CRITICALITY EXPERIMENTS WITH FAST TEST
REACTOR FUEL PINS IN AN ORGANIC MODERATOR

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PREFACE

In Japan, Fast Breeder Reactors (FBRs) are being actively developed by the Power Reactor and Nuclear Fuel Development Corporation (PNC). The prototype reactor "MONJU" is now under construction with the first criticality expected in the early 1990s. Also, a pilot-scale Fast Breeder Reactor Fuel Recycling Plant is currently being designed which will recycle fuel from the existing experimental reactor "JOYO" and the prototype reactor "MONJU." The design and operation of such a facility involves criticality conditions which are much different from those encountered in the light water reactor fuel cycle. Experimental criticality data are needed in support of these design and operating activities. Consequently, in August, 1983, the PNC entered into a agreement with the U. S. Department of Energy (DOE) to study the nuclear criticality aspects related to the development of fast breeder reactor recycling technology. This arrangement was developed through the DOE and PNC agreement in the field of Liquid Metal-Cooled Fast Breeder Reactors.

Prior to the joint Memorandum of Agreement (MOA) on nuclear criticality, the United States had initiated an experimental program at the DOE Hanford Critical Mass Laboratory (CML), operated by the Pacific Northwest Laboratories of Battelle Memorial Institute, to provide basic criticality data on plutonium-uranium systems in support of the U. S. Liquid Metal Fast Breeder Reactor Program. Many experiments were carried out at the CML as part of what was to become known as the Consolidated Fuel Reprocessing Program. Under the MOA, PNC has promoted and enlarged the DOE program which examine areas of mutual interest as well as areas of specific interest to PNC. The Subtask 220 series of experiments covered in this report are the first completed under the joint agreement between PNC and DOE.

The performance of the experimental measurements presented in this report required the cooperation and assistance of many people. The following contributions are especially recognized:

- o Dr. Ray Gold and his staff of the Hanford Engineering Development Laboratory (HEDL) for their advice and guidance in planning the reaction rate measurements and in the device fabrication-data reduction associated with these measurements. The fission and capture rate data reported herein could not have been obtained without their facilities and capabilities.
- o Joe Williams and his staff of HEDL in procuring, assembling and disassembling in a timely manner, the FTR fuel pins used in the reaction rate measurements.
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- o Dr. Hachiya of PNC in the design and planning of the fission and capture rate measurements.
- o Consolidated Fuel Reprocessing staff in the overall coordination between PNC, DOE and the CML of these and other experiments covered by the MOA.
- o J. H. Smith, Senior Reactor Operator, for his cooperation and valuable advice in carrying out the experiments in a safe and timely manner.
- o L. N. Terry, for the typing, proofing and assistance in the preparation of this report.

SUMMARY

The results obtained in a series of criticality experiments performed as part of a joint program on criticality data development between the United States Department of Energy and the Power Reactor and Nuclear Fuel Development Corporation of Japan are presented in this report along with a complete description of the experiments. The experiments involved lattices of Fast Test Reactor (FTR) fuel pins in an organic moderator mixture similar to that used in the solvent extraction stage of fuel reprocessing.

The experiments are designed to provide data for direct comparison with previously performed experimental measurements with water moderated lattices of FTR fuel pins. The same lattice arrangements and FTR fuel pin types are used in these organic moderated experimental assemblies as were used in the water moderated experiments. The organic moderator is a mixture of 38 wt% tributylphosphate in a normal paraffin hydrocarbon mixture of $C_{11}H_{24}$ to $C_{15}H_{32}$ molecules. Critical sizes of 1054.8, 599.2, 301.8, 199.5 and 165.3 fuel pins were obtained respectively for organic moderated lattices having 0.761 cm, 0.968 cm, 1.242 cm, 1.537 cm and 1.935 cm square lattice pitches as compared to 1046.9, 571.9, 293.9, 199.7 and 165.1 fuel pins for the same lattices water moderated.

Reaction rate measurements using solid state track recorders and ^{238}U foils were also performed to determine the ^{232}Th , ^{235}U , ^{238}U , ^{237}Np and ^{239}Pu fission rates in a fuel pin and in the moderator region between fuel pins. The gross fission rate in the fuel material was also determined as was ^{238}U capture both in the fuel and in the moderator between pins.

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CRITICALITY EXPERIMENTS WITH FAST TEST REACTOR FUEL PINS IN AN ORGANIC MODERATOR

1.0 INTRODUCTION

The design and operation of facilities for recycling fast breeder reactor fuels involves criticality conditions which are much different from those encountered in the light water reactor fuel cycle. Conditions such as high plutonium content in solution with uranium, complex equipment shapes and the usage of neutron absorbing materials for criticality control require experimental criticality data for verification of calculations and nuclear data used in facility design, operational procedures and related licensing activities. In August, 1983 the U. S. Department of Energy (DOE) and the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan entered into an agreement to study such nuclear criticality aspects as they related to the development of fast breeder reactor recycling technology. This arrangement was developed through the DOE and PNC Agreement in the Field of Liquid Metal-Cooled Fast Breeder Reactors. Prior to this Joint Memorandum of Agreement (MOA) for Nuclear Criticality Data Development, DOE had initiated an experimental program at the DOE Hanford Critical Mass Laboratory to provide basic criticality data on plutonium-uranium systems in support of the U. S. Liquid Metal Fast Breeder Reactor Programs. Under the MOA, PNC has promoted and enlarged the DOE Program to cover areas of mutual interest as well as areas of specific interest to PNC. Results of the Subtask 220 series of experiments in this program, designed to provide data for comparing organic with aqueous moderated plutonium-uranium systems, are presented in this paper.

In evaluating non-reactor systems for licensing, operational controls and similar activities, water moderation is generally assumed to result in conditions for which a system is most reactive. However, some calculational

studies (Davenport, 1977) have identified various organic media which may result in more reactive conditions than water. One such material is dodecane, a primary component of the organic phase during solvent extraction in reprocessing plutonium-uranium fuels. Thus an organic phase may present a more reactive condition than an aqueous phase. Also the organic mixture used in solvent extraction is a complex mixture of large molecules, the modeling of which may result in calculational errors. To obtain data on plutonium-uranium in an organic moderator for comparison with aqueous moderation, a series of five previously performed criticality experiments (Bierman, 1979 and Durst, 1980), with Fast Test Reactor (FTR) fuel pins in water were repeated with an organic typical of the solvent extraction process.

2.0 GENERAL DESCRIPTION OF EXPERIMENTAL ASSEMBLIES

The experimental system used in making the measurements covered by this report is 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 in performing the measurements covered in this report. The system (Fuel Element Array System or FEAS), consists of a 1.8 m x 3 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. The FEAS was modified by positioning a 112 cm diameter open-top, carbon-steel tank beneath the control and safety blade drives to limit the volume of organic solution used in the experiments to that required by the measurements. This open-top tank was connected to the moderator/reflector dump valve and two 2600 liter covered polyethylene tanks for mixing and storing the organic solution used in the experiments. A flow diagram of the modified system, including the mix-storage tanks, is shown in Figure 2.1. Engineering Drawings SK-2-3885, sheets 1 and 2, giving details of the experimental vessel and assembly support structures, have been reproduced and included as Appendix A.

Data were obtained on experimental lattice assemblies of FTR fuel pins having center-to-center fuel pin spacings of 1.935 cm, 1.537 cm, 1.242 cm, 0.968 cm and 0.761 cm in a square arrangement. Each experimental assembly consisted of a single uniform lattice of FTR fuel pins submerged in either water or in an organic mixture of tributylphosphate (TBP) and a normal paraffin hydrocarbon (NPH) diluent. A photograph of an experimental assembly in place in the FEAS is shown in Figure 2.2 with the moderator/reflector solution removed from the assembly for clarity. Each assembly was fully reflected on all sides by at least 15 cm of solution except on the top face. The top reflector region

Figure 2.1 Flow Diagram of Experimental System

Figure 2.2 Photograph of Experimental Assembly 063 with Moderator Removed

of each assembly was perforated by the fuel pin hardware immediately above the fuel region.

Relative elevations present in each experimental assembly are given in Figure 2.3. A layout plan showing the relative arrangement and location of neutron detectors lattice plates support columns and other hardware present in each assembly is given in Figure 2.4. All instrumentation inside the experimental vessel is shown in Figure 2.4. In all of the measurements, the instrument thimbles were at least 15 cm from the fuel region. Error limits given in Figure 2.3 are one standard deviation based on multiple measurements except that the fuel pin lengths are from the fabrication specifications (see Appendix B).

2.2 FUEL PINS

The same type and arrangement of FTR fuel pins were used in the experiments reported herein as were used previously in near identical water moderated and reflected assemblies (Bierman, 1979 and Durst, 1980). The fuel for the FTR is a mixture of PuO_2 and UO_2 . The weight ratio of UO_2 to PuO_2 is normally in the region from 2 to 4, and the uranium is either natural or depleted. Two types of FTR fuel pins were available for use in the critical experiments: Type 3.1 and Type 3.2. Composition of each type fuel pin is given in Figure 2.5. These compositions are based on measured data from pellet lots used in fabricating the fuel pins and are more accurate than those previously reported. Physically, both types of fuel pins are essentially identical. A diagram giving both the common dimensions and those dimensions that differ between the two types of pins is shown in Figure 2.5. Both types of fuel pins are ~2.4 m in length. In either fuel pins, the actual fuel region is restricted to a ~91.4 cm length near the bottom of the pin. The remainder of the pin consists of endcaps and other types of hardware. Detailed engineering drawings of the fuel pins have been reproduced and included as Appendix B.

- (a) Elevation for Type 3.2 Fuel Pins. Type 3.1 Fuel Pins are 0.5 cm Less
 (b) Elevation of lowest SS TR in fuel column when present
 (c) Elevation of reaction rate capsules in moderator when present

Figure 2.3 Experimental Assembly Elevations

Figure 2.4 Experimental Assembly Layout Plan

- (a) Referenced Division of Reactor Development and Technology standard.
 (b) Isotopics based on measured data from pellet lots. Americium-241 contents as of January 1, 1976 based on Plutonium-241 half life of 14.35 yrs.
 (c) 35.6 mm for type 3.1 fuel pins.

Figure 2.5 Simplified Description of Fast Test Reactor Fuel Pin

The primary differences between the two types of fuel pins are in the composition of the $\text{PuO}_2\text{-UO}_2$ fuel mixtures. The Type 3.1 fuel pins contain 24.39 wt% plutonium in the $\text{PuO}_2\text{-UO}_2$, while the Type 3.2 fuel pins contain 19.84 wt% plutonium. A complete composition breakdown of each type of fuel mixture is given in Figure 2.5. The plutonium in either type of fuel pin contained 11.5 wt% ^{240}Pu . The uranium in the $\text{PuO}_2\text{-UO}_2$ mixture was natural uranium for both the Type 3.1 and Type 3.2 fuel pins. To the extent possible, only Type 3.2 fuel pins were used in the experiments.

2.3 MODERATOR

In two water moderated/reflected reference measurements, deionized water was used. An impurities analysis of the water is given in Appendix C. In the organic moderated/reflected measurements an organic mixture of $\text{C}_{11}\text{H}_{24}$ through $\text{C}_{15}\text{H}_{32}$ normal paraffin hydrocarbons (NPH) containing 38.0 ± 0.2 wt% TBP, $(\text{C}_4\text{H}_9\text{O})_3\text{PO}$ was used. The average C-11 through C-15 weight fractions of the NPH component were respectively 0.0051 ± 0.0005 , 0.1278 ± 0.0023 , 0.5455 ± 0.0006 , 0.3156 ± 0.0078 , and 0.0023 ± 0.0004 . The average specific gravity of the TBP-NPH mixture was 0.8244 ± 0.0011 .

Although the organic mixture is composed of components having boiling points in the range of about $100^\circ - 200^\circ \text{C}$, some vaporization, especially of the lighter components, occurs. To verify the stability of the organic mixture used in the experiments, samples were periodically taken and analyzed for specific gravity, wt% TBP and wt% C-10 through C-15. The analytical results for each sample are given in Appendix D, along with a plot of the mixture composition as a function of time during the experiments. The data indicates the composition of the organic did not change during the experiments.

2.4 LATTICE PLATES AND SUPPORTS

Four 1.31 cm thick, polypropylene lattice plates, having a C_3H_6 molecular structure and a density of 0.904 g/cm^3 , were used to achieve and maintain uniform spacings between the fuel pins in each experimental assembly as indicated in Figure 2.3. One of these plates, which has neutronic properties similar to the water and organic moderators, was the only structural material in the fuel-moderator region of each assembly. Trace impurity levels for the lattice plates are given in Appendix E.

In each assembly the fuel pins 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 on four T6061 aluminum support columns as shown in Appendix A. The elevation of the acrylic support plate, relative to the moderator/reflector tank and other components in the experimental assembly, is shown in Figure 2.3. The four aluminum support columns were all outside the fuel/moderator core region of each experimental assembly as shown in the fuel loading diagrams (Section 3) and Appendix A. The American Society for Testing Materials (ASTM specifications for the type T6061 aluminum used in these support columns are given in Appendix F.

2.5 CONTROL AND SAFETY BLADES

The FEAS control and safety blade drives were provided with Boral blades such that each experimental assembly could be constructed in compliance with operating regulations and procedures. These blades and their associated Type 6061 aluminum guides were located opposite each other, adjacent and parallel to the fuel/moderator core region of each assembly such that they fall by gravity into the assembly should an out-of-range condition exist on the control channels shown in Figure 2.4. The control and safety blades are not defined since all of the criticality data reported herein are with these blades fully withdrawn from the experimental assemblies. The control and safety blade guides extended from the bottom of the fuel pins to above the top

reflector. The locations and size of each guide relative to the fuel/moderator core region on each assembly are shown in the respective loading diagrams (Section 3) for each experimental assembly. ASTM specifications for the aluminum guide material are given in Appendix F.

2.6 REACTION RATE DEVICES AND HOLDERS

In one experimental assembly, fission and capture rate measurements were made using solid state track recorders and foils. These devices and their locations in the measurements will be discussed with the measurement data in Section 3. The devices and holders were not present during the criticality measurements.

3.0 EXPERIMENTAL RESULTS

The measurement techniques used to obtain the criticality and reaction rate data are presented in this section along with the measurement results. The factors affecting the accuracy of the measurement results and sources of error are also covered in this section.

3.1 CRITICALITY EXPERIMENTS

The objective of these measurements was to obtain data for comparing organic with water moderated lattices of $\text{PuO}_2\text{-UO}_2$ fuel pins typical of the fast breeder reactor fuel cycle. Direct experimental data was desired for organic moderated assemblies using the same fuel and lattice plates as were previously used in a series of water moderated experiments (Bierman, 1979 and Durst, 1980). As with the water moderated assemblies, the organic moderated assemblies were to contain only perturbations that could be precisely and easily defined, or experimentally evaluated in terms of their effect on the experimental assembly. Consequently the experiments were performed with assemblies constructed such that only the perturbation caused by a polypropylene lattice plate exists in the experimental data. Also the experiments were performed with the same lattice arrangements and FTR fuel pin types as were used in the previous water moderated experiments (Bierman, 1979 and Durst, 1980). The organic moderated experimental assemblies having center-to-center lattice spacings of 1.935 cm, 1.537 cm, 1.242 cm and 0.968 cm, were constructed using the same lattice plates as were used in the water moderated experiments. The previously used set of lattice plates having a center-to-center spacing of 0.767 ± 0.013 no longer existed. Therefore a set of lattice plates was fabricated for this experimental assembly.

Although experimental assemblies were taken critical by partially withdrawing the control blade, the critical sizes reported herein were obtained by extrapolation of subcritical data with the blade fully withdrawn, as discussed in the section that follows.

3.1.1 Criticality Measurement Technique

The critical size of each experimental assembly was determined by extrapolation of subcritical data obtained as the delayed critical condition was approached. 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" 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 being the only perturbing variable. In each of the experiments covered by this report, fuel was loaded into the lattice plates in increments that were neutronicallly symmetrical to each other. At each incremental loading, neutron count rates were obtained using the three boron-lined proportional detectors identified as data channels in Figure 2.4.

Although the data channel detectors shown in Figure 2.4 are located to minimize spatial effects in the count rate data, far subcritical loadings will exhibit spatial dependencies between detector-fuel loading locations and result in different critical sizes being predicted by the count rate data from the three data channels. As the delayed critical condition is approached, however, the neutron flux becomes relatively large and the fuel loading increments, for safety reasons, become smaller. Under these conditions spatial effects become negligible and the count rates from all three data channels tend to predict the same number of fuel rods for delayed critical. Near this delayed critical condition the neutron count rate data will begin to vary linearly and a linear least squares fit of count rate data as a function of subcritical fuel loading can be made to obtain a very accurate determination of the delayed critical condition.

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.

The critical size reported for each of the experimental assemblies covered herein was determined by averaging that obtained from linear extrapolations of the inverse count rate as a function of fuel loading to the delayed critical condition and by a similar extrapolation of the product of the fuel loading and inverse count rate. Computerized plots and extrapolation of the data for each experimental assembly are presented in Appendix G.

3.1.2 Criticality Data

The experimental criticality data obtained during this recent series of measurements are summarized in Table 3.1 along with data previously obtained with corresponding water moderated assemblies (Bierman, 1979 and Durst, 1980). As discussed in Section 3.1.1, Criticality Measurements Technique, the critical sizes reported in Table 3.1 were obtained by extrapolation of subcritical neutron multiplication data obtained as fuel pins were loaded into each experimental assembly in increments that were neutronically symmetrical to each other.

In rectangular geometry, the smallest neutronically symmetrical fuel addition is a half-width. Consequently each of the critical sizes reported in Table 3.1 were determined by extrapolating, to the critical condition, subcritical count rate data obtained in half-width increments. At least three half-width incremental loadings were used whenever possible to assure any spatial dependency remaining in the approach-to-critical data was accounted for in these extrapolations. For those assemblies in which spatial dependency obviously existed in all but the last two incremental fuel loadings, only data from these two loadings were used in extrapolating to the delayed critical condition.

Although the number of fuel pins required for criticality can be predicted very accurately by extrapolation, caution must be exercised when describing rectangular systems for computer input. Consider, for example, experiment

TABLE 3.1 Experimental Criticality Data-Type 3.2 FTR Fuel Pins Moderated and Fully Reflected by Either Water or an Organic Solution of TBP-NPH

Lattice Spacing ^(a) (b) (cm)	Lattice Width (Fuel Pins)	Water Moderator ^(b)			Organic Moderator ^(b)		
		Experiment Number	Date	Critical Number of Fuel Pins	Experiment Number	Date	Critical Number of Fuel Pins
0.761 ± 0.001	36	067	7-17-85	1046.9 ± 0.2 ^(c)	065	6-5-85	1054.8 ± 0.2 ^{(c) (e)}
0.767 ± 0.013	36	003R	1-24-78	1036.8 ± 0.5 ^(d)	--	--	--
0.968 ± 0.001	25	021	11-3-78	571.9 ± 0.2	063	5-21-85	599.2 ± 0.8 ^(e)
1.242 ± 0.001	20	043	1-9-79	293.9 ± 0.1	062	5-15-85	301.8 ± 0.2
1.537 ± 0.001	15	013	10-9-78	196.7 ± 0.2	--	--	--
1.537 ± 0.001	15	068R	7-25-85	199.7 ± 0.3 ^(f)	061	5-14-85	199.5 ± 0.3
1.935 ± 0.002	15	032	12-14-78	165.1 ± 0.4	060	5-8-85	165.3 ± 0.1

(a) Center-to-center spacing between fuel pins in a square pattern

(b) Error limits are one standard deviation

(c) Includes Type 3.1 FTR Fuel Pins on a 1.522 cm lattice pitch positioned on either side (36 one side) of a 27 x 36 fuel pin array of Type 3.2 FTR Fuel Pins on a 0.761 cm lattice pitch

(d) Includes Type 3.1 FTR Fuel Pins on a 1.532 cm lattice pitch positioned on either side (36 one side) of a 27 x 36 fuel pin array of Type 3.2 FTR Fuel Pins on a 0.767 cm lattice pitch

(e) Assembly loaded with an additional fuel pin was slightly supercritical.

(f) Experiment number 068 on 7-23-85 resulted in a predicted 199.7 ± 0.3 fuel pins for criticality

number 061, shown in Table 3.1. At a square lattice pitch of 1.537 cm, 199.5 fuel pins would be required for criticality with a lattice 15 fuel pins wide. This is 13 full rows (195 fuel pins) plus 4.5 additional fuel pins. Physically these last 4.5 fuel pins were not placed in the experimental assembly. (The critical number of 199.5 was obtained by extrapolation from the final loading of 195 fuel pins). However, these pins should be included in a calculation. Depending on the sensitivity of the calculational techniques, the exact location of these pins in the 14th fuel row will affect the calculational results. These fuel pins would have the least effect on the reactivity of the assembly placed in the outer positions of the row, and the greatest effect if positioned in the innermost locations. To correctly describe the experimental assemblies in calculations, the last partial row of fuel pins should be described as a full row of fractional fuel cells. Thus in experiment 061, the description would be 13 full rows of 15 full length fuel cells each plus one full row of 15 full length fuel cells that are only 30% (0.4611 cm) as thick as a normal fuel cell (1.537 cm).

Basically the data presented in Table 3.1 were obtained on assemblies of fuel pins moderated by either water or an organic mixture of 38.0 wt% TBP - 62.0 wt% NPH perturbed only by a single polypropylene lattice plate in the fuel region (see Figure 2.3). However, procedures developed for removing the organic from the FTR fuel pins, following completion of the experiments, required that a soluble fluorescent dye penetrant (Magnaflux Type ZL-22A) be used in the organic. Although only a small amount (~500 ml) of this dye was required, samples of the dye were analyzed for suspected neutron poisons and the initial experiment (060) was performed first (as 059) without the dye and then with the dye in the organic moderator mixture. The sample analyses indicated no significant amount of neutron poisons (see Appendix D) and no measurable effect was observed on the critical size with or without the dye (see Experiments CFRP-PNC-FTR-059 and 060 Approach-to-Critical Data, Appendix G).

Layout plan views of the experimental assemblies showing fuel location, fuel arrangement and final fuel loading are presented in Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7 for each set of current data presented in Table 3.1.

Except for those assemblies having center-to-center lattice spacings of 0.761 cm and 0.767 cm, only Type 3.2 fuel pins were used in the experiments. At these two lattice spacings the number of fuel pins required for criticality exceeded the number of Type 3.2 fuel pins available for the measurements. To obtain criticality data in these assemblies, Type 3.1 fuel pins at a more reactive spacing were positioned on either side of 36 x 27 array of Type 3.2 fuel pins as indicated in Table 3.1 and Figures 3.1 and 3.2. The fuel arrangements in the organic moderated and in the water moderated assemblies are identical except for the number of fuel pins required for criticality.

The organic and water moderator sizes are compared in Figure 3.8 relative to a ratio of one. Atomic H/Pu ratios for each of the experimental assemblies are superimposed over the data shown in Figure 3.8 to indicate the almost one-to-one relationship that existed between related assemblies for this parameter.

To obtain organic moderated data for comparison with the water moderated data at a center-to-center fuel spacing of 0.767 cm, new lattice plates were fabricated as indicated previously. The center-to-center fuel spacing with these new plates was slightly less at 0.761 cm. Consequently the critical size of this assembly was determined for both water and organic moderation to provide direct comparable data. The results of both measurements are presented in Table 3.1 as well as that previously obtained at the lattice spacing of 0.767 cm. As can be seen in Table 3.1 the critical size is slightly larger for the 0.761 cm spacing than that previously obtained for the 0.767 cm spacing. Since the assemblies are very undermoderated the smaller spacing would be expected to result in a larger number of fuel pins for criticality.

Figure 3.1 Layout Showing Final Subcritical Loading Arrangement of Experiment 065 FTR Fuel Pins Immersed in Organic Moderator

Figure 3.2 Layout Showing Final Subcritical Loading Arrangement of Experiment 067 FTR Fuel Pins Immersed in Water Moderator

Figure 3.3 Layout Showing Final Subcritical Loading Arrangement of Experiment 063 FTR Fuel Pins Immersed in Organic Moderator

Figure 3.4 Layout Showing Final Subcritical Loading Arrangement of Experiment 062 FTR Fuel Pins Immersed in Organic Moderator

Figure 3.5 Layout Showing Final Subcritical Loading Arrangement of Experiment 061 FTR Fuel Pins Immersed in Organic Moderator

Figure 3.6 Layout Showing Final Subcritical Loading Arrangement of Experiment 068R FTR Fuel Pins Immersed in Water Moderator

Figure 3.7 Layout Showing Final Subcritical Loading Arrangement of
Experiment 060 FTR Fuel Pins Immersed in Organic Moderator

Figure 3.8 Critical Size Comparison of Organic and Water Moderated FTR Fuel Pin Lattices

However it should be noted that a part of this difference can be attributed to the decay of ^{241}Pu and the resulting buildup of ^{241}Am during the intervening 7.5 years (1-24-78 to 7-17-85).

Since the opportunity existed for obtaining experimental data on the effect of ^{241}Am buildup on criticality, a near optimum water moderated experiment (1.537 cm lattice spacing) was repeated. The results are recorded in Table 3.1 as experiment number 068R and indicate that the ^{241}Am buildup effect over an 81.5 month time period is marginally observable. As can be seen in Table 3.1, the critical size increased by only three fuel pins (1.52%) over the 81.5 month decay of the ^{241}Am . Part of this increase in assembly critical size could be attributed to reproducibility type errors. Calculational studies beyond the scope of work covered herein are needed for evaluating the correlation between the increase in assembly size with depletion (~ 1.8 wt% to ~ 1.3 wt%) of ^{241}Pu and corresponding buildup of ^{241}Am .

As will be discussed later in the section on errors, the primary, and least defined, source for errors in reproducing the water moderated experimental assemblies is the possible formation of air bubbles, and thus voids, in the fuel-moderator region of each assembly. Although precautions are routinely taken to assure voids do not exist in an assembly during the approach-to-critical measurements, the 068 assembly was monitored over a 2 day period for buildup of voids and none were either visually or experimentally observed. As indicated in Table 3.1, critical approach measurements were performed twice to determine the critical size of the 068 assembly. Following the initial measurement on July 23, 1985, with the assembly visually free of voids, 15 fuel pins were removed from the assembly periphery and the approach-to-critical measurement repeated 2 days later, as recorded in Table 3.1, there was no observable change in the assembly critical size over this 2 day period. Thus outgassing of trapped air in the water moderator did not create sufficient voids in the assembly to have a measureable effect on the critical size.

3.1.3 Sources of Error in Criticality Data

Since the primary objective of the experimental measurements is to obtain comparative data for water and organic moderated lattices of fuel pins, the data are relatively free of error sources. The same fuel pin types, fuel arrangements and lattice plates were used in the organic and the water moderated assemblies. Reproducibility is estimated to be within one fuel pin. However each of the data are subject to the following sources of error:

- o formation of voids in the moderator
- o variations in center-to-center fuel pin spacings within a lattice plate
- o variations in fuel composition and fuel pin loadings
- o stability and composition of moderator
- o approach-to-critical data and extrapolation of data to the delayed critical condition.

Except for the void formations in the moderator, error limits were determined and are reported in this report for each of the above.

Trapped air or vaporized gases in the water and organic moderators can result in void accumulations in the fuel-moderator region of the experimental assemblies. Such voids, of course, have a negative reactivity effect on these undermoderated assemblies. To assure such voids were not present, measurements were not performed until visual inspection gave assurances that bubble formation, if any, had stopped and that bubbles were not accumulated under the lattice plates or on the fuel pins. Also multiple measurements were performed on selected assemblies to verify that voids were not accumulating during the approach-to-critical measurements.

Following fabrication of the lattice plates, representative sections of each lattice plate was measured to determine as-built lattice spacings and hole diameters. Error limits based on these measurements are reported in Table 3.1 for each set of lattice plates used in the experiments.

Fabrication of the FTR fuel pins is in accordance with very tight quality control procedures and in accordance with the standards referenced in Figure 2.5. The dimensions and error limits given in Figure 2.5 are based on these referenced standards and the engineering drawings (see Appendix B). The plutonium-uranium content given in Figure 2.5 are the average values of several hundred FTR fuel pins.

The organic moderator mixture of TBP and NPH was not used in experiments for several days following mixing to permit any vaporization of light ends to occur before use. To monitor the stability of the organic moderator during the experiments, samples were taken before, during and at completion of the criticality measurements as covered in Appendix D. The error limits quoted are for the overall average composition.

The error limits quoted on the critical sizes given in Table 3.1 are estimated standard deviations obtained from the larger of either the linear least squares analyses of the critical approach data or one half the difference obtained by the two approach-to-critical extrapolation methods discussed in Section 3.1.1. The linear least squares analyses and extrapolation of the data are presented in Appendix G for each of the approach-to-critical measurements covered by this report.

3.2 REACTION RATE MEASUREMENTS

The objective of these measurements was to obtain absolute fission rates for ^{232}Th , ^{235}U , ^{238}U , ^{237}Np and ^{239}Pu in the neutron energy spectrum of the fuel pins and the organic moderator between the fuel pins of the very undermoderated experimental assembly having a center-to-center fuel pin spacing of 0.761 cm. Also the absolute fission rate in the fuel and ^{238}U capture in both the fuel pins and the organic moderator were to be measured. In addition, epi-cadmium fission and capture rates were to be obtained in the organic moderator between the fuel pins. The results of these measurements are

summarized in this section. Detailed count rate data and track densities along with the derivation of correction factors are presented in a separate report (Gold, 1986).

3.2.1 Reaction Rate Measurement Technique

The absolute fission rate measurements were made using solid state track recorders (SSTR) prepared and analyzed by the Irradiation and Environment Group of Westinghouse Hanford Company. The use of SSTR to measure absolute fission rates is extensively discussed in readily available publications (Gold, 1968, Lippincott, 1979 and Roberts 1968). Briefly, however, fission rate measurements with SSTR are carried out using isotopic deposits of a fissionable material in contact with a recorder material such as mica. A typical SSTR geometrical configuration is shown in Figure 3.9 for a single deposit. Fissions in the deposit produce fission fragments that create damage tracks in the mica. These tracks can be optically counted, after suitable etching, to determine the number of fissions per atom of deposit per unit time of irradiation. These measured fission rates can be input to a computer code such as FERRET - SAND-II (Schmittroth, 1979, McElroy, 1967) together with a starting neutron spectrum to obtain an adjusted calculated spectral shape (Lippincott, 1979).

The ^{238}U capture, rate measurements were made by irradiating thin foils of ^{238}U and observing the decay of ^{239}Np as indicated below:

3.2.2 Reaction Rate Data

Both the fission and capture rate measurement data were obtained near the center and at approximately midplane of the fuel region in the experimental assembly. These locations are identified as 1, 2, 3, 4 and 6 in the layout

Figure 3.9 Typical SSTR Geometrical Configuration

Experiment: 066

Lattice Pitch: 0.761 ± 0.001 cm

Control Blade: Out 44.7 cm

From Bottom of Fuel Pin

Safety Blade: Out of System

Fuel Pins: 1055 (See Comments)

Comments: Same Experimental

Assembly as 065 with

Two Additional Type 3.1

Fuel Pins for Irradiation

of Reaction Rate Devices

● Reaction Rate Assembly 2

● Reaction Rate Assembly 4

● Reaction Rate Assembly 6

Figure 3.10 Layout of Experimental Assembly 066 Showing Fuel Pin Loading and Location of Reaction Rate Devices

Experiment: 066R
 Lattice Pitch: 0.761 ± 0.001 cm
 Control Blade: Out 44.7 cm
 From Bottom of Fuel Pin
 Safety Blade: Out of System
 Fuel Pins: 1055 (See Comments)
 Comments: Same Experimental
 Assembly as 065 with
 Two Additional Type 3.1
 Fuel Pins for Irradiation
 of Reaction Rate Devices

○ Reaction Rate Assembly 1
 △ Reaction Rate Assembly 3

Figure 3.11 Layout of Experimental Assembly 066R Showing Fuel
 Pin Loading and Location of Reaction Rate Devices

arrangement shown in Figures 3.10 and 3.11 for experimental assemblies 066 and 066R. Each of the locations are approximately equal distance from the center of the assembly and thus should be neutronically symmetrical to each other. Elevations for each of the devices used in the measurements are shown in Figure 2.3 and Figure 3.12. In locations 2, 4 and 6, the SSTR and ^{238}U foils are in the FTR fuel pins. Figure 3.12 is a direct full scale reproduction of a radiograph over the region of the three fuel pins containing the track recorders and the ^{238}U foils. The precise elevation of each device is defined by the point shown 68.9 cm from the bottom of the fuel in Figure 3.12. In locations 1 and 3, the SSTR and ^{238}U foils essentially span the moderator region between fuel pins. All of the fuel pin devices were irradiated simultaneously and all of the moderator devices were irradiated simultaneously. Both irradiations were for a predetermined time at an integrated power level, P , given by

$$P = P_0 [\tau (1 - e^{-\Delta t/\tau}) + t],$$

where t is the irradiation time at a constant power level, P_0 , and τ is the period at which this power level was approached.

3.2.2.1 Fission Rates in the FTR Fuel Pins

To determine the fission rates reported for ^{239}Pu , ^{235}U , ^{238}U , ^{232}Th and ^{237}Np in the neutron spectra of the fuel, three Type 3.2 FTR fuel pins, CW78348, CW78361 and CW78500, were downloaded and reassembled as Pins 2, 4 and 6 respectively, with the reaction rate devices. Isotopic deposits of ^{239}Pu , ^{235}U , ^{238}U , ^{232}Th and ^{237}Np having the same diameter as the FTR fuel pellets were prepared and loaded, with mica recorders, in between the fuel pellets of Pin 2 as shown in Figure 3.12. The deposits and associated mica were distributed over a region of the Pin 2 fuel column to minimize voiding perturbations in the neutron spectra of the fuel. The track recorders were approximately equally spaced, just above midplane of the fuel column with

		^{237}Np 9.6 mil SSTR	^{232}Th 8.0 mil SSTR	^{238}U 8.0 mil SSTR	^{235}U 10.7 mil SSTR	^{239}Pu 10.6 mil SSTR	Pin 2
^{238}U 25.8 mil SSTR	^{238}U 21.0 mil SSTR	^{238}U 16.1 mil Foil	^{238}U 8.5 mil SSTR	^{238}U 15.6 mil SSTR	^{238}U 11.8 mil SSTR	^{238}U 8.6 mil SSTR	Pin 4
^{235}U 30 mil SSTR	^{238}U 24.1 mil SSTR	^{235}U 14.1 mil Foil	^{235}U 11.3 mil SSTR	^{235}U 19.7 mil SSTR	^{235}U 14.8 mil SSTR	^{235}U 10.5 mil SSTR	Pin 6

Figure 3.12 Radiograph of the Fuel Column Sections in Fuel Pins 2, 4 and 6 Containing the Reaction Rate Devices

five fuel pellets between each SSTR. The track recorders varied in thickness from 8.0 to 10.7 mils (~0.020 to ~0.027cm).

Since the axial dependence and the voiding perturbation created by the location and size of the track recorders in Pin 2 could be non-negligible it was necessary to quantify this effect. To quantify the axial dependency of the neutron flux as a function of energy, two ^{238}U SSTR of approximately the same thickness (8.5 and 8.6 mils) and two ^{235}U SSTR of approximately the same thickness (11.3 and 10.5 mils) were located at different elevations in Pins 4 and 6 respectively as shown in Figure 3.12. The ^{238}U and ^{235}U fission rates measured in these two pins, as a function of elevation, along with the fission rates measured in Pin 2 with track recorders of approximately the same thickness (8 mils for ^{238}U and 11 mils for ^{235}U), are given in Table 3.2.

TABLE 3.2 Spatial Comparison of Fission Rate

(cm)	10^{-17} Fission/Atom Sec. -a) -b)			
	^{238}U		^{235}U	
	Pin 2	Pin 4	Pin 2	Pin 6
68.95		$1.664 \pm 2.5(8.6)$		
68.90				$120.0 \pm 7.0(10.5)$
72.17			$120.2 \pm 6.4(10.7)$	
75.37	$1.572 \pm 2.3(8.0)$			
78.60		$1.464 \pm 2.5(8.5)$		
78.55				$90.3 \pm 4.8(11.3)$

-a) Gap created in fuel column by SSTR shown parenthetically in mils.

-b) Experimental uncertainties are in percent at the one sigma level.

The threshold energy dependent fission rate data shown above are not dependent on variations in the ^{238}U mass deposits; however, for the broad based thermal energy dependent fission rate data variations in ^{235}U mass deposits must be considered. Consequently fission track densities can be used to define axial dependency in the ^{238}U data, whereas fission rates must be used for the ^{235}U data.

Least squares analyses of the ^{238}U fission track densities and the ^{235}U fission rates yield the following axial dependent relationships respectively:

$$F_{28}(Z) = \left[1.4017(10)^6 \pm 1.6387(10)^4 \right] \cos(Z/24.106 \pm 1.389)$$

$$F_{25}(Z) = \left[1.2518(10)^{-15} \pm 6.7390(10)^{-17} \right] \cos(Z/16.063 \pm 1.732)$$

Where $F_{28}(Z)$ is fission track density, in tracks per cm^2 , as a function distance, in centimeters, from the fuel midplane and $F_{25}(Z)$ is similarly fissions per atom second. These data and the associated least squares determined fit of the data are shown in Figures 3.13 and 3.14.

As can be seen in Figures 3.13 and 3.14 the ^{238}U axial data are of much better quality. This can be directly attributed to the fact that fission track densities could be used directly in determining the axial dependency in the ^{238}U data whereas uncertainties in the ^{235}U mass data as well as those associated with the track densities are reflected in the ^{235}U data. Since the neutron spectral variation over the axial range of interest ($Z \leq 22$ cm) is negligible, the ^{238}U data was used to correct all of the in-fuel fission rate data to the same elevation as the moderator data (81.97 cm above the bottom of the fuel pins). The axially adjusted in-fuel data are shown in Table 3.3.

Figure 3.13 Spatial Dependence in ²³⁸U Fission Rates for a Fuel Gap of Approximately 8.5 Mils

Figure 3.14 Spatial Dependence in ^{235}U Fission Rates
for a Fuel Gap of Approximately 11 Mils

TABLE 3.3 Axially Adjusted In-Fuel FTR Pin 2 Data

<u>SSTR ID</u>	<u>Fuel Gap (Mils)</u>	<u>Isotope</u>	<u>Fission^{-a) -c)} Rate Fissions/(Atom • Sec)</u>
26	9.6	Np-237	7.03E-17 (2.8)
24	8.0	Th-232	3.33E-17 (2.9)
23	8.0	U-238	1.35E-17 (2.6)
23 -b)	8.0	U-238	1.14E-16 (3.5) ^{-d)}
22	10.7	U-235	9.86E-16 (6.5)
21	10.6	Pu-239	11.9E-16 (3.4)

-a) Reaction rates adjusted to an elevation of 81.97cm above the bottom of the fuel pin.

-b) The same asymptotic foil used in the SSTR was also counted for the U-238 capture rate measurement.

-c) Value in parenthesis is the experimental uncertainty in percent at the 1σ level.

-d) Capture rate in units of captures/(atom • sec). Capture rates of 1.10 E-16 and 0.563E-16 measured respectively in radially symmetrical pins 4 and 6.

To quantify energy dependent voiding perturbations created by the track recorders being positioned between the fuel pellets of Pin 2, recorders varying in thickness from 8.5 mils and 30 mils and with either ^{235}U or ^{238}U deposits were located at different elevations in Pins 4 and 6. The fission rates measured by these recorders were corrected to an axial location 81.97 cm above the bottom of the fuel pins using the axial corrections discussed previously. A least squares analyses of these axially adjusted data

to

$$F(g) = b_1 + gb_2,$$

yields

$$F_{28}(g) = [1.1996(10)^{-17} \pm 3.7540(10)^{-19}] + [1.5916(10)^{-19} \pm 2.7491(10)^{-20}]g$$

and

$$F_{25}(g) = [7.444(10)^{-16} \pm 9.0979(10)^{-17}] + [1.0259(10)^{-17} \pm 4.9457(10)^{-18}]g,$$

where g is the gap, in centimeters, created by the track recorders and F is the measured fissions per atom second for ^{238}U and ^{235}U respectively. The measurement data and the associated least squares determined fit of the data are shown in Figures 3.15 and 3.16 respectively for ^{238}U and ^{235}U (see Gold 1986 for detailed discussion and presentation of the least squares analyses).

A relative gap-perturbation correction factor, $C(g)$, can be obtained for the threshold energy dependent ^{238}U fission rates and the broad based thermal energy dependent ^{235}U fission rates from:

$$C(g) = \frac{F(0)}{F(g)}$$

Since $F(0)$ is equal to b_1 ,

$$C(g) = [1 + g (b_2/b_1)]^{-1}$$

Figure 3.15 Variation in ^{238}U Fission Rates with Gap Thickness

Figure 3.16 Variation in ^{235}U Fission Rates with Gap Thickness

Hence, the relative gap-perturbation correction depends only on the ratio (b_2/b_1) of the least squares coefficients. Since the ratios b_2/b_1 , for ^{238}U and ^{235}U (0.01327 and 0.01378 respectively) differ by less than 4 percent the relative gap-perturbation effect is essentially energy independent. Consequently, the more accurate ^{238}U fission rate correction factor was used to correct all of the in-fuel reaction rates to zero thickness. These corrected data are presented in Table 3.4.

3.2.2.2 ^{238}U Capture Rate in the FTR Fuel Pins

To measure the ^{238}U capture rate in the fuel pins, foils of ^{238}U , having the same diameter as the FTR fuel pellets, were prepared and loaded between pellets in Pins 4 and 6. In addition the ^{238}U SSTR (ID23) deposit in Pin 2 was also counted for ^{238}U capture. As indicated in Figure 3.12 both sets of ^{238}U foils and the SSTR were located at approximately the same elevations in the fuel pins.

Captures per atom second of $1.14(10)^{-16}$, $1.10(10)^{-16}$ and $0.563(10)^{-16}$, uncorrected for voiding effects, were measured in pins 2, 4 and 6 respectively. Since all three pins were symmetrically located and free of external perturbations (especially pins 4 and 6) it was concluded that the measurement result from pin 6 was in error. Deleting the pin 6 data results in a void corrected average value of $0.969(10)^{-16} \pm 9.1\%$ captures per atom second in the fuel 81.97 cm from the bottom of the fuel pins 2 and 4.

3.2.2.3 Fission Rates in the Moderator Region Between FTR Fuel Pins

To determine the fission rates for ^{239}Pu , ^{235}U , ^{238}U , ^{232}Th and ^{237}Np in the neutron spectra of the organic moderator between the fuel pins, two capsules were loaded with track recorders and located at positions 1 and 3 in the experimental assembly, as indicated in Figure 3.11, 81.97 cm from the bottom of the fuel pin. As discussed previously the capsules were located such that each would be neutronically symmetrical to each other and to the in-fuel

TABLE 3.4 In-Fuel Corrected Reaction Rate Results for FTR Pin 2

<u>SSTR ID</u>	<u>Isotope</u>	Corrected ^{-a) -b)} Fission Rate	
		<u>Fission/(Atom · sec)</u>	
26	Np-237	6.236E-17	(3.6)
24	Th-232	3.010E-18	(3.5)
23	U-238	1.217E-17	(3.2)
23 ^{-c)}	U-238	1.031E-16	(4.0) ^{-d)}
22	U-235	8.633E-16	(6.9)
21	Pu-239	1.043E-15	(4.2)
69	Fuel	-e)	

-a) Reaction rates adjusted to an elevation of 81.97 cm above the bottom of the fuel and corrected for the fuel-gap perturbation effect.

-b) Value in parenthesis is the experimental uncertainty in percent at the 1 σ level.

-c) The same asymptotic foil used in the SSTR was also counted for the U-238 capture rate measurement.

-d) Capture rate in captures/(atom · sec). Corrected capture rates of 1.10E-16 and 0.563E-16 measured respectively in radially symmetrical pins 4 and 6.

-e) SSTR located in pin 6. Fissions/atom · sec is approximately 2.0E-16. Additional follow-on work is planned to obtain a more accurate value.

reaction rate devices. The capsule at position 1 was made of aluminum. The capsule at position 3 was made of cadmium to obtain epi-cadmium reaction rates. Each capsule also contained ^{238}U foils for capture rate measurements. The track recorder and foil loading arrangements in each capsule are shown in Figure 3.17.

Reaction rate results for the moderator capsules 1 and 3 are given in Tables 3.5 and 3.6 respectively. The ^{238}U capture rate results reported in Tables 3.5 and 3.6 have been corrected for neutron self-shielding using a slab geometry approximation. In this approximation, the neutron self-shielding factor, f , which is the ratio of the observed capture rate, R_0 , to the infinitely dilute capture rate, R_{ID} , is given by

$$f = \frac{R_0}{R_{ID}} = \left[1 + 1.2 \times 10^4 (\rho x) \right]^{-1/2}$$

Here ρ is the density in atoms per cm^3 and x is the thickness of the slab in cm^3 per barn. In contrast, no self-shielding correction has been applied to the ^{238}U capture rate measurements in the fuel pins, for in this case it is the in-fuel reaction rate that is desired. Based on comparison of the above equation with actual measurements, the uncertainty introduced through this self-shielding correction is estimated to be roughly 15 percent (Gold 1968) for the ^{238}U capture rate foils used in moderator capsules 1 and 3.

3.2.2.4 Gradient Observations

A number of the in-fuel and moderator track recorders were scanned to investigate the existence of reaction rate gradients. This study of gradient effects was restricted to SSTR having uniform deposits. Only the ^{238}U and ^{232}Th have sufficiently uniform deposits to permit observing possible

Figure 3.17 Loading Arrangement for PNC Subtask 220 Reaction Rate Capsules 1 and 3 (Moderator Capsules)

TABLE 3.5 Reaction Rates in Moderator Region - Aluminum Capsule at Location 1

<u>SSTR ID</u>	<u>Isotope</u>	Track ^{-a)} Density (Tracks/cm ²)	Fission ^{-a)} Rate Fission/(Atom · sec).
T	Np-237	563 ^{-b)} (4.2)	7.20E-17 (4.7)
S	Th-232	2.762E + 05 (2.0)	3.31E-18 (2.8)
No Mica ^{-c)}	U-238	-----	5.13E-16 (16) ^{-d)}
P	U-238	1.080E + 06 (1.1)	1.29E-17 (2.3)
O	U-235	5.359E + 05 (1.2)	1.36E-15 (4.1)
N ^{-e)}	Pu-239	-----	-----

-a) Value in parenthesis is the uncertainty in percent at the 1 σ level.

-b) Total observed tracks.

-c) In-moderator capture rate measurement in U-238.

-d) Capture rate in captures/(atom · sec). Correction for neutron self-shielding has been applied.

-e) SSTR damaged

TABLE 3.6 Reaction Rates in Moderator Region - Cadmium Capsule at Location 3

<u>SSTR ID</u>	<u>Isotope</u>	Track ^{-a)} Density <u>(Tracks/cm²)</u>		Fission ^{-a)} Rate <u>Fissions/(Atom • sec.)</u>	
Δ	Np-237	726	(6.6)	5.28E-17	(7.0)
Z	Th-232	2.525E + 05	(1.9)	3.02E-18	(3.5)
No Mica ^{-c)}	U-238	-----		4.98E-16	(15) ^{-d)}
X	U-238	1.064E + 06	(10)	1.241E-17	(2.2)
W ^{-e)}	U-235	-----		-----	
V	Pu-239	393 ^{-c)}	(4.0)	7.67E-16	(5.2)

-a) Value in parenthesis is the uncertainty in percent at the 1σ level.

-b) Total observed tracks.

-c) In-moderator capture rate measurement in U-238.

-d) Capture rate in captures/(atom • sec). Correction for neutron self-shielding has been applied.

-e) SSTR damaged.

gradients across the track recorder. No significant reaction rate gradients were observed in the measurements (see Gold 1986 for detailed count rate data and analyses).

3.2.2.5 Neutron Energy Derivation

Derivation of the fuel and the moderator neutron spectra was performed using the corrected measured fission rates given in Tables 3.4 through 3.6 and the FERRET-SAND II codes (McElroy 1967, Schmittroth 1979). A detailed discussion of the analyses and derived group fluxes is given in HEDL -7571 (Gold 1986). Integral flux values are given in Table 3.7.

3.2.3 Sources of Error in Reaction Rate Data

The sources of error associated with the various reaction rate measurements are discussed in HEDL - 7571 (Gold 1986) along with the specific measurement data. In summary, however, errors primarily occur due to:

- o counting statistics
- o isotope deposit mass
- o corrections for void effects
- o adjustments for axial location
- o self shielding (^{238}U capture in moderator)
- o defining location of each measurement device.

TABLE 3.7 Integral Neutron Flux Values in the Fuel and Moderator Regions of Experimental Assembly 066

<u>Energy Group</u>	<u>Neutron Flux</u> ^{-a) -b)}	
	<u>Fuel Pin 2</u>	<u>Moderator Location 1</u>
E > 0.0 MeV	$6.181(10)^7 \pm 13\%$	$9.287(10)^7 \pm 13\%$
E > 0.1 MeV	$4.666(10)^7 \pm 13\%$	$5.605(10)^7 \pm 14\%$
E > 1.0 MeV	$2.894(10)^7 \pm 6\%$	$3.053(10)^7 \pm 6\%$
E < 0.414 eV	$1.548(10)^6 \pm 6\%$	$2.990(10)^6 \pm 16\%$

-a) Percent uncertainty at one standard deviation level.

-b) 81.97 cm from bottom of fuel pins.

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APPENDIX A

ENGINEERING DRAWINGS OF EXPERIMENTAL VESSEL AND ASSEMBLY SUPPORT STRUCTURE

APPENDIX A

ENGINEERING DRAWINGS OF EXPERIMENTAL VESSEL AND ASSEMBLY SUPPORT STRUCTURE

Engineering drawings showing dimensions and materials of construction of the moderator/reflector tank placed inside the FEAS to limit the amount of organic solution used to that required by the experiments are presented in this Appendix. Also presented are the details of the support structure to which the different lattice plates were attached. Dimensions, materials of construction and the location of the structure inside the moderator/reflector tank are shown. Details of the different lattice plates are not given in this Appendix. The lattice plates are an integral part of the experimental data. Their material of construction, precise location, etc., are covered in the main body of the report.

APPENDIX B

ENGINEERING DRAWINGS OF FTR FUEL PINS

APPENDIX B

ENGINEERING DRAWINGS OF FTR FUEL PINS

Engineering drawings of the Type 3.1 and 3.2 FTR fuel pins are presented in this Appendix.

APPENDIX C

WATER SAMPLE ANALYSIS

APPENDIX C

WATER SAMPLE ANALYSIS

A single sample, PNC 14, was taken July 22, 1985 of the deionized water used in the water moderated assemblies covered by this report. The results of the sample analyses is 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 C.1 Analysis of Deionized Water Sample

<u>Analysis</u>	<u>PNC-14</u>
pH	6.7
Total alkalinity mg/liter as CaCO_3	14.7
Bicarbonate alkalinity mg/liter as CaCO_3	14.0
Carbonate alkalinity mg/liter as CaCO_3	<0.5
Total dissolved solids mg/liter	39
Sulfate mg/liter	2.8
Nitrate (as N) mg/liter	<0.2
Fluoride mg/liter	<0.1
Chloride mg/liter	0.6
Cadmium mg/liter	0.0048
Copper mg/liter	<0.01
Chromium mg/liter	1.2
Iron mg/liter	0.24
Lead mg/liter	0.006
Manganese mg/liter	<0.01
Zinc mg/liter	0.96

APPENDIX D

ANALYTICAL RESULTS OF ORGANIC MIXTURE SAMPLES

APPENDIX D

ANALYTICAL RESULTS OF ORGANIC MIXTURE SAMPLES

The analysis results obtained from samples taken of the TBP-NPH solution used in the experiments are presented in this Appendix.

The same TBP-NPH solution was used in all of the experimental assemblies. Samples were taken at the beginning, near the middle and at the end of the experiments to monitor any changes in the composition during the course of performing the experiments. Two samples were taken each time and analyzed by the Chemical Laboratory Unit of Rockwell Hanford Operations to determine specific gravity, and chemical composition of the organic mixture. Specific gravity was determined using a calibrated pycnometer. The organic molecular distributions were determined simultaneously using high resolution chromatigraphic absorption. These sample analyses are tabulated in this Appendix. The average results for each set of samples is also presented graphically herein to more clearly show the lack of variation that occurred in the composition of the organic mixture during the time period it was used in the experiments.

Two organic mixture samples were analyzed by the Geoscience and Engineering Laboratory of the Battelle Pacific Northwest Laboratories using energy dispersive x-ray fluorescence analysis to identify any impurities, and to determine the magnitude of their concentrations. The sample analyses are presented in this Appendix.

Prior to mixing the TBP and NPH solutions, the NPH component was sampled and analyzed to determine specific gravity and molecular composition. The results of this sample analysis are presented in this Appendix.

A dye penetrant was added to the organic mixture following experiment 059 to make it fluorescent such that complete organic removal from the fuel pins upon completion of the experiments could be verified. The dye was analyzed for halogens and sulfur by the Chemistry and Analysis Laboratory of Westinghouse Hanford Company using a parr oxygen bomb and ion chromatographic absorption for sulfur, amperometric titration for chlorine and ion selection electrode for fluorine. The results are presented in this Appendix.

TABLE D.1 Chemical Analyses of Tributylphosphaste Normal Paraffin Hydrocarbon Mixture Samples

Date	Experiment Number	Sample Number	Specific Gravity ^(a)	TBP Wt% ^(b)	Normal Parrafin Hydrocarbon ^(c)				
					Wt% C-11	Wt% C-12	Wt% C-13	Wt% C-14	Wt% C-15
06/29/84	---	PNC5	0.7592	0	2.23	11.80	54.40	30.38	1.11
05/07/85	059	PNC3	0.8233	38.2	0.56	13.01	54.59	31.56	0.28
05/07/85	059	PNC4	0.8231	37.6	0.58	13.05	54.54	31.54	0.28
-----	059	Avg. ^(d)	0.8232	37.9	0.57	13.03	54.57	31.55	0.28
05/21/85	063	PNC6	0.8239	37.4	0.49	12.70	54.49	30.07	0.22
05/21/85	063	PNC7	0.8254	38.1	0.48	12.75	54.55	31.99	0.20
-----	063	Avg. ^(d)	0.8246	37.8	0.48	12.73	54.52	31.03	0.21
06/05/85	065	PNC8	0.8254	38.4	0.47	12.42	54.66	32.26	0.20
06/05/85	065	PNC9	0.8252	38.0	0.49	12.72	54.59	31.97	0.24
-----	065	Avg. ^(d)	0.8253	38.2	0.48	12.57	54.63	32.12	0.22
-----	---	Ave. ^(e)	0.8244	38.0	0.51	12.78	54.55	31.56	0.23
-----	---	S ^(f)	± 0.0011	± 0.2	± 0.05	± 0.23	± 0.06	± 0.78	± 0.04
-----	---	△ ^(g)	+ 0.0021	+ 0.3	- 0.09	- 0.06	+ 0.06	+ 0.57	- 0.06

(a) Relative to water at 25 °C. Standard deviation on individual sample analysis is 0.00005

(b) Wt% TBP in TBP-NPH mixture. Standard deviation on individual sample analysis is less than 3%

(c) Wt% NPH components in NPH mixture.

(d) Average of two preceding identical samples

(e) Average of all mixture samples

(f) Standard deviation observed in mixture sample results

(g) Difference between initial sample and final sample

Figure D.1 Variation in TBP-NPH Mixture Composition During Experiments

TABLE D.2 Energy Dispersive X-Ray Fluorescence Analyses
of TBP-NPH Mixture Samples for Impurities

<u>Element</u>	<u>PNC-1 (PPM)</u>	<u>PNC-2 (PPM)</u>
Al	<550.00	<530.00
Si	<350.00	<330.00
P	47000.00 ± 2400.00	41500.00 ± 2100.00
S	144.00 ± 36.00	101.00 ± 33.00
Cl	<20.00	33.00 ± 12.00
K	<4.60	<3.90
Ca	8.80 ± 1.80	6.90 ± 1.60
Ti	<9.70	<8.50
V	<6.20	<5.50
Cr	<3.90	<3.50
Mn	<2.30	<2.10
Fe	12.40 ± 1.20	4.65 ± 0.01
Co	<1.10	<0.97
Ni	<0.76	<0.66
Cu	2.68 ± 0.36	1.99 ± 0.33
Zn	0.74 ± 0.23	2.20 ± 0.25
Ga	<3.30	<0.20
Mg	<1.20	<1.20
Se	<0.20	<0.28
Pb	<0.79	<0.80
As	<0.24	<0.24
Br	<0.26	<0.25
Rb	<0.30	<0.30

TABLE D.3 Analyses of Magnaflux Type ZL-22A Batch #4JD2W Fluorescent
Dye Penetrant Sample for Halogens and Sulfur

<u>Element</u>	<u>g/liter</u>
F	0.00066
Cl	0.03700
S	0.25000

APPENDIX E

TRACE IMPURITIES MEASURED IN LATTICE PLATE MATERIAL

APPENDIX E

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 a sample taken from, and considered representative of, the polypropylene during fabrication of the lattice plates. The spectrographic analysis were performed by the Hanford Engineering Development Laboratory, Richland, Washington, on October 17, 1985.

TABLE E.1 Trace Impurities Present in Lattice Plates

<u>Element</u>	<u>Parts per Million by Weight</u>
Li	2
Be	1
B	0.04
Na	30
Mg	6
Al	30
Si	10
P	5
Cl	1
K	40
Ti	<100
V	10
Cr	<10
Mn	<2
Cu	100
Zn	50
As	8

APPENDIX F

DENSITY AND CHEMICAL COMPOSITION OF TYPE 6061 ALUMINUM

APPENDIX F

DENSITY AND CHEMICAL COMPOSITION OF TYPE 6061 ALUMINUM

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

TABLE F.1 ASTM Standard B210-78 Specifications for Type 6061 Aluminum

Chemical Composition

<u>Element</u>	<u>Wt%</u>
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)
Zr	0.25 (Maximum)
Ti	0.15 (Maximum)
V	0.15 (Maximum)
Al	Remainder

Maximum Impurities

<u>All Other Elements</u>	<u>Wt%</u>
Each	0.05
Total	0.15

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

APPENDIX G

COMPUTERIZED PLOTS AND EXTRAPOLATIONS OF APPROACH-TO-CRITICAL DATA

APPENDIX G

COMPUTERIZED PLOTS AND EXTRAPOLATION OF APPROACH-TO-CRITICAL DATA

The observed neutron multiplication as a function of experimental assembly fuel loading is presented in this Appendix for each set of data used in determining the critical size of the respective assemblies. Computer plots showing the linear least squares calculated fit of the data obtained from each of the three data channels, and the associated extrapolation to the critical size, are shown for each assembly. Computerized plots of both the inverse neutron count rate and the inverse neutron count rate times the fuel loading are presented as a function of fuel loading for each experimental assembly associated with the critical sizes given in Table 3.1 of this report. The average of the extrapolated critical sizes obtained from the three data channels is also presented in each of the computerized plots.

CFRP-PNC-FTR-059 MAY 7, 1985 TYPE 3.2 FTR FUEL PINS 20.0C
 FULL ORGANIC REFLECTION, 1.995 CM SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.1 CFRP-PNC-FTR-059 May 7, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-059 MAY 7, 1985 TYPE 3.2 FTR FUEL PINS 20.0C
 FULL ORGANIC REFLECTION, 1.995 CM SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.2 CFRP-PNC-FTR-059 May 7, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-060 MAY 8, 1985 TYPE 3.2 FTR FUEL PINS, 20.0C
 FULL ORGANIC REFLECTION, 1.935CM, SQUARE PITCH LATTICE 15 FUEL PINS WIDE
 FLOURESCENT DYE ADDED TO ORGANIC

Figure G.3 CFRP-PNC-FTR-060 May 8, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-060 MAY 8, 1985 TYPE 3.2 FTR FUEL PINS, 20.0C
 FULL ORGANIC REFLECTION, 1.935CM, SQUARE PITCH LATTICE 15 FUEL PINS WIDE
 FLOURESCENT DYE ADDED TO ORGANIC

Figure G.4 CFRP-PNC-FTR-060 May 8, 1985 - Rod/Count Rate Approach

CFRP-PNC-FTR-061 MAY 14, 1985 TYPE 3.2 FTR FUEL PINS 22.0C
 FULL ORGANIC REFLECTION, 1.597CM, SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.5 CFRP-PNC-FTR-061 May 14, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-061 MAY 14, 1985 TYPE 3.2 FTR FUEL PINS 22.0C
 FULL ORGANIC REFLECTION, 1.537CM, SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.6 CFRP-PNC-FTR-061 May 14, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-062 MAY 15, 1985 TYPE 3.2 FTR FUEL PINS 22.0C
 FULL ORGANIC REFLECTION, 1.242CM SQUARE PITCH LATTICE 20 FUEL PINS WIDE

Figure G.7 CFRP-PNC-FTR-062 May 15, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-062 MAY 15, 1985 TYPE 3.2 FTR FUEL PINS 22.0C
 FULL ORGANIC REFLECTION, 1.242CM SQUARE PITCH LATTICE 20 FUEL PINS WIDE

Figure G.8 CFRP-PNC-FTR-062 May 15, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-063 MAY 21, 1985 TYPE 3.2 FTR FUEL PINS 27.0C
 FULL ORGANIC REFLECTION, 0.988CM SQUARE PITCH LATTICE 25 FUEL PINS WIDE

Figure G.9 CFRP-PNC-FTR-063 May 21, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-063 MAY 21, 1985 TYPE 3.2 FTR FUEL PINS 27.0C
 FULL ORGANIC REFLECTION, 0.968CM SQUARE PITCH LATTICE 25 FUEL PINS WIDE

Figure G.10 CFRP-PNC-FTR-063 May 21, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-065 JUNE 5, 1985 TYPE 3.2 & 3.1 FTR FUEL PINS 28.0C
 FULL ORGANIC REFLECTION, 0.761CM, SQUARE PITCH LATTICE 36 FUEL PINS WIDE

Figure G.11 CFRP-PNC-FTR-065 June 5, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-065 JUNE 5, 1985 TYPE 3.2 & 3.1 FTR FUEL PINS 28.0C
 FULL ORGANIC REFLECTION, 0.761CM, SQUARE PITCH LATTICE 36 FUEL PINS WIDE

Figure G.12 CFRP-PNC-FTR-065 June 5, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-067 JULY 17, 1985 TYPE 3.2 & 3.1 FTR FUEL PINS 28.0C
 FULL WATER REFLECTION 0.761CM SQUARE PITCH LATTICE 36 FUEL PINS WIDE

Figure G.13 CFRP-PNC-FTR-067 July 17, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-067 JULY 17, 1985 TYPE 3.2 & 3.1 FTR FUEL PINS 26.0C
 FULL WATER REFLECTION 0.761CM SQUARE PITCH LATTICE 36 FUEL PINS WIDE

Figure G.14 CFRP-PNC-FTR-067 July 17, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-068 JULY 23, 1985 TYPE 3.2 FTR FUEL PINS, 20.0C
 FULL WATER REFLECTION 1.597CM SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.15 CFRP-PNC-FTR-068 July 23, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-068 JULY 23, 1985 TYPE 3.2 FTR FUEL PINS, 20.0C
 FULL WATER REFLECTION 1.537CM SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.16 CFRP-PNC-FTR-068 July 23, 1985 - Rods/Count Rate Approach

CFRP-PNC-FTR-068R JULY 7, 1985 TYPE 3.2 FTR FUEL PINS, 20.0C
 FULL WATER REFLECTION 1.537CM SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.17 CFRP-PNC-FTR-068R July 7, 1985 - 1/Count Rate Approach

CFRP-PNC-FTR-068R JULY 7, 1985 TYPE 3.2 FTR FUEL PINS, 20.0C
 FULL WATER REFLECTION 1.537CM SQUARE PITCH LATTICE 15 FUEL PINS WIDE

Figure G.18 CFRP-PNC-FTR-068 July 7, 1985 - Rods/Count Rate Approach

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ITEM	PN	DESCRIPTION	MATERIAL
1	1	ASSEMBLY	
2	2	TANK	SMES-2
3	3	LATTICE SUPPORT	
4	4	LATTICE SUPPORT	
5	5	LIFTING YOKES	
6	6	SPACE ANGLE	
7	7	FUEL PIN SUPPORT PL	
8	8	STD BEVEL WASHER	
9	9	HEX HD BOLT 1/2-13 UNC-2A 1/2 L	ASTM A 305
10	10	HEX HD BOLT 1/2-13 UNC-2A 1/2 L 17MM3 L	ASTM A 305
11	11	HEX HD BOLT 1/2-13 UNC-2A 1/2 L	ASTM A 305
12	12	HEX NUT 1/2-13 UNC-2B	ASTM A 305

GENERAL NOTES

UNLESS OTHERWISE SPECIFIED

- 1- ALL WELD AS SPECIFIED OR APPROVED EQUIV
- 2- DIMENSIONING & TOLERANCING PER ANSI 14.5 1973
- 3- REMOVE ALL BURRS & BREAK ALL SHARP EDGES
- 4- TOLERANCES
FRACTIONS $\pm \frac{1}{32}$ (25 4516-ALLOWER 1/2)
DECIMALS $\pm .005$
ANGLES $\pm 1^\circ$
- 5- ALL WELDING PER AWS D11.83 EXCEPT WELDER QUALIFICATION PER ASME SECT II OR AWS B 3.0 77
- 6- CONTRACTOR SHALL FURNISH CUST. WITH AN INLET SHIM STOCK MAX .003 (500 SER 557) THICK PER LAYER TOTAL THICKNESS 3/32 IN. BLOCK (G) BLOCKS 1'x3', (2) BLOCKS 2'x3' & (3) BLOCKS 2'x3'
- 7- PAINT VESSEL PN 2 INTERIOR WITH LIGHT REFLECTING KEROSENE RESISTANT PAINT
- 8- INSTALL PN 6 BEFORE REMOVAL OF LATTICE SUPPORT PN 3 FROM TK - REMOVE ANGLE PN 6 AFTER PN 3 IS SECURED TO TK

PLAN

EXISTING TK SEE
DWG M-2-335A1 R
M-2-33542

[illegible]

PLAN

NOTE * LOCATE AT POINT OF BALANCE

SECTION A-A

SCALE 1/2"=1'-0"

NOTE

* MATCH PN. LOCATION PN 2 PROVIDE SLIP FIT. NON BINDING

LIFTING YOKE

SCALE 3/4"=1'-0"

MATL ASTM A36

FUEL PIN SUPPORT PL

SCALE 1/2"=1'-0"

MATL 2" THK LUCITE

BRACE ANGLE

SCALE 3/4"=1'-0"

MATL AL T6061

LATTICE SUPPORT (SHOWN)

LATTICE SUPPORT (OPP HAND)

SCALE 1/2"=1'-0"

MATL AL T6061

REV	DATE	BY	CHKD	DESCRIPTION
1	10-29-84	JQP		ISSUED FOR CONSTRUCTION
2	10-29-84	JQP		REVISED
3	10-29-84	JQP		REVISED
4	10-29-84	JQP		REVISED
5	10-29-84	JQP		REVISED
6	10-29-84	JQP		REVISED
7	10-29-84	JQP		REVISED
8	10-29-84	JQP		REVISED
9	10-29-84	JQP		REVISED
10	10-29-84	JQP		REVISED

2-155-10-29-84 JQP# 1505

U. S. Department Of Energy Richland Operations Office	
PACIFIC NORTHWEST LABORATORY OPERATED BY BATTTELLE MEMORIAL INSTITUTE	
TANK & LATTICE SUPPORTS MISC. DETAILS	
DATE: 10-29-84	SCALE: 1/2"=1'-0"
DESIGNED BY: JQP	CHECKED BY: JQP
NOT RECD	DATE: 10-29-84
BLANKET: NONE	DATE: 10-29-84
SK-2-3885	2/2

NEXT USED ON SK-20290, SK-20487, SK-20569, SK-20570, H-4-20581		
REFERENCE DRAWINGS		
OWB. NO.	REV. NO.	DRAWING TITLE OR INDEX NO.

BILL OF MATERIAL						NO. REQ.		
NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION		GR. 1	GR. 2	GR. 3
	1	INSULATOR PELLET		SEE NOTE A & B		1		

A. NATURAL UO_2

B. DENSITY = $10.42 \text{ g/cm}^3 \pm .22 \text{ g/cm}^3$

S OR
AMFER

NOTES:

- INSULATOR PELLET TO CONFORM TO RDT E13-7
FFTF DRIVER FUEL INSULATOR PELLET

BY DATE FOR BY DATE FOR REV BY DATE		DESCRIPTION		REV NO.
APPD		APPD		
REVISIONS				
(M)	COMMENT PRT ISSUE NO.	DATE	CHECK PRT ISSUE NO.	DATE
DRAWING STATUS				
U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATIONS OFFICE PACIFIC NORTHWEST LABORATORY OPERATED BY BATTELLE MEMORIAL INSTITUTE WESTINGHOUSE ELECTRIC CORP. FFTF DRIVER FUEL PIN INSULATOR PELLET FAST FLUX TEST FACILITY				
J. P. Stephens 8/25/70 APPD 50 Clinebor 3/12/74 ENGR E. Pyson 8/25/70 CHECKED A. WINEMAN 8-28-70 DRAWN A. MCFARLAND 5-3-70 SCALE 4:1				
CLASSIFIED BY NOT REQUIRED		BLDG. NO. 0405	INDEX NO. 490040	
CLASSIFICATION NONE		OWB NO. H-4-20296	SHEET NO. 1	SHEETS 1

ENGINEERING RELEASE BY
WADCO CORPORATION
By C 6021 - 4/23/11
RMC Rev. 0 Date

ITEM NO.	DIM. A	DIM. B
1	.094	1.400
2	.109	1.600

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES AND THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE. VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED CONCENTRICITY (TIR) MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES 320. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ASA B1.1 - PIPE THREADS PER ASA B2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°

NEXT USED ON H-4-20581

REFERENCE DRAWINGS

DWG. NO.	REV. NO.	DRAWING TITLE OR INDEX NO.

BILL OF MATERIAL

NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION	NO. REQ.		
					GR. 1	GR. 2	GR. 3
B	1	END CAP-BOTTOM		SEE NOTE A	1		
C	2	END CAP-BOTTOM		SEE NOTE A	1		

- A. END CAP TO CONFORM TO RDT E13-9,
FFTF DRIVER FUEL PIN END CAPS (TYPE 316
* 20% COLD WORKED STAINLESS STEEL).
- B. FOR USE ON OUTER ENRICHMENT ZONE (ROWS 5 & 6) FUEL PINS
- C. FOR USE ON INNER ENRICHMENT ZONE (ROWS 1 & 4) FUEL PINS

NOTES:

1. $\sqrt[63]{}$ ALL OVER UNLESS OTHERWISE SPECIFIED.
2. BREAK ALL CORNERS .005 R. MAX. UNLESS OTHERWISE NOTED.

2 DIA. THRU
 $2 \times .02 \pm .002$
 ONE SIDE ONLY

$\pm .002$ DIA
 .001

5 DIA.

(M)		WCS 7/24/73		RELEASED ERO C09195 ECN-5112.3 ECP-C-207 NOTE B WAS OUTER CORE ZONE FUEL PINS NOTE C WAS INNER CORE ZONE FUEL PINS .035 $\pm$.020 WAS .036 $\pm$.001 AND ADDED .035 $\pm$.005 WITHIN .09 MIN OF HOLE DELETED "FFTF" FROM DWG TITLE END VIEW, .02 $\pm$.02 DP WAS .030 $\pm$.005 .02 REF WAS .030 REF ADDED DWG DATA TYPE 2		3	
MICRO P.W.D.	BY-DATE APPD	FOR	BY-DATE APPD	FOR	REV BY DATE	DESCRIPTION	REV NO.
REVISIONS							
(M)		COMMENT PRT ISSUE NO.		DATE	CHECK PRT ISSUE NO.		DATE
DRAWING STATUS							
DWG. DATA TYPE 2				U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATIONS OFFICE			
J. J. Shins 8/2/70 APPD J. J. Shins 8/2/70 ARE J. J. Shins 8/2/70 ENGR E. Polson 8/2/70 DWS APPD J. J. Shins 8/2/70 CHECKED A. WIJEMAN 8-28-70 DRAWN J. BELSICK 02-21-70				Hanford Engineering Development Laboratory Westinghouse Hanford Company			
SCALE 4:1				WESTINGHOUSE ELECTRIC CORP.			
CLASSIFIED BY NCT REQUIRED				DRIVER FUEL PIN END CAP - BOTTOM			
CLASSIFICATION NONE				FAST FLUX TEST FACILITY			
ENGINEERING RELEASE BY WADCO CORPORATION By C6017B 7-6-71 RMC Rm2 Date				BLDG. NO. 0405		INDEX NO. 490040	
				DWG NO. H-4-20291		SHEET NO. 11	

SQUARED, GROUND, AND DEBURRED ENDS

COMPRESSION SPRING DATA

MIN. WORKING LOAD AT 5.18 IN. LENGTH	3.27 $\pm$.16 LB.
MAX. WORKING LOAD AT 4.70 IN. LENGTH	4.78 $\pm$.24 LB.
MAX. SOLID HEIGHT	3.9 IN.
SPRING RATE (REF.)	3.14 LB/IN.
WIRE GAUGE (REF.)	21(.0317 DIA)
MAX. SPRING VOLUME	.055 IN. ³
TOTAL NO. OF TURNS (REF.)	123

NEXT USED ON SK-20290, SK-20487, SK-20569, SK-20570 # H-4-20581		
REFERENCE DRAWINGS		
DWG. NO.	REV. NO.	DRAWING TITLE OR INDEX NO.

BILL OF MATERIAL						NO. REQ.		
NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION		GR. 1	GR. 2	GR. 3
	1	SPRING		SEE NOTE A		1		

A. SPRING TO CONFORM TO RDT E 13-12 FFTF
DRIVER FUEL PIN PLENUM SPRING (TYPE
AISI 302 STAINLESS STEEL.)

MICRO FILM M	BY-DATE	FOR	BY-DATE	FOR	REV BY DATE	DESCRIPTION	REV NO.
	APPD		APPD				
	REVISIONS						
	COMMENT PRT ISSUE NO.	DATE	CHECK PRT ISSUE NO.	DATE	LAST REV O		
DRAWING STATUS							
J. H. Harris 8/28/70 APPD J. H. Harris 8/28/70 APPD S. O. Wineson 8/28/70 ENGR E. Peterson 9/15/70 DFTG APPD G. H. Wilkinson 8/28/70 CHECKED A. WINGMAN 8-28-70 DRAWN A. MCFARLAND 8-27-70						U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATIONS OFFICE PACIFIC NORTHWEST LABORATORY OPERATED BY BATTELLE MEMORIAL INSTITUTE 30 WESTINGHOUSE ELECTRIC CORP. FFTF DRIVER FUEL PIN PLENUM SPRING FAST FLUX TEST FACILITY	
SCALE 5:1							
CLASSIFIED BY NOT REQUIRED						BLDG. NO. 0405	INDEX NO. 490040
CLASSIFICATION NONE						DWG. NO. H-4-20293	SHEET NO. 1 SHEETS 1

ENGINEERING RELEASE BY
WADCO CORPORATION
By C 6018 4/23/71
RMC Rev. 0 Date

UNLESS OTHERWISE SPECIFIED THE FOLLOWING

STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE VARIATIONS IN FORM FOR UNMACHINED FEATURES. SURFACE FINISH (RA) MUST BE WITHIN THE LIMITS OF THE TOLERANCES OF THE DIMENSIONS BEING ALL EDGES OR CORNERS $0.005 \pm .002$ (APPROXIMATE RADIUS OR CHAMFER). ALL FILLETS $0.005 \pm .002$ SCREW THREADS PER DIA $0.1 \pm .001$ PIPE THREADS PER DIA $0.1 \pm .001$ WELD DIMENSIONS ARE MINIMUM.

NEXT USED ON H-4-20581		
REFERENCE DRAWINGS		
DWG. NO.	REV. NO.	DRAWING TITLE OR INDEX NO.

BILL OF MATERIAL						NO. REQ.		
NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION		GR. 1	GR. 2	GR. 3
	1	PLENUM SPACER		SEE NOTE A		1		

A. PLENUM SPACER TO CONFORM TO RDT E13-11
FFTF DRIVER FUEL PIN PLENUM SPACER
(TYPE 316, 20% COLD WORKED STAINLESS STEEL).

1. 63/ ALL OVER UNLESS OTHERWISE SPECIFIED.

M	11-10-72	11-10-72	11-10-72	11-10-72	11-10-72	INITIAL RELEASE ERO-0123/C276	3
						ECN-0904 ECRC133 DELETED FFTF FROM TITLE BLK. .193 AVE DIA WAS .193 DIA .33.94 WAS 37.062 .100 WAS .060-ADDED 32 .030 WAS .042-ADDED NOTE 1	
M	9/20/71	9/20/71	9/20/71	9/20/71	9/20/71	ECN-0098 .060 DIA. MIN. WAS .110 DIA. MAX. ADDED .042 MIN.	2
M	6/20/71	6/20/71	6/20/71	6/20/71	6/20/71	ECN-0072 REDRAWN DELETED END PLUG DELETED SK-20250 SK-20487, SK-20569, SK-20570 FROM NEXT USED ON BLOCK SPUN ENDS WERE WELDED END PLUGS IT.1 .0055±.0005 WALL WAS .178 .001 ID±.0055±.0005 WALL .193±.001 DIA WAS .189 DIA REF PLENUM SPACER WAS PLE- NUM SPACER ASSEMBLY	1
MICRO P.M.B	BY DATE	FOR	BY DATE	FOR	REV BY DATE	DESCRIPTION	REV NO.
	APPD		APPD				
REVISIONS							
COMMENT PRT ISSUE NO.				DATE		CHECK PRT ISSUE NO.	DATE
DRAWING STATUS							
DATA TYPE 2				U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATIONS OFFICE HANFORD ENGINEERING DEVELOPMENT LABORATORY Westinghouse Hanford Company			
APPD				WESTINGHOUSE ELECTRIC CORP.			
APPD				DRIVER FUEL PIN PLENUM SPACER			
ENGR				FAST FLUX TEST FACILITY			
DPTS APPD							
CHECKED							
DRAWN							
SCALE 10:1							
CLASSIFIED BY				BLDG. NO. 0405		INDEX NO. 4900	
NOT REQUIRED							
CLASSIFICATION				DWG. NO. H-4-20294		SHEET NO. 111	
NONE							

ENGINEERING RELEASE BY	
W	ARD
BY ERO-0123	11-10-72
DATE	

ING TOLERANCES APPLY

SMALL VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN
IES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS.
HARDENED SURFACE ROUGHNESS OR HOLES: 200 MAX.
APPROXIMATE RADIUS
APPROXIMATE RADIUS

4

1. LENGTH L TO BE SELECTED
THE RANGE $L = .205$ TO $L = .$
SELECTED LENGTH TO BE

.742 (REF.)
SPHERICAL R
TYP BOTH ENDS

DETAIL A
SCALE 20:1

(M)							
M						T.R. 8- 16 -72	O W .2 W I W I W E D N .2 W N I W E N S N E
(M)	12/1/72 P.G. Padler 8/24/72 J. Hopkins 8/25/72 E. Papson 8/26/72			J. Censi 8/27/72		ALW 8/28/72	
(M)	8/29/72 P.G. Padler 11/24/72 J. Hopkins 11/25/72 E. Papson 11/26/72			J. Censi 11/27/72		JCH 11/28/72	
(M)	12/1/72 P.G. Padler 1/24/73 J. Hopkins 1/25/73 E. Papson 1/26/73			R. L. L. 1/27/73		AM 1/28/73	
MICRO P.M.'S		BY-DATE	FOR	BY-DATE	FOR	REV BY	
		APPD		APPD		DATE	

TO LIE WITHIN
±.03. TOLERANCE ON
WITHIN ±.020

NEXT USED ON H-4-20580

REFERENCE DRAWINGS

DWG. NO.	REV. NO.	DRAWING TITLE OR INDEX NO.

BILL OF MATERIAL

					NO. REQ.		
NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION	GR. 1	GR. 2	GR. 3
B-D1	1	PELLET		SEE NOTE A	1		
B-D2	2	PELLET		SEE NOTE A	1		

- A. FUEL PELLETS TO CONFORM TO RDT E13-6,
FFTF DRIVER FUEL PIN MIXED OXIDE FUEL PELLET
- B. TYPE 3.1: .0075 MAX. PELLET-CLAD COLD GAP AND
ENRICHED FOR USE IN OUTER ENRICHMENT ZONE (ROWS 5 & 6)
PLUTONIUM CONTENT: $\frac{PU}{PELLET} = .242$
FISSILE CONTENT: $(239_{PU} + 241_{PU}) = 1.022 \pm .031 \text{ g/IN.}$
- C. TYPE 3.2: .0075 MAX PELLET-CLAD COLD GAP AND ENRICHED
FOR USE IN INNER ENRICHMENT ZONE (ROWS 1 & 4)
PLUTONIUM CONTENT: $\frac{PU}{PELLET} = .198$
FISSILE CONTENT: $(239_{PU} + 241_{PU}) = .836 \pm .025 \text{ g/IN.}$
- D. PLANAR SMEARED DENSITY = $85.5 \pm 2.0\%$ OF THEORETICAL.
NOMINAL PELLET DENSITY = 90.4% OF THEORETICAL (REF).

ENGINEERING RELEASE BY

WARD

BY ERO-0112 10-9-72
DATE

INITIAL RELEASE
ERO-0112

ECN # 0688

TER ENRICH ZONE ROWS (5 & 6)
S CORE ZONES II & III (OUTER)
2 WAS: $2.57, 1.022 \pm .031 \text{ g/IN.}$
S $1.002 \pm .030 \text{ g/IN.}$
NER ENRICH ZONE (ROWS 1-4)
S CORE ZONE I (INNER)
8 WAS: $1.93, .836 \pm .025 \text{ g/IN.}$
S $.816 \pm .024 \text{ g/IN.}$

N-0107

LETED FFTF FROM TITLE
TE B REVISED & PLUT. CONT. =
7 WAS: $2.32 \pm .002 \pm .030 \text{ g/IN.}$
S $.973 \pm .029 \text{ g/IN.}$
TE C REVISED & PLUT. CONT. =
3 WAS: $1.97 \pm .816 \pm .024 \text{ g/IN.}$
S $.828 \pm .025 \text{ g/IN.}$

N-0072

TE B: $.973 \pm .029 \text{ g/IN.}$ WAS
S $.934 \pm .034 \text{ g/IN.}$
TE C: $.828 \pm .025 \text{ g/IN.}$ WAS
S $.828 \pm .029 \text{ g/IN.}$

DESCRIPTION

REV
NO.

VISIONS

(M)	<i>A. Williams</i> 5/24/71 <i>J. Hyatt</i> 5/24/71 <i>E. P. ...</i> 5/24/71	5/24/71	5/24/71	A M	5/24/71	ECN-0055 NOTE B PLUTON. CONT. = .232 WAS ENRICH. = .265 973 ± .034 WAS .984 ± .034. NOTE C PLUT CONT. = .197 WAS ENRICH. = .221 & .828 ± .029 WAS .819 ± .029 DELETED MAXIMUM PELLET DENSITY = 93% OF THEORETICAL	3			
(M)	<i>A. Williams</i> 4-19-71 <i>J. Hyatt</i> 4-19-71 <i>E. P. ...</i> 4/19/71	4-19-71	4/19/71	RAA	4/19/71	ECN-0051 DELETED PACIFIC NORTHWEST STICKER ADDED TO NOTE "D" ADDED DETAIL A (HANFORD STICKER .005 & .010 WAS .005 & .005	2			
(M)	<i>A. Williams</i> 10/13/70 <i>E. P. ...</i> 10/13/70	10/13/70	10/13/70	CA	10/13/70	ECN-0021 CHANGED NOTE "D" CHANGED ENRICHMENT & FISSILE CONTENT IN NOTES B & C. DELETED TABLE 1 & IT.3	1			
BY-DATE FOR BY-DATE FOR		REV BY DATE		DESCRIPTION		REV NO.				
APPD		APPD								
REVISIONS										
(M)	COMMENT PRT ISSUE NO.		DATE		CHECK PRT ISSUE NO.	DATE				
DRAWING STATUS										
DWG. DATA TYPE 2										
U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATIONS OFFICE										
Hanford Engineering Development Laboratory Westinghouse Hanford Company										
WESTINGHOUSE ELECTRIC CORP.										
DRIVER FUEL PIN MIXED OXIDE FUEL PELLET TYPES 3.1 & 3.2										
FAST FLUX TEST FACILITY										
CLASSIFIED BY		BLDG. NO.		INDEX NO.						
NOT REQUIRED		405		1901						
CLASSIFICATION		DWS NO.		SHEET NO.		SHEETS				
NONE		H-4-20579		1		1				

2

10. WELD TO BE OPPOSITE COUNTERSINK. WELD ITEM 4 TO ITEMS 1 OR 5 PRIOR TO WELDING ITEM 4 TO ITEMS 2 OR 11. WELD CONCAVITY SHALL NOT EXCEED .005 IN. PROTRUSION OF FLUG WELD ABOVE ADJACENT END CAP SURFACE SHALL NOT EXCEED .020 IN.

DATE	NO.	NAME OF VENDOR
------	-----	----------------

DATE	BY	DESCRIPTION

BILL OF MATERIAL			NO. REQ.		
NOTE	ITEM	DESCRIPTION QTY. REQ.	UNIT	QTY. REQ.	UNIT
	1	END CAP - BOTTOM	H4-2029	11	1
	2	END CAP - TOP	H4-20548	11	1
	3	CLADDING TUBE	H4-20278	11	1
	4	WRAP WIRE .0555-.0560 DIA.			1
	5	END CAP - BOTTOM	H4-20291	11	1
	6	SPRING	H4-20293	11	1
	7	INSULATOR PELLET	H4-20296	11	1
	8	REFLECTOR	H4-20275	11	1
C	9	FUEL PELLET STACK	H4-20580	62	1
D	10	FUEL PELLET STACK	H4-20580	62	1
	11	END CAP - TOP	H4-20548	11	1
	12	PLENUM SPACER	H4-20274	62	1
E	13	TAG GAS CAPSULE ASSY	H4-2166	62	1
E	14	TAG GAS CAPSULE ASSY	H4-2166	62	1
	15	WRAP WIRE .0560-.0565 DIA.			1
	16	WRAP WIRE .0565-.0570 DIA.			1

- NOTES:**

1. END CAP TO CLAD WELD DIA. SHALL NOT EXCEED .2335
2. FUEL PIN TO CONFORM TO HWS-ISO4 AND RDT STANDARD E13-5 "FTTF DRIVER FUEL PIN"
3. GTAW WELD EACH END. USE TYPE 308L STAINLESS STEEL FILLER WIRE. (OPTIONAL)
4. WIRE WRAP TENSION TO BE 80 ± 0.5 LB.
5. FUEL PIN ASSY. (LESS WIRE WRAP) SHALL BE STRAIGHT WITHIN .010 PER FOOT OF DISTANCE BETWEEN CONTACT POINTS, WITH A MAXIMUM DISTANCE BETWEEN CONTACT POINTS OF ONE FOOT, WHEN LYING UNRESTRAINED ON A SURFACE TABLE AND ORIENTED TO GIVE MAXIMUM GAPS BETWEEN TABLE AND FUEL PIN ASSY.
6. ITEMS 115 TO BE WELDED TO NUMBERED END OF ITEM 3
7. ITEMS 4, 15, 416 TO BE USED AS DETERMINED BY FIGURE 1
8. AVERAGE DIA. OF FUEL PINS 15 TO BE DETERMINED TO $\pm .0001$ INCH WITH A CONFIDENCE LEVEL OF 95%.
9. IDENTIFICATION NUMBER TO BE PLACED ON TOP END CAP. NUMBER TO INCLUDE: VENDOR CODE, SERIAL NUMBER, TYPE NUMBER. CHARACTER HEIGHT IS TC BE .09 $\pm$.02.

(NOTES CONTINUED AT ZONE 7-G.)

M	ECN-09754 AUG 26 1974	AUG 26 1974	863 3/4 PM	REVISED PER ECN-D-0371	B
(2)	ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED DATE 7-21-94 BY SP-4 JAC/STP	4/4/74	4/4/74	RELEASED ERO-C-09754 7-11-74 RN 5208.00 TABLE 7 DELETED NOTES A,2,7 & CHANGED IT.A WAS .05G01.0005 DIR. ITS. 15 & 16 & FIG.1 ADDED	7
(C)	ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED DATE 7-21-94 BY SP-4 JAC/STP	4/4/74	NCS 4/4/74	RELEASED ERO-C-09135 ECN-5112.4 ECP-A-0190 ECP-C-207 ADDED SECTION A-A CONCENTRICITY WAS .010 NOTE C WAS FOR USE IN CORE ZONES II & III (OUTER) NOTE D WAS "FOR USE IN CORE ZONE I (INNER)"	6
(M)	ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED DATE 7-21-94 BY SP-4 JAC/STP	4/4/74	EP 11/26/74 11/27/74	INITIAL RELEASE ERO-0125/C 216 ECN-0906 ECN-133 ADDED NOTE B ADDED ITEM 13 & 14.	E
DATE	DATE	DATE	DATE	DESCRIPTION	DATE
APPROV	APPROV	APPROV	APPROV		

REVISIONS				
COMMENT PRT ISSUE NO.	DATE	CHECK PRT ISSUE NO.	DATE	LAST REV

DATA TYPE 1		DRAWING STATUS		0
		U. S. ATOMIC ENERGY COMMISSION RICHLAND OPERATIONS OFFICE Hanford Engineering Development Laboratory Westinghouse National Laboratory		
		WESTINGHOUSE ELECTRIC CORP.		
		DRIVER FUEL PIN ASSEMBLY		
		TYPES 3,1 & 3.2		
		FAST FLUX TEST FACILITY		
		DRAWING NO. 0405 WORK NO. 490040		
		PART NO. H-4-20581 QUANTITY 1 UNIT PIN		
		QUALITY CONTROL DEFECT REQUIREMENTS

ENGINEERING RELEASE BY
(W) APD
BY:ERO-QJ23 11-10-72
DATE

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

**DATE
FILMED**

5/6/94

END