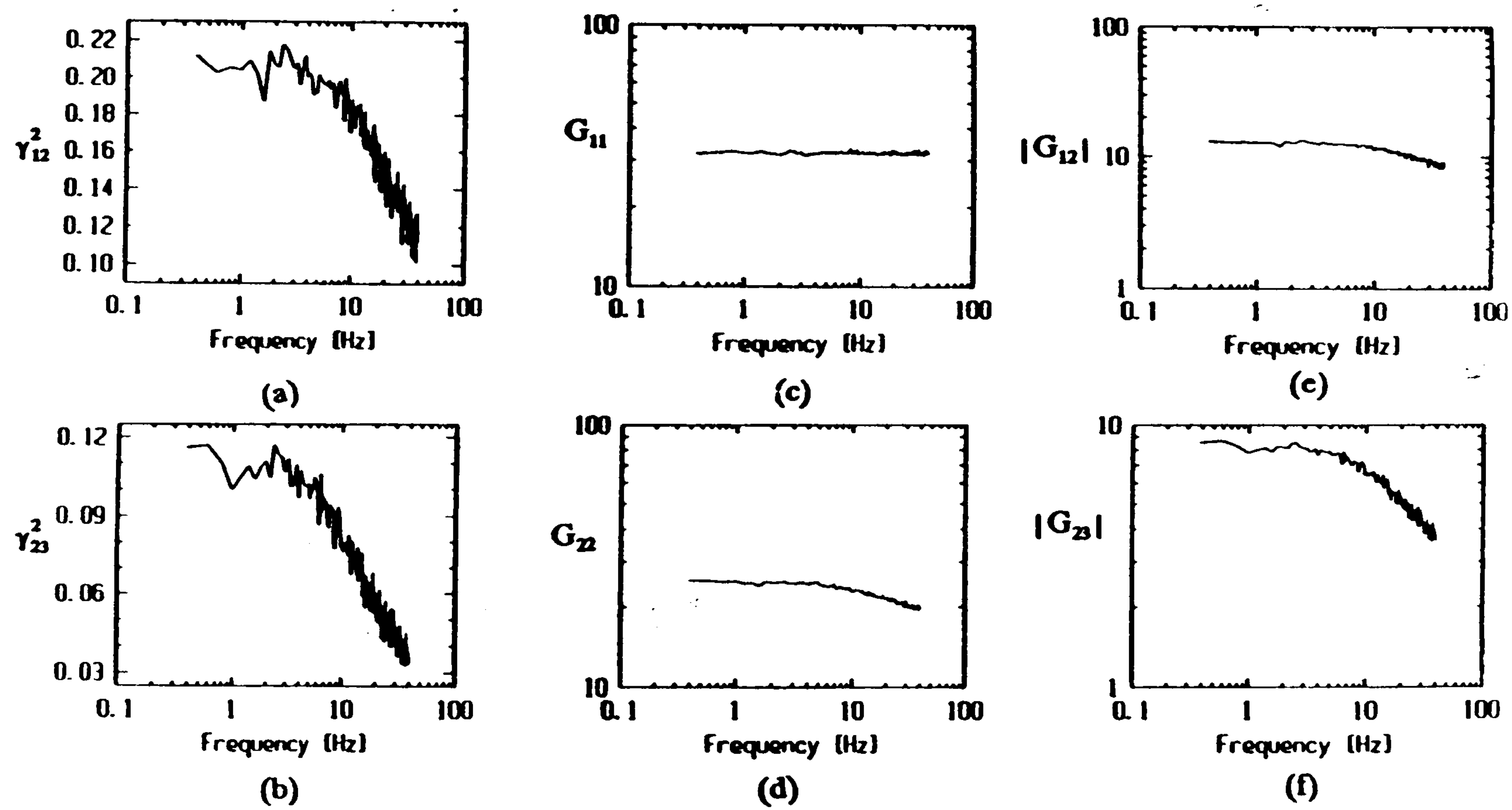

Figure D.3 (a) Coherence Between Source and Detector, (b) Coherence Between Detectors, (c) APSD of Source, (d) APSD of Detector, (e) CPSD Between Source and Detector, and (f) CPSD Between Detectors with Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal with Black Detectors

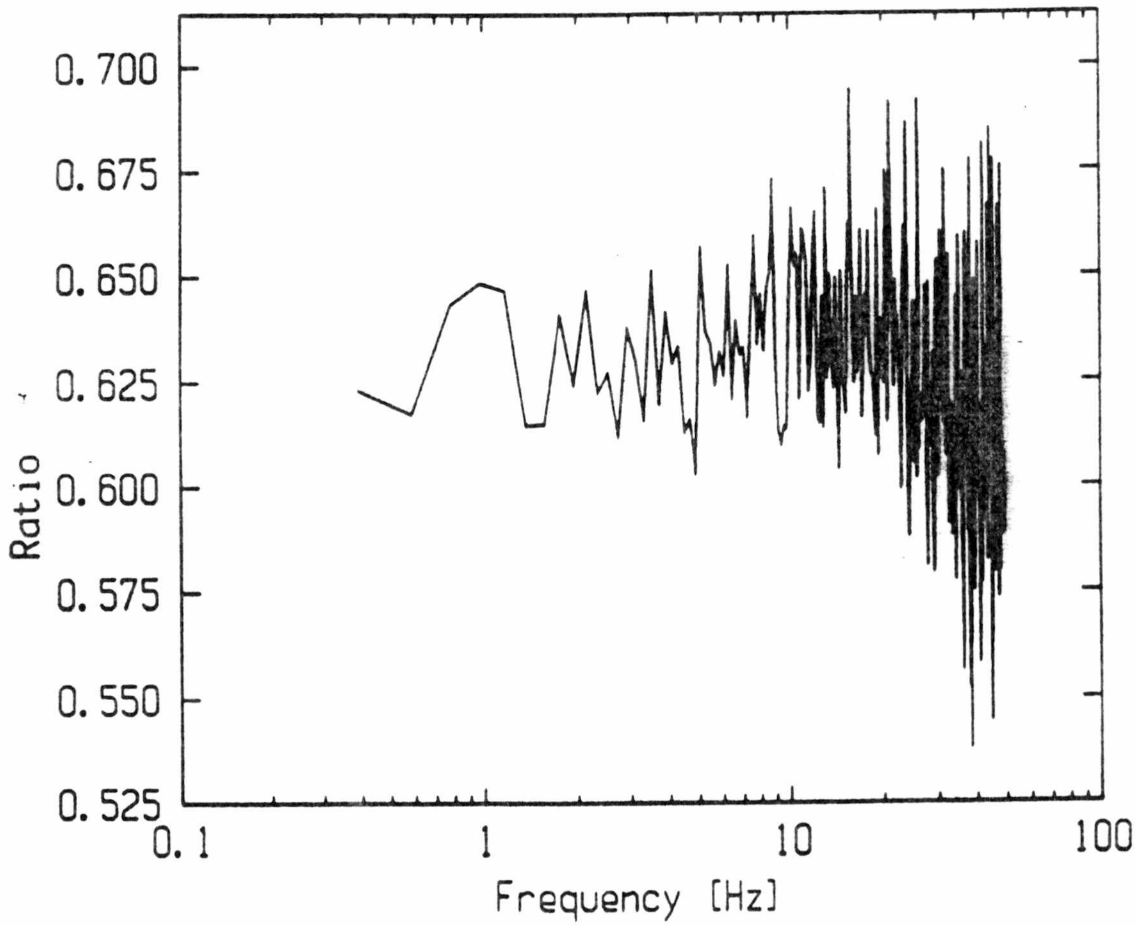

Figure D.4 Ratio of Spectral Densities for Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal with Black Detectors

APPENDIX E

CSDNA RESULTS FOR LOWER FUEL ANNULUS/ISOLATOR ASSEMBLY WITH BLACK DETECTORS

Black detectors are fictitious detectors that are used to decrease the amount of calculation time needed for the results of the KENO-NR code to converge. The coherences and PSDs for the fuel annulus/isolator assembly in the transfer shaft are shown in Fig. E.1. The low frequency values of the coherences and PSDs are greater than those for the capture detector because the coherences and PSDs are a function of detection efficiency. Figure E.2 is a plot of the ratio of spectral densities as a function of frequency for the fuel annulus/isolator assembly in the transfer shaft. The low frequency value of the ratio of spectral densities is higher than that obtained with the capture because the multiplication factor of the fuel annulus/isolator assembly is lower since the black detectors absorb more neutrons than the capture detectors. Although the efficiency of the black detector is much higher than the capture detector, the black detector behaves in the same manner as the capture detector. The ratio of spectral densities obtained from the black detectors can be scaled to match those obtained from the capture detectors since the neutron absorption properties are similar to those of the capture detectors. The low frequency values of the coherences and PSDs for the fuel annulus/isolator assembly in the interim fuel storage canal are shown in Fig. E.3. The ratio of spectral densities for the fuel annulus/isolator assembly in the interim fuel storage canal are shown in Fig. E.4. The results obtained with the fuel annulus/isolator assembly with black detectors in the

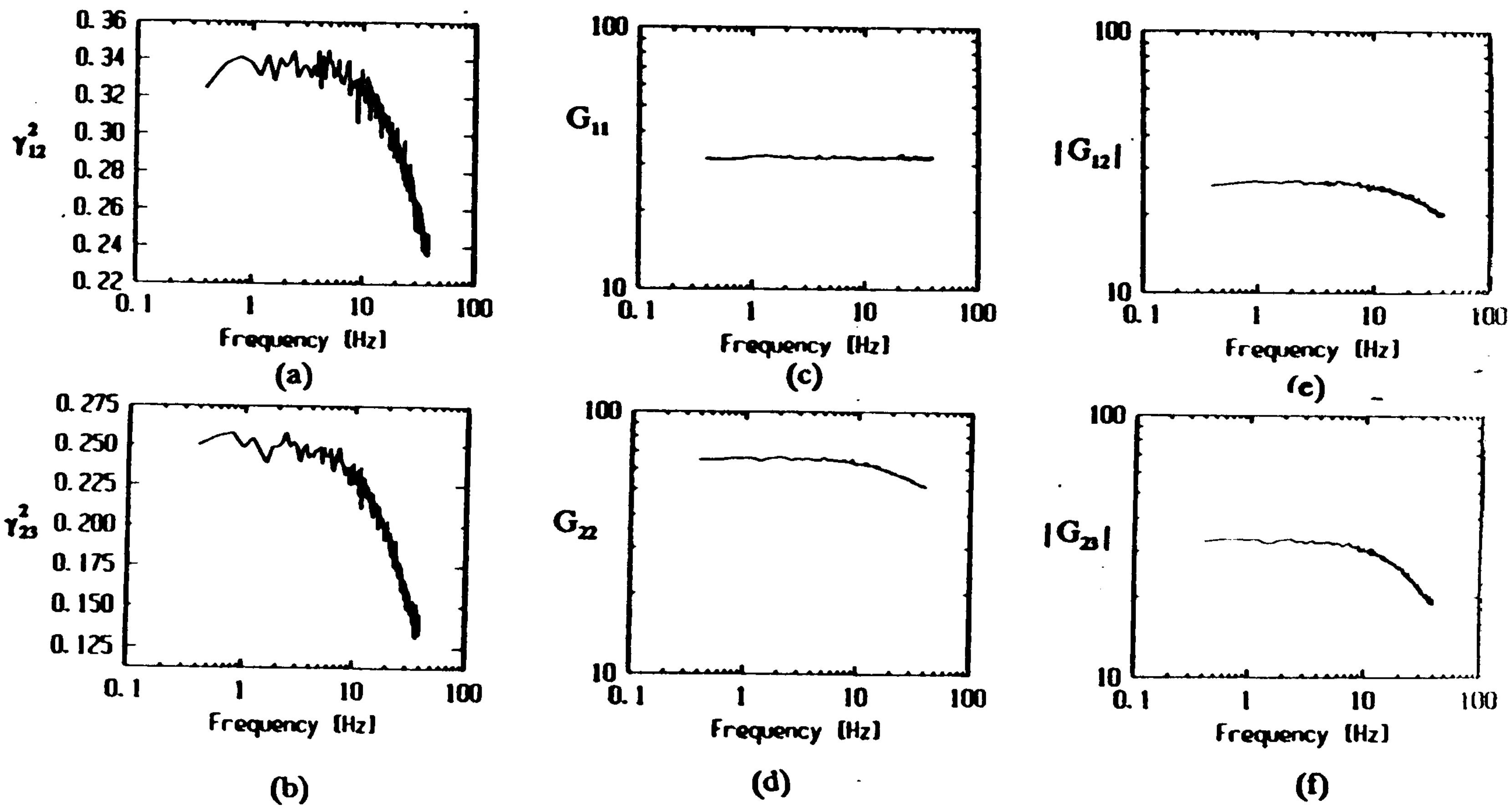

Figure E.1 (a) Coherence Between Source and Detector, (b) Coherence Between Detectors, (c) APSD of Source, (d) APSD of Detector, (e) CPSD Between Source and Detector, and (f) CPSD Between Detectors with Fuel Annulus/Isolator Assembly in the Transfer Shaft with Black Detectors

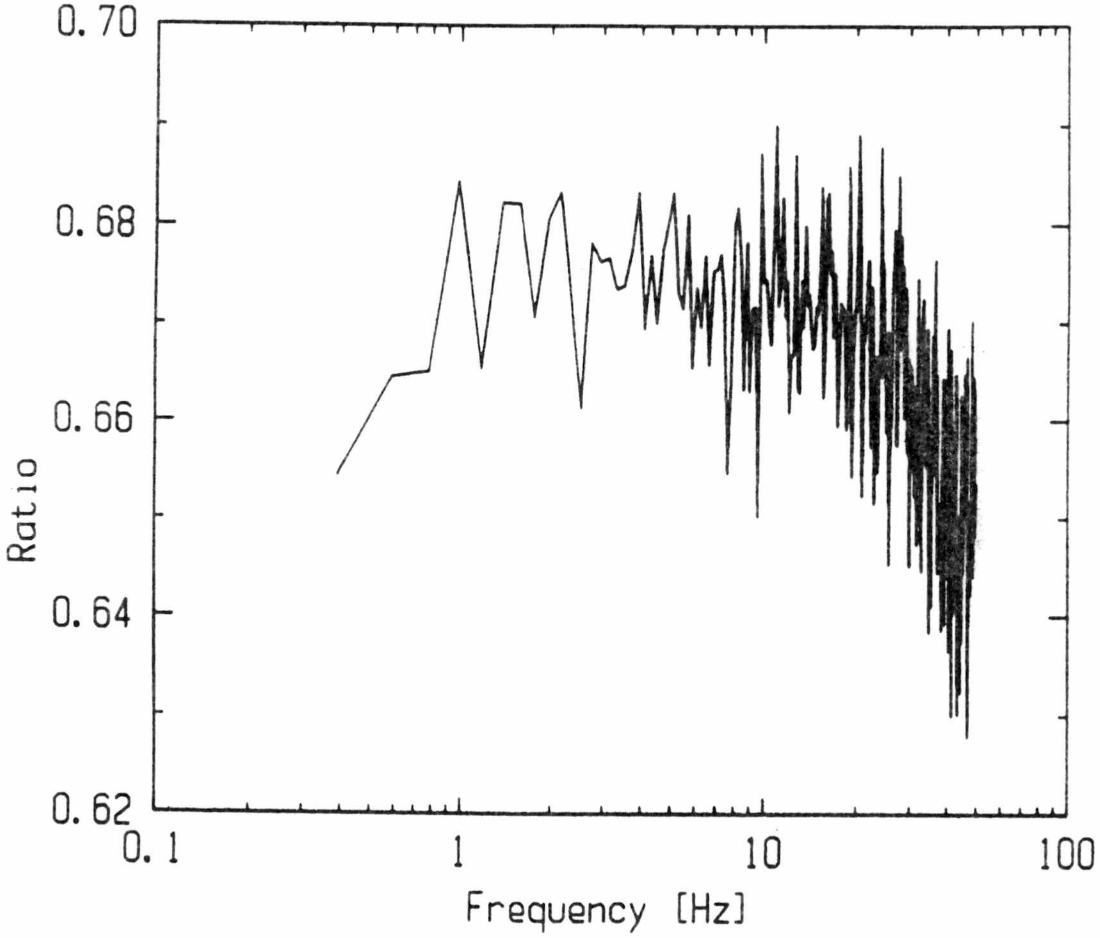

Figure E.2 Ratio of Spectral Densities for Fuel Annulus/Isolator Assembly in the Transfer Shaft with Black Detectors

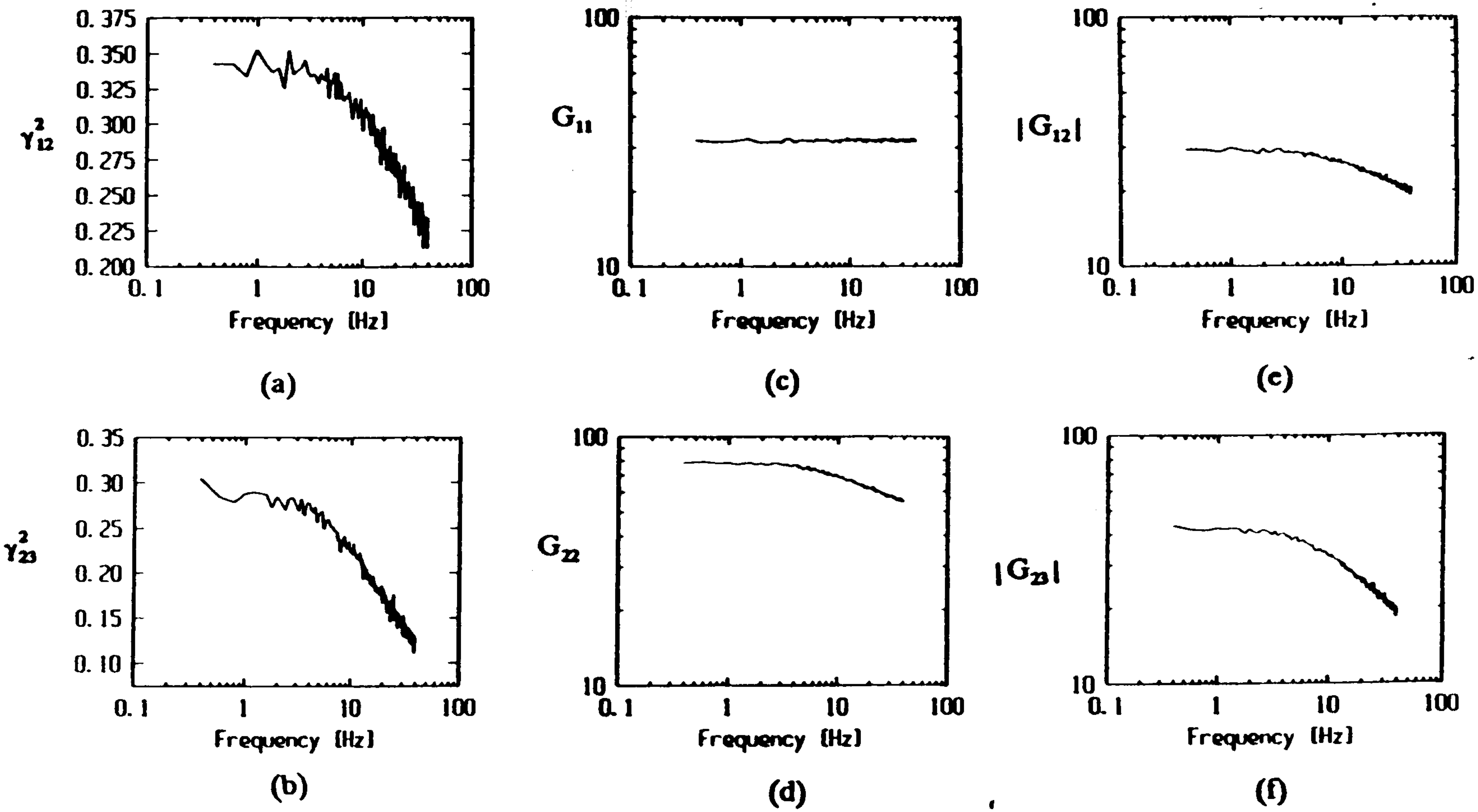

Figure E.3 (a) Coherence Between Source and Detector, (b) Coherence Between Detectors, (c) APSD of Source, (d) APSD of Detector, (e) CPSD Between Source and Detector, and (f) CPSD Between Detectors with Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal with Black Detectors

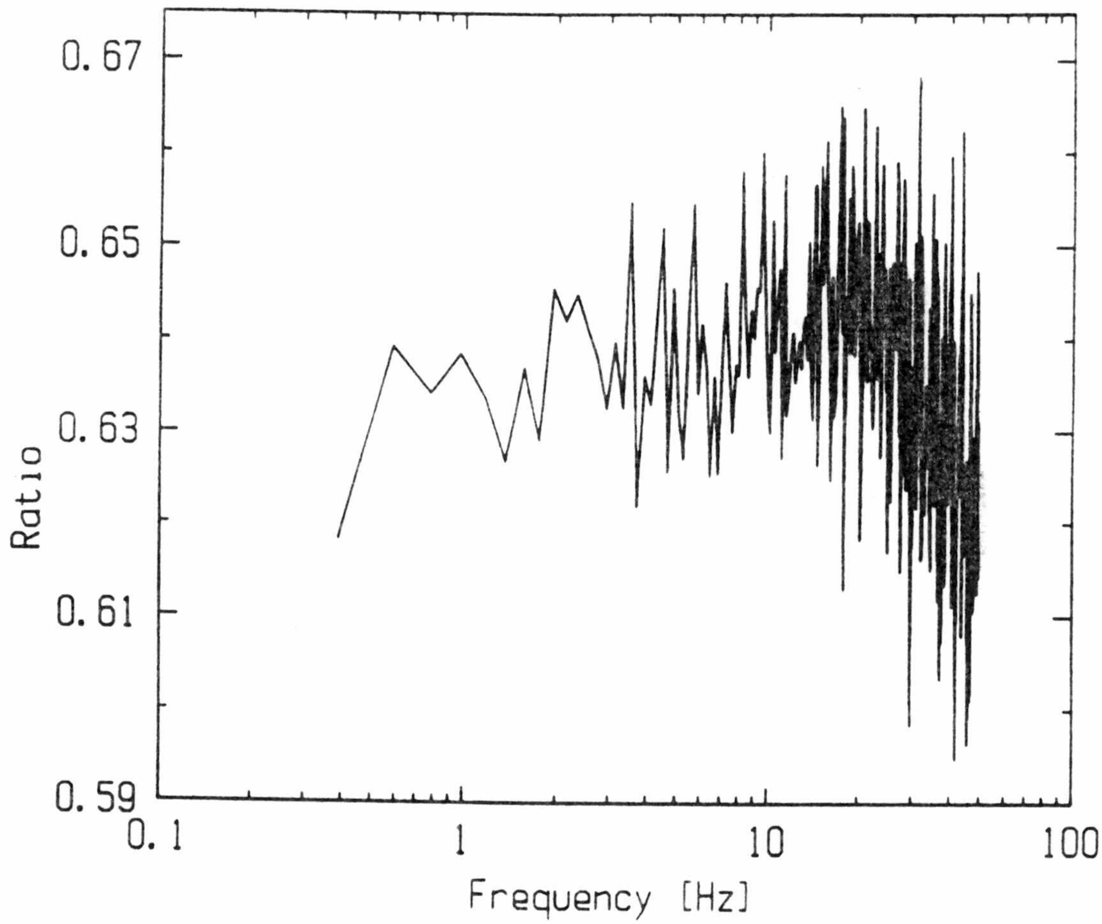

Figure E.4 Ratio of Spectral Densities for Fuel Annulus/Isolator Assembly in the Interim Fuel Storage Canal with Black Detectors interim fuel storage canal are similar to those obtained with the same assembly in the transfer shaft. Normalizing the ratio of spectral densities with the normalization factor obtained for the CSDNA analysis of the upper fuel element, the ratio of spectral densities for the lower fuel element can be obtained.

VITA

Timothy Eugene Valentine was born in Knoxville, Tennessee, on September 26, 1969. He attended Gibbs High School and graduated in June 1987. In August 1987, he enrolled in the University of Tennessee, Knoxville. In February 1990, he married Jennifer Suzanne Mash. In May 1991, he received his Bachelor of Science degree in Nuclear Engineering from The University of Tennessee. He enrolled in graduate school at The University of Tennessee, and in August 1992, he expects to receive a Master of Science degree in Engineering.