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AEC RESEARCH AND
DEVELOPMENT REPORT
DECEMBER 1969

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**SOUTHWEST EXPERIMENTAL
FAST OXIDE REACTOR
DEVELOPMENT PROGRAM
TWENTY-SECOND QUARTERLY REPORT
AUGUST-OCTOBER 1969**

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-540

BREEDER REACTOR DEVELOPMENT OPERATION

GENERAL ELECTRIC

SUNNYVALE, CALIFORNIA

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AEC Research and
Development Report
November 1969

SOUTHWEST EXPERIMENTAL FAST OXIDE REACTOR DEVELOPMENT PROGRAM

Twenty-Second Quarterly Report
August-October 1969

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Prepared for the
Southwest Atomic Energy Associates
for transmittal to the
United States Atomic Energy Commission
under
Contract Number AT(04-3)-540

Printed in U.S.A. Available from the
Clearing House for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia
Price: \$3.00 per copy

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ABSTRACT

This report summarizes the work performed on the Research and Development Program for the Southwest Experimental Fast Oxide Reactor during the

period from August 1 through October 31, 1969. The work was performed under contract AT(04-3)-540 with the United States Atomic Energy Commission.

SECTION I

INTRODUCTION

Southwest Experimental Fast Oxide Reactor (SEFOR) is a 20 MWt, sodium-cooled fast reactor with characteristics similar to the large, soft spectrum fast breeder reactors fueled with mixed $\text{PuO}_2\text{-U-238 O}_2$, for which studies indicate the potential for producing low cost power. SEFOR will be used to obtain physics and engineering data at fuel compositions, temperatures, and crystalline states characteristics of power reactor operating conditions. SEFOR is particularly designed for the systematic determination of the Doppler coefficient of reactivity at temperatures up to the vicinity of fuel melting.

The SEFOR project consists of two major parts: the design and construction of the reactor facility and the related research and development program. Funds for the design and construction of the facility are being provided by the Southwest Atomic Energy Associates (a group of 17 investor-owned utility companies located in the south and southwest of the

United States), together with the Karlsruhe Laboratory of The Federal Republic of Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the research and development program. The R and D program consists of two phases:

Phase I — Preoperational research and development,

Phase II — The reactor test program after the start of reactor operation.

Phase I consists of 10 major tasks divided into 28 subtasks. This report summarizes the tasks scheduled for activity at this time. The remaining tasks will be included in future reports as the work progresses.

The following periodic reports have been issued in partial fulfillment of United States Atomic Energy Commission Contract AT(04-3)-540.

1. "Southwest Experimental Fast Oxide Reactor Development Program, First Quarterly Report, April - June 1964, " GEAP-4594 (July 1964).
2. "Southwest Experimental Fast Oxide Reactor Development Program, Second Quarterly Report, July - September 1964, " GEAP-4742 (October 1964).
3. "Southwest Experimental Fast Oxide Reactor Development Program, Third Quarterly Report, October 1964 - January 1965, " GEAP-4799 (February 1965).
4. "Southwest Experimental Fast Oxide Reactor Development Program, Fourth Quarterly Report, February - April 1965, " GEAP-4864 (May 1965).
5. "Southwest Experimental Fast Oxide Reactor Development Program, Fifth Quarterly Report, May - July 1965, " GEAP-4934 (August 1965).
6. "Southwest Experimental Fast Oxide Reactor Development Program, Sixth Quarterly Report, August - October 1965, " GEAP-4994 (November 1965).
7. "Southwest Experimental Fast Oxide Reactor Development Program, Seventh Quarterly Report, November 1965 - January 1966, " GEAP-5108 (February 1966).
8. "Southwest Experimental Fast Oxide Reactor Development Program, Eighth Quarterly Report, February - April 1966, " GEAP-5160 (May 1966).
9. "Southwest Experimental Fast Oxide Reactor Development Program, Ninth Quarterly Report, May - July 1966, " GEAP-5208 (August 1966).
10. "Southwest Experimental Fast Oxide Reactor Development Program, Tenth Quarterly Report, August - October 1966, " GEAP-5301 (November 1967).
11. "Southwest Experimental Fast Oxide Reactor Development Program, Eleventh Quarterly Report, November 1966 - January 1967, " GEAP-5442 (February 1967).
12. "Southwest Experimental Fast Oxide Reactor Development Program, Twelfth Quarterly Report, February - April 1967, " GEAP-5498 (May 1967).
13. "Southwest Experimental Fast Oxide Reactor Development Program, Thirteenth Quarterly Report, May - July 1967, " GEAP-5533 (August 1967).
14. "Southwest Experimental Fast Oxide Reactor Development Program, Fourteenth Quarterly Report, August - October 1967, " GEAP-5561 (November 1967).

15. "Southwest Experimental Fast Oxide Reactor Development Program, Fifteenth Quarterly Report, November 1967 - January 1968, " GEAP-5595 (February 1968).
16. "Southwest Experimental Fast Oxide Reactor Development Program, Sixteenth Quarterly Report, February - April 1968, " GEAP-5629 (May 1968).
17. "Southwest Experimental Fast Oxide Reactor Development Program, Seventeenth Quarterly Report, May - July 1968, " GEAP-5673 (August 1968).
18. "Southwest Experimental Fast Oxide Reactor Development Program, Eighteenth Quarterly Report, August - October 1968, " GEAP-5705 (November 1968).
19. "Southwest Experimental Fast Oxide Reactor Development Program, Nineteenth Quarterly Report, November 1968 - January 1969, " GEAP-5754.
20. "Southwest Experimental Fast Oxide Reactor Development Program, Twentieth Quarterly Report, February - April 1969, " GEAP-10010 (May 1969).
21. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-first Quarterly Report, May - July 1969, " GEAP-10010-21 (August 1969).

In addition, the following topical reports have been issued:

1. Novak, P. E., and Asamoto, R. R., "A Survey for a High Temperature Sensor for SEFOR, " GEAP-4903 (July 1965).
2. Quinn, E. P., "Vibration of SEFOR Fuel Rods in Parallel Flow, " GEAP-4966 (September 1965).
3. Johnson, M. L., "A Description of Fuel and Other Core Materials Procured for SEFOR Critical Experiments in ZPR-III, " GEAP-5133 (December 1965).
4. Protsik, R., "Epithermal Capture and Fission Distribution in a Fuel Rod - The Computer Code REAX, " GEAP-4973 (April 1966).
5. Novak, P. E., and Asamoto R. R., "An Out-of-Pile Evaluation of W-Re Thermocouple Systems for Use to 4700°F in Mixed Oxide, " GEAP-5166 (May 1966).
6. Pflasterer, G. R., "SEFOR Experimental Program Planning, Vols. I and II, " GEAP-5092 (August 1966).
7. Morrell, R. P., "SEFOR β/ℓ Measurements by Noise Analysis Techniques, " IDO-17210 (August 1966).
8. Williams, R. F., and Polomik, E. E., "Pressure Drop and Dye Tests with Water on the SEFOR Prototype Fuel Bundle, " GEAP-5129 (February 1966).

9. Craig, C.N., Ryer, C.M., and Thompson, M.L., "Plutonium-Uranium Mixed Oxide Fuel Pellet Fabrication Development for the Southwest Experimental Fast Oxide Reactor," GEAP-5285 (October 1966).
10. Polomik, E.E., and Williams, R.F., "Coolant Surface Turbulence Study, SEFOR Reactor Vessel," GEAP-5099 (December 1966).
11. Wilkinson, L., "Use of Neutron Filters for Fast Reactor Fuel Irradiations in a Thermal Core," GEAP-5035 (April 1967).
12. Wilkinson, L., et al., "Devices for Cyclic and Transient Power Control in a Steady-State Neutron Flux Gradient," GEAP-5036 (May 1967).
13. Reynolds, A.B., and Stewart, S.L., "Analysis of the SEFOR Mockup Critical Experiments in ZPR-3," GEAP-5294 (March 1967).
14. Wilkinson, D., "Weighted Doppler Analysis Code - WEDOP," GEAP-5513 (October 1967).
15. Craig, E.R., Fulton, R.H., Damon, J.J., "Design and Testing of Solenoid and Instrument Lead Connector for Use in SEFOR Reactor Vessel," GEAP-5307 (March 1967).
16. Asamoto, R.R., Perry, K.J., and Zebroski, E.L., "The Effective and Diametral Thermal Expansion of UO_2 Under a Radial Temperature Gradient," GEAP-5284 (October 1966).
17. McVean, R.L., Weitzberg, A., Kremser, J.A., Leridon, A.M., and Long, J.K., "Critical Studies of the Southwest Experimental Fast Oxide Reactor (SEFOR) in ZPR-3," ANL-7348.
18. Polomik, E., "Fluid Flow and Vibration Tests, 1/2-Scale Model of SEFOR Reactor Vessel," GEAP-5440 (April 1967).
19. Field, J.H., Johnson, M.L., and Novak, P.E., "An Evaluation of the Effect of Design and Operating Variables on SEFOR Fuel and Fuel Cladding," GEAP-5309 (December 1967).
20. Noble, L.D., "Final Specifications for the SEFOR Experimental Program," GEAP-5576 (April 1968).
21. Russell, C.E., "Flow Distribution Measurements in a 3-Scale Model of the SEFOR Fuel Bundle," GEAP-5184 (May 1968).
22. Cochran, J., "SEFOR Core Clamping Model Tests, One-Sixth Segment," GEAP-5465 (May 1968).
23. Asamoto, R.R., and Novak, P.E., "An In-Pile Evaluation of W-Re Thermocouple Systems for Use to 4700°F in SEFOR Fuel," GEAP-5466 (October 1968).

24. Cochran, J. T., "SEFOR Fuel Assembly Sodium Flow Tests," GEAP-5466 (September 1968).

25. Cochran, J. T., "SEFOR Fuel Rod Sodium Thermal Shock Tests," GEAP-5467 (August 1968). | 26. Craig, E. R., "SEFOR Instrumented Fuel Assembly Design and Development," GEAP-5615, (April 1968).

27. Steamer, A. G., Brynsvold, G. V., and Franckx, L. C., "Fuel Handling and Other Tests in the SEFOR Refueling Cell Mockup", GEAP-5701, (March 1969). |
|---|---|

SECTION II

2. SUMMARY

2.1 COMPLETED TASKS

Experimental and/or analytical work has been completed on the tasks listed below, although in some cases work on topical reports is continuing:

<u>TASK</u>	<u>TITLE</u>
1.1	Specifications for the Reactor and Experimental Program
1.2	Final Specifications of the Experimental Program
2.0	Experimental Program in ZPR-III
3.0	Fuel Development
4.0	Special Instrumentation
5.0	Steady-State and Transient Characteristics of the Core Assembly
6.0	Reactivity Controls Required for Experimentation

<u>TASK</u>	<u>TITLE</u>
7.0	Fuel Handling
8.0	Core Design

2.2 TASK 9 — FUEL FABRICATION

The fourth and fifth instrumented fuel assemblies (IFAs) were started in final assembly after an interruption of the assembly work between July 21 and October 7. One of the fuel rods for the sixth IFA was delayed in fabrication due to problems with the bare wire thermocouple.

Final pre-operational test and analysis work was carried out on the fuel thermocouples in the first three IFAs delivered to the site.

2.3 TASK 10 — START-UP TESTING

The measured temperature coefficient of reactivity for the full size core is -0.59 cent/ $^{\circ}\text{F}$ for a uniform temperature change between 350°F and 400°F . The disparity between the measured and predicted ⁽¹⁾value of -0.68 cents/ $^{\circ}\text{F}$ is probably due to an over-estimate of the calculated radial expansion and sodium density effects, since good agreement was obtained in ZPR-III between calculated and measured Doppler and axial expansion effects, which are the other major components of the isothermal temperature coefficient.

The reflector calibrations for the full size core (Assembly I-D) were in general agreement with results obtained from the partially loaded core (Assembly I-B). The calibrations for the present full power core (Assembly I-E) indicate asymmetric control strengths that are congruous with an asymmetric core loading pattern. Both calibrations show that the worth of a reflector is dependent upon the positions of the adjacent reflectors. The estimated uncertainty in the calibration of fine reflectors by period measurements is approximately one percent in incremental worth (cent/cm) over the position range used for reactivity worth measurements.

The reactivity worth of standard fuel, B_4C , depleted UO_2 , stainless steel, BeO , and spiked fuel rods were measured at various radial locations. Although there is reasonable agreement between measured and calculated values near the core boundary, the central worth calculations are generally ten percent larger than measurements. Reasons for this disparity are being investigated.

Based on a number of measurements on "identical" core configurations, the estimated standard deviation of a single critical position measurement is ± 0.36 cent, and the estimated standard deviation of a small reactivity worth measurement is ± 0.5 cent. Two single critical position measurements are required for one worth measurement.

2.4 TASK 11 — TRANSIENT TESTS

General Electric has received authorization from AEC to rent a fuel transfer cask from Atomics International. The cask will be used to ship selected used fuel rods from SEFOR to a "hot lab" for examination. The cask (B of E 1233) has been received, inspected and cleaned by GE, and is currently being stored at the SEFOR Site.

A draft of the license application including the structural and thermal

analysis has been completed and is being reviewed.

The design of the fuel transfer equipment and the shielding associated with the fuel transfer was completed. Bids were requested for fabrication of this equipment.

2.5 SEFOR SAFETY AUDIT

To enhance the safe operation of the SEFOR Facility, a program for auditing SEFOR operations has been initiated. This audit consists of both a review of periodic reports from the facility, such as modification requests, malfunction reports, daily and weekly reports, and periodic visits to the site.

2.6 SEFOR SUPPORT

Fabrication of the Type II reactor-vessel level probes was essentially completed. Shipment is scheduled for November 1969. One primary cold trap and the intermediate heat exchanger (IHx)

level probe were shipped to the site in October.

2.7 SEFOR OPERATIONS

Activities scheduled for the planned plant outage were completed in August, and reactor operation was resumed on September 1, 1969. A total of 154 reactor startups were made in support of the performance of the Experimental Program. All experimental tests that required the reactor vessel head to be removed were completed; the head was installed and the program continued. The "full power" reactor core was loaded in a manner which permits final adjustments after measurements of the temperature coefficient and reactivity effects which result from the installation of the instrumented fuel assemblies and the drywell. General plant maintenance, repair of equipment malfunctions, and equipment modifications were then accomplished.

SECTION III

3. TASK 9 — FUEL FABRICATION

3.1 PURPOSE

The purpose of Task 9 is to procure fuel rods and associated core components for SEFOR. Fabrication of the hexagonal

fuel channel and all of its internal components are a part of this Task, as well as the instrumented fuel assembly fabrication.

3.2 PAST ACCOMPLISHMENTS

The complete fuel-rod order had been received at SEFOR in previous quarters. Of 50 rods rejected for helium leaks and dimensional deficiencies, some 20 were corrected in a previous quarter. The first three instrumented fuel assemblies (IFA) have been completed and shipped to SEFOR.

3.3 FUEL RODS

Fuel rods for the fifth IFA were completed in the Plutonium Laboratory and delivered to the Irradiation Processing Operation shop. Fuel rods for the sixth IFA were partially completed.

Problems in assembly involving wire breakage in the bare-wire thermocouples required rework and has delayed the completion of the fuel rod fabrication effort.

A loose thermocouple-lead guard used to protect the thermocouple leads during fabrication was found in the inspection of fuel rod G4-1, which is part of the fifth IFA. Special handling was enforced for this rod throughout the remainder of assembly sequence to protect fuel rod integrity.

The fuel pellets to be used in the two fuel rods for the 6th IFA were gamma scanned and selected for proper

enrichment. Regular length pellets will be used to replace the long pellets, which were found to have low enrichment. It was planned to adjust stack lengths by grinding pellets in order to accomplish this replacement.

Work was interrupted on a fuel rod scheduled for use in the 6th IFA due to a broken bare-wire thermocouple. Over half of the fuel thermocouple problems have involved the bare-wire design. It was decided to replace the bare-wire thermocouple with the apparently more reliable 0.140 in. diameter sheathed thermocouple. The sheathed thermocouple can be used to replace a bare wire thermocouple by enlarging the holes in the fuel pellets.

3.4 IFA ASSEMBLY OPERATIONS

The assembly work in the Irradiation Processing Operation shop was suspended during the period between the delivery of the third IFA (on July 21, 1969) and October 7, 1969. The purpose of this delay was to provide time for the plutonium laboratory to make up additional fuel rods required for further assembly effort and to reduce cost by increasing the shop productivity. Since October 7, assembly operations on the 4th and 5th IFA's were completed up to the seal-block brazing operation on each unit. The two units are scheduled for completion during the next report period.

The last three pressure vessel portions containing the electrical pin connectors were nearly completed when inspection indicated alignment defects. The two units will be repaired as required to meet the specified alignment accuracy.

During the inspection and testing of fuel thermocouples, thermocouple resistance and generated voltage information were recorded, which will be of value when the IFA's are operating in the reactor. In the grounded thermocouples, the sheath material (W/26 Re) itself provides a secondary hot junction in case the W/26 Re wire of the thermocouple is broken. Data have been recorded on the response of the secondary as well as the primary thermocouples.

Final fuel-thermocouple test data from the reactor site were used to indicate the as-built condition of the sensor leads to the electrical connectors of the three delivered IFA's.

At the SEFOR Site the first three IFA's were checked out and installed in the refueling cell of the reactor. The work at the site included alteration and addition of brackets to the transport fixtures and addition of keeper wires on the flange bolts. The three units were electrically checked and cleaned for insertion in the reactor. The handling fixtures were adjusted, and some remote handling practice was completed while the refueling cell contained air. The operating crews were also instructed on IFA handling.

SECTION IV

4. TASK 10 - STARTUP TESTING

4.1 PURPOSE

The purpose of Task 10 is to investigate the startup characteristics of a $\text{PuO}_2\text{-UO}_2$ fueled fast reactor and to compare the experimental results to the theoretical calculations. The wet critical tests comprise Task 10.3. Task 10.4 includes the initial approach to full power.

4.2 PAST PERFORMANCE

Initial criticality in SEFOR was attained with a core loading of 550 fuel rods. Later investigations revealed that a number of fuel rods were low in reactivity worth compared to a standard rod.

The low worth rods were removed and a minimum critical loading with 522 fuel rods and 100 tightener rods was attained. This loading was in good agreement with that of the predicted⁽²⁾ minimum critical size of 519 rods. The estimated control strength of the entire reflector system varied from a low value of 9.7 dollars, obtained from analysis of the critical core loading data, to a maximum of 12.7 dollars, the sum of the worths of the individual reflector segments. The previously calculated value⁽²⁾ was 11.2 ± 1.8 dollars. The reactivity worths of regular fuel, B_4C and

stainless steel rods were measured at four radial locations. Experimental results were generally in agreement with calculated results. An extensive investigation was begun into the apparent plutonium deficiency in some SEFOR fuel rods.

4.3 REFLECTOR CALIBRATION

The reflectors were calibrated for both the full size core (Assembly I-D) shown in Figure 1, and the present full power core (Assembly I-E) shown in Figure 2. In each case, the two fine reflectors (#3 and #8) were calibrated in increments by means of period measurements with approximately 1% accuracy (see below) and the worth of each of the eight coarse reflectors was obtained by the rod-swap technique (i.e., the worth of a coarse reflector was determined from the change in positions of the calibrated fine reflectors for critical configurations with the coarse reflector raised and then lowered).

Calibrations for both core configurations are necessary not only for reactivity worth (material and temperature) measurements in those cores, but also to provide data on reflector shadowing effects on individual reflector reactivity worths which will be important in interpreting reactivity

CORE LOADING STATUS

FIGURE 1. FULL SIZE CORE (ASSEMBLY I-D)

CORE LOADING STATUS

FIGURE 2. FULL POWER CORE (ASSEMBLY I-E)

measurements during the approach to full power.

The worths of the two fine reflectors in Assembly I-D are shown as a function of reflector position in Figures 3 and 4. The corresponding worths in Assembly I-E are illustrated in Figures 5 and 6. The values for the total worth of each reflector segment are tabulated below.

The data in Tables 1 and 2 show that the worth of the fine reflectors is nearly identical in Assembly I-D, but that there is

a difference in the worths of these reflectors in Assembly I-E of about 10 percent. The difference in worths combined with an inspection of the core loadings in the two assemblies (Figures 1 and 2) indicates that the B_4C rod and guinea-pig rod distribution in Assembly I-E may be causing an asymmetrical flux distribution with an increase toward the W-side of the core relative to the E-side. The loading in Assembly I-D appears to be more uniform, although the N-E section of the core appears to be somewhat deficient in B_4C relative to the remainder of the core.

TABLE 1
REFLECTOR WORTH (ASSEMBLY I-D)

<u>Reflector Number</u>	<u>Worth (dollars)*</u>	
	<u>Set 1</u> (swapped with #3) (#8 at ~ 50 cm)	<u>Set 2</u> (swapped with #8) (#3 at ~ 50 cm)
1	1.25	
2	1.28	1.02
3	1.27**	
4	1.24	0.99
5	1.25	1.20
6	1.28	
7	1.14	1.29
8	1.25**	
9	1.09	1.24
10	1.26	

*The estimated standard deviation in the difference between two values is approximately ± 0.01 dollars.

**Worth obtained from period measurements.

FIGURE 3. FINE REFLECTOR NO. 3 CALIBRATION CURVE (ASSEMBLY I-D)

FIGURE 4. FINE REFLECTOR NO. 8 CALIBRATION CURVE (ASSEMBLY I-D)

FIGURE 5. FINE REFLECTOR NO. 3 CALIBRATION CURVE (ASSEMBLY I-E)

FIGURE 6. FINE REFLECTOR NO. 8 CALIBRATION CURVE (ASSEMBLY I-E)

TABLE 2
REFLECTOR WORTH (ASSEMBLY I-E)
(Reflector #5 Down)

<u>Reflector Number</u>	<u>Worth (dollars)* (swapped with #3)</u>	<u>Approximate Position of #8 (cm)</u>
1	1.42	44.2
2	1.44	44.6
3	1.32**	--
4	1.00	17.1
5	--	--
6	0.87	2.5
7	0.88	3.6
8	1.20**	--
9	1.00	16.6
10	--	--

*The estimated standard deviation in the difference between two values is approximately ± 0.01 dollars.

**Worth obtained from period measurements.

In addition to the asymmetry noted above, the tabulated worths for both Assemblies I-D and I-E show that the worth of a reflector is influenced by the position of its neighbor. In particular, the total worth of a reflector is less when an adjacent reflector is lowered, or partially lowered, than when both adjacent reflectors are completely raised. For example, in the first set of measurements (Set 1 of Table 1) for Assembly I-D, fine reflector #3 was swapped with the coarse reflector to be calibrated, while fine reflector #8 was adjusted to maintain criticality. For these measurements,

reflector #8 was only partially raised (approximately halfway) during the "swap", and the adjacent reflectors (#7 and #9) are consequently lower in worth than the others. In the second set of measurements in Table 1, the functions of the two fine reflectors were interchanged. This caused the worth of reflector #2 and #4 to be lower than the others. Similarly, the data in Table 2 for Assembly I-E demonstrates this "shadowing" effect. For these measurements, reflector #5 was lowered and #8 was either partially or almost completely lowered. The worths of reflectors #6 and

#7 are thus considerably less in this configuration than the worths of the other reflectors. This occurs for two reasons: (1) reflectors on both sides of #6 and #7 are down, and (2) the apparent asymmetry in flux would cause a decreased reflector worth on that side of the core. The "shadowing effects" appear to be somewhat localized, and the worth of a reflector is nearly independent of the position of non-adjacent reflectors provided that adjacent reflectors are up. Further calibrations of reflectors will be performed with other reflector configurations and core arrangements, to provide additional information about the effects of reflector interaction and asymmetry of flux.

The accuracy of the calibrations for measurements of the fine-reflector period is indicated by the data in Tables 3 and 4. The reactivity values under the second column of the tables were calculated with the in-hour equation using periods obtained from visual observation of flux changes and doubling-time measurements made with a stop watch. The values in the third column were calculated on-line from the neutron-flux signal input to a computer. These data provide two independent checks on the calibration and are in very good agreement. With the small reactivity values (large periods) excepted, the mean-squared deviation is approximately 0.9 percent for reactivity increments of the order of 9 cents. Similar deviations also occur in

six repeated measurements (Step No. 8 through Step No. 8E) listed in Table 4. Thus, a ± 1 percent uncertainty is assigned to the slope of the reflector-worth calibration curve (see Figures 3, 4, 5, and 6). The effects of these deviations on measured reactivity changes are discussed in section 4.4.

4.4 UNCERTAINTIES IN REACTIVITY MEASUREMENTS

Due to small variations in system temperatures, instrumentation, relative reflector-core configurations, etc., the measurement of the critical point (the system conditions for which the reactor is exactly critical) is inexact, and different measurements of the same point show small variations. Evidence for this variation is shown by the two sets of data in Tables 5 and 6, obtained from repeated measurements on two slightly different core configurations. (The core loading was changed slightly between the critical measurements on September 12 and September 13.) Although the mean reactivity is different for the two sets of data, because of the different core loadings, the individual deviation appears to be random. The estimated standard deviation, which is essentially the same for both cases, appears to be unaffected by changes in reactor configuration.

Based on the above measurements, the estimated standard deviation in a single

TABLE 3

FINE REFLECTOR #8 CALIBRATION IN ASSEMBLY I-D

<u>Step No.</u>	<u>Reactivity</u>		<u>% Deviation</u>
	<u>Doubling-time Measurement (cents)</u>	<u>On-line Reactivity Meter (cents)</u>	
1	5.58	5.65	-1.3
2	8.46	8.5	-0.5
3	7.66	7.75	-1.2
4	7.57	7.5	0.9
5	8.59	8.6	-0.1
6	8.68	8.7	-0.2
7	9.10	9.1	0.0
8*	9.41	9.45	-0.4
8A*	9.40	9.3	1.1
8B*	9.35	9.3	0.5
8C*	9.46	9.3	1.7
8D*	9.38	9.3	0.9
8E*	9.12	9.2	-0.9
9	9.24	9.25	-0.1
10	9.33	9.2	1.4
11	7.88	7.9	-0.3
12	8.55	8.6	-0.6
13	9.84	9.75	0.9
14	6.87	6.95	-1.2
15	5.16	5.3	-2.7
16	3.36	3.5	-4.2

*Repeated measurements of the reactivity associated with the movement of reflector #8 between 42.10 cm and 47.14 cm.

TABLE 4
PORTION OF FINE REFLECTOR #3 CALIBRATION
IN ASSEMBLY I-D

<u>Step No.</u>	<u>Reactivity</u>		<u>% Deviation</u>
	<u>Doubling Time</u> <u>Measurement (cents)</u>	<u>On-line Reactivity</u> <u>Meter (cents)</u>	
6	8.72	8.65	0.8
7	8.60	8.5	1.1
8	9.24	9.2	0.4
9	8.51	8.5	0.1
10	8.97	8.8	1.9
11	9.04	9.1	-0.7
12	9.56	9.6	-0.4
13	10.75	10.7	0.5
14	6.45	6.5	-0.8
15	2.87	3	-4.5

measurement of a small reactivity change, calculated from the difference between two measurements of the critical point, is $0.37 \sqrt{2}$ cents, or 0.5 cents (see Tables 6 and 7).

Since the variations noted in Tables 4 and 5 appear to be random in nature, and, as noted before, the uncertainty due to calibration errors in a 9 cent increment is $(0.009) \times 9$ cents, or 0.08 cents, the estimated calibration uncertainty in a 90 cent reactivity change associated with movement of the reflector over ten consecutive increments which, were measured to be worth 9 cents each, would be expected to be $\sim 0.08 \sqrt{10}$ cents, or 0.25 cents. Similarly, the calibration uncertainty in any

reactivity change of magnitude Δk cents would be expected to be approximately $0.08 \sqrt{\Delta k/9}$ cents, and the total uncertainty in any reactivity change would thus be $[2(0.37)^2 + (0.08)^2 \Delta k/9]^{1/2}$. This relation is probably reasonable for reactivity changes which are of the order of 30 cents or less. For larger changes the reflector configuration changes considerably, and the reflector interaction effects noted in the previous section may influence the uncertainties. Additional reflector calibrations planned in the full power core should clarify this point.

4.5 UNIFORM TEMPERATURE COEFFICIENT

The average value of the temperature coefficient for the full size core

TABLE 5
SEFOR CRITICAL CHECKS
(September 1 to September 12)

Measurement Number	Date	Reflector #8		Temperature		X_i Relative Reactivity* at 350°F (cents)
		Position (cm)	Relative Worth (cents)*	Measured (°F)	Reactivity Effect** (Relative to 350°F)	
1	9/1	51.66	73.24	350.0	0.0	73.24
2	9/2	50.78	71.65	347.5	+1.50	73.15
3	9/3	51.65	73.22	350.0	0.0	73.22
4	9/3	52.00	73.85	352.5	-1.50	72.35
5	9/4	52.09	74.02	352.0	-1.20	72.82
6	9/5	51.71	73.33	350.0	0.0	73.33
7	9/12	51.20	72.41	349.5	+0.30	72.71

Average = $\bar{X}$ = 72.97

$$\text{Estimated standard deviation, } \left[\sum_{i=1}^7 (X_i - \bar{X})^2 / 6 \right]^{1/2} = 0.36 \text{ cents}$$

* Relative to the worth with the reflector lowered.

** Using the "measured" temperature coefficient at 350°F of -0.60 cents/°F.

TABLE 6
SEFOR CRITICAL CHECKS
(September 13 to October 7)

Measurement Number	Date	Reflector #8		Temperature		X_i Relative Reactivity* at 350°F (cents)
		Position (cm)	Relative Worth (cents)*	Measured (°F)	Reactivity Effect** (Relative to 350°F)	
1	9/13	52.52	74.79	351.5	-0.90	73.89
2	9/14	52.25	74.30	351.5	-0.90	73.40
3	9/16	50.92	71.90	347.0	+1.80	73.70
4	9/16	52.78	75.27	352.5	-1.50	73.77
5	9/16	52.81	75.32	352.5	-1.50	73.82
6	9/17	51.88	73.64	349.0	+0.60	74.24
7	9/18	51.64	73.20	348.75	+0.75	73.95
8	9/18	52.00	73.85	349.25	+0.45	74.30
9	9/19	52.01	73.87	349.0	+0.60	74.47
10	9/20	53.09	75.83	353.0	-1.80	74.03
11	9/20	52.77	75.25	351.25	-0.75	74.50
12	9/20	51.87	73.62	349.75	+0.15	73.77
13	9/24	50.99	72.03	348.0	+1.20	73.23
14	10/7	52.04	73.93	350.0	0.0	73.93

Average = $\bar{X}$ = 73.93

$$\text{Estimated standard deviation, } \left[\sum_{i=1}^{14} (X_i - \bar{X})^2 / 13 \right]^{1/2} = 0.37 \text{ cents}$$

* Relative to the worth with the reflector lowered.

** Using the "measured" temperature coefficient at 350°F of -0.60 cents/°F.

(Assembly I-D) shown in Figure 1 is -0.59 ± 0.01 cent/ $^{\circ}$ F for a uniform temperature change between approximately 350° F and 400° F. The value of the reactivity coefficient and the estimated standard deviation (± 0.01 cent/ $^{\circ}$ F) was obtained by a least squares fit of a straight line to the values in Table 7. The predicted⁽¹⁾ reactivity coefficient was -0.68 cent/ $^{\circ}$ F. Assuming (based on the agreement⁽³⁾ between experiment and calculation for the SEFOR mockup in ZPR-3) that the calculated Doppler coefficient is correct, the disparity between the calculated and measured value is probably due to an over-estimate of the calculated radial expansion and sodium density effects. If the calculated Doppler coefficient is correct, the reactivity coefficient at 350° F is -0.60 cent/ $^{\circ}$ F. This is slightly higher than the average value between 350 and 400° F because of the logarithmic dependence of the Doppler effect on fuel temperature.

4.6 MATERIAL WORTH MEASUREMENTS

The reactivity worth of fuel (18.7% fissile Pu), B_4C , depleted UO_2 , stainless steel, BeO, and guinea pig (25% fissile Pu) rods were measured at various radial locations in the full size core Assembly I-D as part of the planned experimental program. The measured values are tabulated in Tables 8 and 9 along with the results of preliminary one-dimensional, diffusion-theory perturbation calculations. In Figures 7 through 10, the radial dependence of four of these material worths are shown.

These data show that the measured worth of the reference fuel rod (#781) is higher at location E1.5-N3.0B (a radius of 21.8 cm) than at location W2.5-N1.0B (a radius of 20.6 cm). This may be due to the proximity of three B_4C rods at the latter location and the deficiency of B_4C rods on the N-E portion of the core (see

TABLE 7
TEMPERATURE COEFFICIENT MEASUREMENTS

<u>Temperature ($^{\circ}$F)</u> <u>(estimated uncertainty</u> <u>is $\pm 0.25^{\circ}$F)</u>	<u>Reactivity Change (cents)</u> <u>(relative to initial temperature)</u> <u>(estimated uncertainty = ± 0.5 cents)</u>
350.0	0.0
352.0	-0.7
397.0	-27.7
398.5	-28.3

TABLE 8

MATERIAL REACTIVITY WORTH MEASUREMENTS

(Full Size Core-Assembly I-D)

<u>Core Location</u>	<u>Type of Rod</u>	<u>Worth Relative to Sodium (cents)</u>	
		<u>Measured*</u>	<u>Preliminary Calculation</u>
W2.5-S5.0B (Radius = 42.7 cm)	Fuel	+9.2	+8.5
	Stainless Steel	+2.1	+0.7
	UO ₂	0.0	-1.1
	B ₄ C	-13.0	-17.5
W2.0-S4.0B (Radius = 34.6 cm)	Fuel	+15.4	+16.0
	Stainless Steel	-0.4	-1.4
	UO ₂	-2.7	-4.5
	B ₄ C	-22.1	-28.5
E1.5-N3.0B (Radius = 21.8 cm)	Fuel	+27.6	+30.1
	Stainless Steel	-1.6	-5.1
	UO ₂	-7.6	-11.5
	B ₄ C	-49.1	-54.0
W1.0-S2.0B (Radius = 18.6 cm)	Fuel	+28.8	+32.8
	Stainless Steel	-2.8	-5.9
	UO ₂	-9.8	-13.0
	B ₄ C	-52.3	-60.0
W0.5-S1.0F (Radius = 5.8 cm)	Fuel	+34.5	+38.7
	Stainless Steel	-3.6	-7.3
	UO ₂	-13.0	-17.3
	B ₄ C	-70.9	-79.0

*The estimated standard deviation in the measurement is approximately ± 0.5 cents. (See section 4.4.)

TABLE 9
MATERIAL REACTIVITY WORTH MEASUREMENTS
 (Full Size Core-Assembly I-D)

<u>Core Location</u>	<u>Type of Rod</u>	<u>Worth Relative to Sodium (cents)</u>	
		<u>Measured*</u>	<u>Preliminary Calculation</u>
W0.0-N4.0A (Radius = 26.6 cm)	Fuel	+23.1	+25.0
	Guinea Pig	+33.5	+36.5
W0.0-N4-0B (Radius = 25.1 cm)	Fuel	+24.1	+26.6
	Guinea Pig	+35.4	+39.0
W2.5-N1.0B (Radius = 20.6 cm)	Fuel	+27.0	+31.2
	Guinea Pig	+39.4	+45.5
W2.5-N1.0A (Radius = 18.6 cm)	Fuel	+28.3	+32.8
	Guinea Pig	+41.8	+48.5
W2.5-S5.0	Be0 }	-4.6**	-5.4
E2.5-N5.0 (Radius = 40.3 cm)	Be0 }		
E2.0-N4.0	Be0 }	-5.7**	-5.0
W2.0-S4.0 (Radius = 32.2 cm)	Be0 }		
E1.5-N3.0	Be0 }	-6.1**	-5.2
W1.5-S3.0 (Radius = 24.2 cm)	Be0 }		
W0.5-S1.0	Be0 }	-4.5**	-6.0
E0.5-N1.0 (Radius = 8.0 cm)	Be0 }		

* The estimated standard deviation in the measurement is approximately ± 0.5 cents
 (see section 4.4)

** Worth of two rods relative to stainless steel.

FIGURE 7. RADIAL DEPENDENCE OF FUEL ROD WORTH

FIGURE 8. RADIAL DEPENDENCE OF B_4C ROD WORTH

FIGURE 9. RADIAL DEPENDENCE OF GUINEA PIG ROD WORTH

FIGURE 10. RADIAL DEPENDENCE OF DEPLETED UO_2 ROD WORTH

Figure 1), but it is more probable that the difference is a result of experimental variations.

Although agreement between calculation and experiment is in reasonably good agreement, the calculated fuel, boron, and guinea-pig-rod worths are approximately 10 percent larger in magnitude than measured values. In addition, the calculated UO_2 and the steel worths are everywhere more negative than the measured values.

Calculations using BISYN⁽⁴⁾ with a reactor model which described the radial boron distribution indicated that the preferential radial location of the B_4C rods toward the core center (Figure 1) had relatively little effect on the radial dependence of the material worths of fuel and boron. Calculations to investigate the disparities between measurement and calculation are continuing.

4.7 INHERENT SOURCE MEASUREMENT

A series of measurements were performed in Assembly I-D to determine the relationship between steady-state-detector readings (power) and reflector position (subcritical reactivity) in the near-critical core. The results are shown in Table 10. The indicated subcritical reactivity of the system was obtained from the reflector calibration data using a four-point difference formula. Temperature corrections

were based on the measured temperature coefficient of -0.60 cents/ $^{\circ}\text{F}$.

The data show that the system is critical for all steady-state, wide-range-monitor (WRM) readings greater than $\sim 50 \times 10^{-5}$ and that the product of the WRM reading and the subcritical reactivity is essentially constant. The latter result is in agreement with theory and provides a means of relating the WRM readings to the power of the reactor and to the inherent source of neutrons resulting from the spontaneous fission of Pu-240 and from the alpha-neutron reaction in oxygen due to Pu-239 and Pu-240 alpha decay.

A modal one-energy group analysis⁽²⁾ for a system containing a constant source of neutrons per unit core volume provides the following relationship between the total power P (in watts), the total source of neutrons per second, S , and the subcritical reactivity k (in cents) in a near critical core:

$$P = \frac{100 S}{\nu k \beta C} F$$

where

ν = 2.94 is the average number of neutrons per fission,

β = 0.0032 is the effective delayed neutron fraction,

C = 3×10^{10} fissions per W-sec,

and

TABLE 10

INHERENT SOURCE MEASUREMENT - FULL SIZE CORE-ASSEMBLY I-D

<u>Wide Range Monitor Reading</u>	<u>No. 8 Reflector Position (cm)</u>	<u>Temperature (°F)</u>	<u>Subcritical Reactivity at 375°F (cents)</u>	<u>Product of Subcritical Reactivity and Wide Range Monitor Reading (cents x 10⁶)</u>
39 x 10 ⁻⁸	45.60	375.0	25.87	10.1
50 x 10 ⁻⁸	48.56	375.0	20.42	10.2
6.2 x 10 ⁻⁷	51.64	375.0	14.83	9.2
8.0 x 10 ⁻⁷	53.26	375.0	11.90	9.5
18.0 x 10 ⁻⁷	57.00	375.0	5.25	9.5
24.4 x 10 ⁻⁷	57.73	375.0	3.99	9.7
34.0 x 10 ⁻⁷	58.29	375.0	3.04	10.3
48.0 x 10 ⁻⁷	58.90	374.75	1.86	8.9
7.5 x 10 ⁻⁶	59.24	374.75	1.29	9.7
15.0 x 10 ⁻⁶	59.59	374.75	0.71	10.7
29.0 x 10 ⁻⁶	59.82	374.75	0.33	9.6
49.0 x 10 ⁻⁶	59.83	374.5	0.16	7.8
20.0 x 10 ⁻⁵	59.93	374.5*	0.0	---
32.0 x 10 ⁻⁵	60.11	375.0	0.0	---
49.0 x 10 ⁻⁵	60.11	375.0	0.0	---
44.0 x 10 ⁻⁴	60.11	375.0	0.0	---
				Average = 9.8

*Adjusted to provide agreement with theory. The recorded value of 374.75°F gives a value for the product in the last column of 30.0.

F is the square of the core average of the fundamental flux shape divided by the average of the square of the fundamental flux shape.

For SEFOR, $F \cong 0.9$, and the above expression can be written as

$$P = 3.2 \times 10^{-7} \frac{S}{k}$$

where the power P, source S, and sub-critical reactivity k, are in units of watts, neutrons/sec, and cents, respectively.

The above expression corresponds to the following measured relation (Table 11) between the WRM reading ϕ , and reactivity k:

$$\phi = \frac{9.8 \times 10^{-6}}{k}$$

Thus, if the source strength is known, the relation between the WRM reading and power can be determined. Conversely, if the relation between the WRM reading and

power is known, the inherent source can be determined. The latter relation will be determined later from heat balances and instrument calibrations.

An approximate value for the source strength can be calculated. According to a previous study⁽⁵⁾ the source is given (with an estimated uncertainty of a factor of 1.5) by:

$$S = (1.29 \times 10^6 M_1 + 7.8 \times 10^4 M_2) N$$

where N is the number of fuel rods; $M_1 = 0.0493$ kg/rod is the Pu-240 mass per rod; and $M_2 = 0.5489$ kg/rod is the Pu-239 mass per rod. For the 634 rod core assembly I-D, S is 6.8×10^7 neutrons/sec. Thus, the calculated power level for a WRM reading of 50×10^{-5} is 1100 watts. This value, which is somewhat higher than the corresponding value of 810 watts for assembly I-A, can be checked after the heat balances and instrument calibrations have been performed.

SECTION V

5. TASK 11 - TRANSIENT TEST

5.1 PURPOSE

The purpose of Task 11 is to investigate the behavior of a $\text{PuO}_2\text{-UO}_2$ fueled fast reactor for reactivity changes less than 1 dollar and compare the experimental results with theoretical calculations. The types of tests to be conducted at various power levels include static, oscillation, and subprompt-critical transient reactivity changes.

5.2 PAST PERFORMANCE

The San Francisco Operations Office of the AEC authorized rental of cask B of E 1233 which is intended to be used for the shipment of selected SEFOR fuel rods to a "hot lab" for destructive examination. The cask has been received and inspected by GE, and all deficiencies have been corrected. The inside of the cask has been cleaned and the outside painted. The cask has been shipped to the SEFOR Site where it is being stored.

The license application for AEC and Department of Transportation authorization to use cask B of E 1233 for shipment of irradiated SEFOR fuel rods has been completed and is being reviewed.

The design of the equipment required for the fuel transfer operation was completed, and has been submitted to vendors for bids. The equipment includes the transfer tube and seals between the refueling-cell valve and transfer cask, and the single fuel-rod shipping canister.

Detail drawings were made for shielding around the vertical transfer valve in the SEFOR refueling cell, and were sent to the SEFOR site for comment. The shielding is designed as a semi-permanent structure that need not be removed after each fuel transfer operation. The drawings are being reviewed to determine if the design is adequate.

5.3 CURRENT RESULTS

A container was completed designed to allow three fuel rods to be removed from the refueling cell at one time. Minor modification to other equipment was required to accommodate the three rod containers.

Structural and thermal analyses were made for the shipping cask and its internals. The analyses are required so that the license application will show the cask meets the conditions described in 10CFR71. The

thermal analysis was made to determine the temperature distribution in the cask during normal transportation conditions and after a 30 minute fire at 1475°F. The

structural calculations were made to evaluate the tie-down devices, lifting devices, the puncture resistance and the effects of a 30 ft drop.

SECTION VI

6. SEFOR SAFETY AUDIT

On August 26-29, 1969 a visit was made to the site as part of the audit of SEFOR operations. During this visit, procedures were reviewed and discussions held with the operation's personnel primarily to verify adequacy of procedures and to see that the procedures were being followed. In general, it was determined that the procedures, though cumbersome in certain respects, were adequate and were being followed by the personnel. It was felt that the operation's personnel were making every effort to update the procedures and to make them more useful in light of operating experience. Because of their significance for safety, the procedures and book-keeping to keep track of fuel were examined closely. The basic documents used for this purpose are the Fuel Inventory Record and the Fuel Transfer Record, both of which are kept in the control room. The Fuel Inventory Record represents the results of the taking of a physical inventory that verifies and lists the number and location of every fuel rod on the site. The last such inventory taking was performed on April 29, 1969.

Any fuel transferred following an inventory is recorded in the Fuel Transfer Record. Thus, the location of every fuel rod can be determined at any time by referring to the latest Fuel Inventory Record and the subsequent Fuel Transfer Record. Audit determined that this system is working out quite well. To verify the accuracy of the records, the location of a number of fuel rods in the new-fuel storage vault were checked against the records.

As part of the audit, radiation protection and health physics were discussed with Specialist, Radiation and Industrial Safety. With the approach of the power ascension program, it is planned to initiate an expanded surveillance program. Plans were also discussed concerning modification of the layout of the health physics area in order to divide the area into a clean and a contaminated zone. This will allow better control of access to the reactor building and fuel handling areas. In general, the audit found the radiation control procedures to be adequate.

SECTION VII

7. SEFOR SUPPORT

7.1 PAST ACCOMPLISHMENTS

The plant engineering effort is a supporting function to the SEFOR facility.

Shortly following fuel loading, difficulty was experienced with the sodium-level probes at high flow rates. Design of probes for replacement was initiated. A type I probe, consisting of a low-level tip probe, and type II probes, containing J probe elements, were designed.

Difficulty was experienced with maintaining flow through the primary-sodium cold traps following extended operation of the coolant systems. Procurement of traps for replacement was initiated.

7.2 CURRENT ACTIVITIES

The type I sodium-level probe was completed and installed in the reactor vessel head through one of the fuel-examination ports. The assembly contains three low-level tip probes.

Fabrication of the three type II J probe assemblies was completed. The

type II assemblies will replace the existing probes and provide for removal capability from the reactor vessel.

Fabrication of the first of two cold traps was completed. The first trap was shipped to the site, and the pressure containment welds and fins on the second trap were completed. Instrumentation installation remains to be completed, followed by code inspection.

A study was completed recommending a change from a gaseous argon supply system to a liquid supply system. The liquid supply will provide argon at a lower unit cost, significantly reduce the labor involved in changing bottles, and provide a product with a higher purity.

Initial steps were taken to provide a heated enclosure for the diesel generator. The existing enclosure will be insulated and heated to maintain 40° F during cold weather.

A level probe for the main intermediate heat exchanger dome was fabricated to replace the defective installed unit and shipped to the site.

SECTION VIII

8. SEFOR OPERATIONS

8.1 EXPERIMENTAL PROGRAM

Testing on the planned experimental program, Zero Power Phase, was resumed on September 1, after the two month containment leak check and maintenance outage with Test Procedure I-B.2, "Reflector Worth Measurements (Full Size Core)." Both fine reflectors #3 and #8 were differentially calibrated over their entire length. (See sections 4.3 and 4.4 for evaluation of results). The differential curves were integrated to obtain an integral worth curve and obtain the total worth. Three techniques were used in obtaining the differential values: the period technique; doubling-time techniques, and "Reactivity Meter" technique using the Data Acquisition-Computer System. The period and doubling-time techniques are standard methods which result in period determinations, which are, in turn, reduced to reactivity values by use of the SEFOR in-hour equations, programmed for the SEFOR digital computer. The "Reactivity Meter" technique uses the sampling capabilities of the data acquisition system, to sample a flux signal from one of the WRMs and uses this digitized signal by digital computer in the kinetic inversion calculations to yield reactivity values. Good relative agreement was obtained between these three methods. Effects on reactivity

worths of reflectors created by their proximity to a partially down or fully down reflector were observed, in some cases, as large as 25 cents. Several additional reflector "swap" measurements were made to attain a better understanding of these effects.

The uncertainties associated with fine reflector measurements were estimated to be ± 1 percent on the slope of the differential curve.

Following the reflector worth measurements, the isothermal temperature coefficient at 350°F was measured (Test Procedure I-B.4). (See Section 4.5 for evaluation of results.) The measurements were accomplished by two successive heat-up and cool-down cycles between 350°F and 400°F and determining the critical positions at these two temperatures. The mean value thus determined from the four measurements was -0.59 ± 0.01 cents/°F.

After some core rearrangement and fuel-rod worth measurements (described in a later section) in support of the fuel deficiency anomaly reported in the SEFOR Twenty-First Quarterly Report, the Material Worth Measurements for Full Size Core (Test Procedure I-B.6) was

completed. (See Section 4.6 for evaluation of results.) This test measured the material worth, relative to a sodium hole, of a standard fuel rod, a depleted UO_2 rod, a stainless steel rod, a B_4C rod, on a radial traverse to the center of the core, and at one point on the diameter extended, on the opposite side of the core. During these measurements, the measured worths of standard fuel rods and B_4C rods were lower than calculated values, and so additional measurements were undertaken to determine if the distributed B_4C rods in the proximity of the traverse may have had a stronger effect than anticipated. With 14 B_4C rods uniformly distributed in the full size core, it was impossible to select a radial traverse that did not pass quite close ($\approx$ one channel width) to several B_4C rods. These investigations indicated negligible local depression effects from the distributed B_4C rods, in agreement with calculations of local effects. The disparity between measured and calculated values appears to be a calculational problem (see Section 4.6). Guinea-pig-rod worth measurements made in a few select locations below the through-head ports, provided sufficient data for later core rearrangements. (Technical Specifications restrict guinea pig rods to locations below the through-head refueling ports.) Further, ancillary data providing information to reduce reactivity uncertainties in planning for core II were obtained. The measurements were made on a diametral traverse by successively replacing the

BeO tightener rods presently in core I with stainless steel tightener rods planned to be used in core II. The two tighteners were replaced in equivalent positions, but on diametrically opposite sides of the core, for each determination.

The first phase of the foil activation measurements, power distribution and fission ratio (Test Procedure I-B.7), was performed. This test required the activation of U-235, U-238, and Pu (92.90 percent, Pu-239, 6.44 percent, Pu-240 and 0.58 percent Pu-241) foils at 38 locations distributed throughout the core, to provide information for axial and radial reaction-rate power distributions. These locations were selected to obtain profiles on radii with a reflector partially down and fully up. To verify the necessary activation time, power level for correct counting activities, and handling procedures, a trial activation was performed with a single foil rod with U-235, U-238 and Pu foils. On the basis of the trial activation, the six foil activation rods containing 38 U-235 foils, 38 U-238 foils, and 14 Pu foils were inserted in the reactor and activated to a power level of about 1 kW (9.4×10^{-4} on the WRMs). The controlling fine reflector #8 was near mid-point (47.51 - 47.08 cm) during the irradiation. After removal, cleaning and disassembly of the foil rods, the foils were counted on a multi-channel analyzer with the energy window covering the energy range of 430 to 830 kev, which encompasses several

composite fission product peaks. Counting accuracy of 1 percent (based on count statistics) was maintained for all the counting. Positioning errors in the rod and in-core are estimated to be 1.2 percent (3σ) with respect to the counting accuracy. Evaluation of the test results are in progress. The second part of this experiment was delayed due to difficulty in obtaining foils for track recorder activations. These activations are low power activations of composite foils of Pu-239, Pu-240, U-238 and U-235 in contact with fission track recorders, thin mica discs which can be etched and counted later. The track etch measurements will coincide, at one point in space, with the present activation measurements needed for normalization, to obtain the true fission ratio determination. The track recorder activations can be made in one of the through-head refueling locations (W2.5 - N1.0F) at a later date which coincides at one point with the present activation measurements. The foil activation data was preliminarily evaluated for a power-level determination. This power-level determination yields a value of 600 watts with a WRM reading at 50×10^{-5} .

The reactor noise measurement (Test Procedure I-B.5), which terminated in mid-performance at the end of the last reporting period, had to be deferred again until later in the testing schedule. This reschedule was caused by the requirement

of replacing the vessel head of the reactor before reinstalling the center channel orifice, the restraint for the two He-3 chambers. To improve the data analysis for the noise test, calibration of the system response to be called "white" noise was repeated. This test was performed by placing both He-3 chambers adjacent to one another on the floor of the refueling cell, positioning the 20 curies Co-60 source near to the chambers and recording the resulting noise output.

After the center channel orifice was re-installed, the noise tests were completed and recorded on magnetic tape. The data is being analyzed to determine l/β ratio and to obtain a measure of the power level of the reactor.

A rod-drop experiment was performed to determine the total reflector system worth. The experiment utilized the in-core He-3 system and transient amplifiers with the traces recorded on the high-speed, light-pen oscillograph and on magnetic tape. The test was hampered by an upper limit on the power level due to current saturation of the detectors and at the lower readings by the inherent, reactor-neutron source. These data are now being analyzed.

Full power core loading (Test Procedure I-C.1) was performed, although some additional re-arrangement will be necessary before proceeding to full power.

It is anticipated that this additional re-arrangement will be accomplished when the IFAs are installed. Seven of the anticipated nine guinea-pig rods for the fuel surveillance program were loaded. Two of the guinea pig rods were not loaded because of the uncertainty as to the availability of the through-head port which is now being occupied by the temporary level probes. The loading provides physical access for: the removal of the innermost guinea-pig rods before exceeding 17.5 MWt as required by the technical specifications, and ability to compensate for the reactivity effects from this removal, from the drywell insertion and IFA installation. The core, composed of 14 B_4C rods, 7 guinea-pig rods and 627 standard rods has an excess reactivity of 3.15 dollars. After the isothermal temperature coefficient is completely determined and the other uncertainties ameliorated, the core will be rearranged to have the required total excess reactivity for the approach to full power.

After the preliminary full-power core was completed the reflector worth calibration test (Test Procedure I-C.2) was completed. (See Section 4.3 for evaluation of results.) The results of this test indicated that the total worth of Reflector No. 3 was increased by 8 cents and Reflector No. 8 total worth decreased by 6 cents from the values obtained in the full size core calibration. The worth of the coarse reflectors #1 and #2 were also affected.

The apparent causes of this change in reflector worth distribution appear to be the different positions of reflectors #5 and #10 (to compensate for the increased reactivity of the full power core relative to the full-size core), the asymmetric guinea-pig-rod distribution due to the availability of through-head port locations, and the asymmetrical B_4C rod distribution. The relative importance of these three effects have not been assessed.

Flow and pressure coefficient measurement (Test Procedure I-D.1), was performed. The measured value of the pressure coefficient is so small that it is virtually zero within the accuracy of measurement (± 0.5 cents). The flow coefficient measurement was limited by a maximum flow of ≈ 4000 gpm, because of low sodium-level trips. The value within the accuracy of measurement was virtually zero, also.

The isothermal temperature coefficient ($350^\circ F - 760^\circ F$) (Test Procedure I-D.2), was in progress at the end of the reporting period.

Check-out of the oscillator mechanism was completed and a sample data tape was prepared for checking the analysis procedures. During the oscillator-mechanism check, it is necessary to check, at least partly, the auto-balanced oscillator control. Three problems were encountered

during the check. (1) The servo transmitter on the balanced oscillator was inoperative. (2) The balanced oscillator servo unit would accurately track the oscillator position up to a maximum frequency of about 0.25 cps. (3) The shaft encoder, which keys the data acquisition system to the sample 32 times a second, appeared to be malfunctioning. The servo transmitter was replaced. It was then determined that the tracking capabilities of the balanced oscillator-servo system was acceptable, and so the apparent shaft-encoder problem was traced to the data acquisition system. The problem with the data acquisition system is now being diagnosed.

Three IFAs, which had been received on site, were checked for proper thermo-couple response and stored in the refueling cell. Procedures were completed for installation and check-out upon installation.

A number of measurements and core rearrangements were made as a result of the earlier detection of plutonium-deficient fuel. Relative reactivity-worth measurements were made for the following:

1. Eight fuel rods which were removed and which were suspected of being deficient because of their reworked status.
2. Four re-worked rods which remained in the reactor.
3. Three rods from pellet batch 626 fuel.

All of the planned measurements were completed which required the vessel head of the reactor to be removed. The head was installed and zero-power tests continued.

8.2 OPERATIONS AND MAINTENANCE

The plant outage, which was initiated at the beginning of July for the annual containment leak tests and continued through the month of August, during which modifications and maintenance were performed. Major emphasis was directed toward the elimination of inter-cell leakage between the argon and nitrogen zones. Leakage paths around the irradiated fuel storage tank and through the argon blower-shaft seal were identified and corrected. A thin, all welded, cover plate was installed over the existing refueling-cell floor seal that encircles the reactor vessel. Tests were performed to verify that the inter-cell leakage has been reduced to a negligible value.

During the previous operation of the argon purification loop, NaK was transported from the bubbler and deposited in the pipe return to the refueling cell. The greatest accumulation occurred in the refueling cell isolation valve and adjacent elbows. With continued argon flow the NaK was oxidized, and by the introduction of CO₂, converted to the carbonate. A section of the pipe, the isolation valve, and the elbows were removed from the system, cleaned by reacting the NaK with water, and reinstalled. The remainder of the piping was mechanically cleaned with a Roto-rooter. Tests are planned to determine the NaK carryover as a function

of the argon flow rate. This will aid in the design of a separator to be installed in the bubbler. A sampling device and an orifice to measure flow have been installed.

Instrumented fuel assemblies Nos. 1, 2, and 3 were checked to verify mechanical dimensions and instrumentation response prior to installation in the reactor. Two additional brackets were installed in the refueling cell for storage and for support of the assemblies during grappling when transferred into the reactor. The three assemblies were transferred to the refueling cell.

Other maintenance activities performed during August included:

- ✓ 1. Replacement of the primary vent tank-rupture diaphragm and the 20-in diameter, 4 psi, rupture diaphragm on the argon cooler loop. The diaphragms leaked but were not ruptured. The cause of the malfunction is being investigated.
- ✓ 2. Cleaning and lapping of gaseous radwaste-header check valves.
- ✓ 3. Replacement of manual-reset oil-pressure switches with automatic reset on the gaseous radwaste compressors.
- ✓ 4. Relocation of gaseous radwaste compressor and batch-tank pressure

switches in the air zone to facilitate repairs.

- ✓5. Repositioning of the detectors for the source-range monitors in order to lower the sensitivity by a factor of ten, and reduce the non-linearity during overlap with the intermediate-range monitors.
- ✓6. Repair of the vacuum-distillation station-gate valve.
- ✓7. Exercising of pipe snubbers on the primary sodium system.
- ✓8. Replacement of motor bearings on one nitrogen blower, main bearings in a freon compressor, and fan bearings on a freon condenser unit.
- ✓9. Installation of an additional vaporizer unit on the liquid-nitrogen supply tank.
- ✓10. Installation of a high/low-pressure reactor-building isolation trip and alarm, for the ventilation make-up fan.
11. Installation of thru-head low-level probes in the reactor vessel.
12. Performance of other miscellaneous component and equipment repairs.

The main temperature of the primary sodium was increased to as high as 845°F and cold traps were operated to remove oxides from the system. Performance of the J-type level probes

improved, but additional improvement in linearity and probe-to-probe agreement would be desirable. Proper performance of the reactor-vessel low-level probes was not attained. Consequently, the new thru-head probes were installed. Plugging temperature of the primary system was reduced to approximately 270°F, and the cold traps were operated on an intermittent basis, as needed.

During the period of increased temperature of the primary system, the power to the trace heaters was increased, to allow the system temperature to rise, so that oxides could be removed from the system. Accordingly, power to the heaters for the dome of the auxiliary intermediate heat exchanger was increased. An indication of abnormal temperature was discovered on the dome of the intermediate heat exchanger during routine data recording. The heater voltage was reduced to the preheat setting, the dome vented, and the temperature returned to the bulk sodium temperature. Subsequently, it was found that the monitoring circuit of the level probe would not respond to a low sodium level due to an apparent change in level-probe characteristics. Readjustment of the probe current and monitoring circuit resulted in proper subsequent operation of the low-level trip circuit.

The auxiliary system was drained and cooled down in order to permit

inspection of the dome of the auxiliary intermediate heat exchanger following the indication that an above normal temperature had occurred. Analysis of the data and inspection of the dome showed that the dome reached a temperature in the range of 900°F to 1000°F and that no damage was sustained.

Steps have been taken to prevent a re-occurrence of the situation by restricting to the preheat setting the voltage applied to the dome components, and other plant components of this nature, until permanent corrective measures are adopted.

Following the installation of an emergency vent valve for the argon cover gas in the primary-sodium drain tank, tests were performed which verified that the pressure could be reduced within the time required in the event of a pipe-breakage accident. The tests included the condition in which maximum operating pressure existed in the gaseous radwaste decay tanks.

Reactor operation was resumed on September 1, 1969. A total of 154 start-ups of the reactor were made in support of the experimental program. The predominate portion of the operation was at a nominal 400 watts with a maximum of 5 kW attained during the performance of one of the tests. A total of 19 automatic scrams occurred from the following

causes: eleven from transients during switching of scales on the WRMs; seven from operator error in switching of scales, in changing the flow rate, in advertent bumping of the manual scram button, and in dislodgement of a jumper cable; and one from undetermined cause. A total of 242 tests were performed to satisfy the surveillance requirements of SEFOR 1MW Technical Specifications. A total of 53 standard operating procedures, 114 corrective procedures, and 3 emergency procedures were reviewed as part of the continuing activity of procedure review, primary-system cold traps were operated intermittently as needed to maintain the plugging temperature at low values. The performance of the two traps was marginal. Replacement of the traps is planned for the next outage.

General plant maintenance, repair of equipment malfunctions, and equipment modifications included the following equipment:

- Multi-ton grapple
- Refueling cell crane
- Freon compressors
- Personnel access lock
- Wide range montiros (WRMs)
- Emergency diesel generator
- Nitrogen blowers
- Orifice grapple
- 26.5 V d-c battery charger
- Argon supply

Auxiliary primary leak detectors
 Reactor vessel thermocouples
 Reactor building air conditioner
 Argon purification loop
 Inert gas sample panel
 Radiation detectors

A total of 209 equipment malfunctions were corrected, categorized as follows:

Mechanical	71
Electrical	35
Instrumentation	103

A working platform for use in the installation of the instrumented fuel assemblies, a mockup for verification of procedure for removal of reactor-vessel sodium-level probes, a test platform for check-out of the oscillator, and a hoisting frame for removal of the primary cold traps were constructed.

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