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**POWER REACTOR
HIGH PERFORMANCE UO_2 PROGRAM
PROGRESS REPORT NUMBER 5
JULY 1 - DECEMBER 31, 1967**

COMPILED BY
S. Y. OGAWA

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189
PROJECT AGREEMENT 50

NUCLEAR FUELS DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

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January 1968

POWER REACTOR HIGH PERFORMANCE
UO₂ PROGRAM

Progress Report Number 5
July 1—December 31, 1967

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NUCLEAR FUELS DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

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FOREWORD

The United States and the European Atomic Energy Community (EURATOM) on May 29, and June 18, 1958, signed an agreement which provides a basis for cooperation in programs for the advancement of the peaceful applications of atomic energy. This agreement, in part, provides for the establishment of a joint U.S.-EURATOM research and development program which is aimed at reactors to be constructed in Europe under the Joint Program.

The work described in this report represents the Joint U.S.-EURATOM effort which is in keeping with the spirit of cooperation in contributing to the common good by the sharing of scientific and technical information and minimizing the duplication of effort by the limited pool of technical talent available in Western Europe and the United States.

SECTION I

INTRODUCTION

A research and development program was initiated on September 1, 1966, under Project Agreement 50 of Contract AT(04-3)-189 to irradiate a significant number of Zircaloy-2-clad UO_2 fuel rods to varying degrees of central melting in an operating power reactor. This joint AEC-Euratom program covers the detailed fuel design, including safeguards analysis and reactor license changes necessary to their irradiation, indirect fabrication supervision, irradiation following, and post-irradiation examination and reporting.

Six assemblies are planned for irradiation in the Consumers Big Rock Point reactor to an average exposure of 15,000 MWd/T. Two of the assemblies have been designated Intermediate Performance Fuel, and will operate with incipient melting in the central region of the UO_2 at rated power conditions. These assemblies might be considered the next step toward the elimination of the central melt criterion used as a limit in current fuel design practice. The remaining four assemblies have been designated Advanced Performance Fuel, and will operate with definite but moderate central melting at rated power conditions. These advanced performance assemblies represent a further step in reactor technology wherein the hottest fuel rods in the core are operating with moderate amounts of the UO_2 in the molten state at rated power conditions.

This is the fifth progress report and covers a six-months' period from July 1 through December 31, 1967. A report was deleted at

the end of the third quarter, because after the fabrication of the assemblies had been completed in the second quarter the only significant activity was in obtaining the license to allow the irradiation of the assemblies.

In this issue are included a brief statement of the conditions associated with the license that was granted to irradiate the six fuel assemblies, and highlights of the assembly fabrication.

A separate topical report on the design and fabrication of the assemblies will be issued at a later date. Prior reports issued to the commission under their contract have included the following:

1. GEAP-5402, December 1966:
Progress Report Number 1, July 1 through October 31, 1966,
Arlt, W. H., et. al
2. GEAP-5431, February 1967:
Progress Report Number 2,
November 1 through December 31,
1966, E. A. Lees
3. GEAP-5487, April 1967:
Progress Report Number 3,
January 1, 1967 through March 31,
1967, E. A. Lees
4. GEAP-5521, July 1967:
Progress Report Number 4, April 1 through June 30, 1967, E. A. Lees.

SECTION II

SUMMARY OF THE CENTERMELT FUEL DESIGN

2.1 STATEMENT OF WORK

The Power Reactor High Performance Irradiation Program encompasses activities in the design, the fabrication, the irradiation, and the evaluation of the performance of fuel rods operated in a power-producing BWR at high specific power levels to achieve various degrees of melting in the central regions of the UO_2 fuel. The objectives of the program are to demonstrate the feasibility of applying this mode of fuel operation sustained over a large percentage of the fuel lifetime to several full-size BWR fuel assemblies, to determine the condition of the fuel, and to evaluate its performance by obtaining specific data from post-irradiation examinations, both non-destructive and destructive, of selected rods at interim exposures and at end-of-life.

2.2 DESCRIPTION OF THE FUEL

Six fuel assemblies have been designed and fabricated for irradiation in the Consumers Big Rock Point reactor. A summary of the main characteristics of these assemblies is shown in Table 1. Detailed design of the fuel was described in the previous four progress reports listed as part of the introduction to this report. The two levels of central melting in the UO_2 for which the fuel rods were designed separate the assemblies into two groups as follows:

1. Intermediate Performance Fuel

The two Intermediate Performance Fuel assemblies are designed for operation with incipient central melting of the UO_2 at rated power. Each assembly has 64 rods in an 8×8 array; of these, 36 rods are power producing; the other 28 rods, containing vibratorily compacted depleted UO_2 , are essentially

non-power producing and are used for achieving specific thermal-hydraulic conditions in the assembly design. The power-producing rods in one assembly contain cold pressed and sintered pellets, and those in the other assembly, vibratorily compacted powder. The power rods in each assembly are designed to run at nearly the same relative power levels. Three U-235 enrichments (4.3, 5.0, and 5.6 percent) are used to achieve their power flattening. The distribution of the rods within an assembly is shown in Figure 1a, according to the fuel enrichment and beginning of life relative power.

The rods in these two assemblies are all clad with 0.570-inch-o.d. $\times$ 0.035-inch-wall Zircaloy-2 tubing. A depleted UO_2 sintered insulator pellet is placed at each end of the active fuel column to minimize temperature effects at the lower end plug region and on the spring used in the gas plenum at the upper end of the rod.

The accommodation of the phase change volume expansion of the UO_2 upon melting is by a dish in one end of each pellet, providing a void volume of 5 percent. The powder fuel, compacted to a bulk density of 85 percent of theoretical, will have a 15 percent distributed void volume, which is adequate to accommodate the volume expansion which will occur upon melting in these rods.

2. Advanced Performance Fuel

The Advanced Performance Fuel is designed for operation with definite, but moderate, central melting of the UO_2 at rated power. There are four assemblies in this group. Each assembly has 49 rods in a 7×7 array; of these, 29 rods are power producing; the other 20 rods, containing vibratorily compacted depleted UO_2 , are essentially non-power producing, and are also

TABLE 1
SUMMARY OF
CENTERMELT FUEL DESIGN DETAILS AND OPERATING CONDITIONS

<u>Fuel Assembly</u>	<u>Type</u>	<u>UO₂ Fuel</u>		<u>Number of Rods</u>	<u>Cladding Zircaloy-2, Tube Reduction Process)</u>		<u>Condition</u>
		<u>% TD</u>	<u>% U-235</u>		<u>Outside Diameter (inch)</u>	<u>Wall Thickness (inch)</u>	
<u>Group A</u>							
D-50	Pellet	95	4.3	12	0.570	0.035	Cold Worked and Stress Relieved
(8x8 Lattice)	Pellet	95	5.0	16			
	Pellet	95	5.6	8			
	Powder	85	0.22	28			
D-51	Powder	85	4.3	12	0.570	0.035	Cold Worked and Stress Relieved
(8x8 Lattice)	Powder	85	5.0	16			
	Powder	85	5.6	8			
	Powder	85	0.22	28			
<u>Group B</u>							
D-52	Pellet	95	4.3	12	0.700	0.040	Cold Worked and Stress Relieved
and	Pellet*	95	5.0	12			
D-53	Pellet	95	5.6	5			
(7x7 Lattice)	Powder	85	0.22	20			
D-54	Powder	85	4.3	12	0.700	0.040	Cold Worked and Stress Relieved
and	Powder*	85	5.0	12			
D-55	Powder	85	5.6	5			
(7x7 Lattice)	Powder	85	0.22	20			

<u>UO₂ Fuel</u>		<u>Design Burnup (MWd/TU)</u>	<u>Design Heat Flux (Btu/h-ft²)</u>		<u>Fuel Rod Power (kW/ft)</u>	
			<u>Normal</u>	<u>Overpower</u>	<u>Normal</u>	<u>Overpower</u>
<u>Group A 8x8</u>						
Cold Press and Sinter	Standard Dished	20,000	450,000 ±50,000	550,000	19.65 ±2.18	24.0
Dynapak	Vibratory Compaction	20,000	450,000 ±50,000	550,000	19.65 ±2.18	24.0
<u>Group B 7x7</u>						
Cold Press and Sinter	Standard, 0.100-inch Central Hole	20,000	450,000 ±50,000	550,000	24.15 ±2.68	29.6
Dynapak	Vibratory Compaction	20,000	450,000 ±50,000	550,000	24.15 ±2.68	29.6

* Four rods of this enrichment in each bundle will be replaced with rods containing tungsten wafers, after the first cycle of operation.

D 0.13	A 1.65	B 1.75	B 1.73	B 1.73	B 1.74	A 1.63	D 0.13
A 1.65	A 1.53	D 0.10	D 0.10	D 0.10	D 0.10	A 1.49	A 1.63
B 1.75	D 0.10	D 0.10	C 1.79	D 0.10	C 1.81	D 0.10	B 1.74
B 1.73	D 0.10	C 1.79	D 0.09	C 1.72	D 0.10	D 0.10	B 1.73
B 1.73	D 0.10	D 0.10	C 1.72	D 0.09	C 1.79	D 0.10	B 1.73
B 1.74	D 0.10	C 1.81	D 0.10	C 1.79	D 0.10	D 0.10	B 1.75
A 1.63	A 1.49	D 0.10	D 0.10	D 0.10	D 0.10	A 1.53	A 1.65
D 0.13	A 1.63	B 1.74	B 1.73	B 1.73	B 1.75	A 1.65	D 0.13

a. RELATIVE POWERS OF FUEL RODS IN 8x8 ASSEMBLY AT BEGINNING OF LIFE

D 0.13	A 1.60	B 1.68	B 1.67	B 1.68	A 1.60	D 0.13
A 1.60	A 1.42	D 0.10	D 0.10	D 0.10	A 1.42	A 1.60
B 1.68	D 0.10	C 1.71	D 0.09	C 1.71	D 0.10	B 1.68
B 1.67	D 0.10	D 0.09	C 1.65	D 0.09	D 0.10	B 1.67
B 1.68	D 0.10	C 1.71	D 0.09	C 1.71	D 0.10	B 1.68
A 1.60	A 1.42	D 0.10	D 0.10	D 0.10	A 1.42	A 1.60
D 0.13	A 1.60	B 1.68	B 1.67	B 1.68	A 1.60	D 0.13

UO₂ ENRICHMENTS

A 4.3% U-235
B 5.0% U-235
C 5.6% U-235
D 0.22% U-235

b. RELATIVE POWERS OF FUEL RODS IN 7x7 ASSEMBLY AT BEGINNING OF LIFE.

63-01373

FIGURE 1. DISTRIBUTION OF FUEL RODS IN ASSEMBLY ACCORDING TO POWER LEVELS AND UO₂ ENRICHMENTS

used for achieving specific thermal-hydraulic conditions in the assembly design.

Sintered pellet and compacted powder UO_2 fuels are used. The power-producing rods in two assemblies will have pellet fuel, and those in the other two assemblies will have compacted powder fuel. The U-235 enrichments used in these fuels are the same as those used in the Intermediate Performance Fuel. The distribution of the rods within the assembly is shown in Figure 1b.

The rods in the four assemblies are all clad with 0.700-inch o.d. $\times$ 0.040-inch-wall Zircaloy-2 tubing. A depleted UO_2 sintered insulator pellet is placed at each end of the active fuel column. The enriched pellets in the rods have a 0.100-inch-diameter hole at the center to provide a void volume for the phase change volume expansion of the UO_2 on melting. The 15 percent distributed void volume in the compacted powder fuel is adequate to accommodate the volume expansion on melting in this fuel.

A third fuel-rod design utilizes tungsten wafers placed at approximately 18-inch intervals in the fuel column for the purpose of minimizing axial movement of the molten UO_2 during rod operation. A total of eight rods of this design is planned to be fabricated and inserted into the Advanced Performance Fuel assemblies as replacement rods during an interim examination of the bundles conducted after the first cycle of operation. This feature is planned to be incorporated in both pellet-type and compacted-powder-type fuels.

2.3 PLANNED OPERATION OF THE FUEL

The fuel rods are designed so that central melting in the UO_2 occurs at a surface heat flux of $450,000 \pm 50,000 \text{ Btu/h-ft}^2$. The amount of melting that occurs depends upon the type of fuel. The calculated fractions of the fuel that will be molten over the design surface heat flux range are shown in Figure 2.

FIGURE 2. UO_2 MELT FRACTION VERSUS HEAT FLUX

67-01374

SECTION III

FABRICATION

3.1 FUEL RODS

The fuel rods were completed using conventional fuel loading procedures. The rods were evacuated and backfilled with reactor-grade helium at ambient pressure prior to welding the upper end plug.

Two straight pieces of tantalum wire, 0.094-inch in diameter and approximately 4 inches long, were placed in the gas plenum of all the rods. These wires act as neutron absorbers over a region normally occupied by UO_2 fuel in the regular fuel rods in the other assemblies, and thereby prevent flux peaking.

The tubing was prepared with either both inside and outside surfaces autoclaved or only the outside surface autoclaved. These two inside surface conditions will help in the evaluation of the relative protective nature of the autoclave oxide film. Of the 188 power-producing rods in the six assemblies, 76 rods have tubing without the autoclaved inside surfaces.

Each fuel rod was measured for over-all length and diameter (0 and 90 degree orientations) at 12-inch intervals. Outside diameter profiles were also taken on 72 power-producing rods. The profilometer measurements were of the non-rotational type at 0 and 90 degree orientations, and of the rotational type.

Radiographs were taken of the bottom end and upper plenum regions of each rod to verify that the parts were properly assembled.

The fuel rods containing the tungsten wafers will not be in the initial rod loading of the Advanced Performance Fuel because they have not been fabricated yet. It is planned to have them ready for insertion into the assemblies after the first cycle (approximately 3 months) of operation.

The fuel rods are identified by a serial number metal stamped on the bottom end plug. To facilitate separation of the rods by enrichment and to facilitate the loading of the proper

fuel rods into the correct locations, the rods are further identified by metal stamping the ends of the top plugs with 1/4-inch-high letters referring to the four fuel enrichments as follows: A = 4.3 percent, B = 5.0 percent, C = 5.6 percent, and D = 0.22 percent. This method of identification is illustrated in Figure 3. As a final verification that the rods are properly assembled, a Polaroid photo of the top of the assembly will be taken and the print checked against another record before the top handle is attached after final inspection at the reactor site.

67-013/5

FIGURE 3. TOP END PLUG IDENTIFICATION FOR FUEL ENRICHMENT

3.2 ASSEMBLY AND STRUCTURE

The assembly was designed for all rods to be removed individually. This design feature is illustrated in Figure 4. Removal of the top handle exposes the rods, which can then be grasped with an appropriate tool during underwater rod-replacement operation.

The fully assembled bundle is shown in Figure 5, along with details of the structure in the upper, middle, and lower regions.

HANDLE AND LOCKING PINS

NEGATIVE A—672086

7x7, PARTIALLY LOADED

NEGATIVE A—672049

8x8, PARTIALLY LOADED

NEGATIVE A—672083

FIGURE 4. BUNDLE DESIGN WHICH ALLOWS ALL FUEL RODS TO BE REMOVABLE

FIGURE 5. FULLY ASSEMBLED 7x7 BUNDLE AND STRUCTURAL DETAILS

SECTION IV

IRRADIATION LICENSE

As a result of Division of Reactor Licensing and Advisory Committee on Reactor Safeguards review, permission has been granted to irradiate the six special fuel assemblies. The permission is conditional with respect to the following changes:

1. Increased procedural and administrative controls to maintain low control rod worths at all times.
2. Plans for improved in-service inspection of reactor primary system piping.
3. Plans for improving the emergency core cooling system, including a prerequisite requirement to supply emergency water to the reactor vessel in the event of failure of the existing core spray line.
4. Improved timing on detection of significant increase in offgas activity due to fuel failure.
5. Following the initial period of operation, (after about 3,000 MWd/T

exposure) the four High Performance Fuel assemblies shall be removed from the reactor until destructive examinations are performed in order to confirm the design bases for this fuel and to establish that no added risk is inherent in their operation to the point in life where the degree of melting is maximum (about 10,000 MWd/T).

Analysis work in support of Change 13 to the Big Rock Point Operating License was primarily in the areas of prompt reactivity-induced excursions and loss-of-coolant accidents.

Action is being taken or is planned to be taken to satisfy all of these conditions. Emphasis is on the installation of the emergency cooling water system at the reactor site.

It is planned to insert the six centermelt assemblies into the Big Rock Point reactor during the January-February 1968 refueling shutdown.

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