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THERMAL REACTOR PLUTONIUM FUEL IRRADIATION PROGRAMS
IN THE UNITED STATES

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THERMAL REACTOR PLUTONIUM FUEL IRRADIATION PROGRAMS IN THE UNITED STATES

INTRODUCTION

During the 1968 IAEA Plutonium Utilization Panel meeting, the author briefly described several United States programs on plutonium recycle.^[1] At that time, two of these programs included significant irradiation experiments: (1) irradiation experiments in the Plutonium Recycle Test Reactor as part of the USAEC's Plutonium Utilization Program conducted by Battelle, Pacific Northwest Laboratory, and (2) The USAEC-Westinghouse Saxton Reactor Plutonium Program. Several other irradiation programs were in the planning stage. These latter programs have reached a point where plutonium bearing fuel assemblies have been inserted in power reactors including irradiation demonstration programs in the Big Rock Point and San Onofre reactors by Edison Electric Institute (EEI) in conjunction with General Electric Company and Westinghouse Electric Corporation and in Dresden Unit 1 as a cooperative effort between Commonwealth Edison Company and United Nuclear Corporation. This paper presents brief descriptions and current status of these programs extracted from indicated references and private communications.

PLUTONIUM RECYCLE TEST REACTOR EXPERIMENTS

Experiments in the PRTR were terminated in June, 1969. In addition to special fuels irradiations, a carefully controlled burnup experiment, PRTR Batch Core Experiment, was being conducted in order to obtain nuclear and fuel performance characteristics of a full plutonium core as a function of fuel exposure. The central zone of 55 UO_2 - 2 wt.% PuO_2 fuel assemblies out of total of 85 assemblies made up the Batch Core. From experimental data the average exposure of the Batch Core fuel was projected to reach 14,000 MWd/MTM before loss of reactivity required core modification. At the time the program was terminated, the average exposure had reached   MWd/MTM. Critical experiments were performed on the Batch Core fuel elements at several burnup intervals. These data and analyses of the experiment are presented in another paper for this panel meeting.

SAXTON PLUTONIUM PROGRAM

The original scope and description of the Westinghouse/AEC Saxton Plutonium Program* was described during the 1968 IAEA panel meeting^[1]. The scope of experiments identified (Core II operation) has been completed. The program was expanded to include Overpower Test and Extended Burnup Test (Core III)^[2,3]. The total program is briefly summarized here.

Original Scope (Core II)

The original objectives of the program were to:

- Perform pilot-scale tests on UO_2 - PuO_2 fuel in a PWR environment;
- Provide a statistically valid performance comparison between two economically promising UO_2 - PuO_2 fabrication techniques; and
- Provide a preliminary basis for plutonium fuel selection and design for a PWR.

To accomplish these objectives, nine UO_2 - 6.6 wt.% PuO_2 fuel assemblies were inserted in the central zone surrounded by twelve 5.7% enriched UO_2 assemblies, making up the Saxton Core II fuel loading. Of the nine plutonium assemblies, two contained vibratory compacted fuel and seven contained pelletized fuel. With the exception of thirty fuel rods which were clad with 304 stainless steel, the plutonium fuel rods were clad with Zircaloy-4.

Initial criticality was achieved on December 6, 1965, and the core reached rated power of 23.5 MW_t on February 7, 1966. End of Core II life was achieved in October 1968. The peak burnup on the plutonium fuel is estimated to have been 29,000 MWD/MTM. An extensive post-irradiation

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* The Saxton Plutonium Project is conducted by Westinghouse in cooperation with the Saxton Nuclear Experimental Corporation under USAEC Contract AT(30-1)-3385.

program has been completed. Elements of this examination program included physical, metallurgical, nuclear, and fuel systems analysis. All evidence^[4,5,6] obtained from examination of the fuel and by deduction from reactor operation data shows that, as expected, the plutonium-enriched mixed oxide fuel performs as well as the standard UO₂ fuel.

Overpower Test

The overpower test was designed to establish confidence in the overpower performance of previously irradiated plutonium fuel. Two rods with accumulated average burnups of approximately 13,500 MWd/MTM were placed in a subassembly with an increased lattice pitch. This allowed these rods to be operated at a higher power than the remainder of the core. The rods were successfully irradiated at power to 19 kw/ft. A post-irradiation examination, similar to that for the Core II rods, has been completed. Further evidence as to the complete adequacy of plutonium fuel operating in a uranium-optimized reactor has been accumulated as a result of this sub-program.

Extended Burnup Test (Core III)

The objectives of this program are to:

- Demonstrate the performance of mixed-oxide fuel at linear power and burnup levels consistent with modern PWR technology.
- Obtain design information on the depletion and transuranic isotope generation characteristics of plutonium fuel at higher burnup.

Approximately 250 fuel rods from the Saxton Core II were selected for reconstitution, using new skeleton hardware, into seven Core III open-lattice assemblies. The required Core II fuel assemblies were shipped from the Saxton reactor to the Westinghouse facility at Waltz Mill, Pennsylvania. There, the selected rods were removed from their original assemblies, inspected, and inserted into new assembly hardware in the more open array. The Core III assemblies were then returned to the Saxton

reactor for insertion into the reactor vessel. Upon initial criticality of Core III, operation follow-up and performance analysis work were performed.

Sufficient calculations were carried out to follow the power history of the core. A supporting program of analysis will be carried out to determine the reasons for any discrepancies between analysis and experiment that may occur.

Eight rods with both peak and average exposures will be examined at both mid-life and at end of Core III operation. The specific examinations and sampling plan for these rods will depend largely on the results obtained from the interim evaluation. The scope of this examination will be quite similar in coverage to the Core II post-irradiation examination.

The reactor returned to operation in December, 1969. Presently, peak burnup of 44,000 MWd/MTM and 19.5 Kw/ft operation have been achieved. By early 1972, Saxton Core III plutonium fuel should achieve ~50,000 MWd/MTM peak burnup and will have demonstrated the peak power and burnup levels required for modern PWR's.

EEI-GENERAL ELECTRIC PLUTONIUM RECYCLE DEMONSTRATION PROGRAM^[7,8]

The Edison Electric Institute (EEI) and the General Electric Company are engaged in a second joint program to evaluate the utilization of plutonium in boiling water reactors (BWR's). The objective of the early work (Phase I), reported briefly during the 1968 panel meeting, was to evaluate the technical and economic aspects of the various approaches for return of plutonium to a BWR. The major emphasis of current Phase II program is to obtain performance data through irradiation of prototypic fuel. The Phase II objectives are:

- To provide needed data on the operating performance of recycle fuel rods in a BWR, and
- To perform preliminary design studies of a recycle fuel that would serve as a basis for a batch reload program.

The Phase II irradiation programs are:

1. Thirty-two (32) removable $\text{UO}_2\text{-PuO}_2$ rods of various pellet fuel designs in 16 bundles of uranium reload fuel and 3 fuel bundles of $\text{UO}_2\text{-PuO}_2$ rods have been inserted in the Big Rock Point reactor. The pellet designs used in the 32 rods were solid, dished and annular. All pellets in the 3 fuel bundles were of the annular design. The peak linear power for the 32 rods and the 3 bundles is 14 Kw/ft. and 16 Kw/ft., respectively. The maximum exposure is projected to be by September, 1971 19,500 Mwd/MTM for the 32 rods and 14,600 Mwd/MTM for the 3 bundles. Several of the removable rods have been thoroughly examined in the radioactive materials laboratory with favorable results.
2. Four plutonium bearing fuel bundles will be inserted in the initial core of Vermont Yankee reactor. These bundles include a 12 rod island of $\text{UO}_2\text{-PuO}_2$ and are directly interchangeable with initial core fuel. Two bundles contain solid pellets and 2 contain annular pellets of $\text{UO}_2\text{-PuO}_2$.

The general approach of the program has been to minimize design differences and simply replace UO_2 rods/or bundles or both with outwardly appearing identical $\text{UO}_2\text{-PuO}_2$ rods or bundles. The thermal hydraulic performance of these rods and bundles is similar to that used for the UO_2 so existing licensing limitations are not exceeded. Short-term irradiation surveillance will be used to prove mechanical and thermal fuel performance and long-term irradiation will be used to prove lifetime characteristics of prototypical fuel.

Product, statistical quality control and process specifications have been implemented in realistic fabrication campaigns. Licensing precedents have been established. Shipping and site installation of $\text{UO}_2\text{-PuO}_2$ fuel rods have been accomplished without difficulty, thereby proving one possible mode of bundle assembly for plutonium recycle.

COMMONWEALTH EDISON - UNITED NUCLEAR DEMONSTRATION PROGRAM^[9]

A cooperative demonstration program has been initiated by Commonwealth Edison Co. and United Nuclear Corporation to develop the information needed for supplying a full plutonium recycle reload batch. In this program, 11 prototype plutonium fuel assemblies have been designed and fabricated. These assemblies were loaded into Dresden 1 in the Fall of 1969 as part of the Cycle 7 reload. As of September 1, 1971, the projected average exposure for all plutonium recycle assemblies is 8,300 MWd/MTM, with the highest power assembly having an average exposure of 9,000 MWd/MTM. The highest power $\text{PuO}_2\text{-UO}_2$ rod will have obtained an average exposure of 10,800 MWd/MTM and the highest power pellet an irradiation of 14,800 MWd/MTM.

The principal objectives of the Dresden Plutonium Recycle Program are as follows:

1. Establish the adequacy of the reference plutonium recycle design through operation of full scale plutonium recycle fuel assemblies under actual commercial conditions.
2. Establish the fuel cycle cost basis of fabricating mixed-oxide fuel assemblies on a semi-production scale.
3. Obtain reactivity and local power distribution data on mixed oxide assemblies through performance of critical tests before irradiation at the United Nuclear Pawling Lattice Test Rig Facility (PLATR) and Proof Test Facility (PTF).
4. Evaluate in-core performance of the plutonium assembly in a commercial reactor by means of the in-core instrumentation.

Studies were initiated by United Nuclear Corporation in June 1964 and have continued in order to identify economical plutonium-recycle strategies for BWR's based on the quantity of plutonium available and the operational limits of the system. Based on this work a reference design was selected for the Dresden Demonstration Program. The design

provides for recycling the plutonium recovered from one discharged uranium assembly in a single reload assembly in order to make the station independent of the value of plutonium on the open market. In addition the design provides for concentrating the plutonium in 9 out of the 36 rod locations in order to minimize the following:

1. Fabrication differential associated with $\text{PuO}_2\text{-UO}_2$ assemblies.
2. Local and intra-assembly power peaking.
3. Influence of plutonium on control rod worth.

The plutonium fuel is mixed with natural uranium to improve fuel cycle economics.

The reactivity levels of the mixed oxide assemblies are matched to the reactivity of the uranium assemblies in the cold conditions. The hot operating levels are lower for the plutonium assemblies due to the larger negative moderator and void reactivity coefficients in $\text{PuO}_2\text{-UO}_2$ fuel.

The plutonium-bearing fuel assemblies have uranium rods in all peripheral positions of the assembly to prevent power peaking at interfaces between adjacent plutonium and uranium assemblies. The local power peak in the mixed-oxide assembly occurs in a $\text{PuO}_2\text{-UO}_2$ rod and is equivalent to that in a standard uranium assembly ($\bar{P}/\bar{P} = 1.28$). With burnup the local peaking factor decreases.

The plutonium assemblies have been designed to provide exposure equivalent to the Cycle 7 uranium reload assemblies.

Operational characteristics of the Dresden I reactor are being followed by means of instrumented thimbles during Cycle 7 and will be followed during subsequent cycles to evaluate performance with a partial plutonium reload. The eleven mixed-oxide fuel assemblies will provide a measurable effect on local power distribution and steam void distributions

without significantly affecting the overall reactivity, cycle burnup, shutdown margins and safety characteristics of the reactor.

The assembly design features three removable plutonium rod locations. There is a possibility that individual $\text{PuO}_2\text{-UO}_2$ fuel rods may be removed during shutdown periods for visual and/or metallographic inspection.

EEI-WESTINGHOUSE PLUTONIUM RECYCLE DEMONSTRATION PROGRAM^[3]

In early 1968 the EEI-Westinghouse Plutonium Utilization Program was completed. This program was primarily an analytical feasibility study and constituted the necessary preliminary step toward actual irradiation of plutonium in a commercial PWR. To accomplish the latter, a Plutonium Recycle Demonstration Program Co-sponsored by Edison Electric Institute, Westinghouse Electric Corporation and the USAEC was undertaken. The purpose of this program is to license, operate and evaluate a representative number of plutonium fuel rods in a PWR. A total of 720 $\text{UO}_2\text{-PuO}_2$, Zircaloy-4 clad fuel rods in four fuel assemblies have been loaded in San Onofre reactor. These assemblies, containing 45 Kg of plutonium, were loaded in the reactor during its first refueling shutdown and achieved full power operation in November 1970. They will be operated during three reactor cycles. Periodic measurements and tests will be made as a check on analytical predictions. At the end of each cycle, plutonium fuel rods will be removed, examined, and returned to the core. Some of the 104 removable rods will be replaced and then shipped to Westinghouse for post-irradiation examination. By September, 1971, the demonstration assemblies will have reached about 5,000 MWd/MTM burnup.

The demonstration assembly design configuration consists of all rods containing pelletized $\text{UO}_2\text{-PuO}_2$ fuel. The assemblies also contain three different plutonium enrichments located to control local power peaking near control rod thimbles and at plutonium-uranium interfaces so that the plutonium assembly peak-to-average power would be no higher than in the uranium assemblies. The quantity of plutonium in the assemblies is representative of the initial loading for self-generated

recycle. The enrichments were selected to give equivalent lifetime capability to the 4.0% enriched UO_2 fuel. Installation of the four demonstration assemblies did not change the thermal-hydraulic limits for the San Onofre reactor and had negligible effect on the core average kinetic parameters.

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