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Validation of Multigroup Neutron Cross Sections and Computational Methods for the ANS Against the FOEHN Critical Experiments

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Advanced Neutron Source

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Computational Physics and Engineering Division

**VALIDATION OF MULTIGROUP NEUTRON CROSS SECTIONS AND
CALCULATIONAL METHODS FOR THE ADVANCED NEUTRON SOURCE
AGAINST THE FOEHN CRITICAL EXPERIMENTAL MEASUREMENTS**

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EXECUTIVE SUMMARY

Neutronics analysis of the Advanced Neutron Source (ANS) reactor¹ is being performed at Oak Ridge National Laboratory using the KENO² Monte Carlo transport code, the DORT³ discrete ordinates transport code, and the VENTURE⁴ diffusion theory code. Cross sections derived from the ANSL-V 99-group neutron master library⁵ are used in the calculations. The ANSL-V library was developed specifically for the ANS reactor physics and shielding analysis.

This study was designed to validate multigroup cross sections generated from the ANSL-V library and ANS calculational methods against measured data from the FOEHN critical experiment.⁶ The FOEHN experiment was performed to validate the calculational methods used in the design of the Franco-German High Flux Reactor. The FOEHN criticals have several features that are very similar to the current design of the ANS. The two most notable similarities are the use of highly enriched uranium in an involute fuel-plate geometry and the use of heavy water as the moderator and reflector material.

In the FOEHN experiment, three configurations are examined. The simple configuration consists of only the fuel and control elements in the reflector tank. The intermediate configuration includes boron endplates at the upper and lower edges of the fuel element. The complex configuration includes the boron endplates and reflector components (beam tubes, irradiation facilities, etc.). Critical states, power distributions, and thermal fluxes were measured for each configuration. The rendement, the neutron efficiency of the system, was also measured. The errors associated with these measurements were reported. Estimates of the errors were reevaluated in ref. 9.

Models of the FOEHN experiment were developed for the KENO, DORT, and VENTURE neutronics codes. Because the simple and intermediate configurations of the FOEHN experiment are azimuthally symmetric, these configurations can be explicitly modeled in R-Z geometry, and the correctness of these models is limited only by minor material and geometric assumptions that were made because of incomplete documentation of the experiment. Because the reflector components in the complex FOEHN configuration cannot be explicitly modeled with the current versions of these codes, three reflector component homogenization schemes were developed and evaluated by comparison against measured data.

Cross sections from the ANSL-V 99-group master library were processed using modules from the AMPX¹¹ code system. Eigenvalues were calculated with KENO using both 99-group and 20-group cross sections. The DORT and VENTURE calculations were performed using 20-group cross sections. Power distributions were calculated using KENO with 99-group cross sections. Power distributions, thermal fluxes, and the rendement were computed with DORT and VENTURE.

Table ES.1 shows the average eigenvalues calculated for the critical cases of each configuration. The use of 99 energy groups estimates criticality to within 0.2% for the simple and intermediate configurations. The KENO and DORT transport calculations using 20 groups predict criticality to within 0.5%, while the VENTURE diffusion theory calculations are accurate to within 1.1% for the simple and intermediate configurations. In the analysis in ref. 13, the average values for the simple and intermediate configurations were 0.9982 ± 0.0017 and 0.9951 ± 0.0021 , respectively.

The complex configuration modeled with void in the reflector components overpredicts a multiplication factor of unity because streaming effects in the reflector components are not accurately predicted. The models with aluminum in the void regions of the reflector components and a constant aluminum density in the reflector were forced to yield multiplication factors near unity so that the calculated power distributions could be compared against the measured data.

The average differences between the calculated and measured power density values for each configuration are shown in Table ES.2. The errors in the measured power density values were reported as 1% in the FOEHN report.⁶ Reference 9 reports the errors to be from 4 to 8%. The average differences for the transport calculations are slightly larger than the VENTURE diffusion theory results even though the transport calculations yield eigenvalues closer to unity. The exact uncertainty in the measured data at the upper and lower edges of the fuel element is unknown. The plates holding the measuring probes became deformed after repeated use. If these edge locations are not considered, the average differences are within 4% for all the configurations. Another uncertainty must be considered when comparing power density values at the inner edge of the fuel element. Previously calculated power distributions^{6,9,14} have overestimated the measured values near the tip of the control element. If these points and the upper and lower edge values are not considered, the maximum differences range from -7.66 to -15.11%. The power distributions reported in ref. 9 for each configuration are similar to the results obtained in this report.

Thermal fluxes were calculated with DORT and VENTURE. The average differences between the calculated and measured values for the simple and intermediate configurations are <8%. In ref. 9, experimental errors of 12% must be assumed to yield results that are compatible with the 2 σ statistical uncertainty of the calculated values. Only radially averaged values can be compared for the complex configuration. The largest average difference (13.98%) of the three complex approximations occurs in the model with void in the reflector components. The original FOEHN report states that the thermal flux measurement errors are 2%, although ref. 9 estimates a range from 3.3 to 22.8%.

The work in this report shows that multiplication factors, power distributions, and thermal fluxes for the FOEHN experiment can be calculated within the measurement errors using multigroup cross sections derived from the ANSL-V master cross-section library. The calculated parameters are comparable to those determined in the independent studies documented in refs. 9, 13, and 14. The general trends of overpredicting or underpredicting the measured data are similar. The results show that the calculational methods used in this work accurately predict the measured values of the FOEHN experiment, a highly enriched, heavy-water-moderated system that has many similarities with the current ANS design.

Table ES.1. Average eigenvalues of the critical states of the three FOEHN configurations calculated using different computer codes

Configuration	KENO		DORT 20-group	VENTURE 20-group
	99-group	20-group		
Simple	1.0018 $\pm$ 0.0013 ^a	1.0046 $\pm$ 0.0013	1.0046	1.0108
Intermediate	0.9983 $\pm$ 0.0020	1.0025 $\pm$ 0.0019	1.0008	1.0014
Complex with void in the reflector components	1.0162 $\pm$ 0.0018	1.0205 $\pm$ 0.0018	1.0190	1.0206
Complex with aluminum in the void regions of the reflector components	0.9993 $\pm$ 0.0018	1.0042 $\pm$ 0.0018	1.0030	1.0039
Complex with a constant aluminum density in the reflector	0.9996 $\pm$ 0.0018	1.0030 $\pm$ 0.0019	1.0035	1.0047

^aThe reported statistical uncertainty is two standard deviations.

Table ES.2. Average and maximum percent differences between the measured and calculated power distributions for the three FOEHN configurations

Configuration	Average percent difference ^a			Maximum percent difference ^b		
	KENO 99-group	DORT 20-group	VENTURE 20-group	KENO 99-group	DORT 20-group	VENTURE 20-group
Simple	3.43	3.22	2.94	21.61 (9.33)	18.00 (-8.67)	13.17 (13.17)
Intermediate	4.50 (2.86)	3.45 (1.68)	2.45 (1.87)	-20.50 (-9.67)	-19.88 (-8.33)	-12.46 (-7.66)
Complex with void in the reflector components	--	4.82 (2.92)	3.37 (2.91)	--	-23.17 (-12.28)	-15.42 (-8.39)
Complex with aluminum in the void regions of the reflector components	--	5.11 (3.15)	3.51 (2.96)	--	-22.90 (-12.98)	-14.88 (-8.06)
Complex with a constant aluminum density in the reflector	--	5.74 (3.73)	4.12 (3.45)	--	-22.57 (-15.11)	-14.72 (-10.27)

^aThe average values in parentheses were calculated without including the points at the upper and lower edges of the fuel element.

^bThe maximum values in parentheses for the simple configuration were determined without including the points at the inner edge of the fuel element near the tip of the control element. The maximum values in parentheses for the intermediate and complex configurations were determined without including the points at the upper and lower edges of the fuel element or the points at the inner edge of the element near the tip of the control element.

ABSTRACT

The FOEHN critical experiment was analyzed to validate the use of multigroup cross sections and Oak Ridge National Laboratory neutronics computer codes in the design of the Advanced Neutron Source. The ANSL-V 99-group master cross section library was used for all the calculations. Three different critical configurations were evaluated using the multigroup KENO Monte Carlo transport code, the multigroup DORT discrete ordinates transport code, and the multigroup diffusion theory code VENTURE. The simple configuration consists of only the fuel and control elements with the heavy water reflector. The intermediate configuration includes boron endplates at the upper and lower edges of the fuel element. The complex configuration includes both the boron endplates and components in the reflector.

Cross sections were processed using modules from the AMPX system. Both 99-group and 20-group cross sections were created and used in two-dimensional models of the FOEHN experiment. KENO calculations were performed using both 99-group and 20-group cross sections. The DORT and VENTURE calculations were performed using 20-group cross sections. Because the simple and intermediate configurations are azimuthally symmetric, these configurations can be explicitly modeled in R-Z geometry. Since the reflector components cannot be modeled explicitly using the current versions of these codes, three reflector component homogenization schemes were developed and evaluated for the complex configuration.

Calculated eigenvalues for the simple and intermediate configurations using KENO with 99-group cross sections are within 0.2% of unity. The 20-group transport results are within 0.5% of unity while the diffusion theory results overestimate unity by as much as 1.1%. Eigenvalues calculated using a smeared reflector component model are overpredicted by all three codes by approximately 2%. The reflector compositions in two other models were adjusted to yield eigenvalues near unity so that calculated power distributions could be compared against measured data.

Power density distributions were calculated with KENO using 99-group cross sections and with DORT and VENTURE using 20-group cross sections. The average differences between the measured values and the values calculated with the different computer codes range from 2.45 to 5.74%. Measured thermal fluxes in the reflector are compared to DORT and VENTURE calculated values. The maximum differences between the measured and calculated thermal flux values for the simple and intermediate configurations are $\sim 13\%$, while the average differences are $< 8\%$.

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVE

Neutronics calculations for the Advanced Neutron Source (ANS) reactor¹ are being performed using the multigroup KENO² Monte Carlo transport code, the multigroup DORT³ discrete ordinates transport code, and the multigroup diffusion theory code VENTURE.⁴ Ongoing efforts are being carried out at Oak Ridge National Laboratory (ORNL) to validate the multigroup cross sections derived from the ANSL-V⁵ 99-group library for ANS reactor core analysis. The ANSL-V library was developed specifically for the ANS reactor physics and shielding analysis.

Previous studies have been performed to validate the ANSL-V library against solution criticals and simple critical configurations. The objective of this work is to validate the use of ORNL neutronics computer codes and multigroup cross sections derived from the ANSL-V library against measured data from the FOEHN critical experiment.

1.2 ORGANIZATION OF REPORT

The FOEHN critical experiment is described in Chap. 2. The measured quantities of interest are discussed, and some of the experimental uncertainties are presented. In Chap. 3, the calculational models used in this work are described. The models used for cross section processing and the two-dimensional (2-D) core calculations are presented in detail for the simple, intermediate, and complex configurations. In Chap. 4, calculated multiplication factors, power distributions, and thermal fluxes are compared with measured values. Results are included from the calculations with the KENO, DORT, and VENTURE codes using 99-group and 20-group cross sections. Conclusions are made in Chap. 5, and references are included in Chap. 6.

2. DESCRIPTION OF THE FOEHN EXPERIMENT

2.1 INTRODUCTION

The FOEHN critical experiment was performed to validate the calculational methods used in the design of the Franco-German High Flux Reactor.⁶ The geometries used in this experiment have features similar to those of the ANS reactor, most notably the use of highly enriched uranium in a fuel-plate geometry, the use of heavy water as moderator and reflector material, and the use of experimental facilities (beam tubes, cold source, and hot source) in the heavy water reflector. Therefore, analyses of this experiment will be used to provide an initial validation of the methods used to perform reactor physics analyses of the ANS reactor.

The FOEHN experiment was divided into three parts (simple, intermediate, and complex) based on their general geometry. The simple configuration consists of only the fuel element with no boron endplates or reflector components. The intermediate configuration includes the boron endplates at the upper and lower edges of the fuel element. The complex configuration contains both the boron endplates and the reflector components. The various parts of the FOEHN experiment are described in this chapter. Also, the data measured during the experiment and the experimental uncertainties are discussed.

2.2 COMPONENTS OF THE FOEHN REACTOR

2.2.1 Fuel

The FOEHN fuel consists of a single cylindrical element. Characteristics of the element are outlined in Table 2.1. Involute-shaped fuel plates are held between two cylindrical tubes. The fuel element is 800-mm high. The inner radius of the element is 140 mm, and the outer radius is 195 mm. The cylindrical tubes that hold the fuel plates are 5-mm thick and are fabricated from an AG3-NE aluminum alloy. Some of the excess reactivity during the experiment was compensated by the addition of dissolved boron to the coolant in the gaps between the fuel plates of the fuel element. The fuel element was placed in a watertight vessel so that dissolved boron would be present only in the coolant between the fuel plates. The upper and lower lids of the vessel are 6-mm thick. Using the fuel-plate dimensions, the free volume in the fuel zone region is 27.0 L. When the vessel was filled, the volume was measured to be 28.85 L. The effects of this discrepancy are discussed in Sect. 2.4.1.

2.2.2 Control Element

The control element is a 1-m-long nickel cylindrical tube. The tube is 5-mm thick and has an inner radius of 12.1 mm. The element is driven by a motor from below the fuel element. The control element position is the distance from the fully inserted position to the upper edge of the control element. The fully inserted position (the reference position, 0.0 mm) is 100 mm above the upper edge of the fuel element.

Table 2.1. Characteristics of the FOEHN fuel element

Parameter	Description
Fuel	U-Al alloy with 90 wt. % ^{235}U
Fuel load ($\text{kg } ^{235}\text{U}/\text{m}^2$)	0.568
Total ^{235}U mass (kg)	8.556
Number of fuel plates	276
Plate length (mm)	800 ± 0.5
Plate span (mm)	68.3 ± 0.2
Plate thickness (mm)	1.27 ± 0.05
Thickness of lateral AG3-NE clad (mm)	0.1
Fuel plate involute radius (mm)	134.855
Moderator gap thickness (mm)	1.8

2.2.3 Reflector

The fuel element is located in the center of a cylindrical tank filled with D_2O . The tank has a radius of 1.15 m and a height of 2.2 m. The fuel element is separated from the reflector by a stack. The stack eliminates the possibility of contaminating the entire system with dissolved boron if a leak occurs. The cylindrical tube has an inner radius of 20.217 mm and is fabricated from AG3-NE aluminum alloy. The wall thickness is 6.1 mm.

2.2.4 Boron Endplates

Packages consisting of horizontal borated aluminum plates and pure aluminum plates, each 1-mm thick, were used to simulate boron zones at the upper and lower edges of the FOEHN fuel element. The boron loading in the plates was $5 \times 10^{-3} \text{ g B}_{\text{nat}}/\text{cm}^2$ (1-mm-thick plate). The packages were attached outside the watertight vessel that contains the fuel element. A drawing of the endplate configuration is shown in Fig. 2.1. The boron loading and the metal-to- D_2O ratio of the package correspond to those of the Franco-German High Flux Reactor.

Fig. 2.1. Borated aluminum and aluminum plates in the boron endplate package. (All dimensions are in millimeters.)

2.2.5 Reflector Components

A description of the reflector components is shown Table 2.2. This information is from ref. 7. The structures are made of an AG3-NE alloy with a thickness of 2 mm. Figure 2.2 shows the location of each of the reflector components. The hot and cold sources were mock-ups of the actual sources. Diagrams of the cold and hot sources are shown in Figs. 2.3 and 2.4, respectively.

Table 2.2. Description of reflector components in the FOEHN experiment

Number	Description	Location of the center of component (mm)			Orientation		Length (mm)	Inner diameter (mm)
		x	y	z	θ°	ϕ°		
1	Horizontal beam tube	-278	-482	860	159	0	830	150
2	Horizontal beam tube	-459	-244	860	146	0	765	100
3	Horizontal beam tube	-429	53	1360	261	0	1012	100
4	Horizontal beam tube	-393	-218	1110	297	0	910	100
6	Horizontal beam tube	470	190	1210	307	0	880	100
7	Horizontal beam tube to the hot source	446	79	1260	287	0	975	100
8	Horizontal beam tube	368 ^a	-298 ^a	860	40	0	883	100
9	Horizontal beam tube	515	402	1260	28	0	488	100
10	Horizontal beam tube	383	496	1260	94	0	532	100
11 ^b	Horizontal thermal neutron conductor	-218	448	910	122	0	588	150 ^a
13	Capture gamma horizontal tube	-486	-953	810	30	0	1784	100
14	Cold source	-618	328	1105	0	90	1105	200
15	Hot source	375	325	1010	0	90	1200	150
16	Pneumatic tube	-522	745	1110	0	90	1200	40
17	Pneumatic tube	39	373	1310	0	90	1000	40
19	Slant tube	-310	-442	1360	293	35	800	100
21	Hot source slant tube	503	193	1330	314	35	933	100
22	Hot source slant tube	-122	527	1360	47	35	840	100
23	Vertical electron tube	375	-649	10	0	90	2200	200
24	Cold source slant tube	776	137	1360	230	35	350	100

^aThese values are incorrect in ref. 7 and were corrected based on information from ref. 6.

^bThis tube has a conical shape. The inner diameter of the cone is 150 mm. The conic angle is $5^\circ 30'$, making the outer diameter of the cone 253 mm.

Fig. 2.2. Reflector components in the complex configuration of the FOEHN experiment.

Fig. 2.3. Diagram of the cold source in the FOEHN experiment. (All dimensions are in millimeters.)

Fig. 2.4. Diagram of the hot source in the FOEHN experiment. (All dimensions are in millimeters.)

2.3 MEASURED DATA

The critical states, power distributions, thermal fluxes, and the rendement are the measured parameters of interest to this report. More detail about the measurement methods can be found in ref. 6. Gamma heating and epithermal and fast flux measurements were also made during the experiment.

2.3.1 Critical States

The critical states for the different cases of the configurations were determined by measuring the stable reactor period of various supercritical states. The reactivities for each period are calculated using the Inhour equation and are plotted vs the control element positions. The critical control element position is determined by extrapolation.

2.3.2 Power Distribution

Measurements of the power distribution in the fuel element were made with $5 \times 3 \times 1.27$ -mm probes. The probes were composed of the same material as the fuel plates. These probes were placed in punched holes of special fuel plates and were calibrated by measurement of their natural gamma activity above 130 keV. After irradiation, the gamma activity of the fission products above 511 keV was measured. This activity is proportional to the fission power production that occurred in the probe during irradiation.

2.3.3 Thermal Flux

Thermal flux measurements were made at various points in the reflector for each configuration. Manganese probes, or foils, were used to determine the cadmium ratio. Foils with and without cadmium covers were irradiated. The thermal flux can be determined using the measured activities of the irradiated foils.

2.3.4 Rendement

The rendement is the ratio of the peak thermal flux in the reflector to the total core power. The rendement (r) was determined using

$$r = \frac{A_{Mn,max}}{A_{Mn,R}} \cdot \frac{v}{v_0} \cdot \frac{A_{U,R}}{A_{U,C}} \cdot \frac{1}{\Sigma_{f,th}^U \cdot V_c \cdot Q} \quad (1)$$

where

$A_{Mn,max}$	= activity of manganese probe at the maximum flux position,
$A_{Mn,R}$	= activity of manganese probe in the reflector,
$A_{U,R}$	= activity of the uranium probe in the reflector,
$A_{U,C}$	= activity of the uranium probe in the core,
$\Sigma_{f,th}^U$	= thermal macroscopic uranium fission cross section,
V_c	= the core volume,
Q	= the energy per fission.

The ratio ν/ν_0 and Σ_f^U were calculated using the THERMOS⁸ code, and ν_0 is given in Eq. 2. The calculated thermal microscopic uranium fission cross section was 503 barns. In the calculation of the measured rendement in ref. 6, the energy released per fission, Q , was assumed to be 199.73 MeV.

$$\nu_0 = \frac{2}{\sqrt{\pi}} \cdot 2200 \frac{m}{sec} \quad (2)$$

2.4 EXPERIMENTAL UNCERTAINTIES

2.4.1 Geometrical Uncertainties

In ref. 6, diagrams of the FOEHN reactor are included that show the location of the different components. However, detailed drawings that include component dimensions are not given in the report. The location of components not described in the text of the report has to be determined using either the diagrams, which do not include dimensions, or the model used for the diffusion theory calculations in the report. One example of these uncertainties is the exact geometry of the control element. It is uncertain whether an aluminum structure is present at the upper edge of the control element.

In Sect. 2.2.1, the difference between the calculated volume and actual volume of borated heavy water in the core region was mentioned. The exact location of this extra D₂O is not known and was assumed to be at the inner and outer edge of the fuel element. Because the worth of the borated D₂O is largest for the simple configuration measurements, the location of the borated D₂O has the largest impact on the measured results of this configuration.

2.4.2 Material Compositions

The composition of AG3-NE aluminum alloy is not documented in ref. 6. Furthermore, it is not certain whether some of the components are AG3-NE alloy or pure aluminum. Also, the accuracy of the D₂O purity or the boron-concentration measurements was not discussed.

2.5 ERROR ESTIMATES

2.5.1 Critical States

The error associated with the measurement of the critical states depends on the control-element positions and the dissolved boron-concentration measurements. It was reported that the control-element position could be determined to within ± 1 mm. The error in the measurements of the boron concentration was not discussed.

2.5.2 Power Distribution Measurements

Reference 6 reports the relative error of the individual measuring points to be less than 1% for all points except those points on the upper and lower fuel-plate edges. This error is attributed to the uncertainty in the position of the fuel plates containing the probes. The error in the points at the upper

and lower edges of the fuel element is larger because the plates became somewhat deformed after use. In ref. 9, the errors involved with the power measurements were reevaluated. It is reported that errors in the measurements may be up to 8% when the probe dimensions, counting statistics, and probe positioning are considered. If the error associated with the probe dimensions is not included, the errors range from 1 to 4.15%. In this report, the error associated with all power distribution measurements is assumed to be 4%.

2.5.3 Thermal-Flux Measurements

The error in the thermal-flux measurements was determined to be about 2% by the FOEHN investigators.⁶ In ref. 9, after evaluation of all the contributing factors, it is stated that the errors may range from 3.3 to 22.8%. In this report, the error in the thermal-flux measurements is assumed to be 4%.

2.5.4 Rendement

In ref. 6, the error in the measurement of the rendement is stated as $\pm 2\%$, $\pm 2\%$, and $\pm 3\%$ for the simple, intermediate, and complex FOEHN configurations, respectively. The errors are estimated to be between 2.2 and 16.2% in ref. 9. The upper estimate was determined by accounting for positioning errors and statistical uncertainties.

2.6 SUMMARY

The components of the FOEHN experiment have been described in detail. The methods used to obtain the measured data were explained. Some of the uncertainties in the experiment were identified. The errors associated with the measured parameters calculated by the original experimenters and independently in a separate study were presented.

3. CALCULATIONAL MODELS OF THE FOEHN EXPERIMENT

3.1 INTRODUCTION

The models of each configuration of the FOEHN experiment are described in this chapter. The methods used to create the cross sections for the 2-D calculations are included. The atom densities for the materials in each configuration are included in Appendix A.

3.2 MATERIAL COMPOSITIONS

3.2.1 Fuel

The fuel composition was taken from Table 3.1 in ref. 6. These values were the atom densities for the homogenous fuel element. Atom densities for the impurities in the AG3-NE alloy were calculated using the atom density for aluminum from the reference.

3.2.2 Heavy Water

The density of the heavy water is 1.105 g/cm^3 , which corresponds to a temperature of 20°C . For each configuration, the amount of light water in the D_2O was different. The contamination is 0.253, 0.265, 0.263 at. % for the simple, intermediate, and complex configurations.⁶ This light water contamination was assumed to be the same in both the core and reflector regions.

3.2.3 AG3-NE Alloy

For these calculations, all of the aluminum components in the FOEHN experiment were assumed to be composed of AG3-NE alloy except the borated aluminum and pure aluminum plates used to construct the boron endplate packages. The exact composition of AG3-NE alloy is not documented in ref. 6. The composition assumed for this work is from a mill test¹⁰ of an AG3-NE sample and is listed in Table 3.1.

3.3 CROSS SECTION PROCESSING METHODOLOGY

Cross sections were processed using modules from the AMPX code system. The procedure is outlined in Fig. 3.1. Each step is explained in the following sections. For each case of each FOEHN configuration, 99-group and 20-group neutron cross section working libraries were produced. For each configuration, the ^2H and ^1H atom densities were changed to account for the fluctuations in the light water contamination during the experiment. The ^{10}B concentration in the coolant in the core region was set equal to the measured value for each critical state.

Fig. 3.1. Outline of the procedure used to create multigroup cross sections for the FOEHN calculations.

Table 3.1. Composition of AG3-NE alloy

Element	Weight percent
Al	96.739
Mg	2.78
Fe	0.26
Si	0.15
Mn	0.04
Cr	0.01
Ti	0.01
Zn	0.01
B	0.001
Cu	70 ^a
Pb	20 ^a
Cd	1 ^a

^aValue has units of ppm.

3.3.1 Resonance Processing

3.3.1.1 Unresolved Resonance Energy Range

The BONAMI¹¹ module uses Bondarenko factor data in a self-shielding calculation. In the AMPX system, this approach is used in the unresolved energy range. In the ANSL-V library, two isotopes used in these calculations (²³⁸U and ²³⁵U) have Bondarenko factor data. A one-dimensional (1-D) slab model of a fuel unit cell was used to allow BONAMI to calculate escape probabilities to account for the interaction between fuel lumps.

3.3.1.2 Resolved Resonance Energy Range

The NITAWL¹¹ module was used to process the resolved resonances using the Nordheim Integral Treatment. All nuclides were processed at a temperature of 300 K. The resonance nuclides in the AG3-NE alloy were processed separately for the fuel plates and structural material by changing the lump dimension.

A Dancoff correction factor is required if the interaction between different material lumps must be considered. Calculations were performed using RAFFLE¹² to determine the Dancoff factors for the resonance processing of the nuclides in the fuel plates and the control element. RAFFLE is a Monte Carlo code that calculates first flight collision probabilities. In the analysis, the involute fuel plates were modeled as concentric circular cylinders. The thickness of the fuel cylinders is 1.27 mm, which is equal to the involute fuel-plate thickness. The moderator gap between the fuel plates is 1.8 mm. Using these dimensions, the FOEHN element model consists of 17 cylindrical fuel rings. For the Dancoff factor calculations, the atom densities of the fuel material were not adjusted to conserve the amount of ²³⁵U in the fuel element. The fuel-plate loading was not adjusted because conservation of the actual-fuel plate optical thickness is important in this calculation.

RAFFLE was used to calculate escape probabilities, P_{esc} , for neutrons born within the fuel and control element regions. P_{esc} can be determined using the calculated number of interactions in each material type in the model. The total macroscopic cross sections are required for each material in the model. In the RAFFLE calculations, the D_2O moderator did not contain dissolved boron or light water contamination. The P_{esc} values were then used to calculate the Dancoff correction factor for an infinite slab with the same thickness as the fuel ring. Also, an equivalent slab thickness was calculated. The values determined for the fuel element and the control element are shown in Table 3.2. Either the actual lump dimension and the Dancoff factor or the equivalent lump dimension with a Dancoff factor of zero can be used in NITAWL. Both of these methods result in the same P_{esc} value for the resonance processing.

Table 3.2. Dancoff correction factors and equivalent slab thicknesses for the FOEHN fuel element and control element

Region	Actual lump thickness (mm)	Dancoff correction factor (C)	Equivalent slab thickness (mm)
Fuel element	1.27	0.8115	7.09
Nickel control element	5.00	0.0127	5.08

3.3.2 Unit Cell Calculation

After resonance processing, the XSDRNPM S_n transport code was used to calculate 99-group fluxes over the fuel unit cell shown in Fig. 3.2. These fluxes were then used to create spatially homogenized 99-group unit cell cross sections. The weighted cross sections account for the flux depression in the fuel plate and can be used in homogenous representations of the fuel region.

Fig. 3.2. Unit cell model of a fuel plate in the FOEHN element. (All dimensions are in millimeters.)

3.3.3 Core Radial Transverse Models

The cell-weighted 99-group fuel cross sections were used in an XSDRNPM model of the radial transverse at the midplane of the FOEHN reactor. The dimensions of the model are shown in Fig. 3.3. The height of the fuel element, 800 mm, was used to determine the buckling correction and to calculate the axial leakage from the system. Two models were evaluated: a controlled model that included the nickel control element and an uncontrolled model that did not include the control element.

The calculated 99-group fluxes were used to collapse the 99 energy group cross sections to a 20 energy group structure. The energy group boundaries of the 20-group cross sections are shown in Table 3.3. One cross section set was created for the fuel region. Several cross section sets were created for the AG3-NE alloy and the heavy water in the reflector to account for the changes in the energy spectrum at different positions in the reactor. Trace amounts of the nuclides that make up AG3-NE alloy were added to the reflector region to create 20-group cross sections for the reflector components.

Fig. 3.3. XSDRNPM model of the radial transverse at the midplane of the FOEHN fuel element. (All dimensions are in millimeters.)

Table 3.3. Energy structure of 20-group cross sections collapsed from the 99 energy group structure

	Upper energy (eV)	Energy groups			Upper energy (eV)	Energy groups	
		99-group	20-group			99-group	20-group
1	2.0000E+07	1	1	51	5.5000E+02	51	
2	1.5941E+07	2		52	3.9110E+02	52	
3	1.2706E+07	3		53	2.7811E+02	53	
4	1.0127E+07	4		54	1.9776E+02	54	
5	8.0722E+06	5		55	1.4063E+02	55	
6	6.4340E+06	6		56	1.0000E+02	56	7
7	5.5234E+06	7		57	7.8600E+01	57	
8	4.7417E+06	8		58	6.1780E+01	58	
9	4.0707E+06	9		59	4.8559E+01	59	
10	3.4946E+06	10		60	3.8168E+01	60	
11	3.0000E+06	11	2	61	3.0000E+01	61	8
12	2.7235E+06	12		62	2.4082E+01	62	
13	2.4725E+06	13		63	1.9332E+01	63	
14	2.2447E+06	14		64	1.5518E+01	64	
15	2.0378E+06	15		65	1.2457E+01	65	
16	1.8500E+06	16	3	66	1.0000E+01	66	9
17	1.7497E+06	17		67	7.8600E+00	67	
18	1.6548E+06	18		68	6.1780E+00	68	
19	1.5651E+06	19		69	4.8559E+00	69	
20	1.4803E+06	20		70	3.8168E+00	70	
21	1.4000E+06	21		71	3.0000E+00	71	10
22	1.2816E+06	22		72	2.6996E+00	72	
23	1.1732E+06	23		73	2.4292E+00	73	
24	1.0740E+06	24		74	2.1859E+00	74	
25	9.8315E+05	25		75	1.9670E+00	75	
26	9.0000E+05	26	4	76	1.7700E+00	76	11
27	7.6525E+05	27		77	1.3000E+00	77	
28	6.5068E+05	28		78	1.0000E+00	78	12
29	5.5326E+05	29		79	7.6500E-01	79	
30	4.7043E+05	30		80	6.2500E-01	80	13
31	4.0000E+05	31		81	4.7900E-01	81	
32	3.0314E+05	32		82	3.9700E-01	82	14
33	2.2974E+05	33		83	3.3000E-01	83	
34	1.7411E+05	34		84	2.7000E-01	84	15
35	1.3195E+05	35		85	2.1500E-01	85	
36	1.0000E+05	36	5	86	1.6200E-01	86	16
37	7.0160E+04	37		87	1.0400E-01	87	
38	4.9224E+04	38		88	5.0000E-02	88	17
39	3.4536E+04	39		89	3.0000E-02	89	
40	2.4230E+04	40		90	1.0000E-02	90	18
41	1.7000E+04	41		91	4.4500E-03	91	
42	1.2017E+04	42		92	3.2500E-03	92	19
43	8.4941E+03	43		93	2.6000E-03	93	
44	6.0042E+03	44		94	2.1500E-03	94	20
45	4.2441E+03	45		95	1.8000E-03	95	
46	3.0000E+03	46	6	96	1.4500E-03	96	
47	2.1368E+03	47		97	1.1500E-03	97	
48	1.5220E+03	48		98	8.5000E-04	98	
49	1.0841E+03	49		99	5.5000E-04	99	
50	7.7217E+02	50			1.0000E-05		

3.3.4 Boron Endplate Model

Spatially weighted cross sections were created for the boron endplate regions using the 1-D slab XSDRNPM model shown in Fig. 3.4. This model accurately accounts for the effects of thermal neutrons returning from the D₂O above the fuel element. The spatially weighted 99-group cross sections from the unit cell calculation described in Sect. 3.3.2 were used in the homogenized fuel region. The width of the fuel element (55 mm) was used as the slab width, and the slab was assumed to be infinitely thick. The fluxes from this calculation were used to obtain spatially homogenized 99-group and 20-group cross sections for the boron endplate regions.

Fig. 3.4. XSDRNPM model used to calculate weighted cross sections for the boron endplate regions. (All dimensions are in millimeters.)

3.4 TWO-DIMENSIONAL (R-Z) MODEL DESCRIPTIONS

3.4.1 Simple Configuration

The simple configuration model is shown in Fig. 3.5. The radial dimensions are the same as those used in the 1-D model shown in Fig. 3.3. The boron endplate regions at the upper and lower edges of the fuel element contain heavy water in this configuration.

Fig. 3.5. R-Z geometry FOEHN model used in the KENO, DORT, and VENTURE calculations. (All dimensions are in millimeters.)

3.4.2 Intermediate Configuration

The intermediate configuration model is identical to the simple configuration model except that the boron endplates are included at the upper and lower edges of the fuel element. These endplate regions are represented by homogenous material using spatially weighted cross sections (see Sect. 3.3.4).

3.4.3 Complex Configuration

The complex configuration model is identical to the intermediate configuration model except that components are included in the reflector pool. Three different reflector component descriptions were examined. These descriptions evaluate different ways of modeling the complex shapes of the reflector components in an R-Z geometric model.

3.4.3.1 Void in the Reflector Components

In this approximate model, Monte Carlo methods were used to determine the amount of material in each region of the R-Z model. The MOVI computer code was used for this calculation. Each reflector component is modeled using basic geometry shapes (cylinders, spheres, cones, etc.). MOVI reads the VENTURE geometry file to determine the mesh structure of the problem. The amount of material in each coarse mesh interval is found by calculating the volume of each component using Monte Carlo methods. After each component has been considered, MOVI creates a modified VENTURE input deck that has a new zone map and the atom densities for the zones containing smeared component materials.

3.4.3.2 Aluminum in the Void Regions of the Reflector Components

In this model, aluminum was artificially added to the void regions of the reflector components. This substitution increases the absorption in the reflector and offsets the streaming effects from the void regions in the reflector components that cannot be modeled in R-Z geometry. Again, MOVI was used to create the VENTURE input deck.

3.4.3.3 Constant Aluminum Density in the Reflector

This model examined the use of a constant aluminum density in the reflector to correct for the reactivity effects of the reflector components. The model is much simpler than the smeared model generated by the MOVI code. Aluminum was added in the reflector from a radius of 30 cm to the outer edge of the reflector at 1.150 m over the entire height of the model.

3.5 COMPUTER CODES USED FOR THE TWO-DIMENSIONAL CALCULATIONS

3.5.1 KENO

KENO is a multigroup Monte Carlo transport code used for criticality analysis. The R-Z geometry model was constructed using cylinders and units. The zone structure in the KENO models was identical to the zone structure used in the DORT and VENTURE models. Calculations were performed using 99-group and 20-group cross sections with P_3 scattering order.

3.5.2 DORT

DORT is a multigroup discrete ordinates transport code. The DORT S_4P_1 calculations were performed using 20-group cross sections. The eigenvalue convergence criterion was $1.0E-5$, and the flux convergence criterion was $1.0E-4$. The DORT calculations were performed using the same number of mesh points as in the VENTURE model. DORT mesh points are at the center of each mesh region.

3.5.3 VENTURE

VENTURE is a multigroup finite difference diffusion theory code. The VENTURE calculations were performed using 20-group cross sections. The eigenvalue convergence criterion was $1.0E-5$ and the flux convergence criterion was $1.0E-5$. The number of mesh points was increased until no change occurred in the calculated k_{eff} value. VENTURE mesh points are at the centroid of each mesh region.

3.6 DETERMINATION OF CALCULATED QUANTITIES

3.6.1 Multiplication Factors

In the KENO eigenvalue calculations, 320 batches with 500 source particles per batch were used. The statistical uncertainty of all the reported eigenvalues is two standard deviations. The eigenvalues calculated for the first 119 active batches were not used in the determination of the final k_{eff} value to allow convergence of the fission source. The DORT and VENTURE eigenvalues are the values reported at the final iteration where all the convergence criteria have been met.

3.6.2 Power Distribution

For the KENO power distribution calculations, 550 batches with 10,000 source particles per batch were used. The first 50 batches were not tallied to allow convergence of the fission source. Statistical uncertainties of two sigma are reported for each power density value. The tally regions have a height of 5 mm and a radial thickness of 3 mm. The DORT and VENTURE power density values are point power density values calculated by each code. In the calculation of the power distributions, the energy per fission (Q) was assumed to be 202.47 MeV/fission, which is from ENDF/B-V cross section files for ^{235}U . This value assumes that the gamma radiation produced by the fuel is absorbed in the fuel region.

3.6.3 Thermal Flux

Thermal flux values are reported from DORT and VENTURE calculations. The values are normalized to the total core power of 1 W. In determining the thermal flux, the upper energy boundary was set at the cadmium cutoff energy (0.625 eV).

3.6.4 Rendement

The rendement (r) was determined using

$$r = \frac{\phi_{th,peak}}{P} , \quad (3)$$

where

$\phi_{th,peak}$ = peak thermal flux in the reflector,
 P = the core power.

The peak thermal flux is the largest thermal flux in the reflector calculated by DORT and VENTURE. In these calculations, the energy per fission, Q , was assumed to be 202.47 MeV. A value of 199.73 MeV was used to determine the measured rendement values reported in ref. 6. Each calculated rendement value was multiplied by 202.47 MeV then divided by 199.73 MeV. This re-normalization was done only in the determination of the rendement so that the calculated values could be directly compared to the measured rendement values presented in ref. 6.

3.7 SUMMARY

The models used for the evaluation of each of the FOEHN critical experiment configurations have been described. Necessary assumptions have been discussed. Several of the parameters used in the KENO, DORT, and VENTURE calculations were presented.

4. RESULTS

4.1 INTRODUCTION

Results for each of the FOEHN configurations are discussed in this chapter. The differences between the calculated and the measured values are presented. These differences are the percent difference between the measured and calculated results determined by subtracting the measured value from the calculated value and then dividing by the measured value. The average percent differences were determined by taking the average of the absolute values of the percent differences. Tables of the measured data taken from ref. 6 are included in Appendix B along with tables of the power density and thermal flux values calculated using KENO, DORT, and VENTURE. Some of the calculated results are compared to values determined in refs. 9, 13, and 14. The known differences between the calculational models used in this report and the work in these references are documented in Appendix C.

4.2 SIMPLE CONFIGURATION

4.2.1 Multiplication Factors

Table 4.1 shows the eigenvalues calculated for the eleven critical states of the simple configuration. These results are shown graphically in Figs. 4.1 and 4.2. All of the 99-group KENO results lie within three sigma of unity, and only one value is not within two sigma. The values show a trend of slightly overestimating unity. This bias may be the result of geometrical uncertainties as discussed in Sect. 2.4.1. The k_{eff} values from the 20-group calculations are larger than the 99-group results. The KENO and DORT 20-group results match well. The eigenvalues calculated with VENTURE (diffusion theory) are larger than those calculated using Monte Carlo techniques and S_n transport theory. The average multiplication factor for the simple configuration obtained in an independent analysis using Monte Carlo methods is 0.9982 ± 0.0017 .¹³

4.2.2 Power Distributions

Power distributions were measured for case 6 of Table 4.1. For this case, the control element was positioned at 601 mm, and the dissolved boron concentration was $0.4509 \text{ g }^{10}\text{B/L}$. Power distributions were calculated using KENO, DORT, and VENTURE. Table 4.2 shows the average and maximum differences between the calculated and measured values. The average difference is smallest for the results calculated with KENO using 99-group cross sections. The average statistical uncertainty in the KENO power density values is 3.20%. Table 4.3 shows the nonmatching points for the simple configuration power densities. A nonmatching point is a point where the experimental error and the two-sigma statistical uncertainty of the calculated result do not overlap. The error in the measured data is assumed to be 4%. Seventeen of the 122 data points (13.9%) are nonmatching points. If the three points near the control element are not included (see Sect. 2.4.1), the number of nonmatching points drops to 11.5%. Tables 4.4–4.6 show the differences between the measured and calculated values. Figures 4.3–4.8 show radial and axial traces of the KENO, DORT, and VENTURE calculated and measured power density values. All of the calculations underestimate the measured values for the radial trace at the top of the fuel element ($h=797.5 \text{ mm}$). The deviation trend in the axial trace at a radius of 143.5 mm was seen in all previous calculations.^{6,9,14}

Fig. 4.1. K_{eff} values for the simple FOEHN configuration calculated with KENO using 99-group cross sections.

Fig. 4.2. Comparison of k_{eff} values for the simple FOEHN configuration calculated with different computer codes using 20-group cross sections.

Table 4.1. Comparison of eigenvalues for the simple FOEHN configuration cases using different calculational methods

Case	Control element position (mm)	Boron-10 concentration (g ¹⁰ B/L)	KENO		DORT 20-group	VENTURE 20-group
			99-group	20-group		
1	172.0	0.2477	0.9997 ± 0.0050	1.0012 ± 0.0049	1.0000	1.0098
2	357.0	0.3349	1.0012 ± 0.0040	1.0057 ± 0.0040	1.0014	1.0098
3	455.0	0.3863	1.0033 ± 0.0045	1.0020 ± 0.0045	1.0037	1.0102
4	467.3	0.3855	0.9996 ± 0.0046	1.0006 ± 0.0048	1.0057	1.0098
5	596.0	0.4501	1.0024 ± 0.0042	1.0038 ± 0.0048	1.0048	1.0101
6	601.0	0.4509	0.9996 ± 0.0046	1.0050 ± 0.0047	1.0059	1.0130
7	602.0	0.4536	1.0027 ± 0.0047	1.0046 ± 0.0041	1.0051	1.0114
8	661.0	0.4791	1.0039 ± 0.0044	1.0085 ± 0.0045	1.0049	1.0119
9	857.0	0.5268	1.0025 ± 0.0043	1.0074 ± 0.0044	1.0078	1.0110
10	890.0	0.5386	1.0002 ± 0.0042	1.0057 ± 0.0039	1.0043	1.0100
11	896.0	0.5386	1.0052 ± 0.0043	1.0065 ± 0.0042	1.0073	1.0119
Average	-	-	1.0018 ± 0.0013	1.0046 ± 0.0013	1.0046	1.0108

Table 4.2. Average and maximum power density percent differences for the simple FOEHN configuration

Computer code	Percent difference	
	Average	Maximum ^a
KENO ^b	3.43	21.61 (9.33)
DORT ^c	3.22	18.00 (-8.67)
VENTURE ^c	2.94	13.17 (13.17)

^aThe maximum values in parentheses were determined without including the points at the inner edge of the fuel element near the tip of the control element (see Sect. 2.4.1).

^b99 energy groups.

^c20 energy groups.

4.2.3 Rendement

The rendement was calculated using the peak thermal flux values from the DORT and VENTURE calculations. The measured rendement was 2.480×10^{11} neutrons/(m² s W). Table 4.7 shows the calculated values. The DORT value overestimates the measured value by 10.23%. This result is very similar to the results obtained in ref. 9 (12% higher) and ref. 14 (14% higher). The VENTURE model overestimates the measured rendement by 6.27%.

4.2.4 Thermal Flux

Thermal flux values were measured for case 6 of Table 4.1. Tables 4.8 and 4.9 show the differences between the measured results and values calculated with DORT and VENTURE, respectively. The average difference for the DORT values is 7.66%. For the VENTURE values, the average difference is 4.34%. Figures 4.9–4.12 show radial and axial thermal flux traces comparing the measured and calculated values. Transport theory overestimates the thermal flux near the fuel element ($r = 235$ mm). Similar results were seen in the analysis in ref. 9. The diffusion theory results were not expected to show better agreement with the measured values than the transport theory results. The reason for this occurrence remains to be investigated.

Table 4.3. Nonmatching points for power densities calculated with KENO using 99-group cross sections for the simple FOEHN configuration

	(0=match, 1=nonmatch within two sigma)										
H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	0	0	0	1	0	1	0	1	1	0	0
790.6	1										1
785.5	0					0					0
780.6	0					0					1
771.5	0					0					0
750.0	0	0	0	0	0	0	0	0	0	0	0
725.0	0					0					0
700.0	0					0					0
625.0	0	0	0	0	0	0	0	0	0	0	0
550.0	0					0					0
475.0	0					0					0
400.0	1	0	1	1	0	0	0	0	0	0	0
325.0	1					0					0
250.0	1					0					0
175.0	0	0	0	0	0	0	0	0	0	0	0
100.0	0					0					0
75.0	0					0					0
50.0	1	0	0	0	0	0	0	0	0	0	0
28.5	1					0					0
19.4	0					0					0
14.5	0					0					0
9.4	0										0
2.5	0	0	0	0	0	1	1	0	0	0	1

Table 4.4. Percent differences between measured power densities and values calculated with KENO using 99-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	-5.25	-0.65	-5.93	-7.07	-1.90	-7.97	-1.70	-7.14	-7.13	-2.97	-0.50
790.6	-7.58										-7.58
785.5	-0.15					-2.85					-4.57
780.6	-4.00					-3.29					-8.37
771.5	4.29					4.39					-2.88
750.0	-3.09	-1.42	-2.73	1.49	-0.72	-0.92	-1.10	-3.92	-5.47	-3.63	-5.81
725.0	-1.09					-3.19					-4.70
700.0	-1.44					-0.44					-4.62
625.0	2.69	1.16	-0.23	1.45	1.95	-1.79	-0.32	-0.40	-1.69	0.44	-2.85
550.0	3.45					-0.71					-1.83
475.0	6.75					2.49					-2.26
400.0	15.21	4.33	9.34	9.49	0.41	-0.85	1.18	1.59	-0.11	1.92	0.99
325.0	21.61					1.26					0.43
250.0	10.36					5.48					-5.29
175.0	7.74	0.53	5.87	5.29	0.53	-0.41	3.35	-2.09	-2.21	1.02	-2.31
100.0	6.16					3.12					-0.66
75.0	3.79					-0.36					-2.35
50.0	9.33	0.68	5.55	2.92	2.14		2.96	-1.97	-2.52	2.14	-0.16
28.5	8.98					1.51					-1.73
19.4	8.16					1.40					-1.31
14.5	-1.47					4.28					
9.4	7.46										2.59
2.5	4.44	1.83	4.73	6.21	4.19	8.31	8.58	5.64	2.61	3.80	7.78

Table 4.5. Percent differences between measured power densities and values calculated with DORT using 20-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	-6.36	-3.08	-8.67	-8.28	-4.97	-7.95	-3.86	-6.96	-7.99	-4.68	-7.42
790.6	-7.32										-6.53
785.5	-2.96					-6.78					-4.41
780.6	-3.63					-6.55					-5.60
771.5	-4.06					-2.99					-3.23
750.0	-2.26	-2.65	-2.73	-2.63	-3.39	-3.37	-4.54	-4.04	-4.01	-4.17	-3.30
725.0	-1.60					-2.62					-1.84
700.0	0.30					-1.40					-1.51
625.0	2.15	-0.36	0.41	-0.36	-0.89	-0.83	-1.69	-0.39	-3.55	-0.80	1.73
550.0	3.10					0.39					1.52
475.0	7.98					1.39					2.19
400.0	15.90	6.48	10.33	7.19	3.28	2.77	1.90	0.92	-0.27	2.17	3.78
325.0	18.00					2.66					1.84
250.0	10.87					0.37					0.99
175.0	7.27	1.64	3.79	1.38	-0.24	-0.19	0.3	-2.58	-2.33	0.20	1.23
100.0	5.51					-0.09					1.62
75.0	-0.53					0.01					1.05
50.0	5.38	-0.92	2.51	0.50	1.13	-0.95	0.02	-2.63	-1.85	1.21	2.16
28.5	6.86					-0.68					1.79
19.4	4.95					-1.76					2.91
14.5	-0.77					0.02					
9.4	5.69										0.91
2.5	2.24	0.37	1.40	2.25	2.53	3.95	3.80	2.73	2.88	2.66	1.90

Table 4.6. Percent differences between measured power densities and values calculated with VENTURE using 20-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	-6.32	-1.59	-6.54	-5.67	-2.05	-5.03	-0.57	-3.75	-5.25	-2.57	-5.26
790.6	-1.93										-2.73
785.5	2.92					1.19					-0.09
780.6	1.77					-0.89					-1.02
771.5	0.23					-0.29					0.58
750.0	-1.01	-0.23	-0.17	-0.55	-2.51	-2.89	-1.71	0.91	1.37	0.66	-1.23
725.0	-2.27					-3.29					-1.07
700.0	-1.51					-3.13					-1.45
625.0	-1.05	-2.41	-1.44	-2.45	-3.76	-3.62	-2.41	0.87	-1.79	0.62	0.48
550.0	-0.74					-2.86					-0.11
475.0	3.36					-2.28					0.21
400.0	10.88	3.19	7.26	3.99	-0.81	-1.27	0.14	1.25	0.54	2.65	1.78
325.0	11.18					-1.49					-0.18
250.0	6.61					-2.17					-0.55
175.0	4.14	-0.54	1.88	-0.69	-3.36	-2.94	0.34	-1.01	-0.19	1.83	0.08
100.0	4.72					-1.84					1.40
75.0	-0.23					-0.84					1.37
50.0	7.82	1.58	4.60	1.86	1.31	-0.70	2.75	1.87	2.93	5.42	3.30
28.5	13.17					1.60					4.04
19.4	12.69					3.61					6.09
14.5	6.77					7.73					
9.4	12.84										3.32
2.5	3.42	2.56	4.05	5.29	5.77	7.40	7.67	6.19	5.76	4.67	2.60

Fig. 4.3. Comparison of experimental radial power density traces and KENO values calculated using 99-group cross sections for the simple FOEHN configuration.

Fig. 4.4. Comparison of experimental axial power density traces and KENO values calculated using 99-group cross sections for the simple FOEHN configuration.

Fig. 4.5. Comparison of experimental radial power density traces and DORT values calculated using 20-group cross sections for the simple FOEHN configuration.

Fig. 4.6. Comparison of experimental axial power density traces and DORT values calculated using 20-group cross sections for the simple FOEHN configuration.

Fig. 4.7. Comparison of experimental radial power density traces and VENTURE values calculated using 20-group cross sections for the simple FOEHN configuration.

Fig. 4.8. Comparison of experimental axial power density traces and VENTURE values calculated using 20-group cross sections for the simple FOEHN configuration.

Table 4.7. Rendement values calculated for the simple FOEHN configuration

Computer code	Rendement 10^{11} neutrons/(m ² s W)	Percent difference
DORT	2.7336	10.23
VENTURE	2.6356	6.27

Table 4.8. Percent differences between measured thermal fluxes and values calculated with DORT using 20-group cross sections for the simple FOEHN configuration

H/r(mm)	235	255	275	295	315	335	355	395	435	515	635	755	835
1825	-0.64	-0.21	0.13	-0.06	2.75		1.73	4.24	4.40				
1675	-0.30	0.60	1.15	2.93	4.68		4.61	6.76	6.61	7.81	6.69	4.78	7.48
1525	5.08	0.79	2.76	4.37	4.93	5.10	5.38	7.78	8.37	8.60	7.79	4.30	7.23
1425	9.73	1.85	7.05	6.29	6.38	6.34	6.90	8.32	9.34	11.32	9.05	5.80	7.96
1375	9.72	3.83	5.86	7.59	5.79	6.81	7.75	9.63	9.79				
1325	11.20	4.35	6.94	8.22	8.48	8.93	7.76	9.51	9.76	10.45	9.51	6.21	7.33
1275	10.28	4.74	7.68	8.81	8.04	8.39	8.92	9.87	10.31	11.39	10.73		
1225	9.96	5.17	7.89	8.78	7.08	10.18	8.75	9.49	11.44	11.05	9.30	3.73	8.05
1125	12.07	6.22	8.90	10.06	7.47	9.26	9.10	9.54	10.69	11.14	10.08	7.29	9.36
1075		5.15		9.50		9.44							
975	9.45	4.76	7.53	9.58	8.47	9.91	9.98	10.06	11.13	11.83	10.71	8.41	8.41
925	9.12		7.59		8.69		10.02						
825	7.60	3.66	7.41	9.12	8.05	9.79	8.71	9.15	11.49	12.25		8.50	7.93
725	6.47	3.89	7.90	8.91	8.15		9.66						
625	8.22	8.55	8.68	8.50	3.45		11.53	10.90	9.82	15.38			7.62
525	11.34	10.28	2.82	10.41	9.75								

Table 4.9. Percent differences between measured thermal fluxes and values calculated with VENTURE using 20-group cross sections for the simple FOEHN configuration

H/r(mm)	235	255	275	295	315	335	355	395	435	515	635	755	835
1825	-1.51	-1.12	-0.81	-1.04	1.69		0.59	3.00	3.08				
1675	-3.21	-2.05	-1.30	0.64	2.52		2.69	4.93	4.83	5.99	4.90	3.15	5.94
1525	-1.81	-4.59	-1.82	0.41	1.48	2.03	2.60	5.31	6.12	6.47	5.68	2.36	5.36
1425	2.23	-4.03	1.81	1.80	2.45	2.85	3.74	5.57	6.83	8.93	6.72	3.62	5.84
1375	1.67	-2.46	0.43	2.85	1.71	3.15	4.42	6.72	7.16				
1325	2.70	-2.24	1.25	3.26	4.14	5.05	4.29	6.48	7.03	7.90	6.98	3.82	5.02
1275	1.63	-2.05	1.79	3.68	3.58	4.40	5.30	6.73	7.46	8.72	8.07		
1225	1.21	-1.76	1.87	3.54	2.55	6.03	5.04	6.27	8.48	8.31	6.61	1.23	5.54
1125	3.06	-0.87	2.73	4.66	2.83	5.04	5.28	6.22	7.63	8.28	7.24	4.58	6.68
1075		-1.83		4.14		5.23							
975	1.08	-1.90	1.72	4.43	3.98	5.83	6.26	6.80	8.10	8.93	7.79	5.58	5.64
925	1.03		1.97		4.33		6.40						
825	0.34	-2.14	2.29	4.59	4.08	6.14	5.39	6.19	8.67	9.46		5.66	5.15
725	-0.27	-1.53	3.15	4.77	4.51		6.58						
625	2.39	3.81	4.66	5.00	0.43		8.69	8.25	7.26	12.62			4.93
525	7.56	6.92	-0.04	7.55	7.07

Fig. 4.9. Comparison of experimental radial thermal flux traces with DORT values calculated using 20-group cross sections for the simple FOEHN configuration.

Fig. 4.10. Comparison of experimental axial thermal flux traces with DORT values calculated using 20-group cross sections for the simple FOEHN configuration.

Fig. 4.11. Comparison of experimental radial thermal flux traces with VENTURE values calculated using 20-group cross sections for the simple FOEHN configuration.

Fig. 4.12. Comparison of experimental axial thermal flux traces with VENTURE values calculated using 20-group cross sections for the simple FOEHN configuration.

4.3 INTERMEDIATE CONFIGURATION

4.3.1 Multiplication Factors

Table 4.10 shows the eigenvalues calculated for the six cases of the intermediate FOEHN configuration. All of the values calculated using KENO with 99-group cross sections are within three sigma of unity. Two values are outside two sigma of unity. The average DORT and VENTURE k_{eff} values overestimate unity by 0.08% and 0.14%, respectively. The results are shown graphically in Figs. 4.13 and 4.14. The average multiplication factor for the intermediate configuration obtained in an independent analysis using Monte Carlo methods is 0.9951 ± 0.0021 .¹³

Table 4.10. Comparison of eigenvalues for the intermediate FOEHN configuration cases using different calculational methods

Case	Control element position (mm)	Boron-10 concentration (g ¹⁰ B/L)	KENO		DORT 20-group	VENTURE 20-group
			99-group	20-group		
1	352.2	0.210	0.9953 ± 0.0052	0.9990 ± 0.0044	0.9975	0.9995
2	447.0	0.258	0.9956 ± 0.0053	1.0039 ± 0.0048	1.0009	1.0023
3	457.0	0.270	0.9965 ± 0.0044	1.0031 ± 0.0046	0.9987	1.0000
4	609.0	0.350	0.9954 ± 0.0045	1.0021 ± 0.0046	1.0013	1.0014
5	664.0	0.371	1.0049 ± 0.0047	1.0006 ± 0.0050	1.0033	1.0027
6	815.0	0.419	1.0018 ± 0.0046	1.0065 ± 0.0046	1.0030	1.0025
Average	-	-	0.9983 ± 0.0020	1.0025 ± 0.0019	1.0008	1.0014

4.3.2 Power Distributions

Power distributions were measured for case 2 of Table 4.10. For this case, the control element was positioned at 447 mm, and the dissolved boron concentration was 0.258 g ¹⁰B/L. Table 4.11 shows the average and maximum differences between the calculated and measured values. The maximum differences occur at the upper and lower edges of the fuel element. As stated in Chap. 2, these points have larger experimental errors than the other points because of deformation of the fuel plates. When these points are not considered, the average differences are 2.86%, 1.68%, and 1.87% for the KENO, DORT, and VENTURE results, respectively. Table 4.12 shows the nonmatching points for the power densities calculated with KENO using 99-group cross sections. The error in the measured data is assumed to be 4%. The average statistical uncertainty in the KENO power density values is 3.51%. Twenty-six of the 123 data points (21.1%) are nonmatching points. If the points next to the boron endplates are not included (see Sect. 2.5.2), the number of nonmatching points drops to 5.7%. Tables 4.13 4.15 show the differences between the measured and calculated values. Figures 4.15 4.20 show radial and axial traces of the KENO, DORT, and VENTURE calculated and the measured power density values. The figures show that all of the calculated values underestimate the measured values at the upper edge of the fuel element ($h=797.5$ mm). The agreement is better at the lower edge ($h=2.5$ mm).

Table 4.11. Average and maximum power density percent differences for the intermediate FOEHN configuration

Computer code	Percent difference	
	Average ^a	Maximum ^b
KENO ^c	4.50 (2.86)	-20.50 (-9.67)
DORT ^d	3.45 (1.68)	-19.88 (-8.33)
VENTURE ^d	2.45 (1.87)	-12.46 (-7.66)

^aThe average values in parentheses were calculated without including the points at the upper and lower edges of the fuel element (see Sect. 2.5.2).

^bThe maximum values in parentheses were determined without including the points at the upper and lower edges of the fuel element or the points at the inner edge of the fuel element near the tip of the control element (see Sects. 2.4.1 and 2.5.2).

^c99 energy groups.

^d20 energy groups.

4.3.3 Rendement

The rendement was calculated using the peak thermal flux from the DORT and VENTURE calculations. The measured rendement was 2.56×10^{11} neutrons/(m² s W). Table 4.16 shows the calculated values. The DORT value overestimates the calculated value by 9.19%. This result is very similar to the results obtained in ref. 9 (11.5% higher) and ref. 14 (13% higher). The VENTURE model overestimates the measured rendement by 5.82%.

Fig. 4.13. K_{eff} values for the intermediate FOEHN configuration calculated with KENO using 99-group cross sections.

Fig. 4.14. Comparison of k_{eff} values for the intermediate FOEHN configuration calculated with different computer codes using 20-group cross sections.

Table 4.12. Nonmatching points for power densities calculated with KENO using 99-group cross sections for the intermediate FOEHN configuration

	(0=match, 1=nonmatch within two sigma)										
H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1	1	1	1	1	1	1	1	1	1	1
790.6	1										1
785.5	0					1					1
780.6	0					1					0
771.5	0					0					0
750.0	0	0	0	0	0	0	0	0	0	0	0
725.0	0					0					0
700.0	0					0					0
625.0	0	0	0	0	0	0	0	0	0	0	0
550.0	1					0					0
475.0	0					0					0
400.0	0	0	0	0	0	0	0	0	0	0	0
325.0	0					0					0
250.0	0					0					0
175.0	0	0	0	0	0	0	0	0	0	0	0
100.0	0					0					0
75.0	0					0					0
50.0	0	0	0	0	0	0	0	0	0	0	0
28.5	0					0					0
19.4	0					0					1
14.5	0					0					0
9.4	0										0
2.5	1	0	1	1	1	1	1	0	1	1	0

Table 4.13. Percent differences between measured power densities and values calculated with KENO using 99-group cross sections for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-10.96	-14.74	-20.13	-17.50	-20.50	-19.66	-16.19	-14.15	-10.27	-7.01	-7.74
790.6	-8.56										-7.36
785.5	-0.59					-8.66					-9.19
780.6	1.92					-9.67					-6.13
771.5	-5.77					-2.67					-3.89
750.0	-1.86	-5.73	-3.11	-1.26	-1.72	-4.21	-2.18	-2.28	-4.86	0.50	-4.72
725.0	-1.45					-0.86					-3.38
700.0	-4.08					2.13					-4.15
625.0	0.46	-0.90	0.98	1.48	0.64	-3.86	-0.44	-1.53	-2.41	-0.62	-4.01
550.0	8.22					1.81					-2.90
475.0	5.72					1.90					-3.32
400.0	1.08	1.77	0.98	0.70	3.17	3.64	1.21	-0.53	0.77	-1.57	-1.76
325.0	0.98					0.84					-4.58
250.0	2.94					0.39					-2.41
175.0	-6.66	-1.39	-2.75	-0.43	-0.72	0.06	1.70	-0.47	-0.22	-4.75	-4.59
100.0	-0.83					-0.53					-3.90
75.0	-5.01					-1.84					-3.32
50.0	-5.48	-5.12	0.04	0.64	-4.35	-0.27	-2.10	-1.08	0.46	-3.06	-1.40
28.5	-0.83					-3.86					-5.94
19.4	-5.57					-0.26					-7.04
14.5	1.13					-3.70					-4.30
9.4	-4.79										-4.95
2.5	-9.69	-7.10	-12.17	-11.21	-12.52	-13.64	-9.39	-7.21	-9.22	-8.96	-5.27

Table 4.14. Percent differences between measured power densities and values calculated with DORT using 20-group cross sections for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-11.95	-14.60	-19.83	-19.79	-19.88	-18.77	-14.88	-13.75	-10.56	-7.01	-5.97
790.6	-6.80										-5.06
785.5	-3.78					-8.33					-3.38
780.6	3.58					-7.64					-2.87
771.5	-3.72					-4.10					-3.03
750.0	-1.09	-2.47	-3.42	-2.09	-1.08	-0.59	-0.85	-2.42	-2.12	-0.19	-1.53
725.0	-0.38					0.85					0.27
700.0	1.60					0.49					-0.34
625.0	4.55	2.28	2.24	2.59	1.25	1.05	0.96	-0.76	0.59	0.95	0.10
550.0	8.63					2.71					0.90
475.0	-1.55					0.15					-0.17
400.0	0.86	-1.38	-0.19	0.18	0.64	0.27	0.13	-1.20	0.21	0.94	0.16
325.0	0.04					0.02					-0.01
250.0	1.05					0.17					0.05
175.0	0.59	-0.28	-1.12	0.20	-0.13	0.08	-0.26	-1.30	-0.86	-0.62	-0.72
100.0	0.52					0.63					0.40
75.0	-1.46					0.09					0.48
50.0	-1.44	-2.71	-2.73	-1.74	-0.67	-0.74	-0.67	-0.50	-0.94	0.47	0.60
28.5	-2.78					-3.58					-1.18
19.4	-2.89					-4.39					-0.42
14.5	-3.32					-6.28					-1.85
9.4	-4.82										-2.24
2.5	-8.14	-10.66	-11.51	-12.52	-12.02	-10.65	-9.86	-8.87	-7.08	-4.84	-1.87

Table 4.15. Percent differences between measured power densities and values calculated with VENTURE using 20-group cross sections for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-11.90	-10.49	-12.46	-10.10	-8.44	-6.94	-2.85	-4.40	-4.30	-4.64	-9.80
790.6	-7.45										-7.66
785.5	-5.39					-0.79					-5.80
780.6	1.55					-2.59					-5.09
771.5	-5.24					-2.50					-4.90
750.0	-3.47	-3.81	-4.42	-3.45	-3.25	-2.29	-1.20	-0.88	-0.37	1.02	-3.23
725.0	-3.55					-2.02					-1.41
700.0	-2.01					-2.44					-2.06
625.0	0.41	-0.74	-0.33	0.06	-1.79	-1.85	0.04	-0.06	1.75	1.68	-1.84
550.0	4.25					-0.35					-0.98
475.0	-4.04					-2.05					-1.56
400.0	-0.35	-2.51	-1.65	-1.63	-1.84	-1.67	0.27	0.55	2.32	2.47	-1.10
325.0	-1.56					-1.60					-0.98
250.0	-0.88					-1.33					-0.73
175.0	-0.90	-1.13	-2.10	-1.06	-1.87	-1.20	0.66	1.18	2.06	1.74	-1.12
100.0	-0.37					-0.43					0.16
75.0	-1.80					-0.76					0.43
50.0	-0.72	-1.55	-1.77	-1.20	-1.03	-0.46	1.17	3.04	2.64	3.39	0.48
28.5	-0.28					-0.48					-1.65
19.4	-0.10					2.30					-1.08
14.5	-0.08					2.67					-2.78
9.4	-0.42										-3.57
2.5	-1.54	-1.04	1.03	1.79	3.96	4.87	4.16	2.27	0.95	-0.66	-3.05

Fig. 4.15. Comparison of experimental radial power density traces and KENO values calculated using 99-group cross sections for the intermediate FOEHN configuration.

Fig. 4.16. Comparison of experimental axial power density traces and KENO values calculated using 99-group cross sections for the intermediate FOEHN configuration.

Fig. 4.17. Comparison of experimental radial power density traces and DORT values calculated using 20-group cross sections for the intermediate FOEHN configuration.

Fig. 4.18. Comparison of experimental axial power density traces and DORT values calculated using 20-group cross sections for the intermediate FOEHN configuration.

Fig. 4.19. Comparison of experimental radial power density traces and VENTURE values calculated using 20-group cross sections for the intermediate FOEHN configuration.

Fig. 4.20. Comparison of experimental axial power density traces and VENTURE values calculated using 20-group cross sections for the intermediate FOEHN configuration.

**Table 4.16. Rendement values calculated
for the intermediate FOEHN configuration**

Computer code	Rendement 10^{11} neutrons/(m ² s W)	Percent difference
DORT	2.7954	9.19
VENTURE	2.7090	5.82

4.3.4 Thermal Flux

Thermal flux values were measured for case 2 of Table 4.10. Tables 4.17 and 4.18 show the differences between the measured results and values calculated with DORT and VENTURE, respectively. The average difference for the DORT values is 6.27%. For the VENTURE values, the average difference is 4.46%. Figures 4.21–4.24 show radial and axial thermal flux traces comparing the measured and calculated values. As with the simple configuration, the calculated flux values overestimate the measured values near the peak in the reflector. Again, the diffusion theory results were not expected to show better agreement with the measured values than the transport theory results; the reason for this occurrence remains to be investigated.

Table 4.17. Percent differences between measured thermal fluxes and values calculated with DORT using 20-group cross sections for the intermediate FOEHN configuration

H/r(mm)	235	275	315	335	355	375	395	435	515	675	755	835	915	955
1810	-6.18	-2.79	0.46		2.62									
1710	-8.69	-1.68	0.75		3.91		3.89							
1610	-0.95	2.40	3.54		4.93		5.24	6.37				3.60		
1510	-0.16	3.37	4.36		5.57		5.37	7.97				4.91		
1410	1.14	5.29	6.14		8.00	8.25	7.26	8.84	8.53			5.36		
1310	2.39	6.68	6.62		7.65	8.98	7.34	9.24	9.16	6.72	6.13	5.55		
1260				8.68	6.99	8.27	7.88							
1210	1.50	6.07	6.80	8.29	7.95	8.53	8.26	8.31	9.18	7.36	6.75	5.67	2.31	2.73
1160				8.56	7.02	8.67	8.07							
1110	1.21	6.26	6.99	8.02	8.48	8.19	8.53	8.21	9.38	7.63	6.45	5.65	2.31	2.04
1060				8.29		8.47								
1010	1.73	6.39	8.05	8.15	7.78	7.78	7.75	8.17	8.78	7.74	6.02	6.09	3.38	2.04
910	0.13	6.13	6.67		7.65	8.22	7.80	7.09	8.54	7.91	6.21	6.01		
810	1.19	7.22	7.12		7.29		8.25	9.01	8.64	7.01	6.76	5.77		
710	1.71	6.72	7.40		7.74			7.99	8.79				5.75	
610	-0.45	4.89	7.51		8.44			10.13						
510	5.78	8.05	10.48		10.26									

Table 4.18. Percent differences between measured thermal fluxes and values calculated with VENTURE using 20-group cross sections for the intermediate FOEHN configuration

H/r(mm)	235	275	315	335	355	375	395	435	515	675	755	835	915	955
1810	-8.45	-5.06	-1.83		0.33									
1710	-12.04	-4.84	-2.12		1.19		1.32							
1610	-7.24	-2.20	-0.14		1.77		2.41	3.71				1.94		
1510	-7.80	-1.96	0.29		2.21		2.46	5.26				3.08		
1410	-6.48	-0.27	1.92		4.55	5.07	4.33	6.17	6.09			3.43		
1310	-5.46	1.01	2.40		4.28	5.87	4.49	6.66	6.80	4.49	4.00	3.58		
1260				4.96	3.71	5.25	5.09							
1210	-6.12	0.61	2.74	4.67	4.72	5.58	5.53	5.89	6.92	5.15	4.63	3.69	0.54	1.04
1160				5.04	3.92	5.81	5.43							
1110	-5.97	1.11	3.19	4.65	5.46	5.45	5.99	5.95	7.24	5.49	4.39	3.71	0.56	0.37
1060				5.06		5.84								
1010	-5.14	1.55	4.47	5.03	5.02	5.27	5.43	6.09	6.80	5.69	4.05	4.21	1.68	0.42
910	-6.30	1.59	3.40		5.10	5.90	5.67	5.19	6.69	5.96	4.33	4.22		
810	-4.88	2.97	4.10		4.96		6.27	7.20	6.89	5.19	4.99	4.11		
710	-4.32	2.82	4.64		5.59		6.15	7.08				4.24		
610	-5.54	1.61	5.10		6.47		8.36							
510	2.43	5.63	8.50		8.51

Fig. 4.21. Comparison of experimental radial thermal flux traces with DORT values calculated using 20-group cross sections for the intermediate FOEHN configuration.

Fig. 4.22. Comparison of experimental axial thermal flux traces with DORT values calculated using 20-group cross sections for the intermediate FOEHN configuration.

Fig. 4.23. Comparison of experimental radial thermal flux traces with VENTURE values calculated using 20-group cross sections for the intermediate FOEHN configuration.

Fig. 4.24. Comparison of experimental axial thermal flux traces with VENTURE values calculated using 20-group cross sections for the intermediate FOEHN configuration.

4.4 COMPLEX CONFIGURATION

4.4.1 Multiplication Factors

Three different complex FOEHN configuration models were evaluated. The eigenvalue results are shown in Tables 4.19–4.21. The results are shown graphically in Figs. 4.25–4.30. The smeared model with void in the reflector components overestimates the critical states by approximately 1.6%. The streaming effects of the void regions cannot be correctly treated in the smeared R-Z model.

The models that have aluminum in the void region of the reflector components and a constant aluminum density in the reflector were forced to yield k_{eff} values near unity. These corrected models demonstrate methods of obtaining equivalent reflector component models. The comparisons with the measured critical states and power distributions will indicate how well such a model will perform under varying conditions. For both models, the amount of aluminum in the reflector was adjusted until the k_{eff} value calculated with KENO using 99-group cross sections was within two sigma of unity for the case with the control element at 804 mm and a boron concentration of 0.347 g $^{10}\text{B/L}$. The density of the aluminum in the void regions was determined to be 1.08 g/cm³, or 40% of 2.7 g/cm³ (the density of pure aluminum). The aluminum density that yields a multiplication factor near unity for the model with a constant aluminum density in the reflector is 0.0567 g/cm³, or 2.1% of 2.7 g/cm³.

For the two corrected models, all of the KENO 99-group eigenvalues are within three sigma of unity. Three of the values are just outside two sigma of unity. The results for the corrected models using 20-group calculations overestimate unity by 0.03 to 0.05%. The average multiplication factor obtained in the analysis of the complex configuration using an explicit representation of the reflector components is 0.9923 ± 0.0021 .¹³

4.4.2 Power Distributions

Power distributions were measured with the control element positioned at 471 mm and the dissolved boron concentration equal to 0.177 g $^{10}\text{B/L}$. Table 4.22 shows the average and maximum differences between the calculated and measured values. The average values calculated without including the points at the upper and lower edges of the fuel element are also included. Tables 4.23–4.28 show the differences between the measured and calculated values. Figs. 4.31–4.34 show radial and axial traces of the DORT and VENTURE calculated and the measured power density values. The figures show that the distributions calculated with the three different models vary only slightly at the outer edge of the fuel element ($r = 193.9$ mm).

4.4.3 Rendement

The rendement was calculated using the peak thermal flux from the DORT and VENTURE calculations. The measured rendement is 2.30×10^{11} neutrons/(m² s W). Table 4.29 shows the calculated values. The model with void in the reflector components yields the largest rendement. The values calculated using VENTURE are smaller than the DORT results. These results are slightly larger than the rendement obtained in ref. 9 which is 4.84% higher than the measured value. The complex FOEHN configuration model for the calculations in ref. 9 included explicit reflector components.

Table 4.19. Comparison of eigenvalues for the complex FOEHN configuration cases using different calculational methods with void in the reflector components

Case	Control element position (mm)	Boron-10 concentration (g ¹⁰ B/L)	KENO		DORT 20-group	VENTURE 20-group
			99-group	20-group		
1	804	0.347	1.0166 ± 0.0045	1.0176 ± 0.0046	1.0175	1.0173
2	711	0.311	1.0146 ± 0.0049	1.0234 ± 0.0046	1.0212	1.0208
3	596	0.260	1.0167 ± 0.0048	1.0226 ± 0.0049	1.0212	1.0217
4	579	0.248	1.0209 ± 0.0048	1.0219 ± 0.0049	1.0216	1.0231
5	503	0.210	1.0167 ± 0.0046	1.0179 ± 0.0051	1.0196	1.0217
6	385	0.143	1.0154 ± 0.0045	1.0237 ± 0.0049	1.0172	1.0206
7	249	0.078	1.0124 ± 0.0050	1.0162 ± 0.0051	1.0150	1.0189
Average	-	-	1.0162 ± 0.0018	1.0205 ± 0.0018	1.0190	1.0206

Table 4.20. Comparison of eigenvalues for the complex FOEHN configuration cases using different calculational methods with aluminum in the void regions of the reflector components

Case	Control element position (mm)	Boron-10 concentration (g ¹⁰ B/L)	KENO		DORT 20-group	VENTURE 20-group
			99-group	20-group		
1	804	0.347	0.9971 ± 0.0047	0.9996 ± 0.0051	1.0033	1.0016
2	711	0.311	1.0045 ± 0.0049	1.0060 ± 0.0048	1.0049	1.0049
3	596	0.260	1.0022 ± 0.0045	1.0048 ± 0.0045	1.0033	1.0053
4	579	0.248	1.0009 ± 0.0046	1.0101 ± 0.0045	1.0101	1.0066
5	503	0.210	1.0015 ± 0.0048	1.0029 ± 0.0050	1.0028	1.0049
6	385	0.143	0.9947 ± 0.0050	1.0061 ± 0.0048	1.0002	1.0031
7	249	0.078	0.9943 ± 0.0050	0.9997 ± 0.0052	0.9965	1.0007
Average	-	-	0.9993 ± 0.0018	1.0042 ± 0.0018	1.0030	1.0039

Table 4.21. Comparison of eigenvalues for the complex FOEHN configuration cases using different calculational methods with a constant aluminum density in the reflector

Case	Control element position (mm)	Boron-10 concentration (g ¹⁰ B/L)	KENO		DORT 20-group	VENTURE 20-group
			99-group	20-group		
1	804	0.347	0.9987 ± 0.0047	1.0005 ± 0.0052	1.0031	1.0022
2	711	0.311	0.9978 ± 0.0052	1.0056 ± 0.0050	1.0068	1.0057
3	596	0.260	1.0013 ± 0.0047	1.0064 ± 0.0044	1.0048	1.0063
4	579	0.248	1.0040 ± 0.0048	1.0049 ± 0.0045	1.0061	1.0076
5	503	0.210	1.0008 ± 0.0050	1.0049 ± 0.0051	1.0053	1.0059
6	385	0.143	0.9997 ± 0.0046	1.0011 ± 0.0046	1.0013	1.0041
7	249	0.078	0.9946 ± 0.0050	0.9974 ± 0.0054	0.9971	1.0013
Average	-	-	0.9996 ± 0.0018	1.0030 ± 0.0019	1.0035	1.0047

Table 4.22. Average and maximum power density percent differences for the different models of the complex FOEHN configuration

Model	Computer code	Percent difference	
		Average ^a	Maximum ^b
Void in the reflector components	DORT	4.82 (2.92)	-23.17 (-12.28)
	VENTURE	3.37 (2.91)	-15.42 (-8.39)
Aluminum in the void regions of the reflector components	DORT	5.11 (3.15)	-22.90 (-12.98)
	VENTURE	3.51 (2.96)	-14.88 (-8.06)
Constant aluminum density in the reflector	DORT	5.74 (3.73)	-22.57 (-15.11)
	VENTURE	4.12 (3.45)	-14.72 (-10.27)

^aThe average values in parentheses were calculated without including the points at the upper and lower edges of the fuel element (see Sect. 2.5.2).

^bThe maximum values in parentheses were determined without including the points at the upper and lower edges of the fuel element or the points at the inner edge of the fuel element near the tip of the control element (see Sects. 2.4.1 and 2.5.2).

Fig. 4.25. K_{eff} values for the complex FOEHN configuration calculated with KENO using 99-group cross sections and void in the reflector components.

Fig. 4.26. Comparison of k_{eff} values for the complex FOEHN configuration calculated with different computer codes using 20-group cross sections and void in the reflector components.

Fig. 4.27. K_{eff} values for the complex FOEHN configuration calculated with KENO using 99-group cross sections and aluminum in the void regions of the reflector components.

Fig. 4.28. Comparison of k_{eff} values for the complex FOEHN configuration calculated with different computer codes using 20-group cross sections and aluminum in the void regions of the reflector components.

Fig. 4.29. K_{eff} values for the complex FOEHN configuration calculated with KENO using 99-group cross sections and a constant aluminum density in the reflector.

Fig. 4.30. Comparison of k_{eff} values for the complex FOEHN configuration calculated with different computer codes using 20-group cross sections and a constant aluminum density in the reflector.

Table 4.23. Percent differences between measured power densities and values calculated with DORT using 20-group cross sections for the complex FOEHN configuration with void in the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-16.12	-17.67	-19.83	-23.17	-21.86	-16.99	-15.68	-15.55		-6.86	-8.03
795.0											-3.71
790.6	-7.79										-3.05
785.5	-6.76					-10.55					-2.85
780.6	-7.30					-10.68					-1.75
771.5	-5.07					-2.07					-0.69
750.0	-4.58	-4.69	-3.54	-5.74	-3.67	-2.38	-1.83	-5.06	-1.44	-0.21	-0.81
725.0	-3.74					-1.43					0.69
700.0	-2.91					-3.65					1.07
625.0	0.35	-1.15	0.14	-1.74	-1.71	-0.81	-1.11	-2.66	-1.47	0.62	1.41
550.0	1.82					0.51					2.33
475.0	8.13					1.16					2.73
400.0	3.53	1.59	1.40	-1.59	-0.79	-0.62	-1.01	-2.79	-0.89	0.26	0.55
325.0	-0.79					-1.55					1.13
250.0	-0.98					-2.38					-0.08
175.0	-1.56	-2.19	-3.34	-4.44	-2.67	-2.81	-3.38	-4.01	-3.89	-2.80	-1.19
100.0	-4.79					-3.44					-0.79
75.0	-0.81					-4.89					-1.29
50.0	-2.10	-2.06	-5.47	-5.27	-4.50	-4.40	-4.63	-2.90	-3.41	-2.56	-0.89
28.5	-6.03					-5.10					-0.69
19.4	-6.45					-7.79					-1.56
14.5	-1.70					-12.28					-2.03
9.4											-2.70
5.0											-3.85
2.5	-10.70	-11.74	-13.91	-15.82	-15.69	-14.71	-13.74	-12.99	-10.98	-8.45	

Table 4.24. Percent differences between measured power densities and values calculated with DORT using 20-group cross sections for the complex FOEHN configuration with aluminum in the void regions of the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-15.75	-17.31	-19.49	-22.90	-21.74	-17.19	-16.28	-16.42		-8.09	-9.43
795.0											-5.15
790.6	-7.27										-4.47
785.5	-6.17					-10.56					-4.25
780.6	-6.65					-10.67					-3.15
771.5	-4.27					-1.97					-2.08
750.0	-3.59	-3.74	-2.64	-4.92	-3.05	-2.16	-2.09	-5.69	-2.26	-1.22	-2.11
725.0	-2.60					-1.09					-0.54
700.0	-1.67					-3.22					-0.10
625.0	1.78	0.23	1.47	-0.51	-0.71	-0.21	-1.01	-2.96	-1.96	-0.06	0.40
550.0	3.34					1.20					1.41
475.0	9.74					1.85					1.85
400.0	4.98	2.95	2.68	-0.43	0.14	-0.09	-0.93	-3.08	-1.34	-0.37	-0.37
325.0	0.48					-1.15					0.11
250.0	0.17					-2.14					-1.25
175.0	-0.59	-1.30	-2.55	-3.75	-2.22	-2.79	-3.81	-4.80	-4.83	-3.91	-2.60
100.0	-4.07					-3.70					-2.53
75.0	-0.15					-5.26					-3.14
50.0	-1.57	-1.61	-5.13	-5.03	-4.56	-4.91	-5.62	-4.27	-4.94	-4.26	-2.88
28.5	-5.65					-5.74					-2.81
19.4	-6.20					-8.49					-3.71
14.5	-1.50					-12.98					-4.20
9.4											-4.89
5.0											-6.04
2.5	-10.65	-11.76	-14.00	-16.01	-16.16	-15.62	-15.06	-14.60	-12.75	-10.39	

Table 4.25. Percent differences between measured power densities and values calculated with DORT using 20-group cross sections for the complex FOEHN configuration with a constant aluminum density in the reflector

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-15.44	-17.00	-19.17	-22.57	-21.39	-16.79	-15.82	-15.93		-7.55	-8.86
795.0											-4.52
790.6	-6.90										-3.79
785.5	-5.77					-10.03					-3.51
780.6	-6.24					-10.11					-2.35
771.5	-3.82					-1.32					-1.18
750.0	-3.09	-3.22	-2.09	-4.37	-2.43	-1.42	-1.74	-4.79	-1.30	-0.20	-1.04
725.0	-2.07					-0.27					0.70
700.0	-1.12					-2.40					1.25
625.0	2.31	0.76	2.04	0.08	-0.03	0.63	-0.01	-1.84	-0.76	1.21	1.79
550.0	3.73					1.86					2.57
475.0	9.94					2.24					2.60
400.0	4.91	2.89	2.64	-0.46	0.14	-0.03	-0.80	-2.90	-1.14	-0.14	-0.10
325.0	0.08					-1.50					-0.14
250.0	-0.58					-2.89					-2.01
175.0	-1.67	-2.38	-3.63	-4.83	-3.35	-3.94	-4.97	-5.97	-6.02	-5.11	-3.84
100.0	-5.46					-5.30					-4.38
75.0	-1.73					-7.02					-5.24
50.0	-3.29	-3.36	-6.84	-6.78	-6.40	-6.88	-7.70	-6.48	-7.17	-6.55	-5.28
28.5	-7.45					-7.89					-5.48
19.4	-8.08					-10.67					-6.49
14.5	-3.54					-15.11					-7.03
9.4											-7.77
5.0											-8.97
2.5	-12.62	-13.74	-15.96	-17.97	-18.23	-17.88	-17.51	-17.16	-15.42	-13.19	

Table 4.26. Percent differences between measured power densities and values calculated with VENTURE using 20-group cross sections for the complex FOEHN configuration with void in the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-15.42	-12.83	-11.49	-13.91	-11.04	-4.75	-3.58	-5.64		-3.19	-11.38
795.0											-6.37
790.6	-8.39										-5.66
785.5	-8.22					-2.16					-5.43
780.6	-8.94					-6.03					-4.18
771.5	-6.38					-0.28					-2.73
750.0	-6.78	-5.89	-4.55	-7.29	-5.56	-4.03	-1.34	-3.39	0.93	1.85	-2.68
725.0	-6.54					-3.68					-1.25
700.0	-6.00					-5.98					-0.99
625.0	-3.12	-3.47	-2.00	-4.46	-4.54	-3.40	-1.61	-1.78	0.18	2.05	-0.97
550.0	-1.76					-2.09					-0.12
475.0	4.88					-1.46					0.41
400.0	1.88	0.93	0.93	-2.56	-2.08	-1.81	-0.35	-1.02	1.59	2.41	-1.25
325.0	-2.17					-2.89					-0.25
250.0	-2.29					-3.33					-1.11
175.0	-2.48	-2.58	-3.81	-5.48	-3.89	-3.45	-1.74	-1.12	-0.27	0.48	-1.84
100.0	-5.00					-3.57					-0.96
75.0	-0.52					-4.77					-1.31
50.0	-0.92	-0.52	-4.05	-4.42	-4.10	-3.66	-1.81	1.07	1.10	1.57	-0.91
28.5	-3.31					-1.39					-1.03
19.4	-3.74					-1.32					-2.24
14.5	1.21					-2.78					-2.85
9.4											-3.67
5.0											-4.97
2.5	-5.00	-2.73	-2.02	-2.93	-1.20	-0.13	-0.11	-1.76	-1.92	-3.44	

Table 4.27. Percent differences between measured power densities and values calculated with VENTURE using 20-group cross sections for the complex FOEHN configuration with aluminum in the void regions of the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-14.88	-12.33	-11.05	-13.55	-10.88	-4.96	-4.21	-6.54		-4.35	-12.61
795.0											-7.67
790.6	-7.67										-6.96
785.5	-7.41					-2.13					-6.72
780.6	-8.06					-5.92					-5.48
771.5	-5.36					-0.07					-4.03
750.0	-5.57	-4.72	-3.42	-6.27	-4.77	-3.69	-1.55	-4.01	0.10	0.83	-3.93
725.0	-5.19					-3.24					-2.45
700.0	-4.56					-5.48					-2.14
625.0	-1.51	-1.93	-0.51	-3.09	-3.43	-2.75	-1.51	-2.11	-0.35	1.32	-1.97
550.0	-0.10					-1.38					-1.04
475.0	6.63					-0.76					-0.48
400.0	3.45	2.41	2.33	-1.31	-1.08	-1.26	-0.30	-1.35	1.07	1.72	-2.18
325.0	-0.79					-2.49					-1.29
250.0	-1.05					-3.10					-2.32
175.0	-1.41	-1.59	-2.94	-4.73	-3.42	-3.44	-2.25	-2.02	-1.35	-0.77	-3.31
100.0	-4.16					-3.85					-2.79
75.0	0.27					-5.16					-3.26
50.0	-0.27	0.04	-3.62	-4.11	-4.11	-4.18	-2.90	-0.47	-0.61	-0.30	-2.99
28.5	-2.86					-2.10					-3.22
19.4	-3.42					-2.15					-4.44
14.5	1.47					-3.68					-5.07
9.4											-5.90
5.0											-7.19
2.5	-5.02	-2.87	-2.28	-3.32	-1.94	-1.36	-1.77	-3.68	-3.95	-5.54	

Table 4.28. Percent differences between measured power densities and values calculated with VENTURE using 20-group cross sections for the complex FOEHN configuration with a constant aluminum density in the reflector

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	-14.72	-12.15	-10.85	-13.35	-10.64	-4.68	-3.91	-6.25		-4.05	-12.33
795.0											-7.34
790.6	-7.43										-6.57
785.5	-7.13					-1.70					-6.27
780.6	-7.75					-5.47					-4.97
771.5	-4.98					0.49					-3.41
750.0	-5.09	-4.22	-2.89	-5.73	-4.17	-3.02	-0.79	-3.24	0.91	1.68	-3.10
725.0	-4.63					-2.46					-1.43
700.0	-3.96					-4.65					-0.99
625.0	-0.88	-1.27	0.18	-2.40	-2.67	-1.87	-0.49	-1.02	0.80	2.53	-0.74
550.0	0.44					-0.64					-0.02
475.0	7.02					-0.27					0.15
400.0	3.58	2.54	2.47	-1.17	-0.94	-1.10	-0.13	-1.19	1.24	1.88	-2.02
325.0	-0.98					-2.73					-1.66
250.0	-1.58					-3.75					-3.20
175.0	-2.27	-2.47	-3.82	-5.62	-4.38	-4.50	-3.43	-3.29	-2.66	-2.12	-4.68
100.0	-5.36					-5.39					-4.80
75.0	-1.14					-6.86					-5.53
50.0	-1.85	-1.58	-5.22	-5.74	-5.86	-6.13	-5.10	-2.87	-3.08	-2.85	-5.57
28.5	-4.60					-4.34					-6.08
19.4	-5.27					-4.53					-7.39
14.5	-0.54					-6.11					-8.07
9.4											-8.95
5.0											-10.27
2.5	-7.12	-5.07	-4.56	-5.64	-4.45	-4.11	-4.74	-6.73	-7.05	-8.63

Fig. 4.31. Comparison of experimental radial power density traces and DORT values calculated using 20-group cross sections for the different models of the complex FOEHN configuration.

Fig. 4.32. Comparison of experimental axial power density traces and DORT values calculated using 20-group cross sections for the different models of the complex FOEHN configuration.

Fig. 4.33. Comparison of experimental radial power density traces and VENTURE values calculated using 20-group cross sections for the different models of the complex FOEHN configuration.

Fig. 4.34. Comparison of experimental axial power density traces and VENTURE values calculated using 20-group cross sections for the different models of the complex FOEHN configuration.

Table 4.29. Rendement values calculated for the different models of the complex FOEHN configuration

Model	Computer code			
	DORT		VENTURE	
	Rendement 10^{11} neutrons/(m ² s W)	Percent difference	Rendement 10^{11} neutrons/(m ² s W)	Percent difference
Void in the reflector components	2.6191	13.87	2.5676	11.63
Aluminum in the void regions of the reflector components	2.5447	10.64	2.4826	7.94
Constant aluminum density in the reflector	2.5864	12.45	2.5000	8.70

4.4.4 Thermal Flux

Table 4.30 shows the average and maximum differences between the calculated and measured thermal flux values for the complex configuration models. The measured values were determined by averaging several points measured at the core midplane and at a specific distance from the core. This allows the data to be compared with values determined from the R-Z models. Tables 4.31 and 4.32, respectively, show the differences between the measured results and values calculated with DORT and VENTURE. Figures 4.35 and 4.36 show radial flux traces comparing the measured and calculated values. The model with void in the reflector components calculated the largest peak thermal flux. The VENTURE flux results for the two corrected models differ slightly.

4.5 SUMMARY

The three configurations of the FOEHN critical experiment have been evaluated using the KENO, DORT, and VENTURE computer codes. Calculated results have been compared to measured data. Some of the differences between the calculated and measured results can be attributed to uncertainties in the exact geometry and material compositions of the components in the experiment.

Table 4.30. Average and maximum thermal flux percent differences for the different models of the complex FOEHN configuration

Model	Computer code	Percent difference	
		Average	Maximum
Void in the reflector components	DORT	13.13	17.78
	VENTURE	10.86	20.64
Aluminum in the void regions of the reflector components	DORT	13.98	-30.73
	VENTURE	8.42	13.38
Constant aluminum density in the reflector	DORT	10.20	16.46
	VENTURE	8.15	14.17

Table 4.31. Percent differences between measured thermal fluxes and values calculated with DORT using 20-group cross sections for the different models of the complex FOEHN configuration

Radius ^a (mm)	Complex FOEHN configuration model		
	Void in the reflector components	Aluminum in the void regions of the reflector components	Constant aluminum density in the reflector
275	10.86	8.76	9.46
315	10.78	7.79	9.16
435	17.78	11.11	16.46
515	10.83	1.54	11.61
675	-11.52	-23.96	-6.11
755	-17.04	-30.73	8.40

^aHeight = 1110 mm, the midplane of the fuel element.

Table 4.32. Percent differences between measured thermal fluxes and values calculated with VENTURE using 20-group cross sections for different models of the complex FOEHN configuration

Radius ^a (mm)	Complex FOEHN configuration model		
	Void in the reflector components	Aluminum in the void regions of the reflector components	Constant aluminum density in the reflector
275	5.38	3.21	3.44
315	7.83	4.74	5.09
435	20.64	13.38	14.17
515	18.23	7.59	9.62
675	5.97	-9.97	-7.39
755	7.12	-11.62	-9.20

^aHeight = 1110 mm, the midplane of the fuel element.

Fig. 4.35. Comparison of experimental radial thermal flux traces with DORT values calculated using 20-group cross sections for the different models of the complex FOEHN configuration.

Fig. 4.36. Comparison of experimental radial thermal flux traces with VENTURE values calculated using 20-group cross sections for the different models of the complex FOEHN configuration.

5. CONCLUSIONS

This report documents the analysis of the FOEHN critical experiment using ORNL neutronics codes and multigroup cross sections from the ANSL-V master library. Results from calculations using the KENO Monte Carlo transport code, the DORT discrete ordinates transport code, and the VENTURE diffusion theory code show reasonable agreement with the measured data and are within the experimental errors. Because the simple and intermediate configurations are azimuthally symmetric, the correctness of the models is limited only by the minor geometric and material composition assumptions. The multiplication factors for the simple and intermediate configurations were predicted to within 0.2% of unity using KENO with 99-group cross sections. The 20-group transport results were within 0.5% of unity, while the diffusion theory results are within 1.1%.

The KENO, DORT, and VENTURE calculations yield average power density differences less than 5% for the simple and intermediate configurations. The results obtained for the power density values at the upper and lower edges of the fuel element do not match the measured data. The error in these measurements cannot be determined quantitatively because the exact position of the boron endplates and the measurement probes is not known. When these points are not considered, the maximum power density differences calculated with KENO and DORT are less than 10%, and less than 14% when considering the diffusion theory results.

In the evaluation of the complex configuration, three models that approximate the reflector components were developed. The first model smears material of the reflector components into an R-Z mesh conserving the amount of material present in the structures. The k_{eff} values calculated with this model overpredict unity by up to 2.1% because the streaming in the void regions of the reflector components cannot be accounted for in R-Z geometry. The second model developed examines the artificial addition of aluminum to the void regions of the reflector components. The third model investigates the use of aluminum at a constant density in the reflector region. The aluminum density in the last two models was adjusted until the calculated multiplication factors matched the critical state. The average power density differences calculated using these models are less than 4% when the points at the upper and lower edges of the fuel element are not considered. The maximum differences are less than 15.2%. The power density distributions for the adjusted models match the measured values well; however, when equivalent models of other systems (such as the ANS) are developed, the results will have to be compared with explicit models analyzed using Monte Carlo techniques.

The work in this report shows that multiplication factors, power distributions, and thermal fluxes for the FOEHN experiment can be calculated within the measurement errors using multigroup cross sections derived from the ANSL-V master cross-section library. The calculated parameters are comparable to those determined in the independent studies documented in refs. 9, 13, and 14. The general trends of overpredicting or underpredicting the measured data are similar. The results show that the calculational methods used in this work accurately predict the measured values of the FOEHN experiment, a highly enriched, heavy water moderated system that has many similarities with the current ANS design.

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APPENDIX A

ATOM DENSITIES FOR FOEHN EXPERIMENT MATERIALS

The atom densities for the materials in each of the three FOEHN configurations are presented in Tables A.1–A.3 of this appendix. The control element positions and boron concentrations for each critical state are documented in Tables A.4–A.6.

Table A.1. Atom densities for materials in the simple FOEHN configuration model

Element	Material					
	Heavy water	Borated heavy water	AG3-NE alloy	Control element	Fuel plate	Homogenous core region
D	6.6304-2 ^a	6.6304-2				3.8875-2
H	1.6817-4	1.6817-4				9.8601-5
O	3.3236-2	3.3236-2				1.9487-2
²³⁵ U					1.1448-3	4.7360-4
²³⁸ U					1.1313-4	4.6800-5
¹⁰ B		<i>b</i>	2.9811-7		3.0483-7	<i>b</i>
¹¹ B			1.1999-6		1.2269-6	5.0756-7
Ni				9.1300-2		
Al			5.8061-2		5.9369-2	2.4560-2
Mg			1.8523-3		1.8940-3	7.8353-4
Mn			1.1791-5		1.2057-5	4.9876-6
Cr			3.1145-6		3.1847-6	1.3174-6
Si			8.6489-5		8.8438-5	3.6585-5
Fe			7.5392-5		7.7091-5	3.1891-5
Ti			3.3808-6		3.4570-6	1.4301-6
Zn			2.4769-6		2.5327-6	1.0477-6
Cu			4.2072-6		4.3020-6	1.7797-6
Pb			1.2021-6		1.2292-6	5.0849-7

^aRead as 6.6304×10^{-2} . Units are atoms/(barn cm).

^bBoron-10 atom densities for each critical case are listed in Table A.4.

Table A.2. Atom densities for materials in the intermediate FOEHN configuration model

Element	Material								
	Heavy water	Borated heavy water	AG3-NE alloy	Control element	Fuel plate	Homogeneous core region	Boron plate	Aluminum plate	Homogenous boron endplate region
D	6.6296-2 ^a	6.6296-2				3.8871-2			3.8624-2
H	1.7615-4	1.7615-4				1.0328-5			1.0262-4
O	3.3236-2	3.3236-2				1.9487-2			1.9363-2
²³⁵ U					1.1448-3	4.7360-4			
²³⁸ U					1.1313-4	4.6800-5			
¹⁰ B		<i>b</i>	2.9811-7		3.0483-7	<i>b</i>	5.5424-4		1.5170-4
¹¹ B			1.1999-6		1.2269-6	5.0756-7			
Ni				9.1300-2					
Al			5.8061-2		5.9369-2	2.4560-2	6.0265-2	6.0265-2	2.4800-2
Mg			1.8523-3		1.8940-3	7.8353-4			
Mn			1.1791-5		1.2057-5	4.9876-6			
Cr			3.1145-6		3.1847-6	1.3174-6			
Si			8.6489-5		8.8438-5	3.6585-5			
Fe			7.5392-5		7.7091-5	3.1891-5			
Ti			3.3808-6		3.4570-6	1.4301-6			
Zn			2.4769-6		2.5327-6	1.0477-6			
Cu			4.2072-6		4.3020-6	1.7797-6			
Pb			1.2021-6		1.2292-6	5.0849-7			

^aRead as 6.6296 × 10⁻². Units are atoms/(barn cm).^bBoron-10 atom densities for each critical case are listed in Table A.5.

Table A.3. Atom densities for materials in the complex FOEHN configuration model

Element	Material											
	Heavy water	Borated heavy water	AG3-NE alloy	Control element	Fuel plate	Homogeneous core region	Boron plate	Aluminum plate	Homogeneous boron endplate region	Graphite	Zircaloy-4	Stainless steel
D	6.6297-2 ^a	6.6297-2				3.8871-2			3.8624-2			
H	1.7482-4	1.7482-4				1.0250-4			1.0185-4			
O	3.3236-2	3.3236-2				1.9487-2			1.9363-2			
²³⁵ U					1.1448-3	4.7360-4						
²³⁸ U					1.1313-4	4.6800-5						
¹⁰ B		^b	2.9811-7		3.0483-7	^b	5.5424-4		1.5170-4			
¹¹ B			1.1999-6		1.2269-6	5.0756-7						
Ni				9.1300-2							4.7827-6	7.2175-3
Al			5.8061-2		5.9369-2	2.4560-2	6.0265-2	6.0265-2	2.4800-2			
Mg			1.8523-3		1.8940-3	7.8353-4						
Mn			1.1791-5		1.2057-5	4.9876-6						
Cr			3.1145-6		3.1847-6	1.3174-6					7.6439-5	1.7201-2
Si			8.6489-5		8.8438-5	3.6585-5						
Fe			7.5392-5		7.7091-5	3.1891-5					1.4234-4	6.0689-2
Ti			3.3808-6		3.4570-6	1.4301-6						
Zn			2.4769-6		2.5327-6	1.0477-6						
Cu			4.2072-6		4.3020-6	1.7797-6						
Pb			1.2021-6		1.2269-6	5.0849-7						
C										8.0220-2		
Zr											4.2753-2	
Sn											5.0230-4	

^aRead as 6.6297 × 10⁻². Units are atoms/(barn cm).

^bBoron-10 atom densities for each critical case are listed in Table A.6.

Table A.4. Boron-10 concentrations and control element positions for the simple FOEHN configuration cases

Case	Control element position (mm)	Boron-10 concentration (g $^{10}\text{B/L}$)	Boron-10 atom density in the borated heavy water atoms/(barn cm)	Boron-10 atom density in the homogeneous core region atoms/(barn cm)
1	172.0	0.2477	1.4897-5 ^a	8.8605-6
2	357.0	0.3349	2.0142-5	1.1936-5
3	455.0	0.3863	2.3233-5	1.3748-5
4	467.3	0.3855	2.3185-5	1.3720-5
5	596.0	0.4501	2.7070-5	1.5998-5
6 ^b	601.0	0.4509	2.7118-5	1.6026-5
7	602.0	0.4536	2.7280-5	1.6121-5
8	661.0	0.4791	2.8814-5	1.7020-5
9	857.0	0.5268	3.1683-5	1.8702-5
10	890.0	0.5386	3.2393-5	1.9119-5
11	896.0	0.5386	3.2393-5	1.9119-5

^aRead as 1.4897×10^{-5} .

^bThe power distribution in the fuel element and the thermal flux distribution in the reflector were measured for this case.

Table A.5. Boron-10 concentrations and control element positions for the intermediate FOEHN configuration cases

Case	Control element position (mm)	Boron-10 concentration (g $^{10}\text{B/L}$)	Boron-10 atom density in the borated heavy water atoms/(barn cm)	Boron-10 atom density in the homogeneous core region atoms/(barn cm)
1	352.2	0.210	1.2630-5 ^a	7.5313-6
2 ^b	447.0	0.258	1.5517-5	9.2240-6
3	457.0	0.270	1.6238-5	9.6468-6
4	609.0	0.350	2.1050-5	1.2468-5
5	664.0	0.371	2.2313-5	1.3209-5
6	815.0	0.419	2.5200-5	1.4901-5

^aRead as 1.2630×10^{-5} .

^bThe power distribution in the fuel element and the thermal flux distribution in the reflector were measured for this case.

Table A.6. Boron-10 concentrations and control element positions for the complex FOEHN configuration cases

Case	Control element position (mm)	Boron-10 concentration (g $^{10}\text{B/L}$)	Boron-10 atom density in the borated heavy water atoms/(barn cm)	Boron-10 atom density in the homogeneous core region atoms/(barn cm)
1	804.0	0.347	$2.0869 \cdot 5^a$	$1.2362 \cdot 5$
2	771.0	0.311	$1.8704 \cdot 5$	$1.1093 \cdot 5$
3	596.0	0.260	$1.5637 \cdot 5$	$9.2944 \cdot 6$
4	579.0	0.248	$1.4915 \cdot 5$	$8.8712 \cdot 6$
5	503.0	0.210	$1.2630 \cdot 5$	$7.5312 \cdot 6$
6	385.0	0.143	$8.6003 \cdot 6$	$5.1686 \cdot 6$
7	249.0	0.078	$4.6911 \cdot 6$	$2.8766 \cdot 6$
8^b	471.0	0.177	$1.0645 \cdot 5$	$6.3675 \cdot 6$
9^c	594.0	0.255	$1.5336 \cdot 5$	$9.1179 \cdot 6$

^aRead as 2.0869×10^{-5} .

^bThe power distribution in the fuel element was measured for this case.

^cThe thermal flux distribution in the reflector was measured for this case.

APPENDIX B

TABLES OF MEASURED AND CALCULATED RELATIVE POWER DENSITY AND THERMAL FLUX VALUES

Tables of the measured and calculated relative power density and thermal flux values are included in this appendix. The measured values in Tables B.1-B.6 are from ref. 6. Values calculated with the KENO, DORT, and VENTURE models of the simple, intermediate, and complex FOEHN configurations are shown in Tables B.7-B.26.

Table B.1. Measured relative power density values for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	2.5247	2.2931	2.3323	2.2518	2.1002	2.1656	2.1556	2.3767	2.5115	2.5618	2.9004
790.6	2.0302										2.6260
785.5	1.7642						1.2226				2.4228
780.6	1.6608						1.0912				2.3470
771.5	1.5239						0.9205				2.1803
750.0	1.3380	1.1518	1.0203	0.9272	0.8218	0.8020	0.9149	1.1075	1.2551	1.4642	2.0507
725.0	1.2673						0.7715				1.9772
700.0	1.2375						0.7730				1.9769
625.0	1.2820	1.1417	1.0136	0.9371	0.8407	0.8270	0.9440	1.1293	1.3157	1.4818	2.0233
550.0	1.3340						0.8600				2.1180
475.0	1.2910						0.8630				2.1315
400.0	1.1620	1.0985	0.9491	0.8971	0.8348	0.8280	0.9442	1.1541	1.3180	1.4889	2.0459
325.0	1.0266						0.7600				1.9600
250.0	0.7326						0.6440				1.7807
175.0	0.6279	0.6011	0.5472	0.5335	0.5237	0.5580	0.6627	0.8574	0.9755	1.1134	1.5648
100.0	0.5291					0.4706					1.3556
75.0	0.5354					0.4467					1.3130
50.0	0.5015	0.4839	0.4361	0.4241	0.4057	0.4440	0.5312	0.6897	0.7862	0.8977	1.2751
28.5	0.5315					0.4836					1.3029
19.4	0.5870					0.5430					1.3195
14.5	0.6646								0.5862		
9.4	0.6899										1.4421
2.5	0.8992	0.8945	0.8782	0.8707	0.8902	0.9384	1.0359	1.1621	1.2329	1.3258	1.5329

Table B.2. Measured thermal flux values for the simple FOEHN configuration

(Units are 10^{11} neutrons/(m² s) and values are normalized to a power of 1 W)

H/r(mm)	235	255	275	295	315	335	355	395	435	515	635	755	835
1825	1.041	1.030	1.016	1.004	0.960		0.928	0.857	0.802				
1675	1.566	1.568	1.561	1.523	1.477		1.414	1.303	1.211	1.003	0.740	0.523	0.384
1525	1.604	1.840	1.912	1.943	1.957	1.950	1.919	1.782	1.644	1.351	0.963	0.674	0.488
1425	1.411	1.834	1.950	2.096	2.167	2.194	2.173	2.055	1.892	1.521	1.082	0.746	0.541
1375	1.462	1.873	2.063	2.174	2.294	2.304	2.277	2.147	1.992				
1325	1.501	1.941	2.128	2.254	2.334	2.358	2.377	2.244	2.079	1.683	1.172	0.802	0.585
1275	1.560	1.993	2.178	2.310	2.415	2.442	2.423	2.304	2.130	1.716	1.189		
1225	1.590	2.017	2.209	2.348	2.476	2.441	2.466	2.349	2.142	1.748	1.222	0.852	0.602
1125	1.538	1.970	2.160	2.292	2.438	2.434	2.432	2.326	2.139	1.736	1.209	0.822	0.594
1075		1.931		2.239		2.365							
975	1.368	1.743	1.916	2.023	2.129	2.139	2.139	2.064	1.910	1.563	1.104	0.755	0.539
925	1.272		1.781		1.982		2.000						
825	1.076	1.366	1.492	1.585	1.673	1.682	1.706	1.654	1.526	1.271		0.644	0.484
725	0.956	1.154	1.230	1.298	1.356		1.365						
625	0.885	0.950	1.000	1.037	1.110		1.037	1.017	0.979	0.808			0.353
525	0.652	0.701	0.785	0.752	0.769								

Table B.3. Measured relative power density values for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.2617	1.1367	1.0807	0.9924	0.9023	0.8946	0.9708	1.1586	1.2664	1.4038	1.8400
790.6	1.1577										1.7956
785.5	1.1152					0.7138					1.7609
780.6	1.0300					0.7054					1.7518
771.5	1.0978					0.6885					1.7620
750.0	1.0947	0.9687	0.8770	0.7968	0.7082	0.6966	0.8015	0.9889	1.1146	1.2653	1.7799
725.0	1.1423					0.7301					1.8183
700.0	1.1813					0.7740					1.9097
625.0	1.3150	1.1794	1.0616	0.9743	0.8880	0.8800	0.9931	1.2161	1.3458	1.5414	2.1313
550.0	1.3564					0.9315					2.2620
475.0	1.3118					0.9275					2.3172
400.0	1.0142	0.9537	0.8855	0.8438	0.8084	0.8560	1.0112	1.2612	1.4062	1.6161	2.2504
325.0	0.9511					0.8000					2.1266
250.0	0.8502					0.7224					1.9383
175.0	0.7313	0.6753	0.6400	0.6051	0.5872	0.6257	0.7491	0.9407	1.0623	1.2310	1.7123
100.0	0.5930					0.5121					1.4317
75.0	0.5567					0.4770					1.3421
50.0	0.5110	0.4742	0.4459	0.4239	0.4093	0.4420	0.5392	0.6769	0.7785	0.8976	1.2601
28.5	0.4847					0.4245					1.2224
19.4	0.4794					0.4167					1.1911
14.5	0.4794					0.4238					1.2000
9.4	0.4839										1.1990
2.5	0.5018	0.4759	0.4512	0.4397	0.4338	0.4766	0.5805	0.7211	0.8090	0.9171	1.1850

Table B.4. Measured thermal flux values for the intermediate FOEHN configuration

(Units are 10^{11} neutrons/(m² s) and values are normalized to a power of 1 W)

H/r(mm)	235	275	315	335	355	375	395	435	515	675	755	835	915	955
1810	0.9574	0.9224	0.8768		0.8310									
1710	1.2638	1.2162	1.1836		1.1168	1.0672								
1610	1.3973	1.4562	1.4784		1.4394	1.3761	1.2787					0.4229		
1510	1.2904	1.6412	1.7851		1.7830	1.7232	1.5762					0.4879		
1410	1.4636	1.9093	2.1072		2.0986	2.0637	2.0328	1.8666	1.5366			0.5460		
1310	1.6640	2.1611	2.3967		2.3952	2.3266	2.3001	2.0950	1.7026	1.0479	0.7964	0.5892		
1260				2.4761	2.5041	2.4317	2.3750							
1210	1.7829	2.3089	2.5402	2.5368	2.5333	2.4760	2.4152	2.2340	1.7928	1.0887	0.8250	0.6118	0.4427	0.3581
1160				2.5383	2.5641	2.4823	2.4292							
1110	1.7532	2.2716	2.5066	2.5170	2.4976	2.4631	2.3909	2.2225	1.7824	1.0843	0.8266	0.6117	0.4427	0.3606
1060				2.4383		2.3901								
1010	1.6042	2.0957	2.3018	2.3356	2.3398	2.3056	2.2500	2.0846	1.6920	1.0342	0.7956	0.5858	0.4223	0.3479
910	1.4069	1.8222	2.0323		2.0529	2.0178	1.9817	1.8660	1.5200	0.9437	0.7312	0.5428		
810	1.1239	1.4658	1.6560		1.6981		1.6400	1.5362	1.2937	0.8336	0.6438	0.4853		
710	0.8863	1.1489	1.2847		1.3208		1.2941	1.2236				0.4176		
610	0.8242	0.9216	0.9719		0.9851		0.9560							
510	0.6045	0.6648	0.6882		0.7016									

Table B.5. Measured relative power density values for the complex FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	1.2958	1.1534	1.0572	1.0238	0.9171	0.8625	0.9632	1.1537		1.3556	1.8193
795.0											1.7183
790.6	1.1528										1.7021
785.5	1.1344					0.7188					1.6985
780.6	1.1352					0.7285					1.6806
771.5	1.1000					0.6721					1.6685
750.0	1.1257	0.9867	0.8775	0.8289	0.7265	0.7100	0.7993	1.0039	1.0851	1.2325	1.7150
725.0	1.1729					0.7442					1.7600
700.0	1.2275					0.8055					1.8327
625.0	1.3661	1.2192	1.0878	1.0273	0.9211	0.9003	1.0106	1.2300	1.3538	1.5147	2.0550
550.0	1.4596					0.9621					2.1906
475.0	1.3656					0.9684					2.2314
400.0	1.0555	0.9788	0.9144	0.8984	0.8473	0.8850	1.0357	1.2898	1.4189	1.6113	2.2120
325.0	0.9626					0.8191					2.0636
250.0	0.8609					0.7408					1.8965
175.0	0.7386	0.6832	0.6508	0.6328	0.6002	0.6410	0.7650	0.9542	1.0744	1.2272	1.6764
100.0	0.6163					0.5283					1.4047
75.0	0.5441					0.4965					1.3249
50.0	0.5061	0.4655	0.4540	0.4359	0.4214	0.4560	0.5526	0.6827	0.7796	0.8979	1.2395
28.5	0.4920					0.4270					1.1787
19.4	0.4880					0.4295					1.1697
14.5	0.4629					0.4437					1.1657
9.4											1.1654
5.0											1.1739
2.5	0.5033	0.4701	0.4529	0.4492	0.4462	0.4908	0.5958	0.7363	0.8162	0.9236	

Table B.6. Measured thermal flux values for the complex FOEHN configuration

Radius ^a (mm)	Thermal flux 10 ¹¹ neutrons/(m ² s)
275	2.11
315	2.30
435	1.82
515	1.48
675	0.97
755	0.72

Height = 1110 mm, the midplane of the fuel element.

Table B.7. Relative power density values calculated with KENO using 99-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	2.3922	2.2783	2.1940	2.0926	2.0602	1.9931	2.1190	2.2070	2.3325	2.4858	2.8859
790.6	1.8764	1.7324	1.5652	1.4883	1.4068	1.4003	1.4578	1.6245	1.7620	1.9217	2.4270
785.5	1.7615	1.5073	1.4383	1.3110	1.1753	1.1878	1.2660	1.4383	1.5768	1.7425	2.3121
780.6	1.5944	1.4063	1.2637	1.1734	1.0530	1.0553	1.1257	1.3193	1.4763	1.6397	2.1505
771.5	1.5893	1.3725	1.1873	1.1123	0.9859	0.9609	1.0577	1.2596	1.3545	1.5707	2.1176
750.0	1.2966	1.1355	0.9924	0.9410	0.8159	0.7946	0.9048	1.0641	1.1864	1.4110	1.9315
725.0	1.2535	1.0720	0.9553	0.8636	0.7886	0.7469	0.8752	1.0762	1.1651	1.3549	1.8842
700.0	1.2197	1.0540	0.9678	0.8923	0.7821	0.7696	0.8673	1.0452	1.1943	1.4133	1.8856
625.0	1.3165	1.1549	1.0113	0.9507	0.8571	0.8122	0.9410	1.1248	1.2934	1.4883	1.9657
500.0	1.3800	1.1929	1.0836	0.9725	0.8886	0.8539	0.9836	1.1966	1.3429	1.5656	2.0792
475.0	1.3781	1.2197	1.1128	0.9678	0.8775	0.8845	0.9942	1.1980	1.3452	1.5494	2.0834
400.0	1.3387	1.1461	1.0377	0.9822	0.8382	0.8210	0.9553	1.1725	1.3165	1.5175	2.0662
325.0	1.2484	1.0479	0.9474	0.8956	0.7863	0.7696	0.8984	1.1030	1.2494	1.4175	1.9685
250.0	0.8085	0.7053	0.6761	0.6451	0.5988	0.6793	0.7812	0.9701	1.0655	1.2651	1.6865
175.0	0.6765	0.6043	0.5793	0.5617	0.5265	0.5557	0.6849	0.8395	0.9539	1.1248	1.5286
100.0	0.5617	0.5029	0.4614	0.4635	0.4441	0.4853	0.5659	0.7219	0.8294	0.9655	1.3466
75.0	0.5557	0.4927	0.4541	0.4275	0.4079	0.4451	0.5543	0.6798	0.7937	0.9155	1.2822
50.0	0.5483	0.4872	0.4603	0.4365	0.4144	0.4440	0.5469	0.6761	0.7664	0.9169	1.2730
28.5	0.5793	0.5122	0.4746	0.4746	0.4640	0.4909	0.5524	0.7196	0.8178	0.9641	1.2804
19.4	0.6349	0.5747	0.5339	0.5321	0.5186	0.5506	0.6233	0.7645	0.8446	0.9599	1.3022
14.5	0.6548	0.6191	0.5918	0.5534	0.5742	0.6113	0.7085	0.8196	0.9160	1.0058	1.4355
9.4	0.7414	0.7150	0.6886	0.6520	0.6580	0.7006	0.7766	0.9016	0.9766	1.1095	1.4795
2.5	0.9391	0.9109	0.9197	0.9248	0.9275	1.0164	1.1248	1.2276	1.2651	1.3762	1.6522

Table B.8. Two sigma standard deviations for the relative power density values calculated with KENO using 99-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	0.0258	0.0274	0.0262	0.0274	0.0264	0.0256	0.0246	0.0234	0.0228	0.0220	0.0204
790.6	0.0280	0.0288	0.0288	0.0292	0.0278	0.0280	0.0270	0.0266	0.0274	0.0250	0.0230
785.5	0.0282	0.0276	0.0292	0.0310	0.0324	0.0314	0.0292	0.0276	0.0262	0.0244	0.0236
780.6	0.0304	0.0296	0.0308	0.0316	0.0312	0.0312	0.0306	0.0296	0.0264	0.0262	0.0228
771.5	0.0330	0.0326	0.0342	0.0344	0.0348	0.0350	0.0330	0.0312	0.0300	0.0276	0.0270
750.0	0.0332	0.0344	0.0346	0.0348	0.0336	0.0336	0.0334	0.0320	0.0290	0.0272	0.0246
725.0	0.0330	0.0328	0.0334	0.0352	0.0334	0.0320	0.0302	0.0306	0.0292	0.0266	0.0252
700.0	0.0328	0.0332	0.0318	0.0322	0.0336	0.0326	0.0296	0.0306	0.0264	0.0276	0.0250
625.0	0.0312	0.0302	0.0312	0.0338	0.0312	0.0294	0.0302	0.0300	0.0270	0.0258	0.0242
550.0	0.0284	0.0310	0.0282	0.0304	0.0306	0.0310	0.0298	0.0284	0.0262	0.0254	0.0244
475.0	0.0296	0.0314	0.0308	0.0294	0.0310	0.0306	0.0284	0.0278	0.0278	0.0242	0.0232
400.0	0.0302	0.0306	0.0316	0.0312	0.0320	0.0316	0.0296	0.0278	0.0260	0.0250	0.0224
325.0	0.0330	0.0328	0.0328	0.0326	0.0316	0.0304	0.0294	0.0288	0.0300	0.0260	0.0238
250.0	0.0352	0.0334	0.0348	0.0346	0.0370	0.0342	0.0332	0.0300	0.0296	0.0288	0.0252
175.0	0.0368	0.0386	0.0378	0.0382	0.0354	0.0370	0.0342	0.0312	0.0302	0.0302	0.0260
100.0	0.0430	0.0440	0.0416	0.0452	0.0428	0.0394	0.0392	0.0358	0.0332	0.0330	0.0292
75.0	0.0422	0.0430	0.0414	0.0442	0.0422	0.0414	0.0380	0.0388	0.0360	0.0328	0.0306
50.0	0.0414	0.0422	0.0418	0.0440	0.0428	0.0410	0.0388	0.0360	0.0372	0.0358	0.0302
28.5	0.0416	0.0432	0.0434	0.0422	0.0442	0.0422	0.0384	0.0380	0.0344	0.0348	0.0302
19.4	0.0418	0.0440	0.0440	0.0444	0.0428	0.0424	0.0406	0.0372	0.0340	0.0324	0.0292
14.5	0.0404	0.0430	0.0426	0.0442	0.0408	0.0382	0.0372	0.0360	0.0342	0.0322	0.0286
9.4	0.0416	0.0408	0.0388	0.0430	0.0392	0.0396	0.0354	0.0334	0.0342	0.0312	0.0288
2.5	0.0368	0.0382	0.0378	0.0386	0.0362	0.0342	0.0314	0.0318	0.0306	0.0302	0.0280

Table B.9. Relative power density values calculated with DORT using 20-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	2.3642	2.2224	2.1301	2.0652	1.9958	1.9933	2.0724	2.2113	2.3108	2.4420	2.6851
790.6	1.8816	1.6813	1.5576	1.4737	1.3843	1.3708	1.4489	1.5989	1.7212	1.8929	2.4546
785.5	1.7119	1.4963	1.3673	1.2765	1.1646	1.1398	1.2307	1.4056	1.5345	1.7168	2.3160
780.6	1.6005	1.3786	1.2408	1.1550	1.0467	1.0197	1.1152	1.2886	1.4194	1.6083	2.2156
771.5	1.4620	1.2566	1.1153	1.0187	0.9176	0.8930	0.9894	1.1654	1.3002	1.5022	2.1098
750.0	1.3077	1.1213	0.9925	0.9028	0.7939	0.7749	0.8734	1.0627	1.2048	1.4031	1.9831
725.0	1.2470	1.0746	0.9551	0.8713	0.7689	0.7513	0.8546	1.0440	1.1829	1.3756	1.9409
700.0	1.2412	1.0729	0.9561	0.8742	0.7757	0.7622	0.8644	1.0538	1.1925	1.3850	1.9471
625.0	1.3095	1.1376	1.0177	0.9337	0.8332	0.8201	0.9280	1.1249	1.2690	1.4699	2.0583
550.0	1.3753	1.1934	1.0695	0.9830	0.8788	0.8633	0.9763	1.1809	1.3322	1.5406	2.1503
475.0	1.3941	1.2098	1.0831	0.9944	0.8876	0.8750	0.9890	1.1964	1.3492	1.5591	2.1781
400.0	1.3468	1.1697	1.0472	0.9616	0.8621	0.8509	0.9621	1.1647	1.3145	1.5212	2.1232
325.0	1.2114	1.0584	0.9519	0.8765	0.7872	0.7802	0.8897	1.0842	1.2264	1.4215	1.9961
250.0	0.8122	0.7361	0.6828	0.6467	0.6144	0.6464	0.7686	0.9566	1.0904	1.2709	1.7983
175.0	0.6735	0.6109	0.5680	0.5409	0.5224	0.5569	0.6672	0.8352	0.9528	1.1157	1.5841
100.0	0.5582	0.5117	0.4779	0.4542	0.4382	0.4702	0.5688	0.7179	0.8226	0.9656	1.3775
75.0	0.5326	0.4857	0.4531	0.4322	0.4172	0.4468	0.5429	0.6872	0.7889	0.9270	1.3268
50.0	0.5285	0.4795	0.4470	0.4262	0.4103	0.4398	0.5313	0.6716	0.7717	0.9085	1.3027
28.5	0.5680	0.5143	0.4807	0.4602	0.4507	0.4803	0.5699	0.6997	0.7934	0.9276	1.3262
19.4	0.6161	0.5601	0.5285	0.5119	0.5025	0.5335	0.6249	0.7511	0.8401	0.9672	1.3579
14.5	0.6595	0.6078	0.5795	0.5625	0.5541	0.5863	0.6733	0.8019	0.8913	1.0121	1.3984
9.4	0.7292	0.6829	0.6601	0.6499	0.6518	0.6910	0.7749	0.8897	0.9736	1.0899	1.4552
2.5	0.9194	0.8978	0.8905	0.8903	0.9128	0.9755	1.0753	1.1938	1.2684	1.3611	1.5621

Table B.10. Relative power density values calculated with VENTURE using 20-group cross sections for the simple FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.95
797.5	2.3651	2.2567	2.1797	2.1240	2.0571	2.0568	2.1475	2.2877	2.3797	2.4960	2.7480
790.6	1.9911	1.8128	1.6892	1.6029	1.5010	1.4845	1.5806	1.7542	1.8799	2.0494	2.5542
785.5	1.8157	1.6190	1.4792	1.3802	1.2611	1.2372	1.3405	1.5344	1.6764	1.8671	2.4207
780.6	1.6902	1.4883	1.3424	1.2375	1.1093	1.0815	1.1909	1.3980	1.5490	1.7503	2.3229
771.5	1.5274	1.3301	1.1849	1.0789	0.9467	0.9178	1.0342	1.2525	1.4096	1.6167	2.1930
750.0	1.3245	1.1492	1.0185	0.9221	0.8012	0.7788	0.8992	1.1176	1.2722	1.4738	2.0255
725.0	1.2385	1.0788	0.9597	0.8718	0.7623	0.7461	0.8660	1.0791	1.2291	1.4241	1.9561
700.0	1.2188	1.0654	0.9511	0.8667	0.7622	0.7488	0.8688	1.0802	1.2288	1.4218	1.9481
625.0	1.2685	1.1141	0.9990	0.9141	0.8091	0.7970	0.9213	1.1391	1.2922	1.4910	2.0329
550.0	1.3241	1.1643	1.0450	0.9570	0.8481	0.8354	0.9640	1.1897	1.3482	1.5542	2.1158
475.0	1.3344	1.1737	1.0537	0.9652	0.8558	0.8433	0.9733	1.2012	1.3612	1.5692	2.1359
400.0	1.2884	1.1335	1.0180	0.9329	0.8280	0.8175	0.9455	1.1686	1.3251	1.5284	2.0823
325.0	1.1414	1.0073	0.9079	0.8353	0.7485	0.7486	0.8756	1.0895	1.2385	1.4315	1.9564
250.0	0.7811	0.7126	0.6628	0.6281	0.5954	0.6300	0.7650	0.9693	1.1085	1.2875	1.7709
175.0	0.6539	0.5979	0.5575	0.5298	0.5061	0.5416	0.6650	0.8488	0.9736	1.1338	1.5660
100.0	0.5541	0.5060	0.4716	0.4482	0.4289	0.4619	0.5725	0.7363	0.8475	0.9900	1.3746
75.0	0.5342	0.4870	0.4532	0.4302	0.4110	0.4429	0.5504	0.7097	0.8178	0.9566	1.3310
50.0	0.5407	0.4915	0.4561	0.4320	0.4110	0.4409	0.5458	0.7026	0.8092	0.9464	1.3172
28.5	0.6015	0.5480	0.5101	0.4846	0.4626	0.4913	0.5926	0.7450	0.8495	0.9850	1.3556
19.4	0.6615	0.6084	0.5721	0.5486	0.5310	0.5626	0.6611	0.8066	0.9066	1.0371	1.3999
14.5	0.7096	0.6597	0.6270	0.6071	0.5956	0.6315	0.7287	0.8675	0.9624	1.0865	1.4365
9.4	0.7785	0.7374	0.7127	0.6995	0.6991	0.7433	0.8408	0.9703	1.0567	1.1689	1.4900
2.5	0.9299	0.9174	0.9137	0.9167	0.9416	1.0079	1.1154	1.2340	1.3040	1.3878	1.5727

Table B.11. Thermal fluxes calculated with DORT using 20-group cross sections for the simple FOEHN configuration

(Units are 10^{11} neutrons/(m² s) and values are normalized to a power of 1 W)

H/r(mm)	235	255	275	295	315	335	355	395	435	515	635	755	835
1825	1.0344	1.0279	1.0173	1.0034	0.9864	0.9664	0.9441	0.8934	0.8373	0.7180	0.5424	0.3861	0.2943
1675	1.5614	1.5775	1.5789	1.5676	1.5461	1.5160	1.4792	1.3911	1.2911	1.0813	0.7895	0.5480	0.4127
1525	1.6855	1.8545	1.9647	2.0280	2.0536	2.0495	2.0222	1.9206	1.7815	1.4672	1.0380	0.7030	0.5233
1425	1.5483	1.8679	2.0875	2.2279	2.3052	2.3330	2.3229	2.2261	2.0686	1.6932	1.1800	0.7893	0.5840
1375	1.6040	1.9448	2.1838	2.3390	2.4267	2.4609	2.4535	2.3538	2.1869	1.7853	1.2375	0.8240	0.6084
1325	1.6691	2.0254	2.2758	2.4392	2.5320	2.5685	2.5614	2.4573	2.2820	1.8589	1.2835	0.8518	0.6279
1275	1.7204	2.0874	2.3453	2.5136	2.6092	2.6468	2.6392	2.5313	2.3496	1.9115	1.3166	0.8719	0.6420
1225	1.7484	2.1212	2.3832	2.5542	2.6512	2.6894	2.6817	2.5719	2.3870	1.9411	1.3357	0.8837	0.6505
1125	1.7237	2.0925	2.3523	2.5226	2.6200	2.6594	2.6534	2.5480	2.3676	1.9294	1.3308	0.8820	0.6496
1075	1.6711	2.0304	2.2843	2.4516	2.5482	2.5883	2.5843	2.4850	2.3122	1.8891	1.3072	0.8684	0.6404
975	1.4973	1.8259	2.0602	2.2167	2.3094	2.3510	2.3526	2.2717	2.1225	1.7479	1.2223	0.8185	0.6060
925	1.3880	1.6957	1.9162	2.0648	2.1542	2.1960	2.2003	2.1304	1.9958	1.6523	1.1637	0.7837	0.5818
825	1.1577	1.4160	1.6026	1.7296	1.8077	1.8466	1.8546	1.8053	1.7014	1.4267	1.0232	0.6987	0.5224
725	1.0179	1.1989	1.3272	1.4137	1.4666	1.4924	1.4969	1.4601	1.3837	1.1783	0.8646	0.6010	0.4532
625	0.9578	1.0312	1.0868	1.1252	1.1483	1.1580	1.1565	1.1278	1.0751	0.9323	0.7030	0.4989	0.3799
525	0.7260	0.7731	0.8072	0.8303	0.8440	0.8499	0.8492	0.8322	0.7999	0.7086	0.5506	0.3994	0.3074

Table B.12. Thermal fluxes calculated with VENTURE using 20-group cross sections for the simple FOEHN configuration

(Units are 10^{11} neutrons/(m² s) and values are normalized to a power of 1 W)

H/r(mm)	235	255	275	295	315	335	355	395	435	515	635	755	835
1825	1.0253	1.0185	1.0078	0.9936	0.9762	0.9560	0.9334	0.8827	0.8267	0.7084	0.5351	0.3814	0.2912
1675	1.5158	1.5358	1.5407	1.5328	1.5142	1.4867	1.4521	1.3672	1.2695	1.0631	0.7763	0.5395	0.4068
1525	1.5750	1.7555	1.8772	1.9510	1.9859	1.9895	1.9688	1.8767	1.7446	1.4384	1.0177	0.6899	0.5141
1425	1.4425	1.7601	1.9853	2.1338	2.2200	2.2565	2.2542	2.1695	2.0212	1.6569	1.1547	0.7730	0.5726
1375	1.4864	1.8270	2.0719	2.2359	2.3332	2.3766	2.3776	2.2913	2.1346	1.7455	1.2099	0.8062	0.5959
1325	1.5415	1.8976	2.1546	2.3275	2.4306	2.4771	2.4790	2.3895	2.2251	1.8159	1.2538	0.8326	0.6144
1275	1.5855	1.9522	2.2169	2.3951	2.5014	2.5495	2.5515	2.4590	2.2889	1.8656	1.2850	0.8516	0.6276
1225	1.6092	1.9815	2.2502	2.4311	2.5392	2.5881	2.5902	2.4963	2.3236	1.8932	1.3028	0.8625	0.6353
1125	1.5850	1.9528	2.2189	2.3988	2.5069	2.5567	2.5603	2.4706	2.3023	1.8797	1.2965	0.8597	0.6337
1075	1.5374	1.8957	2.1555	2.3318	2.4385	2.4886	2.4937	2.4094	2.2481	1.8400	1.2731	0.8461	0.6244
975	1.3828	1.7099	1.9489	2.1127	2.2138	2.2637	2.2728	2.2044	2.0647	1.7026	1.1900	0.7971	0.5905
925	1.2851	1.5914	1.8161	1.9712	2.0679	2.1170	2.1279	2.0688	1.9425	1.6099	1.1330	0.7630	0.5668
825	1.0797	1.3368	1.5261	1.6577	1.7412	1.7853	1.7980	1.7563	1.6583	1.3912	0.9965	0.6805	0.5089
725	0.9534	1.1363	1.2688	1.3599	1.4172	1.4470	1.4548	1.4230	1.3504	1.1497	0.8425	0.5855	0.4417
625	0.9061	0.9862	1.0466	1.0888	1.1148	1.1268	1.1271	1.1009	1.0501	0.9100	0.6853	0.4862	0.3704
525	0.7013	0.7495	0.7847	0.8088	0.8234	0.8299	0.8297	0.8135	0.7817	0.6918	0.5370	0.3895	0.2999

Table B.13. Relative power density values calculated with KENO using 99-group cross sections for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.1234	0.9692	0.8632	0.8187	0.7173	0.7187	0.8136	0.9947	1.1364	1.3054	1.6976
790.6	1.0586	0.9234	0.8053	0.7766	0.6539	0.6659	0.7877	0.9428	1.0595	1.2364	1.6634
785.5	1.1086	0.9127	0.8094	0.7335	0.6747	0.6520	0.7692	0.9322	1.0577	1.1998	1.5990
780.6	1.0498	0.9465	0.7886	0.7474	0.6645	0.6372	0.7645	0.9359	1.0396	1.2304	1.6444
771.5	1.0345	0.8942	0.8136	0.7506	0.6594	0.6701	0.7525	0.9391	1.0637	1.2285	1.6935
750.0	1.0743	0.9132	0.8497	0.7868	0.6960	0.6673	0.7840	0.9664	1.0604	1.2716	1.6958
725.0	1.1257	0.9493	0.8933	0.8057	0.7238	0.7238	0.8576	1.0239	1.1581	1.3003	1.7569
700.0	1.1331	1.0164	0.9456	0.8446	0.7469	0.7905	0.8451	1.0489	1.2017	1.3656	1.8305
625.0	1.3211	1.1688	1.0720	0.9887	0.8937	0.8460	0.9887	1.1975	1.3133	1.5318	2.0459
550.0	1.4679	1.2934	1.2026	1.0878	0.9627	0.9484	1.0850	1.2938	1.4601	1.5990	2.1963
475.0	1.3869	1.2387	1.1364	1.0627	0.9493	0.9451	1.0984	1.2952	1.4712	1.6837	2.2403
400.0	1.0252	0.9706	0.8942	0.8497	0.8340	0.8872	1.0234	1.2545	1.4170	1.5907	2.2107
325.0	0.9604	0.8516	0.8192	0.7840	0.7479	0.8067	0.9655	1.1401	1.3105	1.5207	2.0292
250.0	0.8752	0.7798	0.7344	0.6946	0.6937	0.7252	0.8655	1.0757	1.2151	1.3837	1.8916
175.0	0.6826	0.6659	0.6224	0.6025	0.5830	0.6261	0.7618	0.9363	1.0600	1.1725	1.6337
100.0	0.5881	0.5645	0.5247	0.4765	0.4577	0.5094	0.6085	0.7932	0.8812	0.9947	1.3758
75.0	0.5288	0.5071	0.4649	0.4412	0.4447	0.4682	0.5649	0.7016	0.8178	0.9572	1.2975
50.0	0.4830	0.4499	0.4461	0.4266	0.3915	0.4408	0.5279	0.6696	0.7821	0.8701	1.2424
28.5	0.4807	0.4387	0.4212	0.3781	0.3875	0.4081	0.5103	0.6432	0.7715	0.8724	1.1498
19.4	0.4527	0.4160	0.3913	0.3873	0.3660	0.4156	0.4946	0.6409	0.7252	0.8433	1.1072
14.5	0.4848	0.4308	0.3988	0.3728	0.3715	0.4081	0.4802	0.6224	0.6807	0.8270	1.1484
9.4	0.4607	0.4338	0.4067	0.3687	0.3787	0.4149	0.4876	0.6150	0.7233	0.8238	1.1396
2.5	0.4532	0.4421	0.3963	0.3904	0.3795	0.4116	0.5260	0.6691	0.7344	0.8349	1.1225

Table B.14. Two sigma standard deviations for the relative power density values calculated with KENO using 99-group cross sections for the intermediate FOEHN configuration.

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	0.0350	0.0370	0.0388	0.0382	0.0382	0.0370	0.0372	0.0330	0.0318	0.0304	0.0268
790.6	0.0348	0.0368	0.0364	0.0374	0.0390	0.0386	0.0358	0.0340	0.0306	0.0304	0.0264
785.5	0.0376	0.0364	0.0364	0.0380	0.0382	0.0366	0.0348	0.0338	0.0324	0.0296	0.0272
780.6	0.0348	0.0362	0.0404	0.0398	0.0376	0.0368	0.0354	0.0342	0.0308	0.0304	0.0288
771.5	0.0416	0.0412	0.0396	0.0396	0.0420	0.0416	0.0372	0.0372	0.0338	0.0336	0.0312
750.0	0.0344	0.0340	0.0360	0.0358	0.0358	0.0362	0.0316	0.0320	0.0306	0.0308	0.0268
725.0	0.0336	0.0356	0.0346	0.0370	0.0366	0.0354	0.0322	0.0290	0.0290	0.0300	0.0264
700.0	0.0346	0.0340	0.0338	0.0360	0.0334	0.0314	0.0324	0.0294	0.0298	0.0286	0.0244
625.0	0.0326	0.0324	0.0314	0.0326	0.0318	0.0330	0.0290	0.0308	0.0274	0.0260	0.0246
550.0	0.0304	0.0306	0.0288	0.0322	0.0306	0.0304	0.0274	0.0276	0.0258	0.0262	0.0240
475.0	0.0276	0.0290	0.0296	0.0306	0.0288	0.0296	0.0292	0.0262	0.0244	0.0238	0.0224
400.0	0.0310	0.0302	0.0326	0.0320	0.0306	0.0292	0.0294	0.0264	0.0264	0.0258	0.0220
325.0	0.0332	0.0334	0.0334	0.0318	0.0316	0.0314	0.0290	0.0282	0.0262	0.0258	0.0250
250.0	0.0338	0.0358	0.0350	0.0326	0.0354	0.0356	0.0334	0.0298	0.0276	0.0272	0.0248
175.0	0.0380	0.0376	0.0392	0.0362	0.0382	0.0352	0.0350	0.0334	0.0330	0.0314	0.0262
100.0	0.0410	0.0394	0.0410	0.0426	0.0400	0.0384	0.0370	0.0362	0.0334	0.0310	0.0286
75.0	0.0422	0.0432	0.0434	0.0434	0.0400	0.0418	0.0420	0.0380	0.0360	0.0338	0.0306
50.0	0.0450	0.0460	0.0472	0.0434	0.0460	0.0430	0.0428	0.0388	0.0366	0.0356	0.0308
28.5	0.0476	0.0476	0.0450	0.0498	0.0470	0.0450	0.0396	0.0392	0.0376	0.0348	0.0318
19.4	0.0464	0.0474	0.0494	0.0476	0.0482	0.0472	0.0430	0.0384	0.0372	0.0374	0.0320
14.5	0.0468	0.0512	0.0494	0.0480	0.0448	0.0458	0.0458	0.0376	0.0388	0.0370	0.0330
9.4	0.0478	0.0488	0.0514	0.0500	0.0478	0.0480	0.0436	0.0410	0.0382	0.0362	0.0334
2.5	0.0488	0.0488	0.0494	0.0504	0.0496	0.0470	0.0440	0.0420	0.0394	0.0374	0.0354

Table B.15. Relative power density values calculated with DORT using 20-group cross sections for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.1109	0.9707	0.8664	0.7960	0.7229	0.7267	0.8263	0.9993	1.1327	1.3054	1.7302
790.6	1.0790	0.9422	0.8352	0.7577	0.6823	0.6886	0.7695	0.9374	1.0689	1.2458	1.7047
785.5	1.0731	0.9367	0.8407	0.7594	0.6643	0.6544	0.7514	0.9342	1.0674	1.2388	1.7014
780.6	1.0669	0.9243	0.8277	0.7580	0.6638	0.6515	0.7536	0.9314	1.0639	1.2270	1.7015
771.5	1.0569	0.9218	0.8254	0.7574	0.6729	0.6602	0.7625	0.9395	1.0578	1.2276	1.7086
750.0	1.0828	0.9448	0.8470	0.7802	0.7005	0.6925	0.7947	0.9649	1.0910	1.2628	1.7526
725.0	1.1380	0.9948	0.8936	0.8219	0.7397	0.7363	0.8357	1.0135	1.1417	1.3178	1.8233
700.0	1.2002	1.0494	0.9447	0.8699	0.7837	0.7778	0.8805	1.0647	1.1984	1.3808	1.9031
625.0	1.3749	1.2063	1.0853	0.9995	0.8991	0.8892	1.0026	1.2068	1.3538	1.5560	2.1334
550.0	1.4734	1.2863	1.1586	1.0708	0.9678	0.9568	1.0773	1.2926	1.4514	1.6670	2.2824
475.0	1.2915	1.1498	1.0526	0.9855	0.9133	0.9289	1.0689	1.2980	1.4629	1.6844	2.3133
400.0	1.0230	0.9405	0.8838	0.8453	0.8136	0.8583	1.0126	1.2461	1.4092	1.6312	2.2540
325.0	0.9515	0.8709	0.8213	0.7870	0.7562	0.8001	0.9485	1.1707	1.3270	1.5356	2.1264
250.0	0.8591	0.7845	0.7366	0.7049	0.6817	0.7236	0.8601	1.0632	1.2064	1.3977	1.9393
175.0	0.7356	0.6734	0.6328	0.6063	0.5864	0.6262	0.7471	0.9285	1.0531	1.2233	1.6999
100.0	0.5961	0.5466	0.5139	0.4932	0.4794	0.5154	0.6196	0.7741	0.8821	1.0271	1.4375
75.0	0.5486	0.5024	0.4727	0.4537	0.4419	0.4774	0.5762	0.7227	0.8244	0.9615	1.3486
50.0	0.5036	0.4613	0.4337	0.4165	0.4065	0.4387	0.5356	0.6735	0.7712	0.9018	1.2677
28.5	0.4712	0.4316	0.4058	0.3902	0.3801	0.4093	0.5022	0.6402	0.7300	0.8559	1.2079
19.4	0.4655	0.4258	0.4010	0.3839	0.3695	0.3984	0.4924	0.6270	0.7226	0.8440	1.1862
14.5	0.4635	0.4277	0.4037	0.3849	0.3698	0.3972	0.4843	0.6222	0.7196	0.8425	1.1778
9.4	0.4606	0.4257	0.3994	0.3823	0.3773	0.4117	0.4903	0.6182	0.7128	0.8401	1.1722
2.5	0.4610	0.4251	0.3993	0.3847	0.3817	0.4259	0.5233	0.6571	0.7517	0.8727	1.1629

Table B.16. Relative power density values calculated with VENTURE using 20-group cross sections for the intermediate FOEHN configuration

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.1115	1.0175	0.9460	0.8922	0.8262	0.8326	0.9431	1.1076	1.2119	1.3386	1.6596
790.6	1.0715	0.9586	0.8759	0.8158	0.7442	0.7452	0.8483	1.0138	1.1262	1.2702	1.6581
785.5	1.0551	0.9366	0.8493	0.7859	0.7100	0.7082	0.8109	0.9813	1.0989	1.2508	1.6587
780.6	1.0460	0.9248	0.8350	0.7695	0.6906	0.6872	0.7910	0.9658	1.0871	1.2437	1.6627
771.5	1.0402	0.9170	0.8251	0.7578	0.6759	0.6713	0.7778	0.9585	1.0839	1.2455	1.6756
750.0	1.0567	0.9317	0.8382	0.7693	0.6852	0.6806	0.7919	0.9802	1.1105	1.2782	1.7224
725.0	1.1018	0.9735	0.8774	0.8066	0.7199	0.7154	0.8305	1.0254	1.1602	1.3336	1.7927
700.0	1.1576	1.0244	0.9245	0.8508	0.7605	0.7551	0.8740	1.0757	1.2153	1.3949	1.8704
625.0	1.3204	1.1706	1.0581	0.9749	0.8721	0.8637	0.9935	1.2154	1.3693	1.5674	2.0921
550.0	1.4141	1.2546	1.1348	1.0462	0.9369	0.9283	1.0671	1.3041	1.4684	1.6799	2.2399
475.0	1.2588	1.1316	1.0371	0.9687	0.8909	0.9085	1.0658	1.3157	1.4864	1.7049	2.2809
400.0	1.0107	0.9298	0.8709	0.8301	0.7936	0.8417	1.0139	1.2681	1.4389	1.6561	2.2257
325.0	0.9362	0.8619	0.8080	0.7709	0.7391	0.7872	0.9525	1.1948	1.3573	1.5640	2.1057
250.0	0.8427	0.7761	0.7278	0.6949	0.6672	0.7128	0.8652	1.0878	1.2371	1.4269	1.9242
175.0	0.7247	0.6677	0.6266	0.5987	0.5762	0.6182	0.7541	0.9518	1.0841	1.2524	1.6932
100.0	0.5908	0.5443	0.5110	0.4887	0.4719	0.5099	0.6276	0.7976	0.9113	1.0557	1.4339
75.0	0.5467	0.5035	0.4726	0.4519	0.4369	0.4734	0.5850	0.7460	0.8535	0.9901	1.3479
50.0	0.5073	0.4669	0.4380	0.4188	0.4051	0.4400	0.5455	0.6975	0.7990	0.9280	1.2661
28.5	0.4834	0.4452	0.4182	0.4005	0.3885	0.4225	0.5223	0.6652	0.7609	0.8825	1.2022
19.4	0.4789	0.4426	0.4172	0.4010	0.3914	0.4263	0.5237	0.6613	0.7531	0.8699	1.1782
14.5	0.4790	0.4444	0.4207	0.4058	0.3985	0.4351	0.5319	0.6661	0.7549	0.8678	1.1666
9.4	0.4819	0.4504	0.4293	0.4166	0.4130	0.4529	0.5508	0.6815	0.7663	0.8732	1.1562
2.5	0.4941	0.4709	0.4559	0.4476	0.4510	0.4998	0.6064	0.7375	0.8167	0.9110	1.1489

Table B.17. Thermal fluxes calculated with DORT using 20-group cross sections for the intermediate FOEHN configuration

(Units are 10^{11} neutrons/(m² s) and values are normalized to a power of 1 W)

H/r(mm)	235	275	315	335	355	375	395	435	515	675	755	835	915	955
1810	0.8983	0.8966	0.8808	0.8681	0.8527	0.8351	0.8153	0.7710	0.6709	0.4646	0.3699	0.2832	0.2046	0.1681
1710	1.1539	1.1958	1.1924	1.1794	1.1605	1.1366	1.1087	1.0441	0.8963	0.6030	0.4748	0.3603	0.2586	0.2120
1610	1.3841	1.4912	1.5308	1.5269	1.5103	1.4833	1.4482	1.3602	1.1506	0.7492	0.5827	0.4381	0.3123	0.2553
1510	1.2884	1.6964	1.8630	1.8866	1.8824	1.8569	1.8158	1.7018	1.4181	0.8938	0.6869	0.5118	0.3625	0.2956
1410	1.4802	2.0103	2.2365	2.2704	2.2665	2.2339	2.1804	2.0316	1.6676	1.0222	0.7778	0.5752	0.4052	0.3298
1310	1.7038	2.3056	2.5554	2.5887	2.5785	2.5355	2.4689	2.2886	1.8585	1.1184	0.8452	0.6219	0.4364	0.3547
1260	1.7748	2.3999	2.6578	2.6911	2.6790	2.6329	2.5621	2.3720	1.9209	1.1499	0.8673	0.6372	0.4467	0.3629
1210	1.8097	2.4490	2.7129	2.7470	2.7346	2.6873	2.6146	2.4197	1.9573	1.1688	0.8807	0.6465	0.4529	0.3679
1160	1.8080	2.4526	2.7202	2.7556	2.7442	2.6975	2.6253	2.4305	1.9668	1.1746	0.8849	0.6496	0.4550	0.3696
1110	1.7745	2.4138	2.6819	2.7188	2.7093	2.6648	2.5949	2.4049	1.9495	1.1670	0.8799	0.6463	0.4529	0.3679
1060	1.7147	2.3379	2.6024	2.6405	2.6336	2.5925	2.5266	2.3452	1.9067	1.1467	0.8660	0.6368	0.4467	0.3630
1010	1.6320	2.2297	2.4870	2.5260	2.5219	2.4851	2.4243	2.2549	1.8406	1.1143	0.8435	0.6215	0.4366	0.3550
910	1.4088	1.9338	2.1678	2.2075	2.2099	2.1836	2.1363	1.9984	1.6498	1.0183	0.7766	0.5754	0.4059	0.3306
810	1.1372	1.5716	1.7739	1.8130	1.8219	1.8074	1.7754	1.6746	1.4054	0.8921	0.6873	0.5133	0.3642	0.2973
710	0.9014	1.2261	1.3798	1.4122	1.4230	1.4168	1.3976	1.3311	1.1408	0.7504	0.5856	0.4416	0.3156	0.2583
610	0.8205	0.9666	1.0449	1.0624	1.0682	1.0644	1.0528	1.0117	0.8870	0.6074	0.4809	0.3666	0.2641	0.2168
510	0.6395	0.7183	0.7603	0.7701	0.7736	0.7716	0.7651	0.7411	0.6645	0.4739	0.3807	0.2935	0.2132	0.1755

Table B.18. Thermal fluxes calculated with VENTURE using 20-group cross sections for the intermediate FOEHN configuration

(Units are 10^{11} neutrons/(m² s) and values are normalized to a power of 1 W)

H/r	235	275	315	335	355	375	395	435	515	675	755	835	915	955
1810	0.8765	0.8758	0.8608	0.8486	0.8337	0.8165	0.7974	0.7543	0.6571	0.4567	0.3646	0.2798	0.2027	0.1667
1710	1.1117	1.1573	1.1585	1.1473	1.1301	1.1078	1.0813	1.0193	0.8763	0.5916	0.4669	0.3552	0.2556	0.2097
1610	1.2962	1.4242	1.4764	1.4774	1.4649	1.4414	1.4092	1.3262	1.1241	0.7341	0.5721	0.4311	0.3080	0.2521
1510	1.1898	1.6090	1.7902	1.8207	1.8224	1.8021	1.7656	1.6591	1.3855	0.8751	0.6737	0.5029	0.3569	0.2914
1410	1.3687	1.9042	2.1476	2.1901	2.1941	2.1683	2.1208	1.9818	1.6302	1.0006	0.7624	0.5648	0.3986	0.3247
1310	1.5731	2.1830	2.4543	2.4984	2.4978	2.4631	2.4034	2.2346	1.8184	1.0949	0.8283	0.6103	0.4290	0.3490
1260	1.6394	2.2738	2.5543	2.5988	2.5969	2.5593	2.4958	2.3174	1.8802	1.1259	0.8500	0.6252	0.4390	0.3569
1210	1.6738	2.3229	2.6098	2.6552	2.6529	2.6142	2.5488	2.3655	1.9169	1.1448	0.8632	0.6344	0.4451	0.3618
1160	1.6758	2.3296	2.6197	2.6662	2.6647	2.6264	2.5612	2.3776	1.9272	1.1507	0.8675	0.6374	0.4472	0.3635
1110	1.6486	2.2968	2.5865	2.6340	2.6339	2.5973	2.5341	2.3547	1.9115	1.1438	0.8629	0.6344	0.4452	0.3619
1060	1.5963	2.2283	2.5135	2.5616	2.5634	2.5297	2.4700	2.2983	1.8709	1.1243	0.8495	0.6253	0.4392	0.3572
1010	1.5218	2.1282	2.4048	2.4531	2.4572	2.4272	2.3721	2.2115	1.8070	1.0930	0.8278	0.6105	0.4294	0.3494
910	1.3182	1.8512	2.1014	2.1488	2.1577	2.1369	2.0940	1.9629	1.6217	0.9999	0.7629	0.5657	0.3996	0.3256
810	1.0691	1.5094	1.7239	1.7687	1.7823	1.7717	1.7428	1.6468	1.3829	0.8769	0.6759	0.5053	0.3590	0.2932
710	0.8480	1.1813	1.3443	1.3806	1.3946	1.3909	1.3737	1.3102	1.1233	0.7384	0.5766	0.4353	0.3115	0.2552
610	0.7785	0.9364	1.0215	1.0412	1.0488	1.0463	1.0359	0.9964	0.8737	0.5984	0.4742	0.3620	0.2612	0.2146
510	0.6192	0.7022	0.7467	0.7572	0.7613	0.7599	0.7538	0.7304	0.6550	0.4676	0.3761	0.2904	0.2113	0.1742

Table B.19. Relative power density values calculated with DORT using 20-group cross sections for the complex FOEHN configuration with void in the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.0869	0.9496	0.8476	0.7866	0.7166	0.7160	0.8122	0.9743	1.0922	1.2626	1.6732
795.0	1.0695	0.9356	0.8318	0.7683	0.7026	0.7131	0.7915	0.9476	1.0640	1.2297	1.6546
790.6	1.0630	0.9329	0.8283	0.7560	0.6760	0.6821	0.7564	0.9229	1.0424	1.2081	1.6502
785.5	1.0577	0.9278	0.8352	0.7582	0.6630	0.6430	0.7460	0.9183	1.0452	1.2019	1.6501
780.6	1.0523	0.9156	0.8226	0.7541	0.6559	0.6507	0.7388	0.9198	1.0389	1.1896	1.6512
771.5	1.0442	0.9146	0.8223	0.7588	0.6730	0.6582	0.7563	0.9260	1.0365	1.1937	1.6569
750.0	1.0742	0.9405	0.8464	0.7813	0.6998	0.6931	0.7847	0.9531	1.0695	1.2299	1.7011
725.0	1.1291	0.9898	0.8917	0.8252	0.7409	0.7336	0.8281	1.0006	1.1196	1.2856	1.7722
700.0	1.1918	1.0459	0.9445	0.8746	0.7847	0.7761	0.8737	1.0530	1.1763	1.3476	1.8522
625.0	1.3708	1.2052	1.0893	1.0094	0.9053	0.8930	0.9994	1.1973	1.3339	1.5241	2.0840
550.0	1.4862	1.3067	1.1800	1.0927	0.9818	0.9670	1.0798	1.2916	1.4380	1.6415	2.2416
475.0	1.4766	1.2991	1.1768	1.0935	0.9874	0.9797	1.0994	1.3183	1.4685	1.6774	2.2923
400.0	1.0928	0.9944	0.9272	0.8841	0.8406	0.8795	1.0252	1.2538	1.4063	1.6154	2.2241
325.0	0.9550	0.8783	0.8257	0.7913	0.7619	0.8064	0.9480	1.1666	1.3117	1.5103	2.0870
250.0	0.8525	0.7828	0.7361	0.7069	0.6810	0.7232	0.8542	1.0541	1.1869	1.3685	1.8950
175.0	0.7271	0.6683	0.6290	0.6047	0.5842	0.6230	0.7392	0.9160	1.0326	1.1929	1.6564
100.0	0.5868	0.5394	0.5085	0.4895	0.4748	0.5101	0.6107	0.7619	0.8619	0.9983	1.3937
75.0	0.5397	0.4963	0.4674	0.4502	0.4381	0.4722	0.5679	0.7108	0.8052	0.9343	1.3079
50.0	0.4955	0.4559	0.4292	0.4129	0.4024	0.4360	0.5270	0.6629	0.7530	0.8749	1.2285
28.5	0.4623	0.4253	0.4014	0.3876	0.3771	0.4052	0.4961	0.6294	0.7138	0.8310	1.1706
19.4	0.4565	0.4192	0.3955	0.3793	0.3631	0.3960	0.4817	0.6179	0.7059	0.8174	1.1515
14.5	0.4550	0.4213	0.3983	0.3813	0.3662	0.3892	0.4805	0.6110	0.7030	0.8176	1.1421
9.4	0.4513	0.4189	0.3942	0.3791	0.3720	0.4063	0.4804	0.6088	0.6957	0.8145	1.1339
5.0	0.4482	0.4143	0.3898	0.3773	0.3764	0.4192	0.5006	0.6232	0.7080	0.8250	1.1287
2.5	0.4494	0.4149	0.3899	0.3781	0.3762	0.4186	0.5140	0.6407	0.7266	0.8455	1.1302

Table B.20. Relative power density values calculated with DORT using 20-group cross sections for the complex FOEHN configuration with aluminum in the void regions of the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.0917	0.9537	0.8511	0.7894	0.7178	0.7142	0.8064	0.9643	1.0794	1.2459	1.6478
795.0	1.0747	0.9400	0.8355	0.7712	0.7038	0.7115	0.7865	0.9384	1.0521	1.2140	1.6298
790.6	1.0690	0.9377	0.8324	0.7593	0.6775	0.6812	0.7524	0.9146	1.0314	1.1933	1.6259
785.5	1.0644	0.9334	0.8398	0.7621	0.6652	0.6429	0.7424	0.9104	1.0344	1.1877	1.6263
780.6	1.0597	0.9219	0.8279	0.7585	0.6587	0.6508	0.7355	0.9120	1.0285	1.1759	1.6277
771.5	1.0530	0.9219	0.8285	0.7640	0.6762	0.6589	0.7533	0.9188	1.0267	1.1804	1.6339
750.0	1.0853	0.9498	0.8544	0.7881	0.7043	0.6947	0.7826	0.9468	1.0605	1.2175	1.6789
725.0	1.1423	1.0011	0.9014	0.8335	0.7467	0.7361	0.8269	0.9950	1.1113	1.2738	1.7505
700.0	1.2069	1.0588	0.9555	0.8842	0.7914	0.7795	0.8731	1.0479	1.1685	1.3363	1.8308
625.0	1.3905	1.2220	1.1038	1.0220	0.9146	0.8984	1.0004	1.1936	1.3273	1.5138	2.0633
550.0	1.5083	1.3257	1.1963	1.1070	0.9925	0.9736	1.0819	1.2888	1.4323	1.6320	2.2216
475.0	1.4986	1.3179	1.1932	1.1079	0.9981	0.9863	1.1016	1.3157	1.4630	1.6682	2.2727
400.0	1.1080	1.0077	0.9389	0.8946	0.8485	0.8842	1.0260	1.2501	1.3998	1.6053	2.2037
325.0	0.9672	0.8890	0.8352	0.7997	0.7681	0.8097	0.9475	1.1618	1.3042	1.4992	2.0659
250.0	0.8623	0.7913	0.7435	0.7134	0.6856	0.7250	0.8525	1.0481	1.1782	1.3563	1.8728
175.0	0.7342	0.6743	0.6342	0.6091	0.5868	0.6231	0.7359	0.9084	1.0225	1.1792	1.6327
100.0	0.5912	0.5431	0.5115	0.4919	0.4757	0.5087	0.6061	0.7532	0.8505	0.9836	1.3692
75.0	0.5433	0.4991	0.4697	0.4519	0.4384	0.4704	0.5628	0.7017	0.7937	0.9194	1.2833
50.0	0.4982	0.4580	0.4307	0.4140	0.4022	0.4336	0.5216	0.6536	0.7411	0.8596	1.2038
28.5	0.4642	0.4267	0.4022	0.3879	0.3763	0.4025	0.4903	0.6195	0.7016	0.8155	1.1456
19.4	0.4578	0.4200	0.3959	0.3793	0.3621	0.3930	0.4757	0.6078	0.6932	0.8016	1.1263
14.5	0.4560	0.4217	0.3983	0.3809	0.3649	0.3861	0.4743	0.6009	0.6902	0.8014	1.1168
9.4	0.4520	0.4191	0.3939	0.3784	0.3702	0.4026	0.4740	0.5984	0.6828	0.7981	1.1085
5.0	0.4486	0.4143	0.3894	0.3765	0.3743	0.4149	0.4932	0.6121	0.6944	0.8079	1.1030
2.5	0.4497	0.4148	0.3895	0.3773	0.3741	0.4141	0.5060	0.6288	0.7121	0.8276	1.1043

Table B.21. Relative power density values calculated with DORT using 20-group cross sections for the complex FOEHN configuration with a constant aluminum density in the reflector

H/(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.0957	0.9573	0.8545	0.7927	0.7210	0.7177	0.8108	0.9699	1.0858	1.2533	1.6581
795.0	1.0788	0.9436	0.8389	0.7746	0.7071	0.7152	0.7910	0.9441	1.0586	1.2216	1.6406
790.6	1.0733	0.9415	0.8359	0.7627	0.6809	0.6850	0.7570	0.9205	1.0382	1.2013	1.6376
785.5	1.0689	0.9374	0.8436	0.7656	0.6687	0.6467	0.7473	0.9167	1.0416	1.1963	1.6388
780.6	1.0644	0.9261	0.8318	0.7622	0.6623	0.6548	0.7406	0.9187	1.0362	1.1851	1.6411
771.5	1.0579	0.9264	0.8326	0.7680	0.6802	0.6632	0.7589	0.9262	1.0353	1.1906	1.6488
750.0	1.0909	0.9549	0.8591	0.7927	0.7089	0.6999	0.7894	0.9558	1.0710	1.2300	1.6972
725.0	1.1486	1.0068	0.9067	0.8387	0.7518	0.7422	0.8348	1.0057	1.1237	1.2886	1.7723
700.0	1.2138	1.0650	0.9614	0.8898	0.7971	0.7862	0.8820	1.0599	1.1825	1.3530	1.8555
625.0	1.3976	1.2285	1.1100	1.0281	0.9208	0.9060	1.0105	1.2074	1.3435	1.5331	2.0918
550.0	1.5141	1.3309	1.2014	1.1119	0.9977	0.9800	1.0906	1.3009	1.4464	1.6490	2.2468
475.0	1.5013	1.3205	1.1957	1.1104	1.0010	0.9901	1.1071	1.3234	1.4722	1.6794	2.2895
400.0	1.1073	1.0071	0.9385	0.8942	0.8485	0.8847	1.0274	1.2524	1.4028	1.6091	2.2098
325.0	0.9633	0.8855	0.8319	0.7965	0.7652	0.8068	0.9445	1.1583	1.3006	1.4951	2.0606
250.0	0.8559	0.7854	0.7379	0.7080	0.6803	0.7194	0.8459	1.0400	1.1692	1.3458	1.8584
175.0	0.7262	0.6669	0.6272	0.6022	0.5801	0.6157	0.7270	0.8972	1.0098	1.1645	1.6121
100.0	0.5826	0.5351	0.5038	0.4844	0.4682	0.5003	0.5955	0.7396	0.8350	0.9654	1.3432
75.0	0.5347	0.4911	0.4620	0.4443	0.4307	0.4617	0.5518	0.6874	0.7772	0.9000	1.2555
50.0	0.4895	0.4499	0.4229	0.4063	0.3944	0.4246	0.5100	0.6385	0.7237	0.8391	1.1741
28.5	0.4553	0.4184	0.3943	0.3800	0.3682	0.3933	0.4783	0.6036	0.6832	0.7937	1.1141
19.4	0.4486	0.4114	0.3877	0.3712	0.3541	0.3837	0.4635	0.5914	0.6741	0.7792	1.0938
14.5	0.4465	0.4128	0.3897	0.3725	0.3565	0.3767	0.4619	0.5843	0.6706	0.7784	1.0838
9.4	0.4423	0.4099	0.3852	0.3698	0.3613	0.3923	0.4612	0.5814	0.6630	0.7744	1.0748
5.0	0.4388	0.4051	0.3806	0.3678	0.3651	0.4039	0.4794	0.5941	0.6736	0.7832	1.0686
2.5	0.4398	0.4055	0.3806	0.3685	0.3649	0.4030	0.4915	0.6100	0.6903	0.8018	1.0698

Table B.22. Relative power density values calculated with VENTURE using 20-group cross sections for the complex FOEHN configuration with void in the reflector components

H/(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.0960	1.0054	0.9357	0.8814	0.8158	0.8215	0.9287	1.0886	1.1900	1.3123	1.6122
795.0	1.0783	0.9795	0.9055	0.8491	0.7824	0.7861	0.8894	1.0481	1.1518	1.2804	1.6088
790.6	1.0561	0.9479	0.8678	0.8077	0.7377	0.7385	0.8382	0.9983	1.1067	1.2447	1.6057
785.5	1.0411	0.9271	0.8426	0.7791	0.7051	0.7033	0.8025	0.9670	1.0804	1.2258	1.6063
780.6	1.0337	0.9172	0.8302	0.7648	0.6879	0.6846	0.7850	0.9535	1.0702	1.2200	1.6103
771.5	1.0298	0.9111	0.8220	0.7547	0.6748	0.6702	0.7731	0.9472	1.0678	1.2223	1.6230
750.0	1.0494	0.9285	0.8376	0.7685	0.6861	0.6814	0.7886	0.9699	1.0952	1.2553	1.6690
725.0	1.0962	0.9719	0.8782	0.8069	0.7218	0.7168	0.8277	1.0152	1.1448	1.3104	1.7380
700.0	1.1538	1.0244	0.9267	0.8523	0.7633	0.7574	0.8717	1.0658	1.2000	1.3716	1.8145
625.0	1.3235	1.1769	1.0661	0.9815	0.8793	0.8697	0.9944	1.2081	1.3562	1.5457	2.0351
550.0	1.4339	1.2755	1.1558	1.0643	0.9535	0.9420	1.0747	1.3032	1.4616	1.6643	2.1879
475.0	1.4323	1.2758	1.1578	1.0679	0.9606	0.9542	1.0941	1.3304	1.4936	1.7022	2.2405
400.0	1.0754	0.9879	0.9229	0.8754	0.8297	0.8690	1.0321	1.2767	1.4414	1.6501	2.1844
325.0	0.9417	0.8693	0.8165	0.7788	0.7476	0.7954	0.9571	1.1928	1.3505	1.5496	2.0584
250.0	0.8412	0.7769	0.7302	0.6970	0.6705	0.7161	0.8653	1.0817	1.2264	1.4090	1.8754
175.0	0.7203	0.6656	0.6260	0.5981	0.5768	0.6189	0.7517	0.9435	1.0715	1.2331	1.6456
100.0	0.5855	0.5411	0.5092	0.4870	0.4713	0.5094	0.6244	0.7892	0.8990	1.0375	1.3912
75.0	0.5413	0.5001	0.4706	0.4501	0.4361	0.4728	0.5819	0.7379	0.8419	0.9729	1.3075
50.0	0.5015	0.4631	0.4356	0.4166	0.4041	0.4393	0.5426	0.6900	0.7881	0.9120	1.2282
28.5	0.4757	0.4398	0.4144	0.3971	0.3866	0.4211	0.5189	0.6578	0.7504	0.8673	1.1666
19.4	0.4697	0.4358	0.4121	0.3963	0.3882	0.4238	0.5195	0.6535	0.7424	0.8548	1.1436
14.5	0.4685	0.4363	0.4142	0.3999	0.3941	0.4313	0.5266	0.6572	0.7435	0.8522	1.1325
9.4	0.4698	0.4408	0.4214	0.4094	0.4073	0.4480	0.5445	0.6721	0.7545	0.8575	1.1226
5.0	0.4740	0.4496	0.4337	0.4242	0.4263	0.4719	0.5727	0.6996	0.7785	0.8746	1.1156
2.5	0.4781	0.4573	0.4437	0.4361	0.4408	0.4902	0.5951	0.7233	0.8006	0.8919	1.1149

Table B.23. Relative power density values calculated with VENTURE using 20-group cross sections for the complex FOEHN configuration with aluminum in the void regions of the reflector components

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.1029	1.0112	0.9404	0.8851	0.8173	0.8197	0.9227	1.0782	1.1772	1.2966	1.5898
795.0	1.0857	0.9858	0.9107	0.8533	0.7843	0.7849	0.8840	1.0385	1.1397	1.2654	1.5865
790.6	1.0644	0.9549	0.8736	0.8125	0.7403	0.7380	0.8339	0.9898	1.0956	1.2305	1.5836
785.5	1.0503	0.9349	0.8491	0.7845	0.7083	0.7035	0.7990	0.9592	1.0699	1.2121	1.5843
780.6	1.0437	0.9256	0.8374	0.7707	0.6916	0.6853	0.7819	0.9461	1.0602	1.2066	1.5884
771.5	1.0410	0.9206	0.8301	0.7615	0.6793	0.6716	0.7706	0.9403	1.0582	1.2093	1.6013
750.0	1.0630	0.9401	0.8475	0.7769	0.6918	0.6838	0.7869	0.9637	1.0861	1.2427	1.6477
725.0	1.1121	0.9854	0.8897	0.8168	0.7286	0.7201	0.8267	1.0095	1.1362	1.2983	1.7169
700.0	1.1715	1.0395	0.9396	0.8634	0.7711	0.7614	0.8714	1.0606	1.1919	1.3598	1.7936
625.0	1.3454	1.1957	1.0823	0.9955	0.8895	0.8755	0.9954	1.2040	1.3490	1.5347	2.0145
550.0	1.4581	1.2963	1.1737	1.0799	0.9649	0.9488	1.0766	1.2998	1.4552	1.6539	2.1679
475.0	1.4562	1.2963	1.1755	1.0833	0.9719	0.9611	1.0959	1.3271	1.4873	1.6920	2.2207
400.0	1.0919	1.0024	0.9357	0.8866	0.8381	0.8739	1.0326	1.2723	1.4341	1.6389	2.1639
325.0	0.9550	0.8809	0.8267	0.7878	0.7541	0.7987	0.9562	1.1872	1.3419	1.5373	2.0370
250.0	0.8518	0.7861	0.7382	0.7039	0.6752	0.7179	0.8630	1.0747	1.2164	1.3953	1.8525
175.0	0.7282	0.6723	0.6317	0.6029	0.5797	0.6189	0.7478	0.9349	1.0599	1.2178	1.6210
100.0	0.5906	0.5454	0.5127	0.4897	0.4724	0.5079	0.6191	0.7793	0.8862	1.0211	1.3655
75.0	0.5455	0.5036	0.4733	0.4521	0.4367	0.4709	0.5762	0.7278	0.8288	0.9562	1.2817
50.0	0.5047	0.4657	0.4376	0.4180	0.4041	0.4369	0.5366	0.6795	0.7749	0.8952	1.2024
28.5	0.4779	0.4415	0.4155	0.3976	0.3858	0.4180	0.5124	0.6470	0.7368	0.8502	1.1407
19.4	0.4713	0.4368	0.4126	0.3963	0.3869	0.4203	0.5125	0.6422	0.7285	0.8375	1.1177
14.5	0.4697	0.4370	0.4144	0.3995	0.3924	0.4274	0.5191	0.6457	0.7292	0.8347	1.1066
9.4	0.4706	0.4410	0.4211	0.4085	0.4050	0.4433	0.5363	0.6598	0.7397	0.8395	1.0966
5.0	0.4743	0.4493	0.4328	0.4228	0.4234	0.4665	0.5635	0.6863	0.7628	0.8558	1.0895
2.5	0.4780	0.4566	0.4426	0.4343	0.4375	0.4841	0.5852	0.7092	0.7840	0.8725	1.0888

Table B.24. Relative power density values calculated with VENTURE using 20-group cross sections for the complex FOEHN configuration with a constant aluminum density in the reflector

H/r(mm)	143.5	146.5	149.5	152.5	159.0	167.5	176.0	182.5	185.5	188.5	193.9
797.5	1.1051	1.0132	0.9425	0.8872	0.8195	0.8221	0.9255	1.0816	1.1809	1.3007	1.5950
795.0	1.0881	0.9881	0.9129	0.8555	0.7866	0.7874	0.8871	1.0421	1.1437	1.2699	1.5922
790.6	1.0672	0.9574	0.8762	0.8150	0.7428	0.7408	0.8372	0.9938	1.1002	1.2356	1.5902
785.5	1.0535	0.9379	0.8520	0.7873	0.7111	0.7066	0.8026	0.9637	1.0750	1.2180	1.5920
780.6	1.0472	0.9289	0.8405	0.7738	0.6947	0.6886	0.7859	0.9511	1.0658	1.2131	1.5971
771.5	1.0452	0.9245	0.8338	0.7650	0.6827	0.6754	0.7752	0.9461	1.0649	1.2170	1.6117
750.0	1.0684	0.9451	0.8521	0.7814	0.6962	0.6886	0.7930	0.9714	1.0950	1.2532	1.6618
725.0	1.1186	0.9914	0.8953	0.8221	0.7339	0.7259	0.8341	1.0192	1.1474	1.3113	1.7348
700.0	1.1789	1.0462	0.9460	0.8696	0.7771	0.7680	0.8799	1.0718	1.2049	1.3750	1.8145
625.0	1.3541	1.2037	1.0897	1.0027	0.8965	0.8834	1.0056	1.2175	1.3646	1.5530	2.0398
550.0	1.4660	1.3035	1.1806	1.0864	0.9713	0.9560	1.0858	1.3118	1.4690	1.6702	2.1902
475.0	1.4614	1.3011	1.1800	1.0877	0.9762	0.9658	1.1019	1.3348	1.4962	1.7024	2.2348
400.0	1.0933	1.0037	0.9370	0.8879	0.8394	0.8752	1.0343	1.2744	1.4364	1.6416	2.1674
325.0	0.9531	0.8792	0.8251	0.7862	0.7524	0.7967	0.9534	1.1833	1.3374	1.5319	2.0293
250.0	0.8473	0.7819	0.7341	0.6999	0.6712	0.7130	0.8565	1.0660	1.2063	1.3833	1.8358
175.0	0.7218	0.6663	0.6259	0.5972	0.5739	0.6122	0.7388	0.9228	1.0458	1.2012	1.5980
100.0	0.5832	0.5384	0.5060	0.4831	0.4656	0.4998	0.6082	0.7646	0.8690	1.0007	1.3372
75.0	0.5379	0.4964	0.4664	0.4453	0.4296	0.4624	0.5648	0.7122	0.8106	0.9347	1.2516
50.0	0.4967	0.4581	0.4303	0.4109	0.3967	0.4280	0.5244	0.6631	0.7556	0.8723	1.1705
28.5	0.4694	0.4334	0.4077	0.3900	0.3778	0.4085	0.4995	0.6296	0.7164	0.8261	1.1071
19.4	0.4623	0.4283	0.4044	0.3882	0.3784	0.4101	0.4989	0.6240	0.7073	0.8126	1.0832
14.5	0.4604	0.4281	0.4058	0.3910	0.3834	0.4166	0.5048	0.6269	0.7075	0.8093	1.0716
9.4	0.4608	0.4317	0.4120	0.3993	0.3953	0.4317	0.5210	0.6399	0.7169	0.8132	1.0611
5.0	0.4641	0.4394	0.4230	0.4129	0.4129	0.4537	0.5468	0.6650	0.7386	0.8282	1.0533
2.5	0.4675	0.4463	0.4322	0.4239	0.4263	0.4706	0.5675	0.6867	0.7586	0.8439	1.0526

Table B.25. Thermal fluxes calculated with DORT using 20-group cross sections for the different models of the complex FOEHN configuration

(Values are normalized to a power of 1 W)

Radius ^a (mm)	Thermal flux 10 ¹¹ neutrons/(m ² s)		
	Void in the reflector components	Aluminum in the void regions of the reflector components	Constant aluminum density in the reflector
275	2.3391	2.2948	2.3097
315	2.5478	2.4792	2.5108
435	2.1436	2.0222	2.1197
515	1.6402	1.5027	1.6519
675	0.8582	0.7376	0.9108
755	0.5973	0.4987	0.6595

^aHeight = 1110 mm, the midplane of the fuel element.

Table B.26. Thermal fluxes calculated with VENTURE using 20-group cross sections for the different models of the complex FOEHN configuration

(Values are normalized to a power of 1 W)

Radius ^a (mm)	Thermal flux 10 ¹¹ neutrons/(m ² s)		
	Void in the reflector components	Aluminum in the void of the reflector components	Constant aluminum density in the reflector
275	2.2236	2.1777	2.1825
315	2.4802	2.4090	2.4171
435	2.1957	2.0636	2.0779
515	1.7498	1.5924	1.6224
675	1.0279	0.8733	0.8983
755	0.7713	0.6364	0.6538

^aHeight = 1110 mm, the midplane of the fuel element.

APPENDIX C

DIFFERENCES IN FOEHN CALCULATIONAL MODELS

Because the results calculated by various institutions are often compared, it is important to document the differences between calculational models. The differences between the model of the FOEHN experiment used for the calculations performed at the Idaho National Engineering Laboratory reported in ref. 9 (INEL model) and the model in this report (ORNL model) are discussed in the following. The differences in the models used in the calculations performed at the Technische Universität München¹⁴ (TUM model) are also presented. Some of the differences are rather trivial but are included for completeness.

1. Additional borated heavy water: The 1971 FOEHN report⁶ documents the fuel element contained 28.85 L of borated D₂O. The calculated volume is 27 L. In the ORNL model, the extra D₂O was assumed to be at the inner and outer edges of the fuel region. The thickness of the inner layer is 0.3 mm, and the thickness of the outer layer is 1.67 mm. The INEL model assumes the extra D₂O to be distributed in three layers. The layer at the edge of the fuel region is 0.3 mm, and the layer at the outer edge of the fuel region is 1.1 mm. The third layer is 0.5481-mm thick and is located at the inside edge of the stack. This region is 0.5-mm thick in the ORNL model and contains unborated D₂O. The 0.5-mm gap is outside the can that holds the fuel element and the borated heavy water. In the TUM model, both the inner and outer gaps are 0.6 mm and are between the fuel element tube and the can. The third gap between the can and the stack is not present in the TUM model.
2. AG3-NE alloy: The impurity content of the AG3-NE alloy must be assumed. The composition used in this report is from a mill test of an AG3-NE sample. The nuclides and atom densities that make up this composition are quite different from those used in the INEL model. In the TUM model, the AG3-NE material cross section was artificially adjusted by adding 5% to the thermal absorption cross section to account for the impurities in the alloy.
3. Light water content: The light water content in the heavy water reflector was reported with the measured results for each configuration of the FOEHN experiment. The reported values of 0.253, 0.265, and 0.263 atom percent for the simple, intermediate, and complex configurations respectively, were used in the ORNL models. The INEL models used a constant value of 0.25 at. % light water for all cases. The TUM models used the reported values.
4. AG3-NE structure above and below the core: The exact position of aluminum structures above and below the core region is unknown. The position of the structures in this report was determined from Fig. 2.1 in the original FOEHN report. A 50-mm-thick region is assumed to be located 190 mm above the upper edge of the fuel element, and a 30-mm region is located 176 mm below the lower edge of the fuel element. A 80-mm-thick region is part of the control element. The lower bound of the region is located at the lower edge of the nickel portion of the control element and moves with the element. The structure above the core in the INEL model is also 50-mm thick and is located 240 mm above the upper edge of the fuel element. The structure below the core is 180 mm below the lower edge of the fuel element and is 18-cm thick. The region inside the control element is 130-mm thick

and is also 180-mm below the lower edge of the fuel element. The region does not move as the control element changes positions. These structures are not present in the TUM model.

4. Hot source graphite atom density: In this report, the density of graphite is assumed to be 1.6 g/cm^3 , which yields $8.02 \times 10^{-2} \text{ atoms/(barn cm)}$. The graphite atom density in the INEL model is $1.67 \times 10^{-2} \text{ atoms/(barn cm)}$. The INEL model uses $S(\alpha, \beta)$ cross section data at 2000 K, while the graphite cross sections in the ORNL model were processed at 293 K. The hot source was a mock-up of the actual facility and was at room temperature. Calculations by the TUM were not performed for the complex FOEHN configuration, which contains the hot source.

5. Reflector components: An explicit model of the reflector components was used in this report to calculate smeared atom densities for the reflector region. Several minor differences between the ORNL and INEL model should be documented. The reflector component positions and descriptions in the ORNL model were based on information obtained from ref. 6. The INEL model described in the appendix in ref. 9 differs from this information in the following ways: (a) the cold source is not filled with heavy water and is surrounded by aluminum, (b) the horizontal channel in the graphite of the hot source is not modeled correctly, (c) the beam tubes do not have caps, (d) beam tube No. 3 is in the incorrect position, and (e) the conical angle for beam tube No. 11 should be $5^\circ 30''$ not $5^\circ 30'$. Calculations were not performed for the complex FOEHN configuration at the TUM.

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