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SAXTON PLUTONIUM PROGRAM

SEMIANNUAL PROGRESS REPORT

FOR THE PERIOD

ENDING JUNE 30, 1966

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Project Manager

Prepared for the New York Operations Office
U. S. Atomic Energy Commission
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July 1966

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SUMMARY

This semiannual report replaces the seventh and eight quarterly reports previously planned and covers the work done during the second half of fiscal 1966.

Objectives

The purpose of the Saxton Plutonium Project is to develop information concerning the utilization of plutonium enriched fuel in pressurized water reactor systems, through design, fabrication and operation of a partial core of $\text{PuO}_2\text{-UO}_2$ in the Saxton reactor. Inpile performance of this fuel will be evaluated and post irradiation examination of fuel samples will be made. Performance will be analyzed and compared with analytical predictions.

Project Administration: Core II has been operated at or near full power during most of this period. Work programs have been approved.

Nuclear Analysis of Operational Performance: During this semiannual report period the startup experimental program was completed. For most of the period the core operated at full rated power. The core has achieved roughly half of the design burnup and there is sufficient reactivity left in the core to significantly exceed the burnup objectives. Close agreement between the measured and calculated reactivities has been demonstrated for control rod and boron worth, and for critical boron concentration requirements. Core

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All project work up through full power operation has been completed. The work remaining consists of continued operation of the fuel in Saxton, core follow, post-irradiation examination of fuel in accordance with the approved sampling plan and comparison of actual performance (nuclear and material's) with predicted performance.

Operation during the first half of 1966 with plutonium fuel assemblies in the central nine locations of the Saxton Reactor was exceptionally smooth with reactor plant problems kept to a minimum by the Saxton Nuclear Experimental Corporation operations staff. At the beginning of the year the reactor was operating at 17.0 MWt, having generated initial power with Core II on December 28, 1965.

Physics parameters and hot channel factors were measured at power during the first week of January. The data, which were evaluated and compared with calculated values, showed excellent agreement between predicted and measured numbers. Power was increased in a stepwise fashion to 21 MWt early on January 8. Power remained at 21 MWt until January 10, when an emergency in the Penelec Utility System required the turbine to be placed on coal plant steam to obtain additional power output from the generator. This was only a brief emergency and was cleared up in a few hours. Advantage of the shutdown was taken to measure the Xenon decay from 21 MWt by carrying out one of the pre-planned shutdown tests. After completion

of this test, power was returned to 17 MWt on January 13 and increased to 21 MWt on January 15.

Reactor physics measurements were continued until February 7, with a brief power reduction from 21 MWt to 17 MWt on January 26-28. Control rod configurations were adjusted to obtain flux wire maps in the peak hot channel factor areas. Power was increased to the licensed value of 23.5 MWt for the first time on February 7. To do this, it was necessary to change three reactor set points in order to operate within the limitations of the Technical Specifications. The set points affected were (1) reduction of the reactor hot leg scram from 554°F to 535°F, (2) reduction of the nuclear overpower scram from 115% to 110% of full power and (3) increase of the low pressure scram setting from 1600 psig to 1800 psig. These limitations, along with administratively controlled rod programming, permitted operation of the reactor at 23.5 MWt.

The reactor was kept at 23.5 MWt until March 31, with a brief shutdown for operator license exams on February 21-25, and for some additional physics measurements on March 1-3.

The shutdown on March 31 was to allow for plant maintenance and to remove the 3x3 subassembly from the reactor. The subassembly was inspected visually with an underwater periscope and found to be in excellent mechanical condition with extremely small amounts of crud on the fuel cladding. This subassembly was at least as free of crud as any subassembly that has ever been removed from this center core

location in the reactor. At the time of removal, the subassembly had reached an average burnup of about 4500 MWD/MTM and a peak burnup of about 6100 MWD/MTM. Present plans call for shipment of the four removable rods from this subassembly to WPIF hot cells in August of 1966 for post-irradiation examination.

The reactor was returned to 23.5 MWt on April 26 and continued at this power level through June except for two brief shutdowns. The first of these, which occurred June 4-6, was initiated by a work stoppage of the Penelec union personnel. The last shutdown occurred on June 27 as scheduled, to enable a SNEC technician to take his AEC Reactor Operators License Test.

At the end of June, the average burnup in the plutonium region of Core II was about 6170 MWD/MTM. This amounts to an average burnup in the hot rod of 9160 MWD/MTM and to a peak pellet burnup of about 12,400 MWD/MTM.

Operation during this semi-annual period has been excellent with no unanticipated problems caused by utilizing plutonium fuel.

Work is presently in progress to obtain a license to operate the plutonium fuel at a significantly higher power level (to 19.1 kw/ft specific power or to 35 MWt reactor power, whichever is reached first) for a 2-3 month period. A complete review of reactor physics, thermal and hydraulics, materials, and of transient response has been completed. A safeguards report is being written by Westinghouse

to justify operation at this higher power. Assuming timely receipt of the necessary license amendment, power escalation is scheduled during the last quarter of calendar '66.

SAX-510 Nuclear Analyses of Operating Performance
F. L. Langford, W. L. Orr, H. I. Sternberg, R. M. Chastain,
A. J. Impink, W. D. Leggett

A. Introduction

1. Purpose

A basic objective of this task is to compare the expected performance of the plutonium fuel in the Saxton reactor with experimental results and to evaluate the differences found between analysis and experiment. A second objective is to provide supporting analysis during the irradiation period. The supporting analysis includes the evaluation of reactivity and power distribution changes with time corresponding to the operating history of the core.

2. Sequence of Events

To fully understand the accomplishments of this semiannual report period, it is desirable to review the sequence of experimental events that have occurred. The following list summarizes some of the more significant experimental events:

<u>Event</u>	<u>Date</u>
Achieve Initial Criticality in Partial Plutonium Core	12/6/65
Complete Zero Power Physics Test Program	12/28/65
Initial Power Operation	12/29/65
Achieve Rated Power, 23.5 MWt	2/7/66
Complete Power Physics Tests	3/11/66

Upon completion of the startup power physics tests, the core was operated at rated power for a major part of the period in order to achieve as much burnup in the plutonium fuel as possible. An average burnup in the plutonium fuel of approximately 6170 MWD/MTM has been achieved.

3. Scope of the Experimental Measurements

The nuclear characteristics of the partial plutonium core were measured at cold, zero-power; hot, zero-power; and at power. The measurements made at each of these conditions were:

Measurements at Cold, Zero-Power and at Hot, Zero-Power

1. Boron endpoints and worths
2. Control rod worth measurements
3. Temperature coefficient measurements
4. Pressure coefficient measurements
5. Minimum shutdown reactivity measurements
6. Xenon decay after shutdown following operation at 21.5 MWt

Measurements at Power

1. Boron worths
2. Control rod worths
3. Temperature coefficients
4. Power coefficients
5. Core depletion
6. Core flux wire and detector maps

4. Scope of the Supporting Analysis

The analysis carried out during the semiannual report period had the following basic objectives:

- a. Calculations were made of boron requirements and control rod worth corresponding to the cold, zero-power and hot, zero-power just critical conditions. These calculations supplement those carried out in advance of the measurements program.¹
- b. Calculations were made to follow the reactivity of the core as a function of the operating history.
- c. Calculations were made to determine the appropriate nuclear factors for relating flux wire and in-core detector measurements to local power. These calculations were carried out in the clean core at the beginning of life to set the power level at which the core could operate and at specific times in the core life

in order to establish the power distribution characteristics of the core with operation.

In comparing the results of the analysis with the experiment, it is informative to make the comparison in two ways. First, it is of value to compare the analytic predictions to the results obtained in the experiment. Second, it is interesting to compare experimental results obtained in the operation of Saxton Core I, an all uranium core, with that obtained in the operation of Saxton Core II, a core containing nine central $\text{PuO}_2\text{-UO}_2$ fuel assemblies. This comparison leads to an increased understanding of some of the performance differences between uranium and plutonium fuels.

B. Boron Endpoint and Worth

1. Experimental Results

Boron endpoint measurements were made for a number of different control rod patterns - all rods out, rod 2 in, rods 2 and 5 in, and rods 2 and 5 in with rods 1 and 6 partially inserted. (See Figure 510.13 for the location of the various control rods). The differential boron worths were then calculated from the boron endpoints and the integral control rod worths discussed in the following section. Table 510.1 contains a summary of the experimental results.

As shown in Table 510.1 the zero-power boron worths, both cold and hot, are approximately the same. Hence, an average of the measurements was adopted as the single, best value for the beginning-of-life, zero-power boron worth.

Recommended Best Single Value of Boron Worth
(Beginning-of-Life, Zero-Power)

Differential Boron Worth ($\frac{\delta \rho}{\delta B}$)	0.00625% $\Delta k/k/ppm$
Inverse Boron Worth ($\frac{\delta B}{\delta \rho}$)	160 ppm/% $\Delta k/k$

TABLE 510.1

SUMMARY OF BORON ENDPOINT AND WORTH MEASUREMENTS

<u>Control Rod Configuration</u>	<u>Endpoint Boron Concentration, ppm</u>	<u>Boron Equivalent, ppm</u>	<u>Integrated Control Rod Worth, mp</u>	<u>Reactivity Worth of Boron, mp/ppm</u>	<u>Inverse Boron Worth, ppm/%ρ</u>
<u>Cold Measurements (150°F)</u>					
All rods out	2718	450	28.66	0.0637	158
Rod 2 in	2268	526	31.63	0.0602	166
Rods 2 and 5 in	1742	225	14.53	0.0646	155
Rods 2 and 5 in 1 and 6 at 18.4"	1516				
<u>Hot Measurements (530°F)</u>					
All rods out	2296	594	36.87	0.0621	161
Rod 2 in	1702	655	40.30	0.0616	162
Rods 2 and 5 in	1047				

2. Comparison of Analysis and Experiment

Predicted boron concentration requirements for the hot, zero-power and cold, zero-power conditions were determined using a LEOPARD-V²-BUBBLE³-PDQ-3⁴ calculation sequence in advance of Saxton Core II operation. Calculations were also made of the reactivity worth of rods 2 and 5 and of the total bank worth at several boron concentrations. When the boron endpoint and differential worth measurements were made, the experimental just-critical rod pattern did not correspond directly to the conditions assumed in the analysis. To use the existing analysis in determining a realistic comparison of the analysis with experimental results, a number of additional calculations at different boron concentrations and rod patterns were carried out. The additional calculations made it possible to establish a map of calculated k_{eff} as a function of boron concentration for different rod configurations. The maps for the cold, zero-power and hot, zero-power conditions are shown in Figures 510.1 and 510.2. From these maps the analytic just-critical boron concentrations corresponding to the rod patterns used in the measurement were determined.* The

* The just-critical line shown in Figure 510.1 and 510.2 contains a total Δk_{eff} allowance of +.018 for (a) a reactivity discrepancy (+0.012)_{eff} in Saxton Core I, (b) the effect of substituting Inconel grids for stainless steel (+0.003), and (c) for a reactivity bias (+0.003) found in the analysis of the Saxton Plutonium critical experiments that was not incorporated in the BUBBLE portion of the analysis sequence.

comparison of the analytic and measured boron concentration requirements is summarized in Table 510.2. The calculated and measured inverse boron worths are compared in Table 510.3.

These two tables show that the calculated and observed values are in excellent agreement.

C. Control Rod Worth

1. Experimental Results

Differential control rod worth data were obtained by moving the rod to be measured in a series of steps and measuring the reactivity change associated with each step using an on-line reactivity computer. The differential and integral control rod worth curves for rod 2 with no other rods inserted are shown in Figure 510.3 for the cold, zero-power and hot, zero-power conditions. Similar data are shown in Figure 510.4 for the rod 5 measurements made with rod 2 inserted and the other rods removed. Each rod worth measurement was made both by withdrawing and inserting the rod. There were no significant differences between the withdrawal and insertion measurements.

TABLE 510.2

CALCULATED AND OBSERVED CRITICAL BORON CONCENTRATIONS

	<u>Calculated (ppm)</u>	<u>Observed (ppm)</u>
<u>Cold</u>		
All rods out	2715	2718
	470	450
Rod 2 in	2245	2268
	555	526
Rods 2 and 5 in	1690	1742
<u>Hot</u>		
All rods out	2240	2296
	640	594
Rods 2 in	1600	1702
	625	655
Rods 2 and 5 in	925	1047

TABLE 510.3

CALCULATED AND OBSERVED INVERSE BORON WORTHS

		Calculated (ppm/% $\Delta\rho$)	Observed (ppm/% $\Delta\rho$)
<u>Cold</u>			
All rods out			
Rod 2 in	>	178	161
Rods 2 and 5 in	>	152	162
<u>Hot</u>			
All rods out			
Rod 2 in	>	148	158
Rods 2 and 5 in	>	132	166

2. Comparison of Analysis with Experiment

Analytic rod worths determined prior to Saxton Core II operation were calculated at different boron concentrations from the just-critical concentrations at which the measurements were actually made. However, the calculated k_{eff} maps described in the previous section provide a basis for determining rod worth at any desired boron concentration. A comparison of the calculated and observed rod worths at the appropriate boron concentrations is included in Table 510.4. This comparison shows excellent agreement between the calculated and observed rod values except for the large discrepancy for rod 5 in the cold core. There is no explanation for a discrepancy of this size. It is believed to be due to an input error in the particular calculation rather than an indication of failure of the analysis method. A review of the calculation is in progress.

D. Temperature Coefficient

1. Experimental Results

Recommended values of the differential temperature coefficient over the operating temperature range of Saxton Core II are shown in Figure 510.5 for a number of boron concentrations. The temperature coefficient measurements were confined to a rather narrow range around 530°F. The curves shown in Figure 510.5 represent measured Core II

TABLE 510.4

CALCULATED AND OBSERVED CONTROL ROD WORTHS

	Calculated (% $\Delta\rho$)	Observed (% $\Delta\rho$)	% Discrepancy $\frac{\text{Calculated} - \text{Observed}}{\text{Observed}} \times 100$
<u>Cold</u>			
Rod 2	3.1	2.9	+ 6.9%
Rod 5 with Rod 2 in	4.1	3.2	+28.1%
<u>Hot (Zero Power)</u>			
Rod 2	3.5	3.7	- 5.4%
Rod 5 with Rod 2 in	4.2	4.0	+ 5.0%
<u>Hot (At Power)</u>			
Rod 2	3.4	3.6	- 5.6%
Rod 5 with Rod 2 in	4.0	3.9	+ 2.6%

data extrapolated to higher and lower temperatures in accordance with the results of a more comprehensive zero-power experimental program carried out at Core I startup.⁵

2. Comparison of Analysis and Experiment

A comparison of the measured and predicted temperature coefficient at 530°F as a function of boron concentration is shown in Figure 510.6. There is a discrepancy of $\sim 10\%$ between the curves at a boron concentration of 1550 ppm. Thus, there is good agreement between analysis and experiment as indicated in this comparison.

E. Power Coefficient

1. Experimental Results

During power operations, numerous measurements were made of the power coefficient. Measurements relating power defect to the on-line computer measured reactivity were carried out over the entire power range to ~ 20 MW. The results of these measurements are shown in Figure 510.7.

2. Comparison of Analysis with Experiment

The Saxton Core II measured power coefficient is compared in Figure 510.8 to that predicted using a LEOPARD II-AIM-5⁶ calculation sequence. This comparison leads to the following observations:

Figure 510.6

A Comparison of the Calculated and Measured Temperature Coefficient
for Saxton Core II for a Variation in Boron Concentration

(530°F, Zero-Power)

- a. The measured power coefficient is more negative at the design power level, 23.5 MW, than that indicated by the analysis.
- b. The total power defect is approximately the same for the measured and calculated curves.
- c. The discrepancy in shape is similar to that found in the comparison of the measured and calculated power coefficient curves for Saxton Core I. The magnitude of the discrepancy between analysis and experiment at 20 MW is larger than that found in the Core I correlations.

Figure 510.8 also includes a comparison of the measured power coefficient of Saxton Core II with that of Saxton Core I. As shown in this figure, the partial plutonium core has a more negative power coefficient than that of the all uranium core at the design power level.

The differences between the calculated and measured Saxton Core II power coefficient is due in part to a difference in fuel temperature between the analysis and experiment. A small reduction in fuel pellet diameter was made after the detailed reactivity coefficient calculations were completed. At that time, it was not possible to re-evaluate the power coefficient for the resulting increase in fuel temperature. Instead, the expected installed reactivity tabulation⁷ was reduced slightly to compensate for a small increase in the

power defect. Later other design changes led to an increase in the plutonium enrichment from 6.0 w/o PuO_2 to 6.6 w/o PuO_2 . The enrichment change was not included in the power coefficient calculations. A major portion of the power coefficient is due to the U-238 present which would be only slightly reduced in the enrichment change. However, the Pu-240 content would be increased by 10%.

If the effect of the increase in fuel temperature and fuel enrichment were included, the correlation between analysis and experiment should be improved. A re-evaluation of the power coefficient is now in progress.

F. Burnup and Core Depletion

1. Burnup

As of June 1, 1966, Saxton Core II had operated for ≈ 2500 MWD. During this period, the plutonium fuel had accumulated an average burnup of ≈ 5000 MWD/MTM. This burnup value is one-half of the original design goal of 10,000 MWD/MTM and the irradiation of the fuel is proceeding ahead of the anticipated schedule.

2. Core Depletion

Core depletion is conveniently expressed in terms of the all-rods out critical boron concentration as a function of operation. A running plot of the main coolant boron concentration versus burnup at a common set of system conditions

was maintained during Saxton Core I operation and is now being used in the follow of Saxton Core II. A comparison of the depletion of Core I and Core II is shown in Figure 510.9.

As shown in this figure the boron concentration was a linear function of burnup in Core I. The slight offset in the experimental data at ≈ 6300 MWD/MTM was due to the replacement of two 9x9 fuel assemblies and two 3x3 subassemblies. The depletion characteristics were linear before and after the fuel change was made. Extrapolation of the Core II depletion data, which is current as of June 1, shows that a core average burnup of $\approx 10,000$ MWD/MTM can be achieved. This burnup is equivalent to core lifetime of ≈ 8500 MWD which is slightly higher than the design goal of 8250 MWD. If the core is allowed to operate for its full lifetime capability, an average burnup in the plutonium fuel of approximately 15,000 MWD/MTM and a peak burnup of 29,000 MWD/MTM can probably be achieved.

The measured Saxton Core II critical boron concentration as a function of lifetime is compared to that expected from the analysis in Figure 510.10. At least part of the discrepancy between the slope of the analytic and experimental curves can be explained. The analytic curve is based on a TURBO* calculation made prior to operation of the core. At intermediate time steps in the TURBO* calculation the reactivity at a particular boron concentration was determined. The cal-

Figure 510.10

A Comparison of the Calculated and Measured Critical Boron Concentration as a Function of Hours Operation for Saxton Core II

culated k_{eff} at these points was not 1.0, therefore, it was necessary to adjust the boron content to just-critical. At these time steps the boron worth was determined for a large change in boron content. Thus, the correction to the just-critical boron requirement was made at the end of the range using boron worth determined over a large change. This procedure results in an underestimate of the boron requirement early in life.

In addition to the difference in slope of the analytic and experimental curves, there is also a difference in the predicted lifetimes. A linear extrapolation of the experimental data indicates a shorter available lifetime than that shown by the TURBO* calculation.

Also shown in Figure 510.10 are the results of calculations made after experimental results were available from power operation. In these calculations the power history of each fuel assembly was known from flux wire measurements. The measured irradiation history was used to determine group constants in the BUBBLE code by interpolation from a previously established boron concentration-irradiation matrix. These constants were then used in PDQ calculations in X-Y geometry. As shown in Figure 510.10 calculations using the procedure adopted for following Saxton Core II operation, LEOPARD V - BUBBLE - PDQ, are in good agreement with the measurements.

While the experimental data show a smaller available lifetime than that indicated by the earlier TURBO* analysis, there is adequate core life to meet the defined lifetime objectives.

G. In-Core Instrumentation Measurements

Since Saxton is an experimental facility, it has an extensive in-core instrumentation system. Flux distribution measurements are made in thimbles located throughout the core using two different methods, the activation of manganese in carbon steel wires and direct reading fission detectors. At the start of life, a large number of flux maps were made to establish the power level and control rod configuration at which the core could operate. Periodic flux maps are being made to follow the power history of the reactor. The measured activity in a flux wire thimble is translated to local power at various core locations by multiplying the measured activity by the calculated power-to-activity ratio from an appropriate PDQ calculation.

A summary of the beginning-of-life axial peaking factors as a function of control rod position for the three maximum power plutonium fuel rods is shown in Figure 510.11. The radial peaking factors for the same fuel rods are shown in Figure 510.12. The rod identification numbers correspond to the core locations shown in Figure 510.13. The maximum measured fuel rod radial power for the all-rods-out condition is 2.17 which is approxi-

Figure 510.11

$$\% \text{ Discrepancy} = \frac{\text{Measured} - \text{Calculated}}{\text{Calculated}} \times 100$$

*Location of Maximum Power Rods

Figure 510.13

Comparison of In-Core Detector Measured Activity
With PDQ Analysis

mately the same as that predicted from PDQ-3 calculations.*
For this comparison the safety factor, which is ordinarily applied before thermal calculations are made, has been neglected. The comparison shows the predicted and measured values of the beginning-of-life maximum fuel rod power are in good agreement.

Figure 510.13 contains a comparison of the measured and calculated activity for one of the two different measurement methods for the core after approximately 2500 MWD operation. The PDQ analysis used burned constants corresponding to the irradiation history of the core. The differences between analysis and experiment shown in this map are representative of the differences normally seen for the in-core detector measurements. A preliminary examination of the maximum fuel rod power shows little reduction in the peak from that determined at the beginning of life. The peak occurs at a different location, but is approximately the same magnitude. During the coming report period, increased emphasis will be placed on determining the effect of burnup on local power peaking.

* A maximum rod power of 2.16 was determined in PDQ-3 calculation at 1000 ppm. Correcting the analysis to the boron concentration of the measurement would result in an increase of approximately 2% in the calculated value.

Phase I of the materials portion of the program has been completed and described in the topical report, EURAEC-1492 (WCAP-3385-53) entitled "Materials Design and Fabrication of the Saxton Partial Plutonium Core". The major objectives of this phase were to provide materials information to the design groups, to develop specifications for the fuel, and to procure the fuel rods required for the program. The remaining objective of the materials program is to complete a pilot test of two promising plutonium fuel fabrication techniques in a commercial type water reactor and, as a result of the test, to provide a preliminary basis for fuel selection and design of plutonium recycle fuel for water reactors.

In selecting the fabrication processes for the program, consideration was given to: (a) the in-pile reliability of fuel fabricated by the method; (b) the projected economics of the process; and (c) the state of development of the process. Evaluation of the available evidence led to selection of vibrational compaction and pelletization of mechanically blended fuel. The data were not sufficient to determine unequivocally which of the two processes would be better. Materials selections for the program are summarized in Table I.

TABLE I

Materials Selections

<u>Form</u>	<u>Powder Prep. Method</u>	<u>Fuel Density % Theoretical</u>	<u>Cladding</u>	<u>No. Rods Inserted*** In Reactor</u>
Pellets*	Mechanical Mixing	94 $\pm$ 2	Zr-4	470
Vipac**	Mech. Mix. - Nupac	87 $\pm$ 1	Zr-4	138
Pellets*	Mechanical Mixing	94 $\pm$ 2	304 SS	20
Vipac**	Mech. Mix. - Nupac	87 $\pm$ 1	304 SS	10

* Pelletized fuel rods fabricated by Nuclear Materials and Equipment Corporation; pellets were cold-pressed and sintered.

** Vipac fuel rods fabricated by Battelle Northwest Laboratories employing their Nupac process.

*** Fuel assemblies designed and built by Westinghouse

Fuel Specifications

Fuel specifications for the program were based on normal Westinghouse UO_2 fuel element and assembly specifications, with modifications to accommodate the special requirements and limitations of PuO_2 - UO_2 fabrication methods. The major changes were: (a) end plug weld quality control was based on destructive testing of dummy rods welded with production process parameters in each fuel rod lot, (b) particle size control of PuO_2 and UO_2 feed powders and autoradiographs of samples of final mixed product to assure satisfactory plutonium distribution; (c) increase in allowable nitrogen content (normally 30 ppm maximum in UO_2 fuel) because a nitrogen atmosphere normally is used for arc-fusing UO_2 vipac feed, and because 8% H_2 -92% N_2 rather than 100% H_2 was used for sintering pellets; and (d) inclusion of gamma absorptometry to verify that the density variation along the vipac rods was within $\pm 1.5\%$ of the average density. In addition to the normal inspections such as helium leak and corrosion testing, the pelletized fuel rods were dye penetrant tested and the vipac fuel rods were re-inspected by Battelle's standard ultrasonic test. Weld zones of the vipac rods were also inspected by Battelle's special ultrasonic technique to ensure that vibrational cycling of the rod during loading did not affect weld integrity.

Results of the major chemical analyses performed by the fabricators are compared to the specifications in Table II. The vipac total gas release limit was difficult to achieve and should be increased in future programs unless improved techniques are developed. Fuel

TABLE II

Comparison of Major Chemical Analyses of Fuel with Specifications

Item	Vipac Fuel		Pellet Fuel		
	Spec.	Results*	Spec.	Results	
				Range	Majority**
H ₂ O	100 ppm max.	14, 33, 44	30 ppm max.	<2-24	11 batches <10
H ₂	5*** ppm max.	5, 5, 5	15 ppm max.	<0.2-2	12 batches <u><1.0</u>
N ₂	100 ppm max.	74, 92, 92	75 ppm max.	17-110	13 batches <u><75</u>
Cl	20 ppm max.	<10, <10, <10	10 ppm max.	<2-10	10 batches <8
F	10 ppm max.	<10, <10, <10	10 ppm max.	3-9	8 batches <8
Total Gas Release	0.06 SCC	.06, .06, .067	0.05 SCC	.004-.045	10 batches <u><0.03</u>
O/M	--	--	1.97-2.02	1.97-2.018	13 batches <2.00
O/Pu	2 $\pm$.1	2.00, 2.00, 2.00	--	--	--
O/U	2 $\pm$ 0.02	2.01, 2.01, 2.02	--	--	--
Pu/U ₂ x 10 ²	7.1 $\pm$ 0.2	6.9, 6.9, 6.9	7.1 $\pm$ 0.1	6.99-7.15	12 batches 7.1 $\pm$ 0.05

* Three fuel batches total

** Fifteen fuel batches total

*** Actual specification refers to H₂ in oil as C-H or Si-H bonds

rod plenum chambers or other design parameters can be adjusted accordingly. Fuel batches which exceeded specified limits of total gas release (vipac) and of N_2 content (pellets) were accepted in a few cases, because compensating decreases were achieved in other impurities, which would decrease the build-up of gas pressure within the fuel cladding accordingly.

It was concluded that the PuO_2-UO_2 manufacturing specifications used can be met reasonably by plutonium fuel fabricators utilizing either pelleted or vipac techniques.

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