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Criticality Experiments with Neutron Flux Traps Containing Voids

S. R. Bierman

April 1990

Prepared for the U.S. Department of Energy
Office of Civilian Nuclear Waste Management
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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Richland, Washington 99352

SUMMARY

A research program was initiated for the U.S. Department of Energy (DOE) by the Sandia National Laboratory Transportation Systems Development Department in 1982 to provide benchmark type experimental criticality data in support of the design and safe operations of nuclear fuel transportation systems. The overall objective of the program is to identify and provide the experimental data needed to form a consistent, firm, and complete data base for verifying calculational models used in the criticality analyses of nuclear transport and related systems.

A report, PNL-6205, issued in June 1988 (Bierman 1988) covered measurement results obtained from a series of experimental assemblies (TTC-1, 2, 3 and 4) involving neutron flux traps. The results obtained on a fifth experimental assembly (TTC-5), modeled after a calculational problem of the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) Working Group, were presented in a report, PNL-6838, issued in October 1989 (Bierman 1989). Criticality experiments to measure the reactivity effect of voiding in neutron flux trap regions are covered in this report. The experiments were performed at the U.S. Department of Energy Hanford Critical Mass Laboratory, operated by Pacific Northwest Laboratory of Battelle Memorial Institute. The work was jointly funded by the DOE Office of Civilian Radioactive Waste Management and the Defense Program.

The measurements were performed in the TTC-3 Experimental Assembly previously described as arrangement 214R in PNL-6205 (Bierman 1988). This assembly consisted of four water moderated units of 4.31 wt% ^{235}U enriched UO_2 fuel rods arranged in a 2 x 2 array and fully reflected by at least 15 cm of water. Each fuel unit was near equal in size with the fuel uniformly arranged on a 1.891 cm center-to-center square spacing (1.6 moderator-to-fuel volume ratio). The four fuel units were separated by a 3.73 cm wide flux trap created by 0.673 cm thick plates of Boral™ 96 cm in length and 45 cm wide. The plates contained 0.36 g B/cm^2 homogeneously dispersed throughout

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each plate. Voiding was created in the flux trap region by using 0.63 cm thick type 6061 aluminum plates uniformly centered between the Boral plates. The critical size of this assembly was determined as voiding was increased from zero in the flux traps to 16.89%, 33.78% and 50.67%. A 17.96% voiding was also created in the flux traps by replacing the aluminum plates with 1.27 cm diameter, type 6061 aluminum rods aligned down the center of each flux trap on a 1.891 cm center-to-center spacing. Measurements also were made to determine the effect that the presence of fuel rods in the flux traps had on the reactivity of the experimental assembly.

Increasing the voiding from zero to 50.67% in the flux traps by using the aluminum plates results in a 9.5% decrease in the number of fuel rods required for delayed criticality. Using aluminum rods instead of an aluminum plate increased the number of fuel rods required for delayed criticality by 0.4% at a voiding of 17.96%. The presence of fuel rods in flux traps reduced the critical size of the reference assembly (zero voids) by 10%.

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CRITICALITY EXPERIMENTS WITH NEUTRON FLUX TRAPS CONTAINING VOIDS

1.0 INTRODUCTION

A research program was initiated for the U.S. Department of Energy (DOE) by the Sandia National Laboratory Transportation Systems Development Department in 1982 to provide benchmark type experimental criticality data in support of the design and safe operations of nuclear fuel transportation systems. The overall objective of the program is to identify and provide the experimental data needed to form a consistent, firm, and complete data base for verifying calculational models used in the criticality analyses of nuclear transport and related systems.

A report, PNL-6205, issued in June 1988 (Bierman 1988) covered measurement results obtained from a series of experimental assemblies (TTC-1, 2, 3 and 4) involving neutron flux traps. The results obtained on a fifth experimental assembly (TTC-5), modeled after a calculational problem of The Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) Working Group, were presented in, PNL-6838, issued in October 1989 (Bierman 1989). Criticality experiments to measure the reactivity effect of voiding in neutron flux trap regions are covered in this report. As with the previous experiments, the measurements were performed at the U.S. DOE Hanford Critical Mass Laboratory, operated by the Pacific Northwest Laboratory of Battelle Memorial Institute. The work was jointly funded by the DOE Office of Civilian Radioactive Waste Management and the Defense Program.

The measurements were performed in the TTC-3 experimental assembly previously described as arrangement 214R in PNL-6205 (Bierman 1988). Briefly, the experimental assembly consisted of four water moderated units of 4.31 wt% ^{235}U enriched UO_2 fuel rods arranged in a 2 x 2 array and fully reflected by at least 15 cm of water. Each fuel unit was near equal in size with the fuel uniformly arranged on a 1.891 cm center-to-center square spacing (1.6 moderator-to-fuel volume ratio). The four fuel units were separated by a 3.73 cm wide neutron flux trap created by 0.673 cm thick plates of Boral™. The plates contained 0.36 g B/cm^2 homogeneously dispersed throughout each plate. Voids were created in the flux trap regions using 0.63 cm thick type 6061 aluminum plates and 1.27 cm diameter type 6061 aluminum rods. The critical size of the assembly was determined as voiding was increased from zero in the flux traps to approximately 17%, 34%, and 51%. A photograph of the assembly partially loaded with fuel and no voiding is shown in Figure 1.1. Details of the measurements and the experimental assembly are given in the sections that follow.

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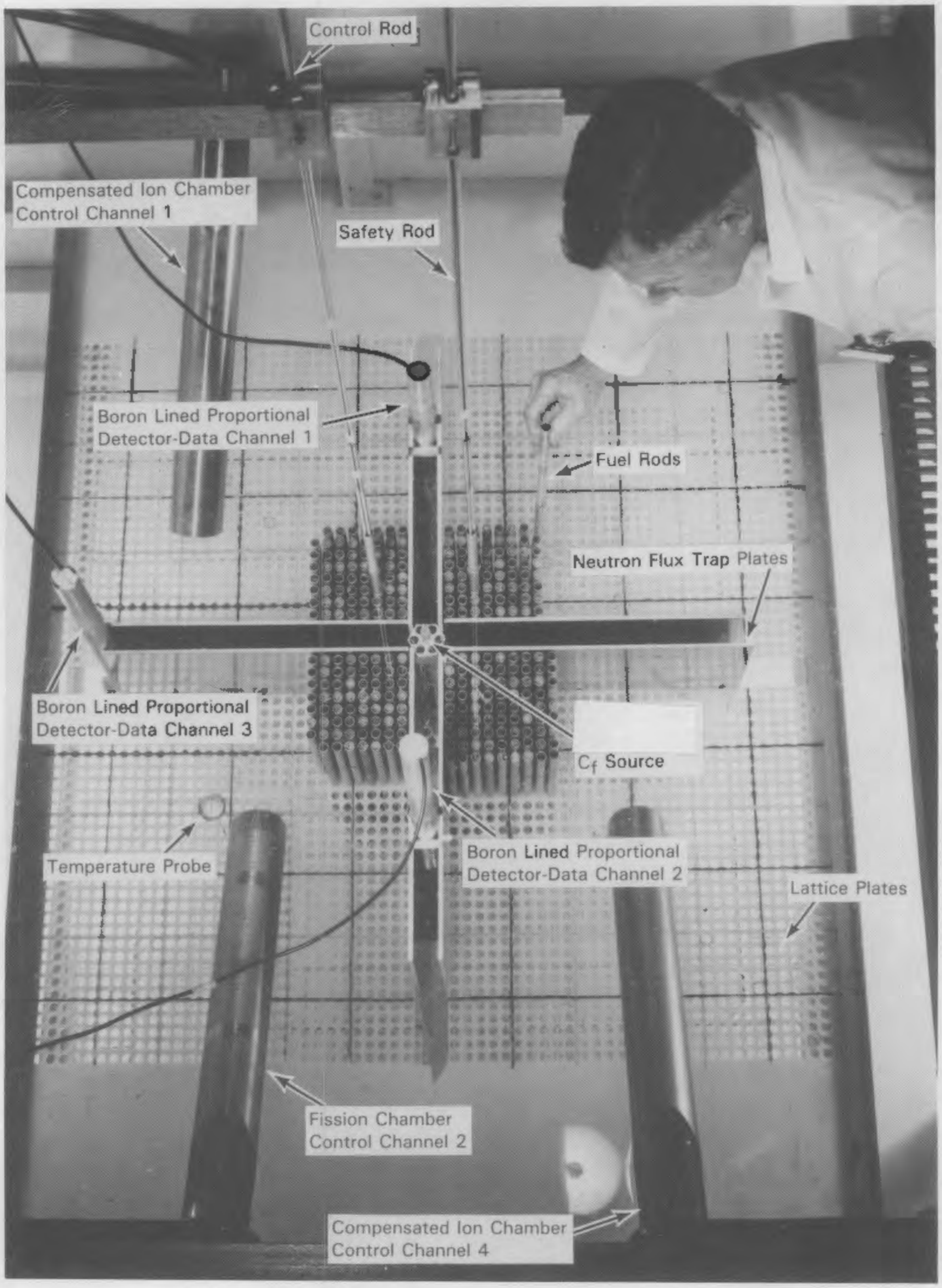


FIGURE 1.1. Photograph of Experimental Assembly Partially Loaded with Fuel

2.0 DESCRIPTION OF EXPERIMENTAL ASSEMBLY

The experimental system and materials associated with the measurements covered by this report are described in this section.

2.1 GENERAL

An existing experimental system used previously in fuel element array studies at the Critical Mass Laboratory was used for performing the measurements covered in this report. This system, the Fuel Element Array System (FEAS), consists of a 1.8 m x 3 m x 2.1 m deep, open-top, carbon-steel tank provided with a moderator/reflector dump valve, a control blade drive, a safety blade drive, a water deionizer, and associated electronic detection and interlock devices. An overall photograph of the system is shown in Figure 2.1.

The control and safety blade drive systems shown in Figure 2.1 were modified to permit replacing the blades with rod-type devices. The experimental assembly shown in Figure 1.1 was positioned in the large tank beneath these drive systems. As shown in Figure 1.1, the experimental assembly consisted of a 2 x 2 array of fuel units. The fuel units were separated by 3.73 cm wide neutron flux trap regions. Each fuel unit was near equal in size and consisted of 4.31 wt% ^{235}U enriched UO_2 fuel rods on a square center-to-center spacing of 1.891 cm. This lattice spacing results in a moderator-to-fuel volume ratio of 1.6, which approximates that typically found in both Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR). The neutron flux trap regions were created by 0.673 cm thick plates of Boral containing 0.36 g B/cm^2.

The assembly was fully reflected by at least 15 cm of water on all sides and essentially free of any structural materials in the fuel and flux trap regions. All of the instrument thimbles were located outside the fuel area. Except for the 1.2 cm diameter type 6061 aluminum guide tubes for the safety-control rods and the 0.2 microgram ^{252}Cf source used in the critical approach measurements, all other material (lattice and base support plates) in the fuel-flux trap regions have neutronic properties similar to the water

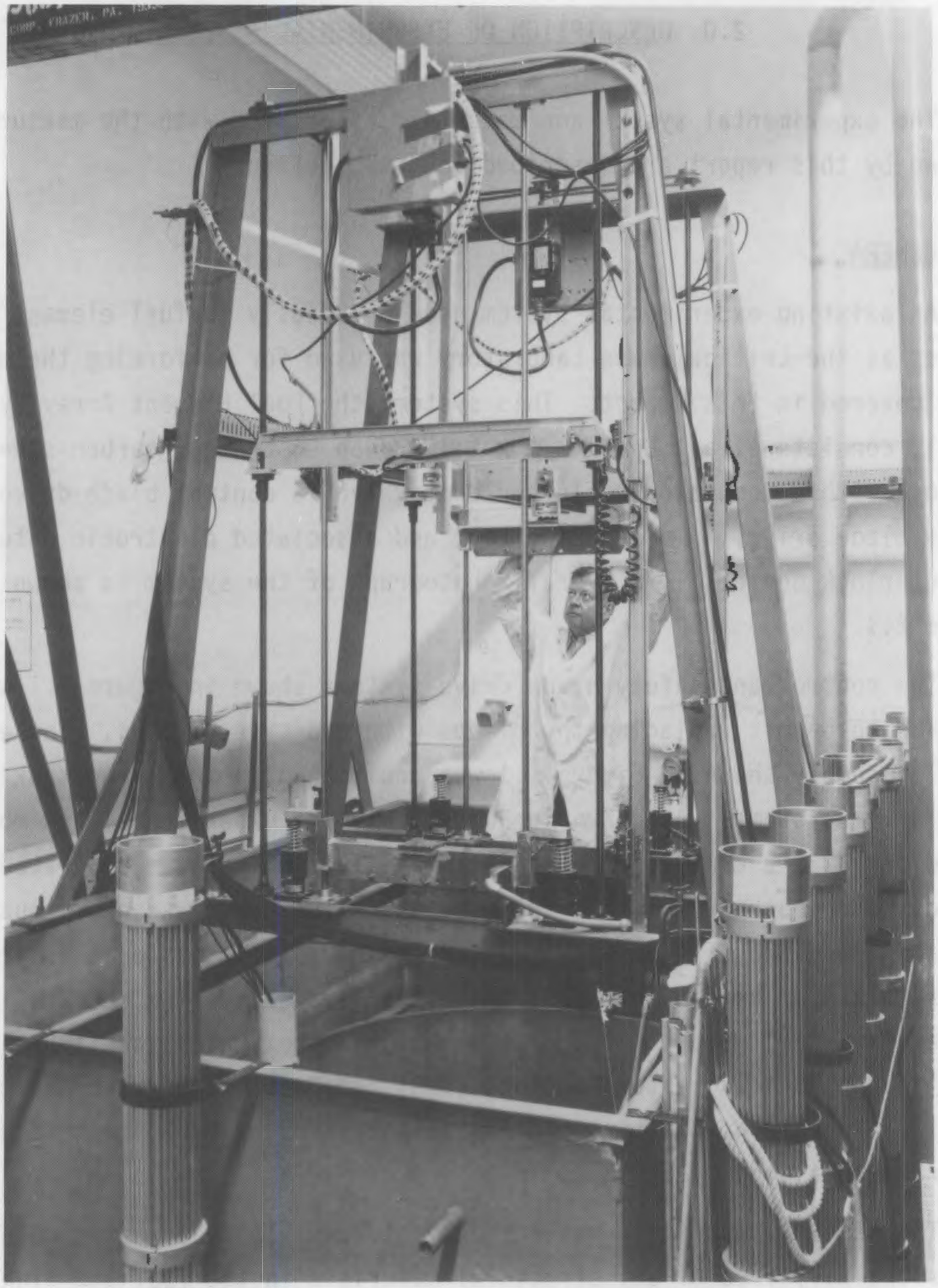
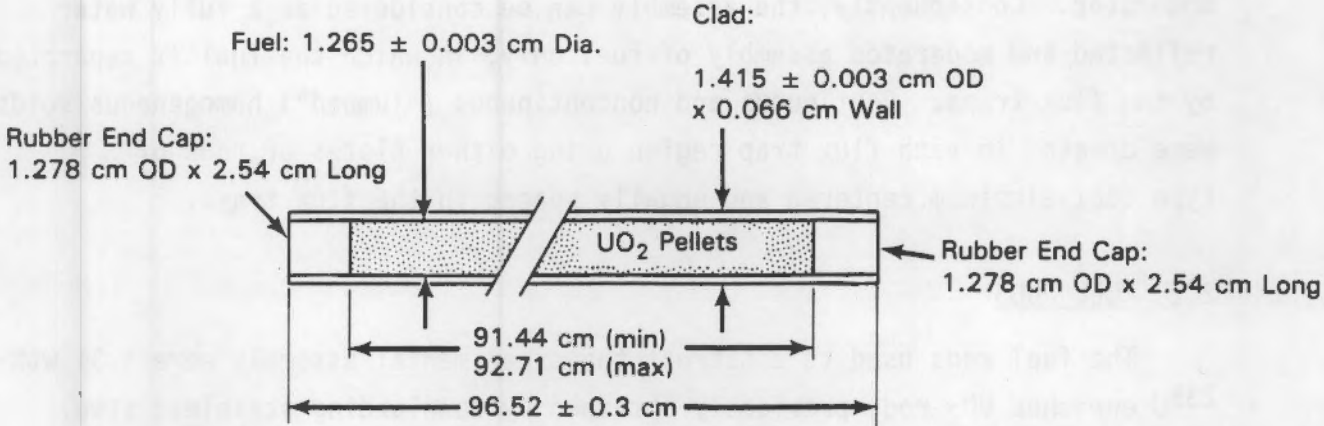


FIGURE 2.1. Experimental System Modified for Use in Experiments



Cladding: 6061 Aluminum Tubing

Loading

Enrichment - 4.306 ± 0.013 wt% ^{235}U
Oxide Density - 10.40 ± 0.06 g/cm^3
UO_2 - 1203.38 ± 4.12 g/Rod
U - 1059.64 ± 4.80 g/Rod

Uranium Composition:

^{234}U - 0.022 ± 0.002 wt%
^{235}U - 4.306 ± 0.013 wt%
^{236}U - 0.022 ± 0.002 wt%
^{238}U - 95.650 ± 0.017 wt%

End Cap:

C-58 ± 1 wt%	S-1.7 ± 0.2 wt%
H-6.5 ± 0.3 wt%	O-22.1 wt% (Balance)
Ca-11.4 ± 1.8 wt%	Si-0.3 ± 0.1 wt%

Notes:

1. Error limits are one standard deviation
2. End Cap Density is 1.321 g/cm^3

FIGURE 2.2. Description of 4.31 wt% ^{235}U Enriched UO_2 Fuel Rods

moderator. Consequently, the assembly can be considered as a fully water reflected and moderated assembly of fuel only, in which the fuel is separated by the flux traps. Continuous and noncontinuous ("lumped") homogeneous voids were created in each flux trap region using either plates or rods of type 6061 aluminum centered and equally spaced in the flux trays.

2.2 FUEL RODS

The fuel rods used to construct the experimental assembly were 4.31 wt% ^{235}U enriched UO_2 rods previously obtained by downloading stainless steel clad rods, originally fabricated for Core II of the N. S. Savannah (Katz 1969), and reloading the pellets into type 6061 aluminum tubes (see Appendix A for American Society for Testing Materials, T6061 Al specifications). A complete description of these rods is given in Figure 2.2. The uranium assay (1059.64 ± 4.80 g/rod) and the ^{235}U enrichment (4.306 ± 0.013%) shown in Figure 2.2 for these rods are the average of six assays and six spectrographic analyses made on fuel pellets chosen at random during the reloading. The oxide density (10.40 ± 0.06 g UO_2/cm^3) given in Figure 2.2 is based on individual volume displacement measurements with 20 pellets selected at random during the reloading operations. The mass of UO_2 per rod (1203.38 ± 4.12 g) is the average mass of the 1865 rods of this type available for use in the experiments. The fuel diameter (1.265 ± 0.003 cm) given in Figure 2.2 was checked repeatedly during the reloading operations and found to agree with that quoted in the document characterizing Core II of the N. S. Savannah (Katz 1969). The rubber end cap density (1.321 g/cm^3) quoted in Figure 2.2 for the 4.31 wt% ^{235}U enriched fuel is the result of a single mass-volume measurement with six end caps selected at random. The composition of the end caps is the result of four analyses on randomly selected end caps.

2.3 MODERATOR-REFLECTOR

As indicated previously, the assembly was moderated and fully reflected with water. Impurities analyses of a water sample taken during the experiments are given in Appendix B.

2.4 LATTICE PLATES AND SUPPORTS

Three 1.23 ± 0.01 cm thick, polypropylene lattice plates, having a C_3H_6 molecular structure and a density of 0.90 g/cm^3, were used to achieve and maintain uniform spacings between the fuel pins in the experimental assembly and between the fuel and the flux traps. Trace impurity levels for the lattice plates are given in Appendix C. These plates, which have neutronic properties similar to the water moderator, were the only structural materials in the fuel-moderator region of each assembly. The elevation of each lattice plate relative to other components in the experimental assembly is shown in Figure 2.3.

The fuel rods were supported on a 5.08 cm thick acrylic plate (1.185 g/cm^3 containing 8 wt% H, 60 wt% C and 32 wt% O) mounted off the FEAS tank walls. The elevation of the acrylic support plate, relative to components in the experimental assembly is shown in Figure 2.3.

2.5 FLUX TRAP PLATES

The neutron flux traps between the fuel units were created by positioning parallel plates of Boral™, separated by 3.73 ± 0.02 cm of water, between the fuel. The fuel units were not encased on all four sides since the measurements are concerned only with interaction between the units. Also, not encasing the fuel on all sides permitted varying the size of the fuel units as voiding in the flux traps varied.

The Boral plates consisted of a homogeneous matrix of aluminum and boron carbide particles sandwiched between two thin (0.102 cm) sheets of type 1100 Al. The boron loading was 0.36 ± 0.02 g B/cm^2. The composition and the physical description of these plates are given in Table 2.1.

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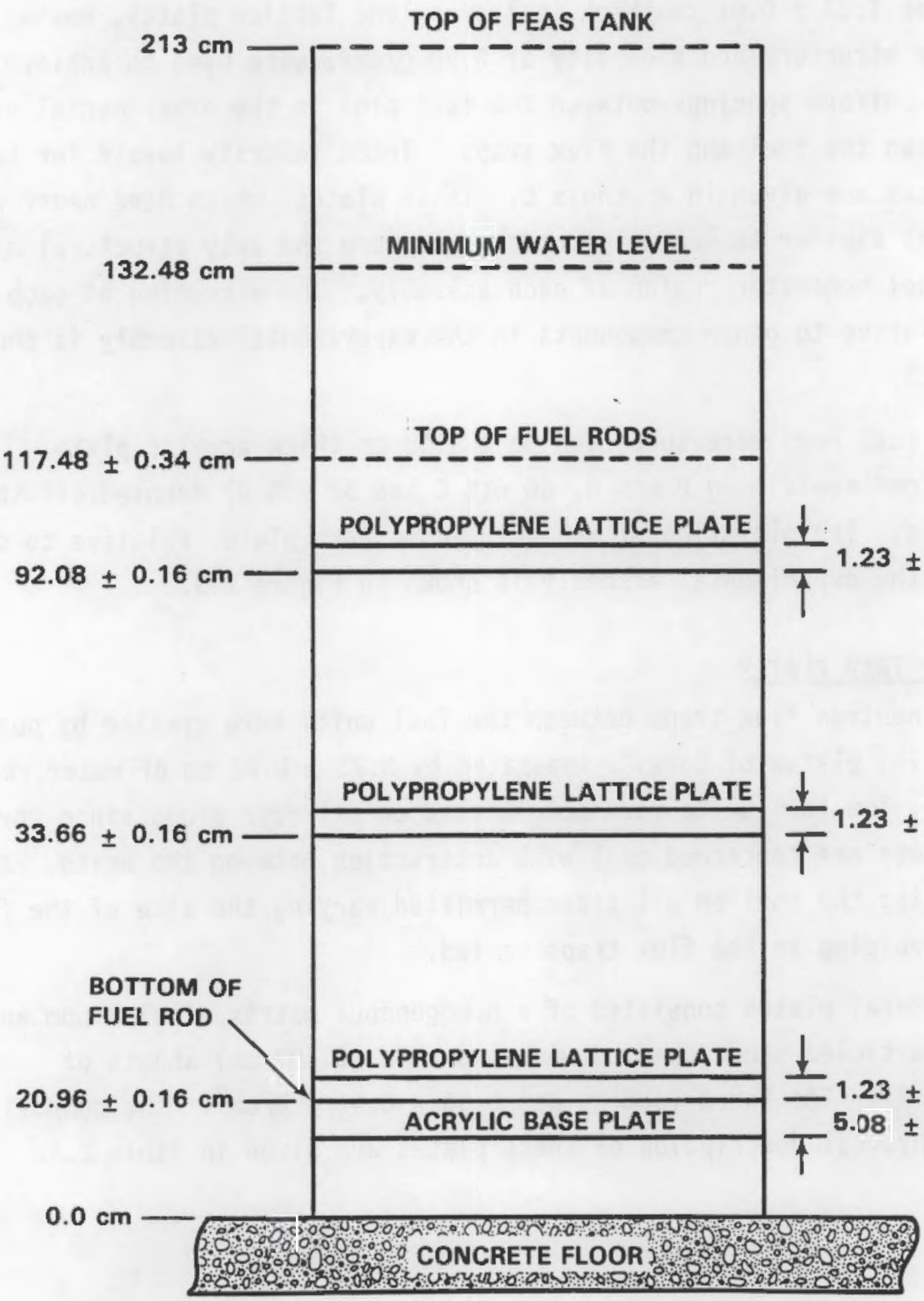

FIGURE 2.3. Experimental Assembly Elevations

TABLE 2.1. Description of Neutron Flux Trap Plates

Element, wt%	wt%
Al	62.54 ± 2.43
B	29.22 ± 1.87
C	8.16 ± 0.52
O	0.06
Fe	0.02
Core Density, g/cm^3	2/64 ± 0.01
Core Thickness, cm	0.470 ± 0.003
Length, cm	96
Width, cm	45

The boron carbide particle size distribution is given in Table 2.2 and American Society for Testing Materials (ASTM) specifications for type 1100 aluminum are given in Appendix A.

TABLE 2.2 Boron Carbide Particle Distribution

Particle Diameter, cm	Distribution, wt%
>0.0300	0
>0.0180	8.6
>0.0045	81.7
<0.0045	9.7

2.6 VOIDING MATERIALS

Continuous homogeneous voidings of 16.89 ± 0.07%, 33.78 ± 0.10% and 50.67 ± 0.12% were created in the neutron flux traps by using 0.630 ± 0.005 cm thick plates of type 6061 aluminum plates equally spaced, and centered, in each flux trap region. To obtain comparable data, 1.27 ± 0.005 cm diameter type 6061 aluminum rods, centered in each flux trap region on 1.891 ± cm center-to-center spacings, were used to create a noncontinuous homogeneous voiding of 17.96 ± 0.09%. ASTM specifications for the type 6061 aluminum are given in Appendix A.

2.7 CONTROL AND SAFETY BLADES

The FEAS control and safety drives were provided with gadolinium rods such that each experimental assembly could be constructed in compliance with operating regulations and procedures. These rods and their associated type 6061 aluminum guides were located in the fuel regions of the experimental assembly such that the rods fall by gravity into the assembly should an out-of-range condition exist in the control channels shown in Figure 1.1. The control and safety rods are not defined since all of the data reported herein were obtained with these rods fully withdrawn from the experimental assembly. ASTM specifications for the aluminum sleeves are given in Appendix A. The aluminum sleeves extended from the acrylic base plate shown in Figure 2.3 to above the top reflector level at locations shown in the loading diagrams for each assembly arrangement. The sleeves had a 1.283 cm inside diameter and a wall thickness of 0.066 cm.

3.0 EXPERIMENTAL MEASUREMENTS AND RESULTS

Since the objective of the experiments is to determine the reactivity effects caused by voids being introduced in neutron flux traps, the measurements were performed in an experimental assembly previously used to obtain data on the reactivity effectiveness of neutron flux traps created by parallel Boral plates positioned between fuel units. The results of these previous experiments demonstrated that the effectiveness of neutron flux traps for criticality control was essentially insensitive to boron loadings above about 0.1 g B/cm^2 (Bierman 1988). To assure that the results obtained on the reactivity effects of voiding were relatively insensitive to errors in the boron loading, the TTC-3 assembly containing neutron flux trap regions created with plates having a boron loading of 0.36 g B/cm^2 was chosen as the reference assembly with zero voiding. A loading diagram for the reference TTC-3 assembly, which was a 2 x 2 array of fuel and is identified as 214R, is given in Appendix D.

Continuous homogeneous voids of 16.89 ± 0.07%, 33.78 ± 0.10% and 50.67 ± 12% were created in the 214R assembly flux trap regions by centering 1, 2 and 3 type 6061 aluminum plates, respectively, in the flux traps. As indicated in Section 2.6, the plates were of equal thickness and positioned such that 1, 2 and 3 equally spaced void regions were created in the flux trap. For each of these voiding conditions, the critical size of the assembly was determined. The results obtained are given in Table 3.1. The fractional changes observed in the critical size as voiding was increased in the experimental assembly are shown in Figure 3.1. Fuel loading and assembly diagrams are given in Appendix D for each voiding condition. To the extent permitted by the delayed critical condition, fuel was distributed equally between the four fuel units for each assembly condition.

The critical size for each condition identified in Table 3.1 was determined by the approach-to-critical method to obtain well-defined, fully water-reflected, neutron flux trap assemblies consisting of water moderated fuel only. In an approach-to-critical measurement to determine the critical conditions for a system, neutron multiplication measurements are made as the parameter of interest is varied such that the system "approaches"

TABLE 3.1. Measurement Results and Summary Description of Experimental Assembly Conditions

Experiment Number	Voiding Material in Each Flux Trap (a)	Voiding in Each Flux Trap (volume %)	Assembly Loading (b) for Delayed Criticality (fuel rods)
214 R	None	0	952 ± 2
214 V1	One Aluminum Plate	16.89 ± 0.07	924.6 ± 1.9
214 V2	Two Aluminum Plates	33.78 ± 0.10	896.2 ± 2.2
214 V3	Three Aluminum Plates	50.67 ± 0.12	862.1 ± 1.2
214 V4	12 Aluminum Rods	–	925.4 ± 1.3
214 V5	14 Aluminum Rods	–	924.9 ± 1.6
(c)	15 Aluminum Rods	17.96 ± 0.09	924.7 (c)
214 F1	11 Fuel Rods	–	873.7 ± 1.0 (d)
214 F2	12 Fuel Rods	–	866.9 ± 0.3 (d)
214 F3	14 Fuel Rods	–	858.5 ± 0.1 (d)
(d)	15 Fuel Rods	22.30 ± 0.11 (e)	856 (d)

(a) Refer to loading diagrams in appendix for location of voiding material in each flux trap
(b) Error limits are one standard deviation estimates
(c) Linear extrapolation of 214 V4 and 214 V5 results
(d) Linear extrapolation of 214 F1, 214 F2 and 214 F3 results, critical loading does not include fuel rods in flux trap regions
(e) Moderator displacement

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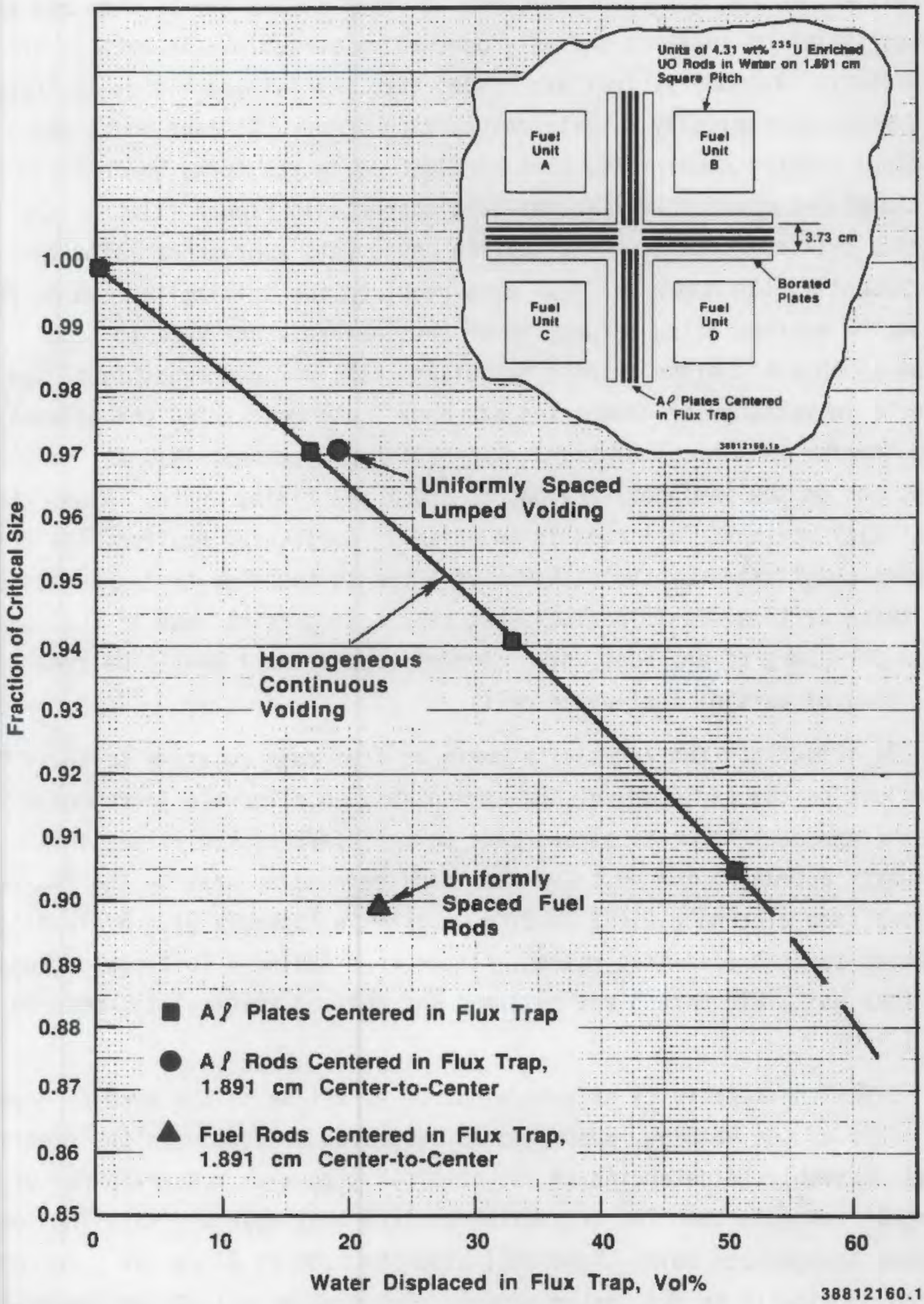


FIGURE 3.1. Variation in Critical Size with Flux Trap Voiding

criticality. By extrapolating subcritical data very near critical, a precise definition of the critical conditions for that system can be obtained with the parameter of interest the only perturbing variable. In each of the experimental assemblies fuel was loaded into the lattice plates in increments that were neutronically symmetrical to each other. At each incremental fuel loading, neutron count rates were obtained using the three boron-lined proportional detectors identified as data channels in Figure 1.1. At the delayed critical condition the neutron count rate approaches infinity. Consequently, the number of fuel pins required for criticality can be predicted by extrapolating a function of the inverse count rate to zero. Although this technique results in "clean" well-defined conditions, the results in rectangular geometries can complicate describing the assembly geometry for use in calculations. In rectangular geometries, all fuel rod locations on the periphery are not of equal reactivity worth. Also, the reactivity worth of fuel rods in an assembly containing neutron flux traps is further complicated by the nearness of a rod to the flux trap. Consequently, for those critical fuel loadings that result in partial rows of fuel in the outer periphery of any fuel unit, partial rows of fuel should be treated as full rows of partial fuel-water cells.

To illustrate the reactivity worth of fuel rods relative to their locations on the periphery of the assemblies, an alternate incremental loading approach to critical was made on the 214V3 assembly. In this alternate approach, the last few fuel rods were added next to the flux trap regions (see alternate 214V3 loading diagram in Appendix D). By loading adjacent to each flux trap region, rather than adding a full row of rods to one fuel unit, 876.6 rods are required for delayed criticality compared to 862.1.

Since the reactivity effects might be sensitive to the form or geometrical shape of the voiding, measurements were also performed in the experimental assembly to determine if the critical size with noncontinuous or "lumped" voids in the flux trap differed from that observed with the continuous homogeneous void. Type 6061 aluminum rods (1.27 cm dia x 96 cm) were spaced vertically in the center of each flux trap on a 1.891 cm center-to-center spacing to obtain "lumped" voiding of 17.96 ± 0.09% in the critical assembly. The results of these measurements are given in Table 3.1 and compared with the continuous voiding results in Figure 3.1. As can be seen in Figure 3.1, the uniformly spaced aluminum rods resulted in a slight decrease in reactivity equivalent to about 0.4% in critical size.

In addition to providing data on the lumping effect of voids in flux traps, the measurements with aluminum rods also provided an opportunity to obtain data on the effect that fuel rods in these regions would have on the reactivity of the assembly. The results of these measurements with the aluminum rods replaced with fuel rods are given in Table 3.1 and compared with the continuous and lumped voiding results in Figure 3.1. Although the reactivity effect is dependent on the number of fuel rods in the flux trap regions, the measurement data indicate a maximum is approached as the number of rods in a region approaches the number in the adjacent array face. This maximum value for the experimental assembly is shown in Figure 3.1. As can be seen, fuel in the flux trap regions has a significant effect (~10%) on the assembly size. Figure 3.2 is a photograph of the assembly with the fuel rods in the flux trap regions.

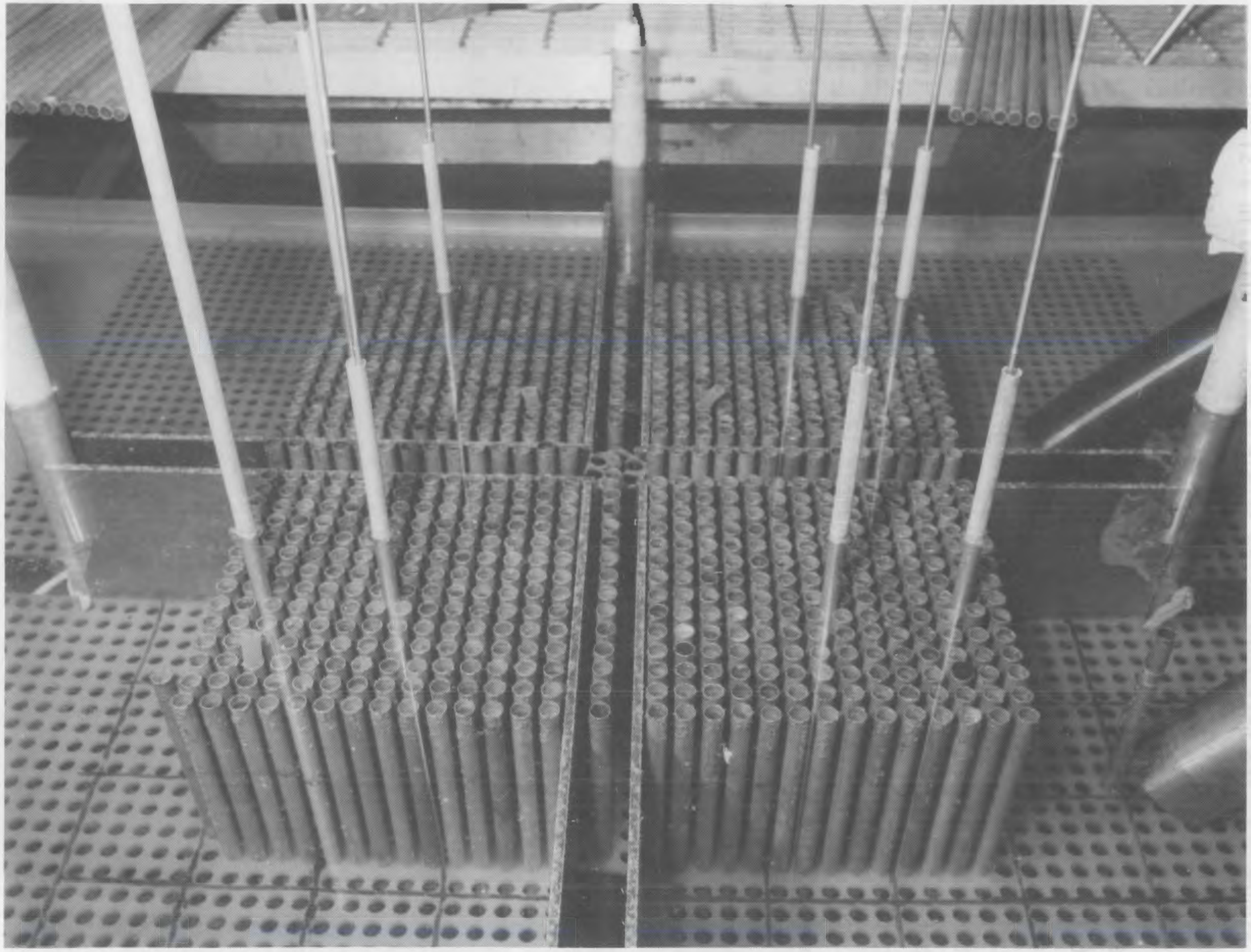


FIGURE 3.2. Photograph of TTC-3 Assembly with Fuel Rods in the Flux Traps

4.0 SUMMARY OF RESULTS

The introduction of up to 51% voiding in the neutron flux trap regions decreased the critical size of the experimental assembly by about 9.5%. The geometry or location of the voids in the flux trap regions appeared to have little effect on the reactivity of the system. It should be noted, however, that this observation may be dependent on the width of the flux trap.

The presence of fuel rods in the flux trap regions increases the reactivity significantly. With fuel rods equally spaced over the length and in the center of the flux trap regions, a decrease of about 10% was observed in the critical size of the experimental assembly.

5.0 ACKNOWLEDGMENTS

The cooperation and assistance of Critical Assembly Operators J. H. Smith and M. A. Covert in performing the experiments is gratefully acknowledged and appreciated. Also appreciated is the review of this report by E. D. Clayton of PNL (Ret.) and G. R. Smolen of the Oak Ridge National Laboratory.

6.0 REFERENCES

Bierman, S. R. 1988. "Criticality Experiments to Provide Benchmark Data on Neutron Flux Traps." PNL-6205, Pacific Northwest Laboratory, Richland, Washington.

Bierman, S. R. 1989. "Reactivity Measurements on an Experimental Assembly of 4.31 WT% ^{235}U Enriched UO_2 Fuel Rods Arranged in a Shipping Cask Geometry." PNL-6838/TTC-0895, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

DENSITY AND CHEMICAL COMPOSITION OF TYPE 6061 AND TYPE 1100 ALUMINUM

APPENDIX A

DENSITY AND CHEMICAL COMPOSITION OF TYPE 6061 AND TYPE 1100 ALUMINUM

Density and American Society for Testing Materials (ASTM) chemical specifications for the aluminum present in the experimental assemblies are presented in this appendix.

TABLE A.1. ASTM Standard B210-78 Specifications for TYPE 6061 Aluminum

Chemical Composition

Element	Wt%
Si	0.40-0.80
Fe	0.7 (Maximum)
Cu	0.15-0.40
Mn	0.15 (Maximum)
Mg	0.8-1.2
Cr	0.04-0.35
Zn	0.25 (Maximum)
Ti	0.15 (Maximum)
Al	Remainder 97.36 → 96.15

Maximum Impurities

Element	Wt%
Each	0.05
Total	0.15

Density: 2.69 g/cm^3
(not part of standard - measured by volume displacement)

TABLE A.2. ASTM Standard B210-78 Specifications for TYPE 1100 Aluminum

Chemical Composition

Element	wt%
Si, Fe	1.0 (combined Maximum
Cr	0.05-0.20
Mn	0.05 (maximum)
Zn	0.10 (maximum)
Al	99.00 (maximum)

Maximum Impurities

Element	wt%
Each	0.05
Total	0.15

Density: 2.70 g/cm^3
(not part of standard - measured by volume displacement)

APPENDIX B

TRACE IMPURITIES PRESENT IN THE WATER MODERATOR-REFLECTOR OF THE EXPERIMENTAL ASSEMBLY

APPENDIX B

TRACE IMPURITIES PRESENT IN THE WATER MODERATOR-REFLECTOR OF THE EXPERIMENTAL ASSEMBLY

Samples were taken during the experiments of the water moderator-reflector. The results of the sample analyses are presented in this appendix. All analyses were performed in accordance with Standard Methods for the Examination of Water and Waste Water, 15th ed., American Public Health Association, Washington, DC.

TABLE B.1. Analysis of Water Sample

Analysis	Sample Number TTC 214F1
pH	7.5
Total alkalinity mg/liter as $CaCO_3$	35
Bicarbonate Alkalinity mg/liter as $CaCO_3$	33
Carbonate alkalinity mg/liter as $CaCO_3$	<0.5
Total dissolved solids mg/liter	83
Sulfate mg/liter	16
Nitrate (as N) mg/liter	2.83
Fluoride mg/liter	0.12
Chloride mg/liter	18
Cadmium mg/liter	0.0006
Copper mg/liter	<0.05
Chromium mg/liter	<0.005
Iron mg/liter	0.20
Lead mg/liter	<0.005
Manganese mg/liter	<0.01
Zinc mg/liter	0.32
Boron mg/liter	<25
Gadolinium mg/liter	<10

APPENDIX C

IMPURITIES MEASURED IN LATTICE PLATE MATERIAL

APPENDIX C

TRACE IMPURITIES MEASURED IN LATTICE PLATE MATERIAL

Trace impurity levels are presented in this appendix for the polypropylene material used in fabricating the lattice plates for these experiments. The analytical results are from a spark source mass spectrographic analysis of samples taken from, and considered representative of, the polypropylene lattice plates. The spectrographic analysis were performed by the Hanford Engineering Development Laboratory, Richland, Washington, on October 17, 1985.

TABLE C.1. Trace Impurities Present in Lattice Plates (parts per million by weight)

Element	Sample Number TTC-4
Li	0.2
Be	1
B	0.04
F	--
Na	<10
Mg	<6
Al	30
Si	8
P	5
Cl	1
K	40
Ca	--
Ti	<100
V	3
Cr	<10
Mn	<2
Fe	--
Cu	100
Zn	<10
Ge	--
As	<5
Rb	--
Y	--
Zr	--
Mo	--
Sn	--
Br	--

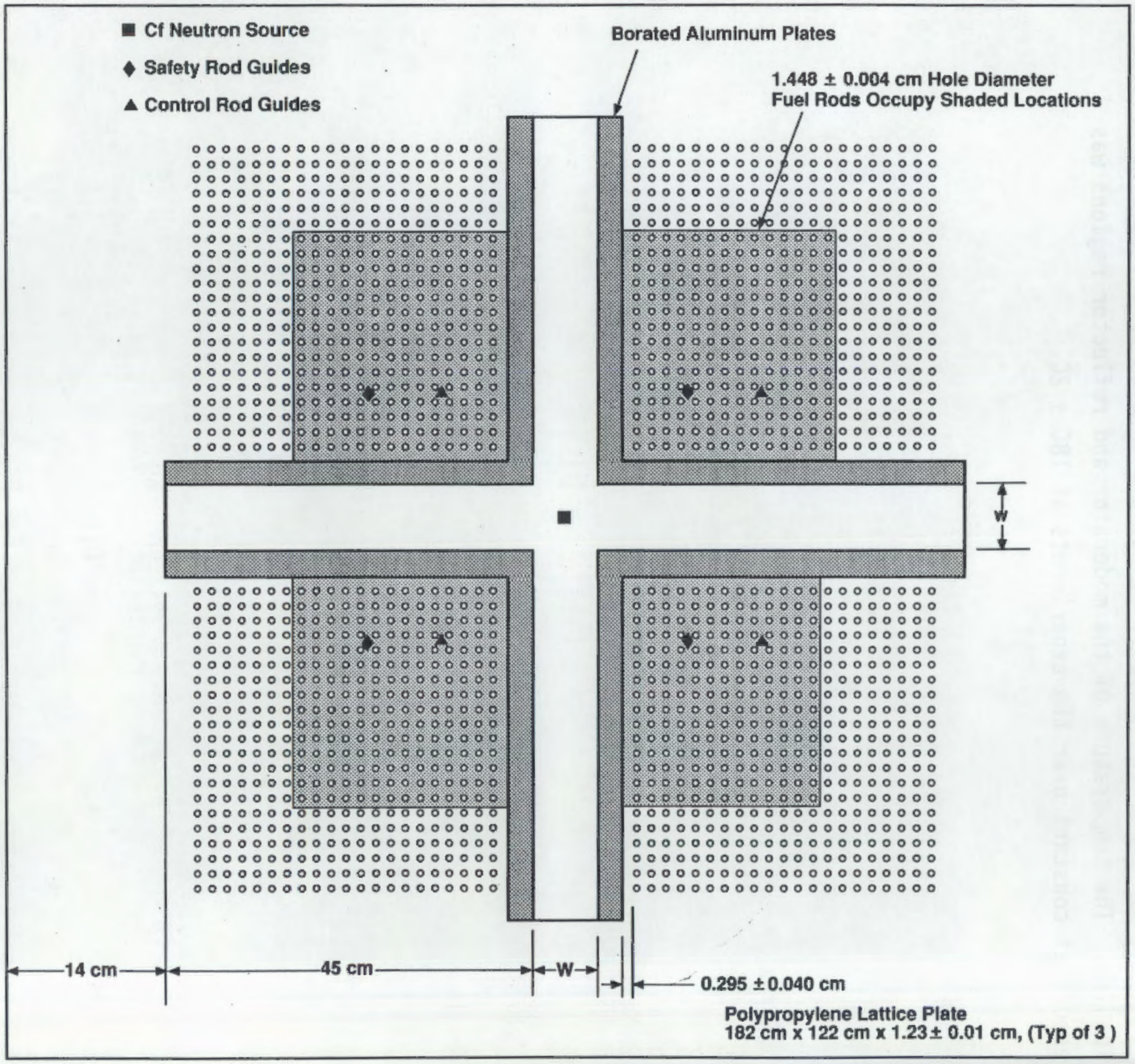
APPENDIX D

LOADING DIAGRAMS OF THE EXPERIMENTAL ASSEMBLIES

APPENDIX D

LOADING DIAGRAMS OF THE EXPERIMENTAL ASSEMBLIES

Diagram plans of the fuel-moderator region of each experimental assembly arrangement are presented in this appendix. The final subcritical fuel loading arrangement is shown and the total number of fuel rods predicted for delayed criticality is given for each assembly. Final fuel loadings for all of the assemblies are within about 1% of the delayed critical loading except for assembly 214F1. Assembly 214F1 was within 2.2% of the delayed critical loading. The temperature of the moderator and reflector regions was essential constant over the experiments at 18C ± 2C.



Assembly Number	: 214R
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 945 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: None
Comments	: 952 Rods Predicted for Delayed Criticality

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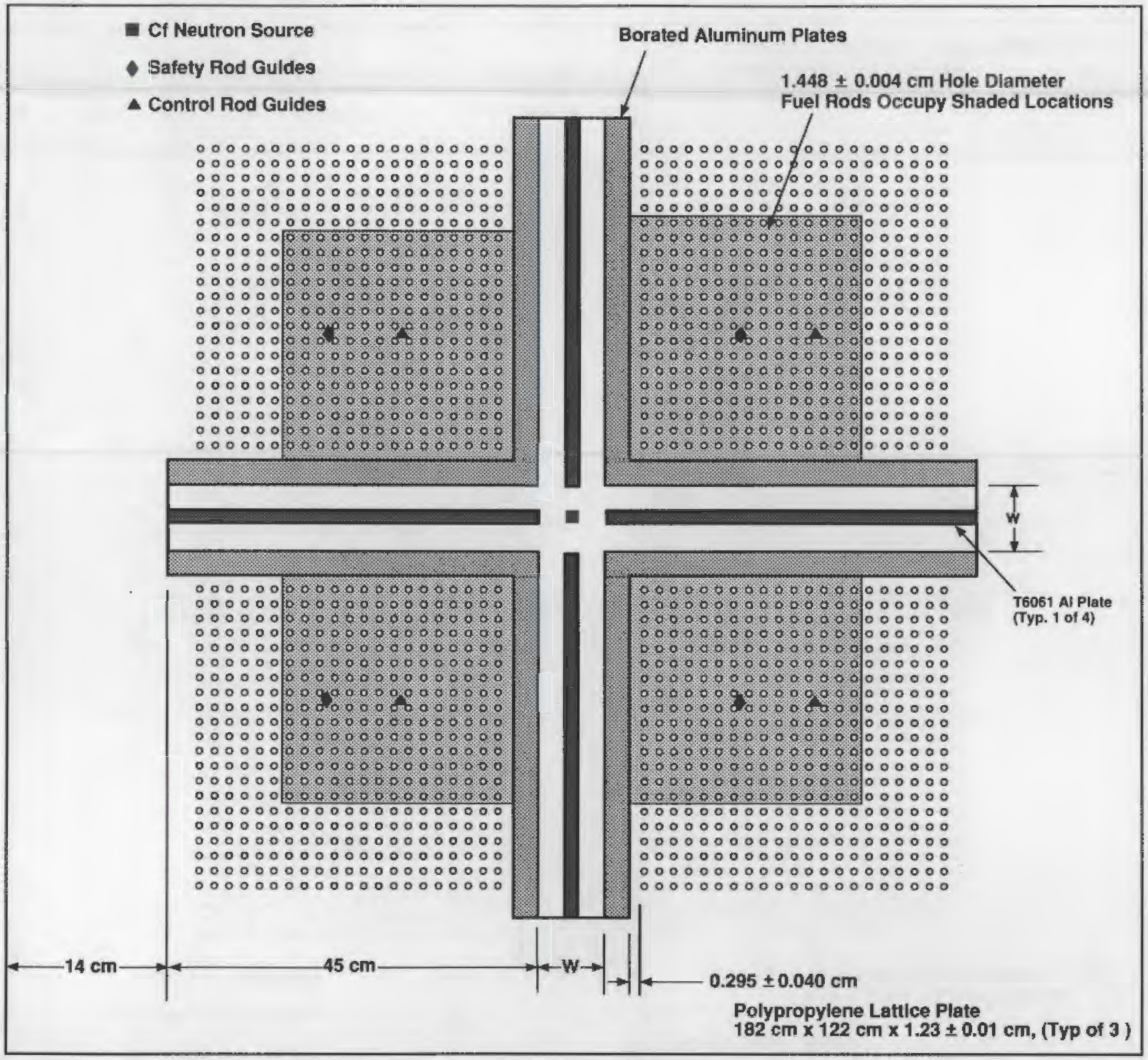
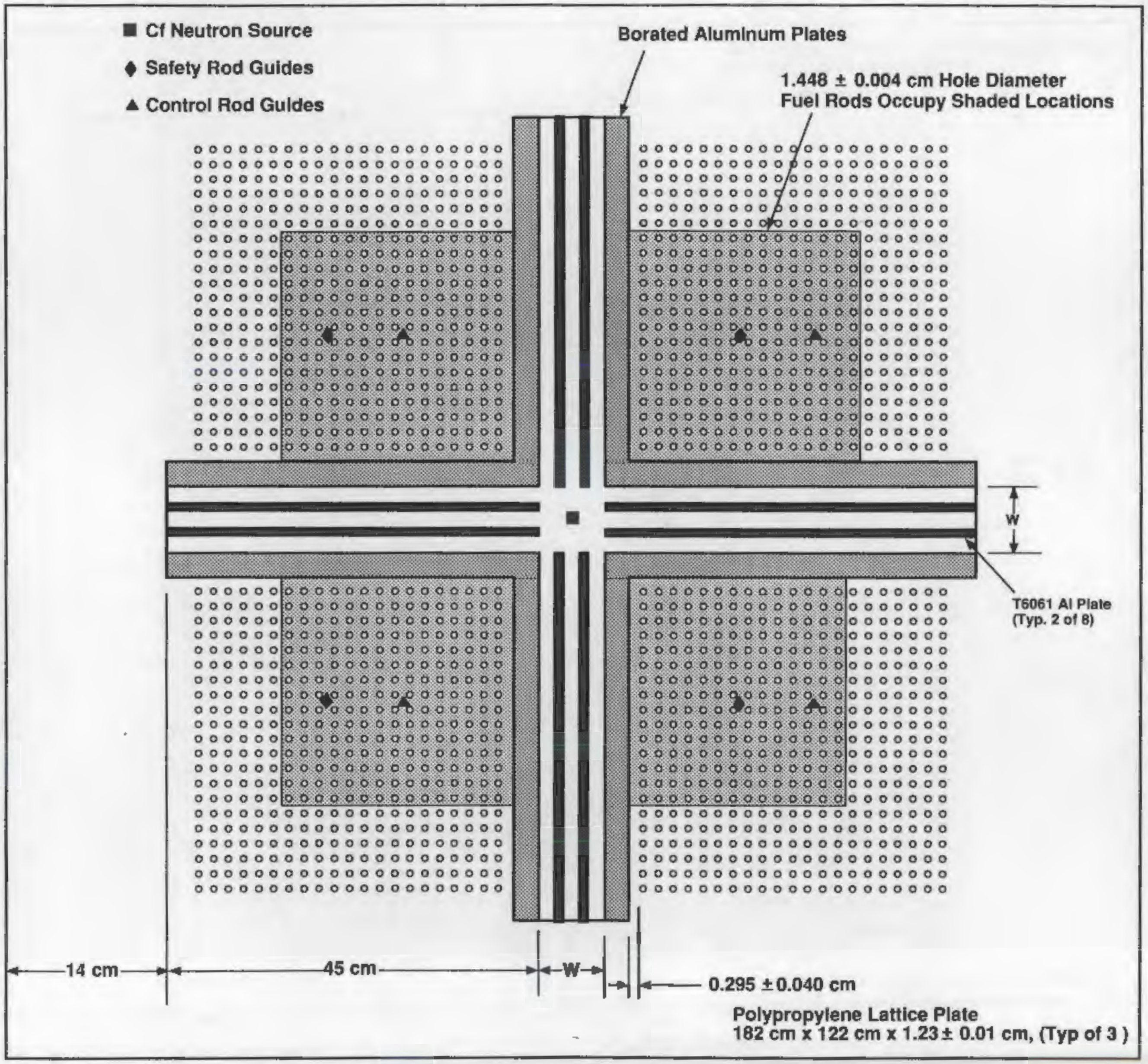


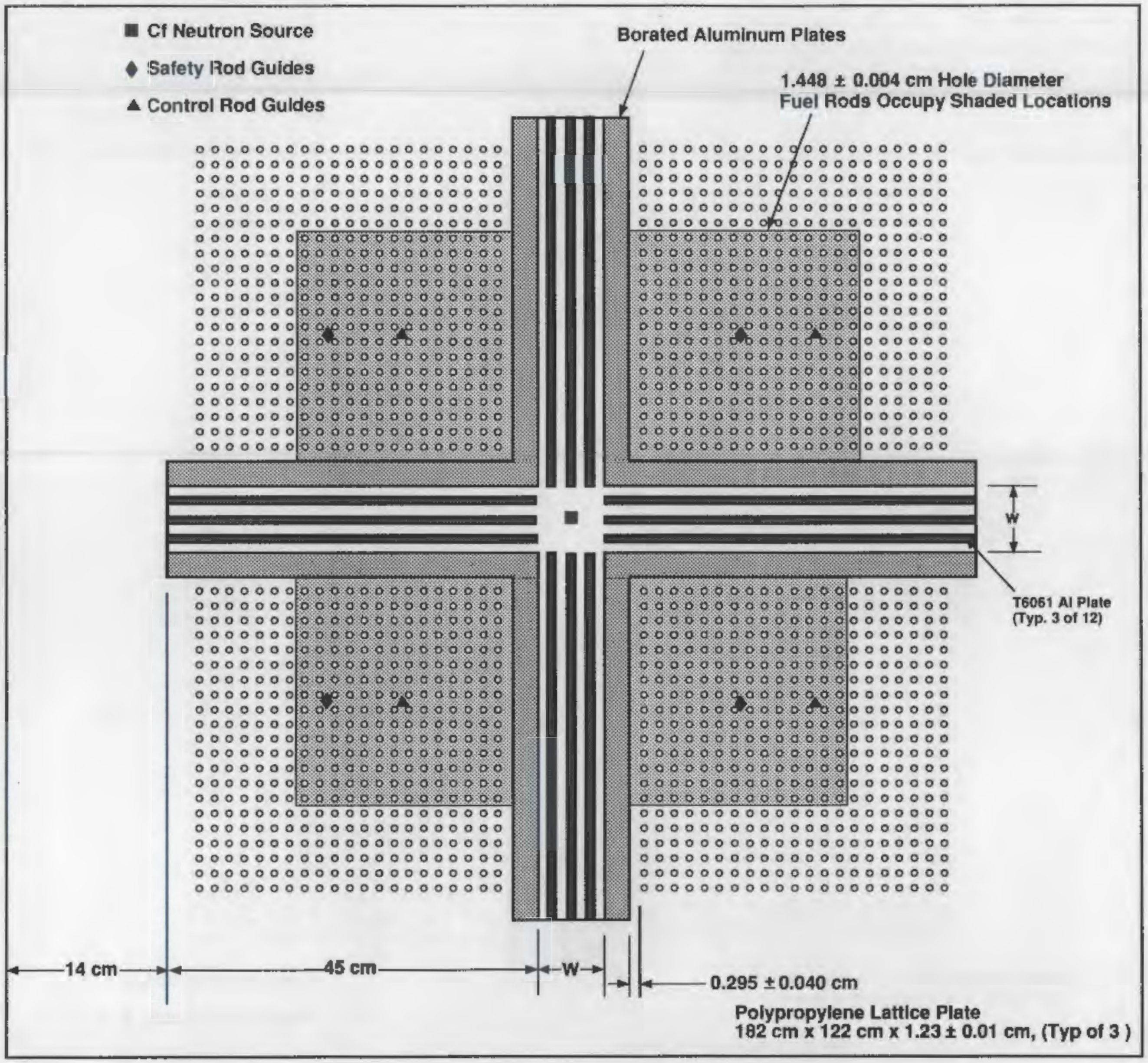
Assembly Number	: 214V1
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 915 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: 0.63 ± 0.001 cm tk Al Plate
Comments	: 924.6±1.9 Rods Predicted for Delayed Criticality

38903076.7M



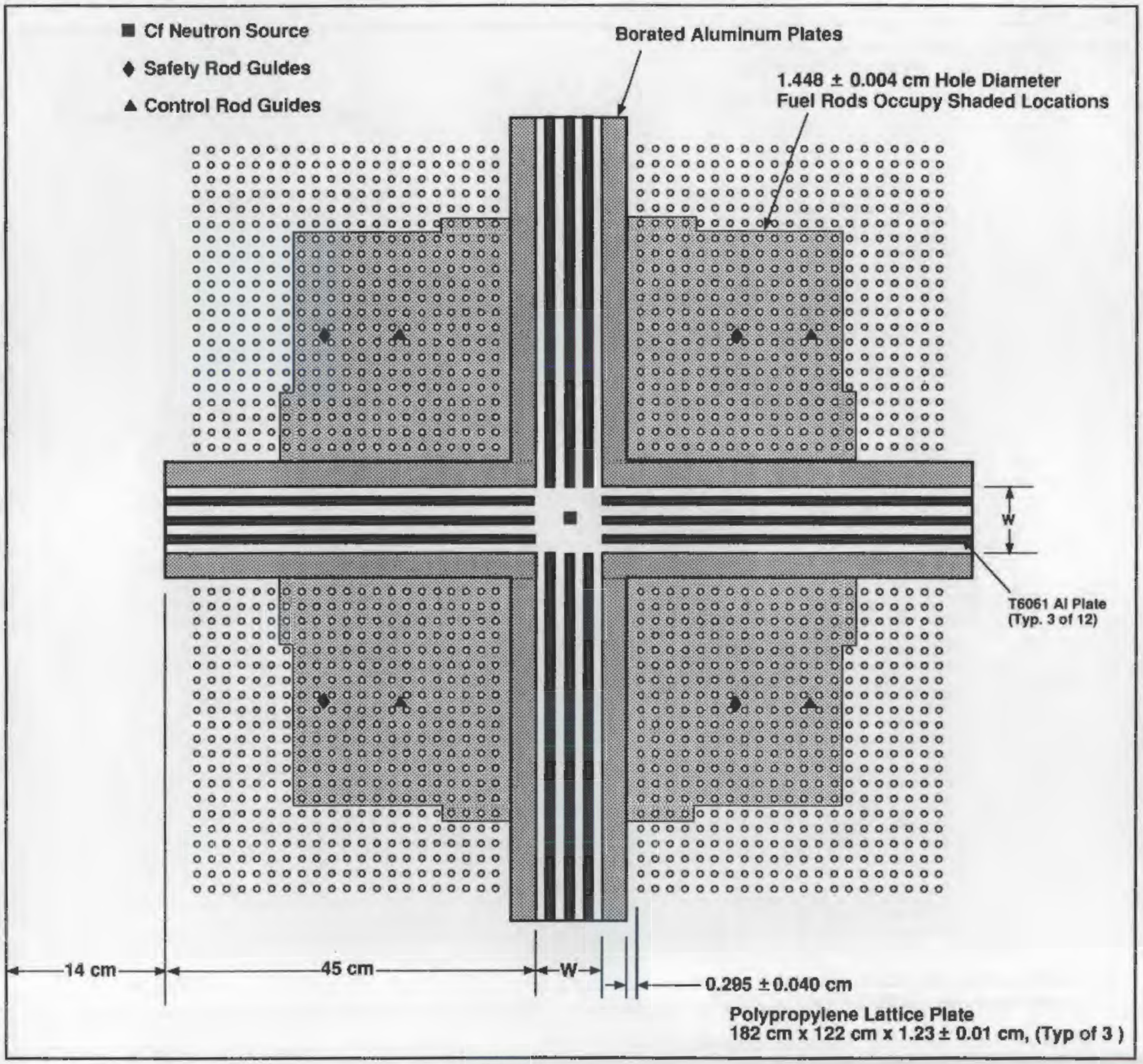
Assembly Number	: 214V2
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 885 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: 0.63 ± 0.001 cm tk Al Plate
Comments	: 896.2± 2.2 Rods Predicted for Delayed Criticality

38903076.8M



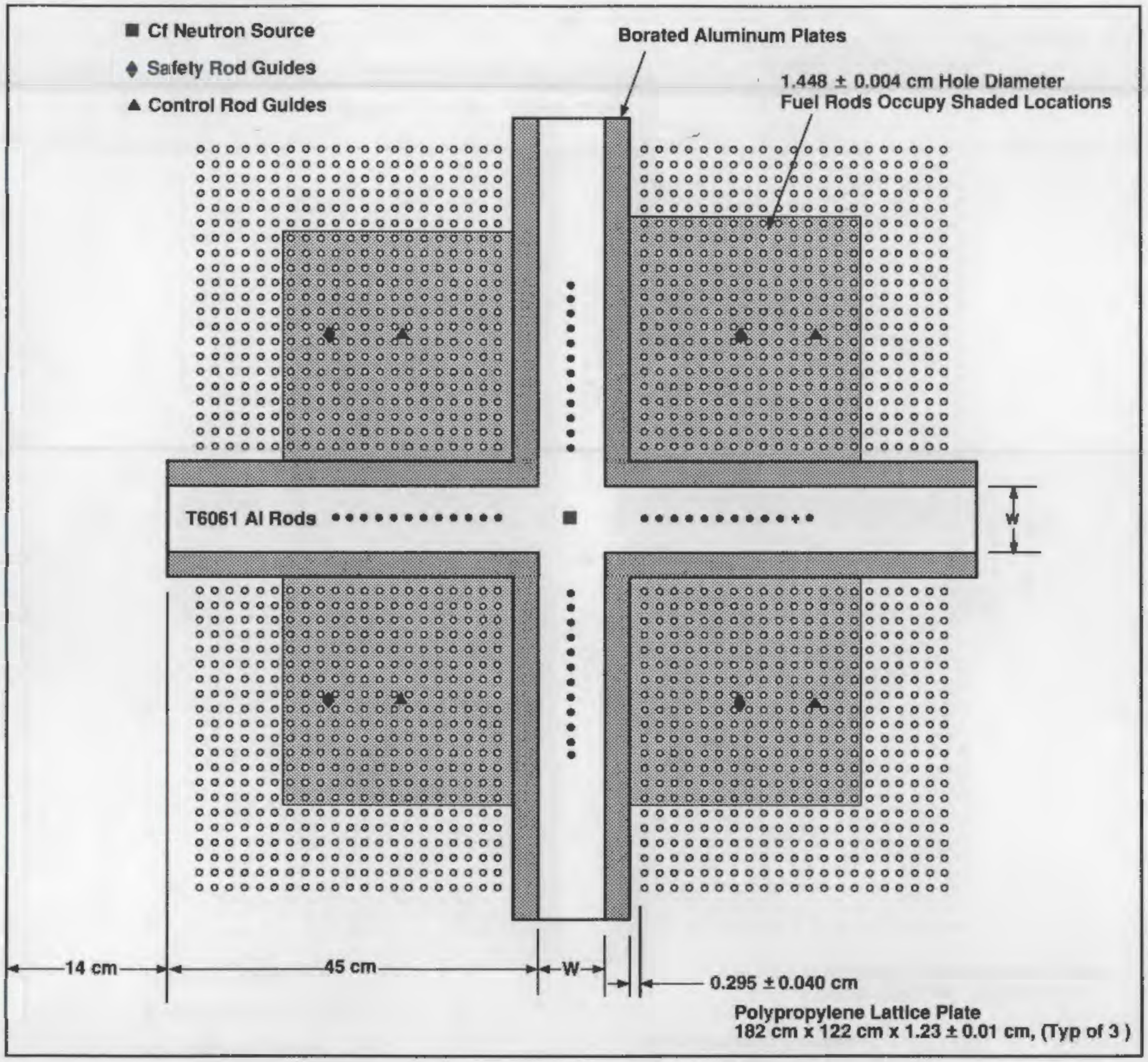
Assembly Number	: 214V3
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 855 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: 0.63 ±0.001 cm tk Al Plate
Comments	: 862.1± 1.2 Rods Predicted for Delayed Criticality

38903076.9M



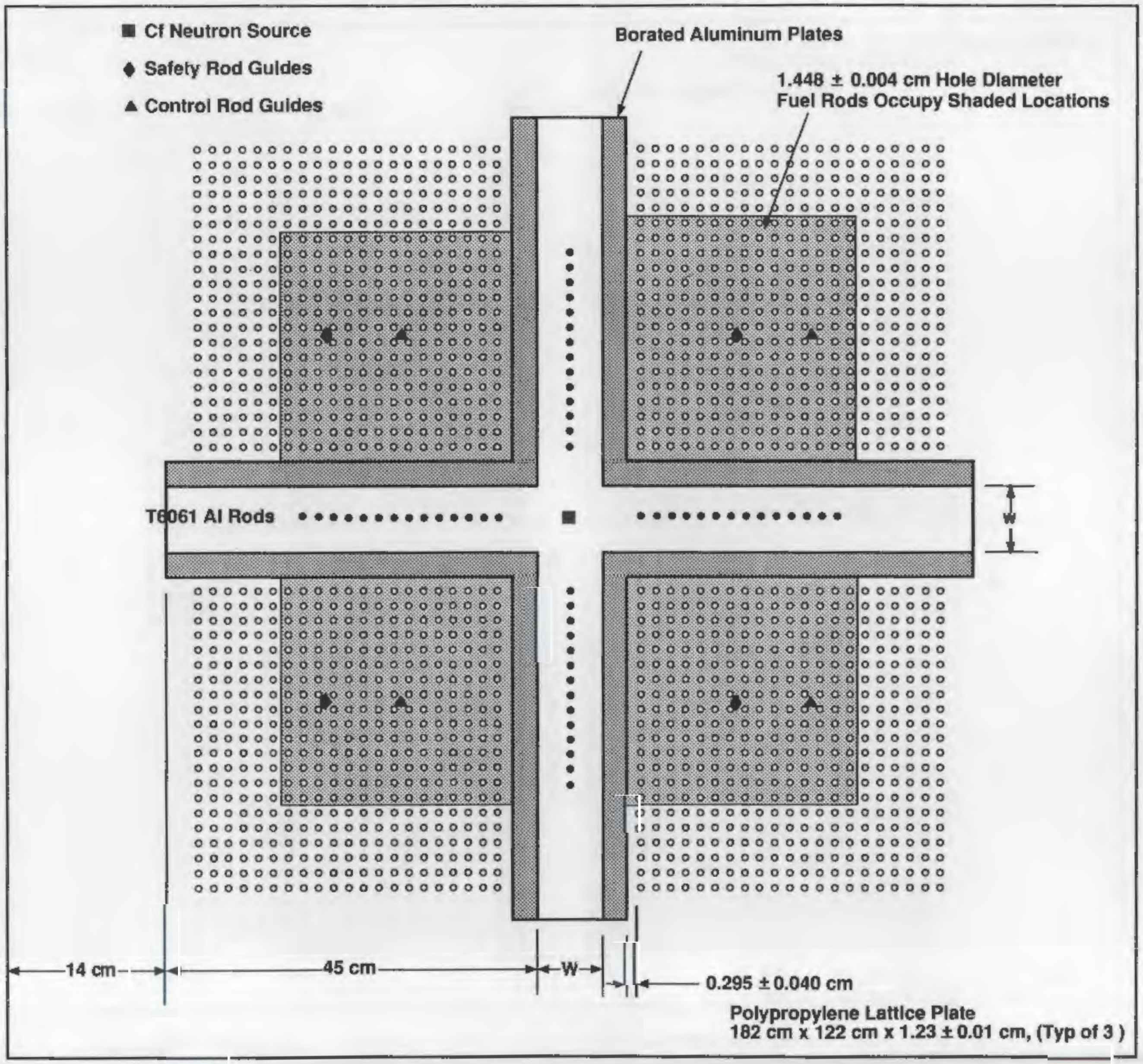
Assembly Number	: 214V3 (Alternant Loading)
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 872 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: 0.63 ±0.001 cm tk Al Plate
Comments	: 876.6± 0.1 Rods Predicted for Delayed Criticality

38903076.10M



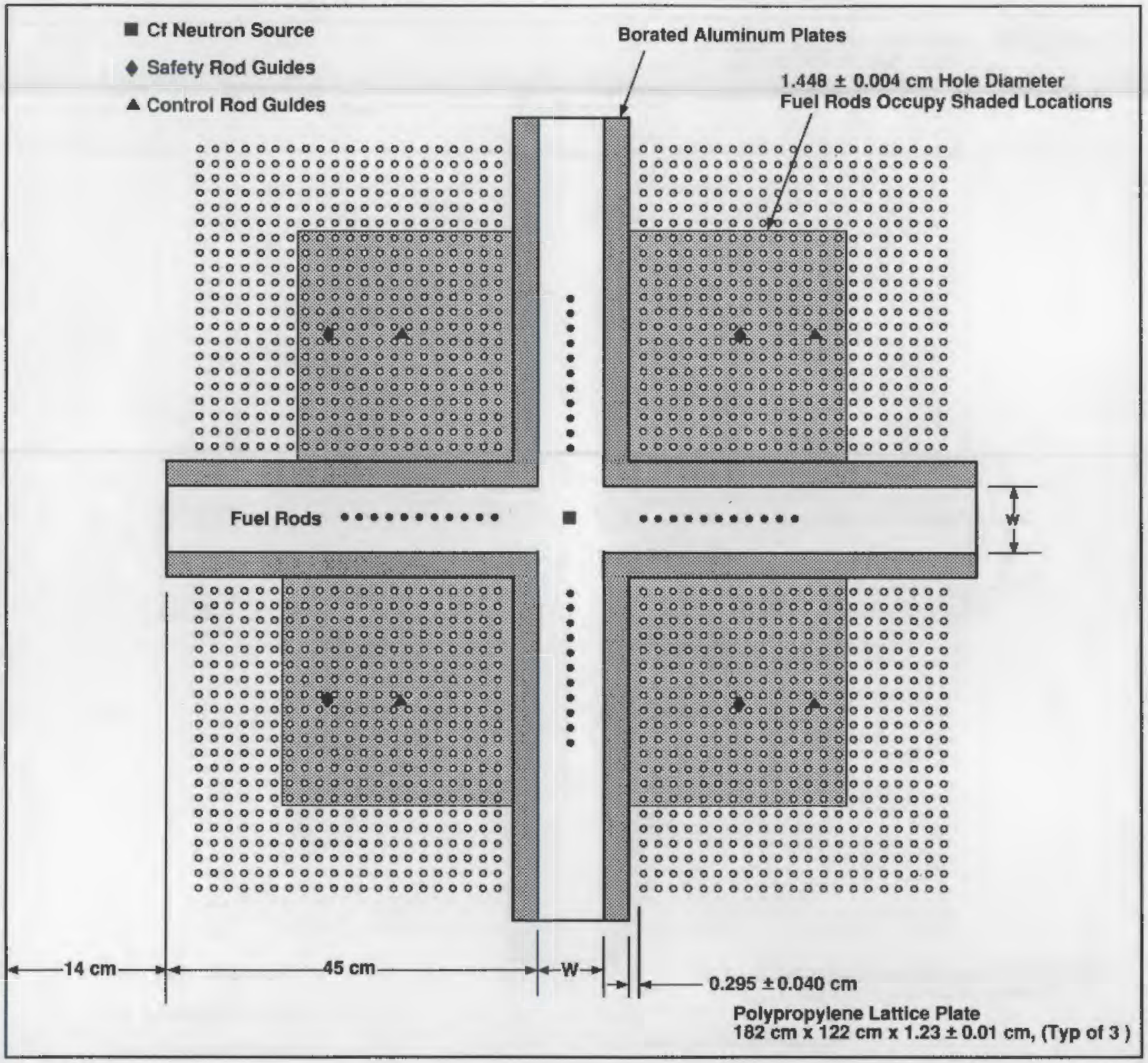
Assembly Number	: 214V4
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 915 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: 1.27 ± 0.005 cm dia. Al Rods
Comments	: 925.4 ± 1.3 Rods Predicted for Delayed Criticality

38903076.5M



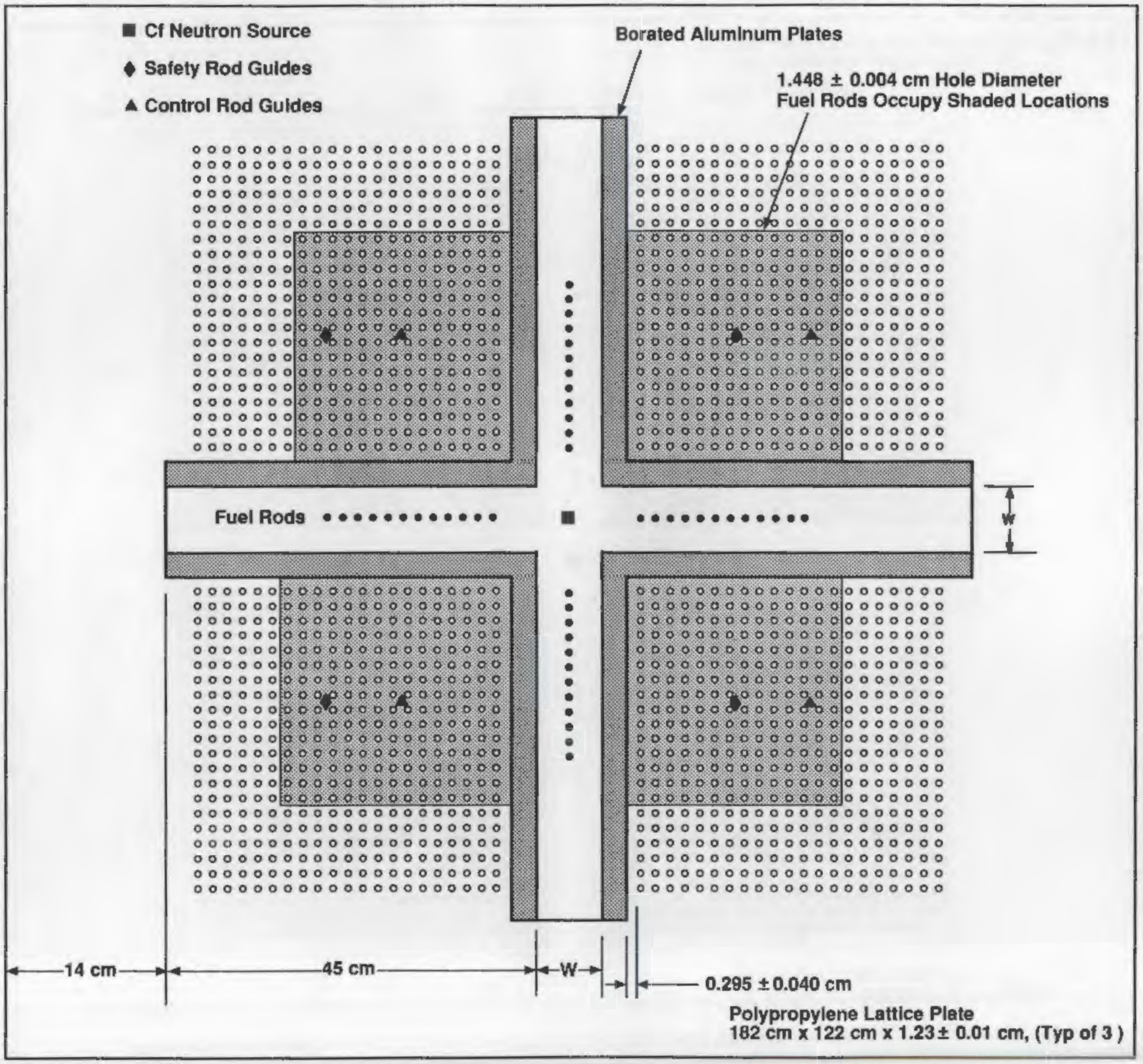
Assembly Number	: 214V5
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 915 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: 1.27 ± 0.005 cm dia. Al Rods
Comments	: 924.9 ± 1.6 Rods Predicted for Delayed Criticality

38903076.6M



Assembly Number	: 214F1
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 855 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: Fuel Rods
Comments	: 873.7 ± 1.0 Rods Predicted for Delayed Criticality (does not include fuel in flux trap regions)

38903076.2M



Assembly Number	: 214F2
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 855 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: Fuel Rods
Comments	: 866.9 ± 3.0 Rods Predicted for Delayed Criticality (does not include fuel in flux trap regions)

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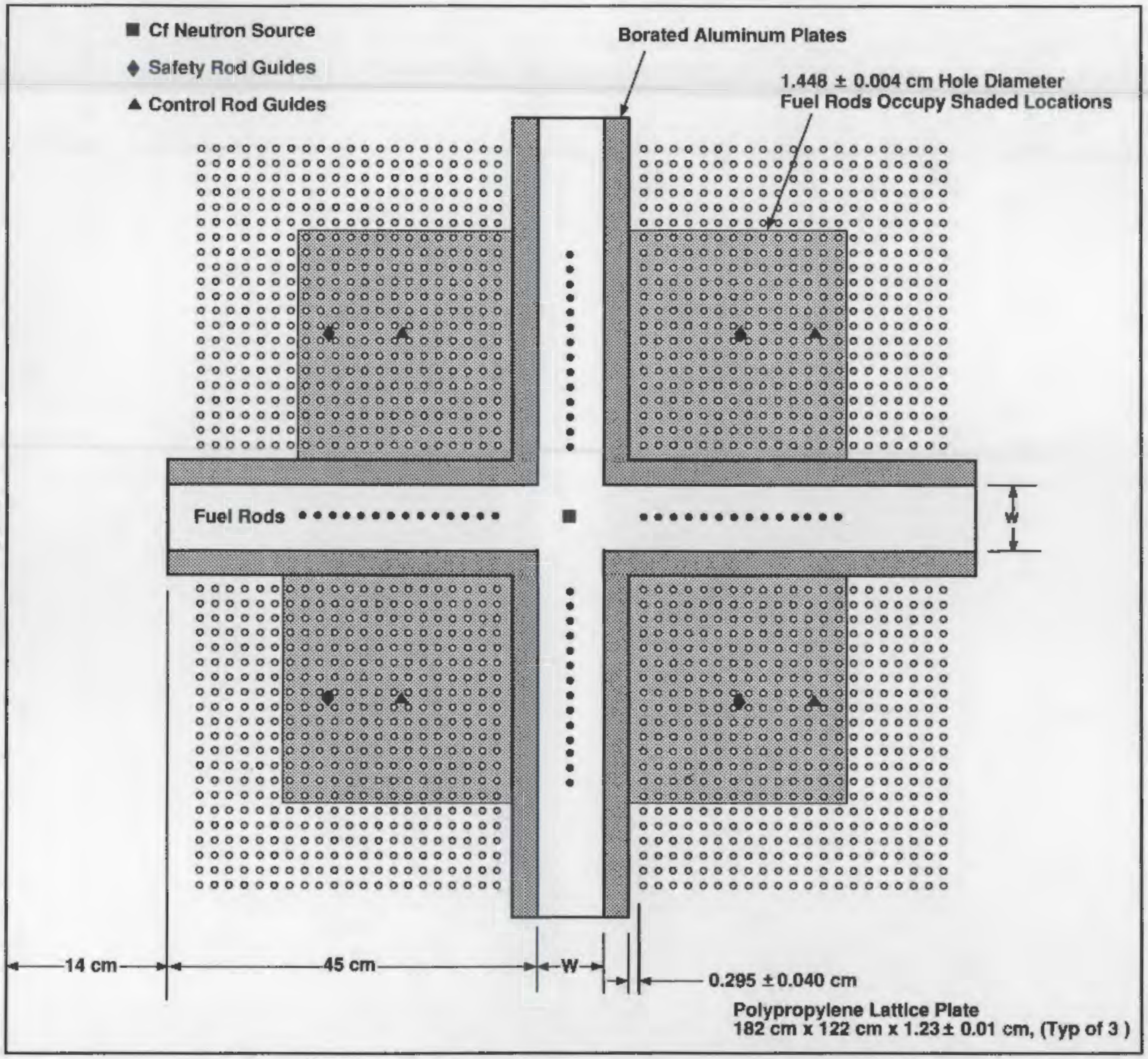

Assembly Number	: 214F3
Lattice Pitch	: 1.891 ± 0.001 cm
Safety Rods	: Out of System
Control Rods	: Out of System
Fuel Rods	: 855 (see comments)
Fuel	: 4.31 wt% ^{235}U Enriched UO_2
Flux Trap Width, W	: 3.73 ± 0.02 cm
Plates	: Boral
Boron	: 0.36 ± 0.02 gB/cm^2
Voiding Material	: Fuel Rods
Comments	: 858.5 ± 0.1 Rods Predicted for Delayed Criticality (does not include fuel in flux trap regions)

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