15
10-12

MASTER

GEAP-10010-29
AEC RESEARCH AND
DEVELOPMENT REPORT
AUGUST 1971

**SOUTHWEST EXPERIMENTAL
FAST OXIDE REACTOR
DEVELOPMENT PROGRAM
TWENTY-NINTH QUARTERLY REPORT
MAY-JULY 1971**

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

GENERAL ELECTRIC

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SOUTHWEST EXPERIMENTAL FAST OXIDE
REACTOR DEVELOPMENT PROGRAM

Twenty-Ninth Quarterly Report

May-July 1971

Compiled by:

G. R. Pflasterer

G. R. Pflasterer, Development Project Engineer
SEFOR Research and Development

R. A. Becker

R. A. Becker, Manager
Program and Analysis

Approved:

P. Greebler

P. Greebler, Manager
Nuclear Engineering

Approved:

J. O. Arterburn

J. O. Arterburn, Manager
SEFOR Facility

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

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

BREEDER REACTOR DEPARTMENT • GENERAL ELECTRIC COMPANY
SUNNYVALE, CALIFORNIA 94086

6348 DevEng 75
305 MJC 9/8/71

GENERAL ELECTRIC

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TABLE OF CONTENTS

	Page
Abstract	1
1 Introduction	1
2 Summary	4
2.1 Completed Tasks	4
2.2 Task 6 – Reactivity Controls Required for Experimentation	5
2.3 Task 9 – Fuel Fabrication	5
2.4 Task 10 – Approach to Power	5
2.5 Task 11 – Transient Results	5
2.6 Safety Audit and Licensing	5
2.7 SEFOR Support	6
2.8 SEFOR Operations	6
3 Task 6 – Reactivity Controls Required for Experimentation	6
3.1 Task 6.1 – Fast Reactivity Excursion Device (FRED)	6
4 Task 9 – Fuel Fabrication	6
4.1 Purpose	6
4.2 Past Accomplishments	6
4.3 Current Results	7
5 Task 10 – Startup Testing	9
5.1 Purpose	9
5.2 Past Performance	9
5.3 Current Results	9
6 Task 11 – Transient Tests	16
6.1 Test Descriptions	16
6.2 Methods Used in the Data Analysis	17
6.3 Analysis of Familiarization Transients	26
6.4 Analysis of the Subprompt Critical Transients	32
6.5 Familiarization Slug Static Calibration Test Results	40
6.6 FRED Static Calibration – Subprompt Critical Slug	40
7 SEFOR Safety Audit and Licensing	48
8 SEFOR Support	48
8.1 Vessel Head Seal	49
8.2 Crane Retrieval	49
8.3 Additional Support	49
9 SEFOR Operation	54
9.1 Experimental Program	54
9.2 Operations and Maintenance	62
References	65
Contributors	65
Distribution	67

LIST OF ILLUSTRATIONS

Figure	Title	Page
4-1	IFA Repair	8
5-1	Amplitude of the Inlet Temperature Oscillation at 19 MW	14
5-2	Phase of the Inlet Temperature Oscillation at 19 MW	15
5-3	Amplitude of 2nd B.O.E. Transfer Function at 19 MW	15
5-4	Phase of 2nd B.O.E. Transfer Function at 19 MW	16
6-1	Familiarization Transient No. 2 — Data from U-238 Fission Channel A	18
6-2	Subprompt Transient No. 3 — Data from U-238 Fission Channel B	19
6-3	T ₁ — Filter Characteristics of the Smoothing Routine on the Data	23
6-4	T ₂ — Filter Characteristics of the Smoothing Routine on the Time Derivative of the Data	23
6-5	T ₃ — Filter Characteristics of the Smoothing Routine on the Second Derivative of the Data	24
6-6	T ₄ — Filter Characteristics of the Smoothing Routine on the Integral of the Data	24
6-7	Smoothed Data from U-238 Fission Channel A for Familiarization Transient No. 2	29
6-8	Comparison of Static and Dynamic Reactivities for Familiarization Transient No. 7	30
6-9	Comparison of Familiarization Test No. 7 Reactivities with Adjusted FRED Curve	30
6-10	Comparison of Predicted and Measured Reactivity for Subprompt Test 1-A	33
6-11	Time Dependent Reactivity During Subprompt Transient No. 2	33
6-12	Time Dependent Reactivity During Subprompt Transient No. 4	34
6-13	Time Dependent Reactivity During Subprompt Transient No. 7	34
6-14	Reactivity Versus Energy Data from Subprompt Tests 2, 4 and 7	37
6-15	Comparison of Reactivity Versus Energy for Subprompt Tests at 2 MW	37
6-16	Power Profile for 0.96\$ Transient from 10 MW	38
6-17	Energy Release from 0.96\$ Transient from 10 MW	38
6-18	Calculated Ratio of Non-Doppler to Total Feedback for a 0.96\$ Transient from 5 MW	39
6-19	Static Reactivity Worth Versus Position Measurements for Familiarization Slug	42
6-20	Familiarization FRED Time Dependent Reactivity Inferred from Static Tests	42

LIST OF ILLUSTRATIONS (Continued)

Figure	Title	Page
6-21	Static Reactivity Worth Versus Position Measurements for Subprompt Slug	46
6-22	FRED Position Versus Time Behavior Measured During Transient Tests	46
6-23	Subprompt FRED Time Dependent Reactivity Inferred from Static Test Data	47
6-24	Subprompt FRED Time Dependent Reactivity	47
8-1	SEFOR Reactor Vessel	50
8-2	SEFOR Backup Seal Installation	51
8-3	Reactor Vessel Head Seal Cap	52
8-4	Reactor Vessel Head Seal Segment	53
9-1	Transient Amplifier Current Voltage Characteristics	55

LIST OF TABLES

Table	Title	Page
5-1	Second Balanced Oscillator Test Data - 10 MW, 40% Flow, 560°F Coolant	10
5-2	Second Balanced Oscillator Tests Data - 10 MW, 40% Flow, 760°F Coolant	11
5-3	Second Balanced Oscillator Test Data - 13 MW, 50% Flow, 760°F Coolant	12
5-4	Second Balanced Oscillator Test Data - 15 MW, 60% Flow, 760°F Coolant	13
5-5	Second Balanced Oscillator Test Data - 19 MW, 75% Flow, 760°F Coolant	13
6-1	FRED Position—Time Data from Familiarization Transient Tests	27
6-2	FRED Position—Time Data from Subprompt Critical Transient Tests	27
6-3	Familiarization Transient—Tape Location Data	28
6-4	Subprompt Critical Transient—Tape Location Data	28
6-5	Familiarization Transients—Slug Worth	31
6-6	Preliminary Results of Subprompt Critical Transients	36
6-7	Comparison of Doppler Energy Coefficients	36
6-8	Familiarization Slug Reactivity Worth Measurements	41
6-9	Familiarization Slug Worth vs Position	41
6-10	FRED Slug Activity Worth Measurements	43
6-11	FRED Slug Reactivity Worth Measurements	43
6-12	FRED Slug Reactivity Worth Measurements	44
6-13	Subprompt Slug Worth vs Position	45
6-14	Averaged FRED Time—Position Data	45
9-1	Subprompt Transient Test Detector Connections	57
9-2	FRED Preoperational Mechanical Check - Subprompt Slug, April 23, 1971	60
9-3	Subprompt Transient Test Fuel Surveillance Results	61

ABSTRACT

This report summarizes the work performed on the Research and Development Program for the Southwest Experimental Fast Oxide Reactor during the period from May 1, 1971, through July 31, 1971. The work was performed under contract AT(04-3)-540 with the United States Atomic Energy Commission.

1. INTRODUCTION

Southwest Experimental Fast Oxide Reactor (SEFOR) is a 20 MW, sodium-cooled fast reactor with characteristics similar to the large, soft spectrum fast breeder reactors fueled with mixed PuO_2 - 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 characteristic 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).

GEAP-10010-29

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).
22. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Second Quarterly Report, August-October 1969," GEAP-10010-22 (November 1969).
23. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Third Quarterly Report, November 1969-January 1970," GEAP-10010-23 (February 1970).
24. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Fourth Quarterly Report, February-April 1970," GEAP-10010-24 (May 1970).
25. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Fifth Quarterly Report, May-July 1970," GEAP-10010-25 (August 1970).
26. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Sixth Quarterly Report, August-October 1970," GEAP-10010-26 (November 1970).

27. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Seventh Quarterly Report, November 1970-January 1971," GEAP-10010-27 (February 1971).
28. "Southwest Experimental Fast Oxide Reactor Development Program, Twenty-Eighth Quarterly Report, February-April 1971," GEAP-10010-28 (May 1971).

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. Carig, 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. Cockran, 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).
28. Johnson, M. L., Becker, R. A., Haar, J. M., "SEFOR Fuel Handling," GEAP-13565 (December 1969).
29. Noble, L. D., et al., "Results of SEFOR Zero Power Experiments," GEAP-13588 (March 1970).
30. Ikeuye, D. T., and Young, F. E., "Fabrication of Non-Fuel Core Components for SEFOR," GEAP-13595 (February 1970).
31. Meyer, R. A., Stewart, S. L., Craig, E. R., Reynolds, A. B., and Johnson, M. L., "Design and Analysis of SEFOR Core I," GEAP-13598 (April 1970).
32. McKeehan, E. R., "Design and Testing of the SEFOR Fast Reactivity Excursion Device (FRED)," GEAP-13649 (October 1970).
33. Noble, L. D., et al., "SEFOR Core I Test Results to 20 MW," GEAP-13702 (April 1971).

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:

TASK	TITLE
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

7.0 Fuel Handling

8.0 Core Design

2.2 TASK 6 – REACTIVITY CONTROLS REQUIRED FOR EXPERIMENTATION

The phase III (< 130 cents) neutron absorber rod was shipped to SEFOR.

2.3 TASK 9 – FUEL FABRICATION

Receiving inspection of the fuel rods and loose fuel pellets fabricated by Nuclear Fuel Services, Inc. was completed. The loose fuel pellets were acceptable and are stored at the GE Vallecitos Nuclear Center. The fuel rod disposition was completed based on the results of the receiving inspections.

A Time Domain Reflectometer (TDR) was used to locate thermocouple short-circuits and open-circuits in several Instrumented Fuel Assemblies (IFAs). The defective circuits were successfully repaired. The 6th IFA was shipped to SEFOR. Electrical faults in two IFAs (VNC-24 and VNC-26) were repaired at the SEFOR site. Plans were made for further diagnostic work with the IFAs after reactor installation.

The Core II Instrumented Fuel Rod (IFR) assembly sequence was established. Work was begun on written assembly procedures and setting up IFR assembly-work areas. IFR specifications are essentially completed except for the fuel thermocouple and assembly specifications. Cost and schedule quotes for the fuel thermocouple were received from vendors. Long lead time material has been received. Fuel and reference thermocouple material compatibility tests were initiated.

2.4 TASK 10 – APPROACH TO POWER

Balanced oscillator Experiments (B.O.E.) of the first (constant temperature) and second (constant power) kinds were performed at reactor power levels from 10 MW to ~19 MW. The amplitude of temperature response due to coolant flow oscillation was smaller than expected. This reduced the magnitude of reactivity effects which could be obtained and therefore reduced the sensitivity of the tests. The results obtained from the first B.O.E. for the value of the reactivity feedback coefficient showed reasonably good agreement with the results obtained from the conventional oscillator tests and have been previously reported. The second B.O.E. tests results are much more sensitive to uncertainties in coolant temperature measurements, however, and the low amplitude of the coolant temperature oscillations, combined with thermocouple measurement anomalies, prevented a good comparison with reactivity effects obtained from other measurements.

2.5 TASK 11 – TRANSIENT TESTS

Analysis of the data obtained from the subprompt critical transient tests provides additional evidence that the value of the Doppler coefficient is $T \frac{dk}{dT} = -0.0081$, as determined by the static and oscillator tests. The familiarization and subprompt critical tests demonstrated consistency and repeatability of data among the tests. The reactivity insertion inferred from the measured transient flux data coupled with the space independent reactor kinetic model was approximately 4% greater than that determined from measurements of the poison slug reactivity worth during static tests.

2.6 SAFETY AUDIT AND LICENSING

The following series of reports were sent to the AEC-DRL: three malfunction reports, three reports giving the results of the power ascension, conventional oscillator, balanced oscillator, and familiarization and subprompt critical transients for Core I, and a report documenting the analysis of the reactor vessel head bolt stresses. Ten safety evaluation were completed for equipment modifications and operating procedure changes. The seventh meeting of the Safety Review Committee was held at the site.

2.7 SEFOR SUPPORT

The backup reactor vessel head seal was fabricated and installed at the site. The seal is designed to reduce cover gas leakage from the existing metal o-ring seals located between the reactor vessel outer head and flange. The crane retrieval system was installed and checked out satisfactorily at the site.

2.8 SEFOR OPERATIONS

A reactor outage initiated on March 14, 1971 to investigate the loading on the reactor vessel outer head studs, which results from differential movement of the vessel flange and head during temperature changes of the primary coolant, was terminated on April 29, 1971. The subprompt critical transient test series was completed, a preliminary calibration of the superprompt transient FRED slug was performed, and the annual outage for containment leak checks was initiated on June 15, 1971. Containment leak tests were accomplished with satisfactory results. Plant and equipment modifications and maintenance were completed and a leak rate retest of the inner containment was initiated subsequent to the modifications.

3. TASK 6 – REACTIVITY CONTROLS REQUIRED FOR EXPERIMENTATION

3.1 TASK 6.1 – FAST REACTIVITY EXCURSION DEVICE (FRED)

3.1.1 Purpose

The purpose of the FRED is to initiate reactor power excursions under controlled conditions. The device developed and fabricated under this task is used in SEFOR to carry out the planned excursion during the experimental program.

3.1.2 Past Accomplishments

The FRED design, fabrication, and testing have been completed and a topical report on the design and testing has been issued.¹

3.1.3 FRED Rod

The experimental program requires neutron absorber rods with three different reactivity worths for the FRED tests. The FRED rods are designed to enable reactivity adjustment and remote assembly and disassembly from the extension shaft.

The Phase III absorber rod was shipped to the SEFOR site for calibration and worth adjustment in preparation for superprompt tests.

3.1.4 FRED Rod and Drywell Emittance Measurements

A report was issued on the surface emittance measurements made of the samples which simulated drywell and FRED rod surface conditions. The emittance values obtained were slightly lower than expected.

4. TASK 9 – FUEL FABRICATION

4.1 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 part of this task, as well as the instrumented fuel assembly fabrication.

4.2 PAST ACCOMPLISHMENTS

The complete core component and fuel rod order has been received at SEFOR in previous quarters. The stainless steel tightener rods for Core II were received. Five instrumented fuel assemblies were shipped to the SEFOR site. Fabrication was started on 102 additional fuel rods. Conceptual design of SEFOR Core II instrumented fuel rods was completed. The design includes three rods located at three separate through-head ports. Each rod contains one fuel thermocouple. Scoping drawings were made of fuel thermocouple design options, the instrumented fuel rod with vessel penetration of thermocouple leadout, and rod handling from shipment to post-irradiation storage.

4.3 CURRENT RESULTS

4.3.1 Fuel Rod Procurement

Nuclear Fuel Services (NFS) is fabricating additional fuel rods and repairing 22 helium-leaking rods under Revision 4 to the original purchase order for fuel rods.

The receiving inspection of the fuel rods and loose fuel pellets shipped from Nuclear Fuel Services, Inc. (NFS) was completed. The fuel rod inspection was done at the SEFOR site and the loose pellet inspection was done at GE Vallecitos Nuclear Center.

The loose fuel pellets were satisfactory and they are stored at GE Vallecitos Nuclear Center for use in instrumented fuel rods that are planned.

Some discrepancies were found during the inspection of the fuel rods. Two tests included in the inspection, He leak check at 800°F and elliptical radiographs of the end plug welds, were more stringent than those agreed upon in the GE-NFS contract and therefore were not part of the acceptance criteria.

The disposition of the fuel rods (new and repair rods) is given below based upon the results of the receiving inspection.

CLASSIFICATION AND DISPOSITION	NUMBER OF FUEL RODS
Acceptable (Retained at SEFOR Site)	81 plus the UO ₂ filled dummy rod
He leak rate greater than 1×10^{-8} cc/sec at room temperature (Return to NFS for repairs)	7
Mechanical discrepancies (Return to NFS for repairs)	4
He leak rate greater than 1×10^{-8} cc/sec at 800°F (Retained at SEFOR site for further investigation)	24
Indicated defects from special radiographic inspection of end plug welds. (Retained at SEFOR site for further investigation).	7

4.3.2 First Core Instrumented Fuel Assemblies (IFA)

4.3.2.1 IFA Circuit Analysis

A number of circuit analyzing tests were conducted on the 6th IFA sensor circuits using a Time Domain Reflectometer (TDR). The usefulness of the TDR as a diagnostic aid in sensor circuit fault analysis was demonstrated, and the TDR was used to locate the fuel thermocouple short-circuit in the 6th IFA (VNC 27). When a possible successful repair was indicated from this analysis, the decision was made to proceed with the repair. The repair work was successfully completed. The 6th IFA passed final inspection and was shipped to the SEFOR Site.

The Time Domain Reflectometer was used at the SEFOR Site to check the sensor circuits in the four IFAs in storage awaiting reactor installation. The extension leads between the constant temperature junction and the reactor vessel were also checked. The results of this work indicated all the extension leads were intact. The work also showed the open circuit in VNC-24 and VNC-26 were in reasonably accessible locations for repair. The open circuits in VNC-24 and VNC-26 were successfully repaired at the SEFOR Site.

4.3.2.2 IFA Repair

The IFA's VNC-24 and VNC-26 were repaired in accordance with previously prepared procedures. The previous work with a Time Domain Reflectometer indicated both IFAs had failed leads in their splice areas. The clam shell sections covering the splice areas were removed by grinding along the weld seams. The exposed splice area allowed the failed leads to be repaired by spot welding. (See Fig 4-1). The resistances of all the leads were measured and recorded after each grinding or welding step to assure they had not been damaged. After rewelding the clam shell section to the

Figure 4-1. IFA Repair

splice tube head, heat was applied and the IFA evacuated overnight to remove any moisture which may have accumulated during the repair. The final step was to straighten the IFA to its original specification.

Both IFAs were repaired in much the same way. The major difference was the need to cut two access holes into the VNC-26 splice region. Although the failed lead could be seen through the first opening cut, it could not be reached with the spot welder. A second opening was cut adjacent the failed lead and it was easily repaired.

Plans were made for modifications to the sensor lead connections at the thermocouple reference junction to simplify monitoring the condition of the IFA thermocouple circuits in the reactor.

Plans were made for the initial (after reactor installation) IFA thermocouple circuit surveillance. This work will take advantage of the previously discussed circuit change. Following further safety analysis, work plans were made for repair of in-reactor sensor circuit faults (open circuits) by "zapping."

The IFA (VNC-27) with a spacer missing (reduced spring force) in the center fuel section was radiographed in the vertical position in the Refueling Cell. The pellet dislocations shown on the radiograph should not effect the fuel temperature measurements. The spring force is not required during reactor operation.

4.3.3 Core II Instrumented Fuel Rods (IFR)

The Core II Instrumented Fuel Rod (IFR) is provided to determine the fuel temperature during the SEFOR superprompt critical transient tests. A special high temperature fast response thermocouple that is designed for these transient test requirements is contained in each IFR to satisfy its operational objective.

An assembly sequence for the IFR components was established. The sequence centers around the fuel thermocouple and builds to the fuel loading as final assembly. The IFR receives minimal handling after the fuel is loaded. Up to and through fuel loading the fuel thermocouple will receive special handling considerations. Work was started on written assembly procedures and on establishing IFR assembly areas.

Work continues on the IFR specifications. The design, assembly, and fuel thermocouple specifications are being resolved for final issue. A preliminary fuel thermocouple specification was used to obtain cost and schedule quotes from three thermocouple vendors. The seal plate assembly design and final specification was issued and an order placed for the assemblies. The mini fuel rod specification and drawings were completed and issued. The cladding, extension rod, and bar materials have all been received. The fuel was segregated for processing tests and loading into the IFRs.

A material compatibility test is being initiated for the reference thermocouple design materials and the fuel. The test will mockup the axial fuel rod temperature gradient and the reactor transient tests time at temperature. The first test phase will determine basic material compatibility. Subsequent tests will determine effects of temperature and time on thermocouple emf output.

5. TASK 10 – STARTUP TESTING

5.1 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 with the theoretical calculations. The wet critical tests comprise Task 10.3. Task 10.4 includes the initial approach to full power.

5.2 PAST PERFORMANCE

Measurements of reactivity feedback using steady state and oscillator tests at power levels up to 20 MW were completed. During these measurements the mixed oxide ($\text{PuO}_2\text{-UO}_2$) fuel temperature reached a calculated maximum temperature of approximately 4700°F. Analysis of the test data provided a measured power-Doppler reactivity relationship with an estimated standard deviation of $\pm 8\%$. Comparison of results with calculations demonstrated that the Doppler component of the feedback can be described by a fuel temperature coefficient ($T_{\text{Dk}}^{\text{dk}}$) of -0.0081 with an estimated standard deviation of ± 0.014 . This coefficient compared favorably with the value of -0.0085 that was predicted prior to the measurements.

5.3 CURRENT RESULTS

5.3.1 Balanced Oscillator Tests

Balanced oscillator tests of the first and second kinds were performed at reactor power levels from 10 MW to ~ 19 MW. Seven frequencies were used covering the range between 0.011 and 0.23 radians per second. The results of the first balanced oscillator tests (constant coolant temperature) are reported in reference 2.

The objective of the second balanced oscillator experiment (B.O.E.) was to measure the time dependent reactivity effects of coolant temperature changes at a constant power. The power was to be held constant by causing the coolant temperature to oscillate with sufficient amplitude to counteract the reactivity effect of a B₄C rod oscillation. The coolant temperature oscillation was induced by oscillating the primary and secondary coolant flows.

For this experiment the model for the relation between the input reactivity, ΔK_{in} , and the oscillating core average coolant temperature, ΔT_c , is (see reference 3).

$$\frac{\Delta K_{in}}{\Delta T_c} = - (C_f F_s + C_q) - C_i \frac{\Delta T_i}{\Delta T_c} + \left[\frac{1}{P G_0} - \alpha_f F_{av} X_f \right] \frac{\Delta P}{\Delta T_c}$$

where P is the reactor power, G_0 is the zero power reactivity transfer function, ΔP is the power oscillation and ΔT_i is the inlet temperature oscillation; C_f , C_q , and C_i are fuel, average coolant, and inlet coolant temperature reactivity coefficients respectively, while α_f is the power reactivity coefficient. F_s and F_{av} are normalized frequency response functions that describe³ the fuel temperature response to power and coolant temperature oscillations, and X_f is the response³ of the total power absorbed in the fuel to the "fission" power.

The measured quantities in the above expression are reactivity, the temperature, and the power oscillations. For a perfect balance, $\Delta P=0$, the last term vanishes, and the fuel and coolant temperature reactivity coefficients can, in principal, be determined from the measured reactivity and temperature oscillations.

Measured data from the second balanced oscillator experiment are tabulated in Tables 5-1 through 5-5. Unless otherwise indicated, the coolant temperature oscillations were obtained from data channels 42 (inlet temperature) and 41 (outlet temperature). The average coolant temperature, which is approximately the average of the inlet and outlet temperature oscillations, was computed from a formula³ that accounts for frequency dependent changes through the core.

Table 5-1
SECOND BALANCED OSCILLATOR TEST DATA
10 MW, 40% Flow, 560°F Coolant
Data Tape 75

File	Frequency (rad/sec)	$\Delta P / \Delta T_c$		$\Delta k / \Delta T_c$		$\Delta T_i / \Delta T_c$	
		Amplitude (MW/°F)	Phase (degrees)	Amplitude (cent/°F)	Phase (degrees)	Real Part	Imaginary Part
16	0.2213	Apparent Balance		0.207	-16.7	0.00	0.00
17	0.1296	Reached for all files		0.192	-32.7	0.64	0.24
18	0.07792			0.254	-29.7	0.84	0.55
19	0.07795			0.255	-29.0	0.80	0.50
20	0.07788			0.266	-27.7	0.74	0.52
21	0.04853			0.282	-22.5	0.78	0.64
22	0.04843			0.309	-21.1	0.64	0.65
23	0.03019			0.317	-15.7	0.59	0.69
24	0.03005			0.322	-15.6	0.51	0.75
25	0.01709			0.328	-1.1	0.40	1.26
26	0.01062			0.299	12.5	0.32	2.00
27	0.01052			0.338	17.4	0.00	1.71
28	0.2109			0.205	-20.0	0.00	0.00

Table 5-2
SECOND BALANCED OSCILLATOR TEST DATA
 10 MW, 40% Flow, 760°F Coolant
 Data Tape 45

File	Frequency (rad/sec)	$\Delta P/\Delta \bar{T}_c$		$\Delta k/\Delta \bar{T}_c$		$\Delta T_i/\Delta \bar{T}_c$	
		Amplitude (MW/°F)	Phase (degrees)	Amplitude (cent/°F)	Phase (degrees)	Real Part	Imaginary Part
11 ^a	0.07769	0.0020	88.0	0.26	-37.0	0.24	0.15
12 ^a	0.07820	0.0021	-160.0	0.29	-31.4	0.24	0.14
13 ^a	0.04938	0.0011	62.6	0.27	-41.1	-0.12	0.33
14 ^a	0.04938	0.0030	21.3	0.30	0.0	-0.36	0.04
15 ^a	0.03100	0.046	20.7	0.52	2.6	-0.48	-0.01
16 ^a	0.03096	0.0054	15.4	0.28	0.0	-0.10	0.36
23	0.07739	0.008	125.0	0.221	-27.8	0.79	0.42
24	0.07750	0.0117	27.0	0.217	-28.6	0.74	0.41
25	0.07747	0.0	0.0	0.227	-33.4	0.78	0.51
26	0.1295	0.0	0.0	0.188	-31.8	0.72	0.07
27	0.04904	0.0	0.0	0.297	-27.2	0.69	0.69
28	0.04899	0.0	0.0	0.290	-27.1	0.70	0.66
29	0.03066	0.0	0.0	0.326	-19.2	0.58	0.90
30	0.03056	0.0	0.0	0.310	-16.3	0.58	0.93
31	0.01780	0.0	0.0	0.362	7.1	0.79	1.72
32	0.01779	0.0	0.0	0.385	3.5	0.56	1.61
33	0.01148	0.071	13.4	1.087	19.9	1.08	4.26
34	0.01166	0.056	15.7	0.969	23.5	0.76	3.81
35	0.2243	0.0	0.0	0.178	-23.4	0.0	0.0
36	0.0113	0.0	0.0	0.741	57.7	-0.77	6.60

^a These data obtained from Data Tape 104, using central IFA inlet and outlet measured temperature oscillations.

Table 5-3
 SECOND BALANCED OSCILLATOR TEST DATA
 13 MW, 50% Flow, 760°F Coolant
 Data Tape 61

File	Frequency (rad/sec)	$\Delta P/\Delta \bar{T}_c$		$\Delta k/\Delta \bar{T}_c$		$\Delta T_i/\Delta \bar{T}_c$	
		Amplitude (MW/°F)	Phase (degrees)	Amplitude (cent/°F)	Phase (degrees)	Real Part	Imaginary Part
17	0.2241	0.0026	-50.68	0.267	-31.00	0.46	-0.22
18	0.2240	0.0009	-58.61	0.179	-30.00	0.46	-0.22
19	0.1301	0.0016	-14.25	0.281	-26.28	0.72	0.29
20	0.1305	0.0007	15.15	0.230	-24.71	0.70	0.26
21	0.07889	0.0008	-123.7	0.222	-40.22	0.63	0.16
22	0.07896	0.0007	-144.3	0.208	-39.00	0.66	0.14
23	0.01145	0.0	0.0	0.451	23.39	1.72	1.90
24	0.07876	0.0	0.0	0.238	-18.34	0.36	1.08
25	0.07889	0.0	0.0	0.210	-31.00	0.66	0.15
26	0.04953	0.0	0.0	0.262	-22.70	0.68	0.57
27	0.04945	0.0	0.0	0.278	-23.69	0.58	0.57
28	0.03103	0.0	0.0	0.283	-10.02	0.43	0.96
29	0.03111	0.0	0.0	0.287	-11.28	0.48	0.91
30	0.01812	0.0	0.0	0.299	29.87	0.0	1.92
31	0.01799	0.0	0.0	0.310	15.47	-0.03	1.79
32	0.01176	0.0012	136.6	0.437	26.83	1.55	1.80
33	0.07914	0.0009	149.6	0.266	-30.34	0.49	0.83
34	0.2318	0.0028	-45.6	0.286	-27.91	0.41	-0.25
35	0.2312	0.0	0.0	0.204	-20.30	0.093	-0.09

Table 5-4
SECOND BALANCED OSCILLATOR TEST DATA
15 MW, 60% Flow, 760°F Coolant
Data Tape 45

File	Frequency (rad/sec)	$\Delta P/\Delta \bar{T}_c$		$\Delta k/\Delta \bar{T}_c$		$\Delta T_i/\Delta \bar{T}_c$	
		Amplitude (MW/°F)	Phase (degrees)	Amplitude (cent/°F)	Phase (degrees)	Real Part	Imaginary Part
8	0.2222	0.0147	-12.75	0.212	-21.92	0.51	0.07
9	0.1302	0.0064	-10.63	0.262	-27.51	0.75	0.31
10	0.07885	0.0051	100.0	0.265	-22.78	0.55	0.26
11	0.07849	0.0053	82.34	0.242	-26.56	0.59	0.22
12	0.07851	0.0034	-163.0	0.241	-30.63	0.57	0.19
13	0.04924	0.0	0.0	0.275	-22.17	0.59	0.62
14	0.03098	0.0072	-37.52	0.330	-20.58	0.36	0.96
15	0.03105	0.0207	-33.71	0.389	-22.16	0.26	1.05
16	0.03096	0.0069	-32.51	0.303	-23.64	0.24	0.75
17	0.03093	0.0146	-31.69	0.353	-19.67	0.35	1.26
18	0.03061	0.0070	-25.91	0.346	-9.55	0.30	1.35
19	0.01748	0.0117	-12.43	0.314	6.52	-0.44	2.21
20	0.01108	0.0293	54.47	0.393	15.20	-0.61	1.22
21	0.0110	0.0268	53.43	0.369	14.20	-0.53	1.17
22	0.1291	0.0	0.0	0.207	-31.71	0.80	0.32

Table 5-5
SECOND BALANCED OSCILLATOR TEST DATA
19 MW, 75% Flow, 760°F Coolant
Tape 113

File	Frequency (rad/sec)	$\Delta P/\Delta \bar{T}_c$		$\Delta k/\Delta \bar{T}_c$		$\Delta T_i/\Delta \bar{T}_c$	
		Amplitude (MW/°F)	Phase (degrees)	Amplitude (cent/°F)	Phase (degrees)	Real Part	Imaginary Part
8	0.07896	0.0	0.0	0.257	-26.00	0.59	0.61
9	0.07903	0.0	0.0	0.241	-25.55	0.62	0.57
10	0.04946	0.0065	76.3	0.276	-13.20	0.64	0.88
12	0.03099	0.0069	3.5	0.291	-18.96	0.14	0.94
13	0.03098	0.0	0.0	0.281	-13.92	0.19	1.03
14	0.1305	0.0	0.0	0.214	-31.55	0.87	0.62
15	0.1307	0.0	0.0	0.225	-31.26	0.78	0.53
16	0.2258	0.0069	-178.0	0.159	-38.13	0.73	0.28
17	0.01778	0.0135	50.8	0.302	6.03	-0.28	1.70
18	0.01106	0.0169	112.3	0.272	22.95	-1.11	2.71

The four thermocouples (TCs) available for measuring core outlet coolant temperature oscillations showed general agreement at all frequencies of oscillation, and their mean temperatures confirmed the measurements of the resistance temperature detector at the vessel outlet. Two TCs (32 and 42) were available for measuring coolant inlet temperature response during the oscillator tests. One (32) was located just at the inlet of a channel containing fuel, while the other (42) was located on the shroud just prior, in the coolant flow path, to the inlet plenum. The TC at the core inlet (32) was suspect, since it indicated an increase in temperature with power level even when the coolant inlet temperature, as measured by 42, and a resistance temperature detector located at the vessel inlet, was held constant. When the flow was held constant (as in a conventional oscillator test), the temperature oscillations indicated by TCs 32 and 43 agreed well, as indicated in Figures 5-1 and 5-2. When the flow was oscillated (as in the 2nd B.O.E.) however, these thermocouples showed the marked differences indicated in Figures 5-1 and 5-2.

The average coolant temperatures were computed from the measured inlet and outlet temperature oscillations, and values of $\Delta K_{in}/\Delta T_c$ were computed for different combinations of inlet and outlet coolant TCs. The "measured" values of $\Delta K_{in}/\Delta T_c$ are compared in Figures 5-3 and 5-4 with the expected behavior $[C_f F_s + C_q]$ obtained from the right hand side of the above equation using coefficients determined from other ⁴ static and conventional oscillator tests and assuming $\Delta P = 0$. The previously measured⁴ (by static tests) value of C_i was small and the term $C_i \Delta T_i / \Delta T_c$ was also neglected. As the curves indicate, no set of measurements is in agreement with the behavior expected from previous experiments. The curves also indicate, as previously discussed, that the coolant outlet thermocouples (31, 33, 39, and 41) are in agreement, while the two inlet TCs (32 and 42) show marked disagreement during the balanced oscillator experiments. This poor comparison between results of the 2nd B.O.E. and previous test results is apparently due to the low magnitude of the oscillations involved (they could not be increased because the flow oscillations are limited to amplitudes of $\pm 14\%$ about their mean values) and the apparent direct influence of flow on the indicated inlet TC responses.

Figure 5-1. Amplitude of the Inlet Temperature Oscillation at 19 MW

Figure 5-2. Phase of the Inlet Temperature Oscillation at 19 MW

Figure 5-3. Amplitude of 2nd B.O.E. Transfer Function at 19 MW

Figure 5-4. Phase of 2nd B.Q.E. Transfer Function at 19 MW

6. TASK 11—TRANSIENT TESTS

6.1 TEST DESCRIPTIONS

The transient tests involve the rapid insertion of positive reactivities (produced by ejecting a B₄C slug from a central channel in a time interval of ~ 0.1 sec) ranging between a minimum of approximately 0.4 dollars and a maximum in excess of 1 dollar. The tests are terminated by introduction of large negative reactivities (reactor scram) within 0.4 sec of transient initiation.

For convenience, the tests have been divided into three groups. These are the familiarization transients, which involve reactivity insertions of 0.5 dollars or less, the subprompt critical transients involving reactivity insertions greater than 0.5 dollars, but less than 1.0 dollars, and the superprompt critical transients that result from reactivity insertions in excess of 1.0 dollars.

The familiarization transients were initiated from two power levels: 1 MWt and 10 MWt. The energy release was small (of the order of 5 MW-sec, or less) during these transients, and the Doppler feedback produced by the fuel temperature changes was less than 2 cents. Consequently, these tests were used to gain familiarity with the system under transient conditions, and to verify test equipment operation and procedures, but not to obtain Doppler feedback information.

The subprompt critical transients involving reactivity insertions greater than 0.5 dollars provide the first measurements of the inherent prompt Doppler feedback characteristic during a rapid transient. These tests were initiated from powers of 1, 2, 5, and 10 MWt. The tests initiated from the higher power levels with reactivity insertions of the order of 0.96 dollars are of primary interest, as the energies released during these transients cause several cents reactivity feedback.

6.2 METHODS USED IN THE DATA ANALYSIS

6.2.1 Data Smoothing

6.2.1.1 Need for Data Smoothing

During a transient test, the flux, temperature, etc., signals are digitized with an analog to digital (A to D) converter, and under programmed digital computer control, the digitized signals are stored on magnet tape. This data sampling and storage equipment is referred to as the data acquisition system (DAS). The DAS samples and stores the signals from the wide range monitors (WRMs), as well as signals from temperature and flow instrumentation, every 7.3 msec. Two transient data channels (connected to either U-238 or γ detectors) as well as the status (open or closed) of the two relays along the length of the Fast Reactivity Excursion Device (FRED) that expels B_4C from the core are sampled and stored every 0.1 msec.

During the familiarization transients, and the sub-prompt critical transients involving reactivity worths of ~ 80 cents, both the wide range monitors and the U-238 fission detectors provided useful signals during the tests. For transients involving larger slug worths, the two wide range monitors quickly saturated (as expected) because of the large power changes (full scale power on the WRMs is 25 MW), and only the signals from the special U-238 fission chambers installed for use during the transient tests provided useful information. The γ detectors are intended for use during the superprompt tests.

Linear amplifiers were used to boost the amplitude of the current signal for those tests in which the change in power level (current) was less than about one decade. For the larger transients, logarithmic amplifiers were used, and the voltage input to the DAS was proportional to the logarithm of the current.

The wide range monitor (WRM) signals exhibited only small (nearly zero) fluctuations prior to and during the transients. However, the U-238 fission chamber signals exhibited four different types of fluctuations during the course of the familiarization and subprompt critical experiments. One type was a high frequency random fluctuation. This fluctuation (shown in Figure 6-1), which may have been caused by noise pick up in the signal transmission cables, was significantly reduced by use of a 5 KC filter. A second fluctuation (also shown in Figure 6-1) was a ~ 200 Hertz oscillation that was quite evident in one of the detectors at the lower power levels. Investigation revealed this oscillation to be a result of vibration (induced by the flowing nitrogen coolant around the detector) of the electrically charged ion collection plates in the detector. The detectors were removed and modified to reduce this oscillation.

The third and fourth types of fluctuations became apparent in the larger transients when the fission chambers were used with the logarithmic amplifiers. See Figure 6-2. One of these was a ~ 6 mV 60 Hertz voltage oscillation in a signal having a mean value of the order of 1 to 2 volts. Because of the logarithmic conversion (with a slope of ~ 300 mV/decade) between voltage and current, (power), the resultant apparent oscillation in relative power was thus ten raised to the power of $\pm 6/300$, which is $\sim 1 \pm 0.05$ or about $\pm 5\%$ oscillation. Due to the logarithmic conversion, the oscillation is the same percentage at all power levels. The fourth type of fluctuation is illustrated by the step changes in Figure 6-2. These are caused by the resolution (~ 2 mV) of the analog to digital converter, and have an insignificant effect on the final results.

The digitized flux data obtained during the transient tests are treated ("smoothed") to obtain a more accurate representation of the transient flux behavior. This treatment reduces the spurious fluctuations (noise) without significantly modifying the true flux values. In addition, the data treatment facilitates the calculation of the reactivity and the energy release from the recorded transient data.

6.2.1.2 Method of Data Smoothing

The smoothing procedure that is used for the SEFOR data is essentially the same as that used for the analysis of SPERT⁵ transient data. With this procedure, a section of recorded data is fitted (in the least squares sense) with a parabola, and the smoothed data point (as well as its first and second time derivatives), at the center of the section is obtained from the fitted curve. The next recorded data point is then incorporated into the section, the first data point of the section is removed, and the next smoothed point is obtained from a fit to the new section of data.

In SEFOR, the data points are all equally spaced in time, so that the central point in a section of data containing an odd number of data points corresponds to the middle of the time interval for that section. The data smoothing code takes advantage of this symmetry about the central point by only fitting sections of data containing an odd number of points. Thus, except for the first (and last) few points of a set of data, the smoothed data point at point j is obtained by fitting to the $N+1$ data points between $j-N/2$ and $j+N/2$, where N is any even number.

Figure 6-1. Familiarization Transient No. 2 - Data from U-238 Fission Channel A

Figure 6-2. Subprompt Transient No. 3 – Data from U-238 Fission Channel B

The data are smoothed by replacing the actual measured points with those obtained from least squares fittings of parabolas to the data. This procedure is based on that given in reference 6. For the "central" data points (those which have at least $N/2$ data on each side of the point in question), the fitted parabola F_j that is valid on the time interval $(j-1/2)\Delta t$ to $(j+1/2)\Delta t$ may be represented as

$$F_j(t) = \sum_{k=1}^3 A_{kj} \left[\frac{t}{\Delta t} - j \right]^{(k-1)} \quad j - 1/2 \leq \frac{t}{\Delta t} \leq j + 1/2$$

where j is an integer and Δt is the time interval between samples.

The coefficients A_{kj} in this expression are obtained from a fitting of the parabola to the $N+1$ data points between $j-N/2$ and $j+N/2$.

It is seen from the above expression that A_{1j} is the "smoothed" data point at time $j\Delta t$, that $A_{2j}/\Delta t$ is the time derivative of the function at time $j\Delta t$ and that $2A_{3j}/(\Delta t)^2$ is the second derivative at time $j\Delta t$. These values are determined (for the central data points) from the recorded data, $G(n)$, between point $j-N/2$ and $j+N/2$ according to the following expression:

$$A_{kj} = \sum_{n=0}^N C_{kn} G(j + n - N/2)$$

where N is even, and where:

$$C_{1n} = \frac{1}{N+1} \left[1 + \frac{5N(N+2)}{4(N-1)(N+3)} - 15 \frac{(n-N/2)^2}{(N-1)(N+3)} \right]$$

$$C_{2n} = \frac{12(n-N/2)}{N(N+1)(N+2)}$$

$$C_{3n} = \frac{-15}{(N-1)(N+1)(N+3)} \left[1 - \frac{12(n-N/2)^2}{N(N+2)} \right]$$

These coefficients make the following sums, S_j , a minimum for each j on the interval $0 \leq N/2 \leq j \leq J_{MAX} - N/2$.

$$S_j = \sum_{n=0}^N \left[G(j + n - N/2) - F_j \left(\Delta t(j + n - N/2) \right) \right]^2$$

where $F_j(t)$ is defined above.

For the first $N/2$ points, and for the last $N/2$ points, in a set of data, the coefficients A_{kj} must be determined from the following relations:

$$A_{1j} = B_1 + B_2(1 - 2j/N) + B_3 \left\{ 1 - 6j/N + 6j(j-1)/[N(N-1)] \right\}$$

$$A_{2j} = -2B_2/N - \frac{6}{N} B_3 [1 - (2j-1)/(N-1)]$$

$$A_{3j} = 6B_3/[N(N-1)]$$

where, with $L = 0$ on the interval $0 \leq j \leq N/2-1$ and $L = J_{MAX}-N$ on the interval $J_{MAX}-N/2+1 \leq j \leq J_{MAX}$, the constants B_1 , B_2 , and B_3 are determined from the data as follows:

$$B_1 = \frac{1}{N+1} \sum_{n=0}^N G(n+L)$$

$$B_2 = \frac{3N}{(N+1)(N+2)} \sum_{n=0}^N \left(1 - \frac{2n}{N}\right) G(n+L)$$

$$B_3 = \frac{5N(N-1)}{(N+1)(N+2)(N+3)} \sum_{n=0}^N G(n+L) \left\{1 - \frac{6n}{N} + \frac{6n(n-1)}{N(N-1)}\right\}$$

The latter sets of equations are taken directly, with a slight change in notation, from reference 6. As is demonstrated in reference 6 these equations yield a parabolic function which minimizes the sum of the squares of the differences between the calculated and measured points over the interval in question. The first sets of equations for the A_{kj} can be calculated directly from the latter set by a shift in the time origin from the zero to the $N/2$ point.

6.2.3 Filtering Characteristics of the Smoothing Routine

The filtering characteristic of the smoothing procedure can be determined by calculating the values of the smoothed function for an input signal of the form $e^{i\omega t}$. Since all signals of interest can be represented, through the Fourier transform, with components of this form, such an assumption for the input signal does not restrict the conclusions.

From the definition for the A_{kj} , given in Section 6.2.1, it is seen that for an input signal $G(j) = e^{i\omega j\Delta t}$ the ratio, T_1 , of A_{1j} to $G(j)$, is

$$T_1 = \frac{A_{1j}}{G_j} = e^{-i\omega \frac{N\Delta t}{2}} \left[\sum_{n=0}^N e^{i\omega n\Delta t} \left\{ \frac{1}{N+1} + \frac{5N(N+2)}{4(N+1)(N-1)(N+3)} \right\} - 15 \sum_{n=0}^N e^{i\omega n\Delta t} \left\{ \frac{(n-N/2)^2}{(N+1)(N-1)(N+3)} \right\} \right]$$

Since the derivative, G'_j , of G_j is $i\omega e^{i\omega j\Delta t}$ and the derivative of the smoothed function is $A_{2j}/\Delta t$, the transfer function, T_2 , of the derivative is

$$T_2 = \frac{A_{2j}/\Delta t}{G'_j} = \frac{e^{-i\omega \frac{N\Delta t}{2}}}{i\omega\Delta t} \frac{12}{N(N+1)(N+2)} \sum_{n=0}^N (n - N/2) e^{i\omega n\Delta t}$$

In a similar manner the transfer function for the second derivative of the input function is

$$T_3 = \frac{2A_{3j}/\Delta t^2}{G''_j} = \frac{e^{-i\omega \frac{N\Delta t}{2}}}{(i\omega\Delta t)^2} \frac{30}{(N-1)(N+1)(N+3)} \sum_{n=0}^N e^{i\omega n\Delta t} \left\{ 1 - \frac{12(n-N/2)^2}{N(N+2)} \right\}$$

Noting that for any $x \neq 1$

$$\sum_{n=0}^N x^n = \frac{x^{N+1} - 1}{x - 1}$$

$$\sum_{n=0}^N (n - N/2)x^n = \frac{N}{2} \left[\frac{x^{N+1} + 1}{x - 1} \right] - \frac{x}{(x - 1)^2} [x^N - 1]$$

and that

$$\sum_{n=0}^N (n - N/2)^2 x^n = \frac{N^2}{4} \left[\frac{x^{N+1} - 1}{x - 1} \right] - \frac{Nx}{(x - 1)^2} \left[x^N + 1 \right] + \frac{(x + 1)x}{(x - 1)^3} \left[x^N - 1 \right]$$

substitution of $e^{i\omega\Delta t}$ for x gives, after rearranging and defining $y = \omega\Delta t/2$, the following values for the transfer functions

$$T_1(N, y) = \frac{3}{2(N+1)(N+3)} \left[-(N-2) \frac{\sin(N+1)y}{\sin y} + \frac{5}{N-1} \left[\frac{\cos y \sin Ny - N \sin y \cos Ny}{\sin^3 y} \right] \right]$$

$$T_2(N, y) = \frac{3}{N(N+1)(N+2)} \left[\frac{\sin Ny - N \sin y \cos(N+1)y}{y \sin^2 y} \right]$$

$$T_3(N, y) = \frac{15}{N(N-1)(N+1)(N+2)(N+3)} \left[\frac{3 \cos y \sin Ny - 3N \sin y \cos Ny - N(N-1) \sin^2 y \sin(N+1)y}{y^2 \sin^3 y} \right]$$

The relationship between the integral from 0 to t of the smoothed function $F(t)$ and the smoothing coefficients is given in Section 6.2.4. For an input function $e^{i\omega t}$, the ratio between the value obtained from a fit to the data and the actual integral

$$\int_0^{N\Delta t} e^{i\omega u} du = \frac{e^{i\omega N\Delta t} - 1}{i\omega}$$

can be written as

$$T_4(N, y) = \frac{\cos y}{(\sin y)/y} \left[T_1 - y^2 T_3/6 \right] + y^2 T_2/2$$

where y , and the functions T_1 , T_2 , and T_3 are defined above.

Note that $T_1(N, y) = T_1(N, -y)$ and that $T_1(N, y + m\pi) = T_1(N, y)$ where m is any integer, i.e., the function is periodic and is symmetric about $\omega\Delta t/2 = m\pi/2$. The periodicity is a result of the finite digitizing interval, and the effect is called aliasing because signals at frequencies greater than $\frac{1}{2\Delta t}$ appear, in the digitized signal, to have a frequency of less than $1/2\Delta t$.

The functions T_1 , T_2 , T_3 , and T_4 are plotted in Figures 6-3 through 6-6. As can be seen from Figure 6-3, the function T_1 decreases to zero when $N\omega\Delta t/2 \sim 5.5$, and it has an absolute value ~ 0.10 when $N\omega\Delta t/2 \sim 15$. Thus, if it is desired to eliminate a particular frequency ω_0 from the data, N may be set equal to $\sim 11/\omega_0\Delta t$, and if it is desired to decrease unwanted signals of frequency $>\omega_0$ by a factor of 10 or more, N should be $\sim 30/\omega_0\Delta t$. Conversely, if all signals with frequencies $\leq \omega_k$ are to be retained with little ($<5\%$) distortion, N should be $\sim 4/\omega_k\Delta t$.

6.2.4 Reactivity Determination

A space independent reactivity model is used to determine the time dependent reactivity, $k(t)$, from the recorded transient flux (power) data, $P(t)$. With this model, the reactivity, in units of dollars, can be expressed as follows:

$$k(t) = 1 - \alpha \frac{S}{P(t)} + \frac{\alpha}{P(t)} \frac{dP(t)}{dt} - \frac{1}{P(t)} \int_{-\infty}^t D(t-u)P(u)du$$

Figure 6-3. T_1 - Filter Characteristics of the Smoothing Routine on the Data

Figure 6-4. T_2 - Filter Characteristics of the Smoothing Routine on the Time Derivative of the Data

Figure 6-5. T_3 - Filter Characteristics of the Smoothing Routine on the Second Derivative of the Data

Figure 6-6. T_4 - Filter Characteristics of the Smoothing Routine on the Integral of the Data

where α is the ratio of the prompt neutron lifetime to the effective delayed neutron fraction, S is the neutron source (assumed constant) and $D(t)$ is the delayed neutron kernel defined as follows:

$$D(t) = \sum_j \sum_i B_{ij} \lambda_{ij} e^{-\lambda_{ij} t}$$

In this expression λ_{ij} is the decay constant for delayed neutrons in delay group i from fissionable isotope j , and B_{ij} is the effective fractional contribution of delayed neutrons in group i from isotope j (i.e. $\sum_j \sum_i B_{ij} = 1$).

The actual values of the delayed neutron parameters which were used in this model were obtained from table 4-4 of reference 4.

Under the assumption that the source contribution is small ($S=0$), and that the power is constant with a value $P(0)$ in the interval $(-\infty, 0)$ the equation for the reactivity can be written

$$k[t, P(t)] = \frac{P(t) - P(0)}{P(t)} + \frac{\alpha}{P(t)} \frac{dP(t)}{dt} - \frac{1}{P(t)} \int_0^t [P(u) - P(0)] D(t - u) du$$

This is the relation that is generally used to determine the reactivity $k(t)$ from the SEFOR transient detector signal $P(t)$, however, cases with nonequilibrium starting conditions can be treated by specifying the initial values of the effective delayed neutron precursors, $C_{ij}(0)$, at time zero, since,

$$\int_{-\infty}^0 P(u) D(t - u) du = \alpha \sum_j \sum_i \lambda_{ij} C_{ij}(0) e^{-\lambda_{ij} t}$$

The quantities $A_{k,j}$ that are generated during the smoothing of the data are directly used in the calculation of net reactivity $k(t)$. The calculation of the reactivity involves the evaluation of a convolution integral, of the form

$$H(\lambda) = \int_{t_0}^t e^{-\gamma(t-u)} F(u) du$$

where γ is constant, and where the function $F(u)$ is obtained from the smoothing of the flux data, and is written as follows:

$$F(u) = \sum_{k=1}^3 A_{k,j} \left(\frac{u}{\Delta t} - j \right)^{k-1} \quad \text{for } j - 1/2 \leq \frac{u}{\Delta t} \leq j + 1/2$$

Since the data are obtained at equally spaced points in time, it is sufficient to evaluate the integral at points $t = m\Delta t$. Thus $H(\gamma)$ becomes

$$H_m = e^{-m\gamma\Delta t} \sum_{\ell=1}^m \int_{(\ell-1)\Delta t}^{\ell\Delta t} e^{\gamma u} F(u) du \quad m \geq 1$$

where H_0 is specified initial value at time t_0 .

Use of the above definitions, integration by parts, and rearrangement of the terms gives

$$H_m = \frac{e^{-m\gamma\Delta t}}{\gamma} \sum_{\ell=1}^m e^{\gamma(\ell-1/2)\Delta t} U_{\ell}(\gamma)$$

where

$$U_{\ell}(\gamma) = \sum_{k=1}^3 \left[A_{k,m-1} (-1)^k S_k(-\gamma\Delta t/2) + A_{k,m} S_k(\gamma\Delta t/2) \right]$$

The $A_{k,m}$ are determined during the smoothing, and S_k is defined as follows:

$$S_k(x) = (k-1)! \left[\left(-\frac{1}{2x}\right)^{k-1} e^x - \sum_{j=1}^k \frac{1}{(k-j)!} \left(\frac{1}{x}\right)^{j-1} \left(-\frac{1}{2}\right)^{k-1} \right]$$

Note that H_m can also be written as

$$H_m(\gamma) = e^{-\gamma\Delta t} H_{m-1}(\gamma) + e^{-\gamma\Delta t/2} U_m(\gamma)$$

The convolution of the delayed neutron kernel and the reactor power can be written in terms of the above functions as follows:

$$I_m = \int_{-\infty}^{m\Delta t} D(m\Delta t - u)P(u)du = \sum_j \sum_i F_{ij}(m\Delta t)$$

where $F_{ij}(m\Delta t)$ is related to the effective delayed neutron precursors by

$$F_{ij}(m\Delta t) = \alpha \lambda_{ij} C_{ij}(m\Delta t) = \alpha \lambda_{ij} C_{ij}(0) e^{-\lambda_{ij} m\Delta t} + B_{ij} \lambda_{ij} H_m(\lambda_{ij})$$

where, with $H_0(\gamma) = 0$, $H_m(\gamma)$ is the integral defined above.

The reactivity, k_m , at time $m\Delta t$ can then be written as

$$k_m = 1 + \frac{\alpha}{\Delta t} \frac{A_{2m}}{A_{1m}} - \frac{I_m}{A_{1m}}$$

6.2.5 Energy Release

The energy (i.e., the time integral of the power) is a particular case of the general integral considered above and may be obtained from the expressions for $H(\gamma)$ in the case where $\gamma = 0$. The change in energy, ΔE_m , is given by

$$\Delta E_m = \frac{\Delta t}{2} \sum_{\ell=1}^m \left[(A_{1,\ell-1} + A_{3,\ell}) + \frac{1}{4} (A_{2,\ell-1} - A_{2,\ell}) + \frac{1}{12} (A_{3,\ell-1} + A_{3,\ell}) \right]$$

where $\Delta E_0 = 0$.

6.3 ANALYSIS OF FAMILIARIZATION TRANSIENTS

The recorded signals from the WRMs and the fission chambers were analyzed as described in Section 6.2 to obtain a "smoothed" transient power and time dependent reactivity.

The data from the FRED position relays are listed in Tables 6-1 and 6-2. There are four relays: two (which are labeled T0 and T1) of these are lift-off switches which close at FRED lift-off; the other two are magnetic proximity switches (labeled P1 and P2) located approximately 10 and 20 inches respectively, from the lift-off position. For consistency, and because it is one of the computer program sampling controls, all times are measured relative to T0 closure. The difference in lift-off times as given by T0 and T1 is typically less than 1 msec. FRED firing is defined to occur at T0 closure.

For reference purposes, the data tape numbers and the location of T0 on these tapes are listed in Tables 6-3 and 6-4. As the tables indicate, there are two sets of tapes for each transient. One set contains data from the FRED position signals and the transient detectors (U-238 or γ). On this tape, 0.1 msec is the time interval between successive samples

Table 6-1
FRED POSITION-TIME DATA FROM FAMILIARIZATION TRANSIENT TESTS

Test	Initial Power (MW)	Nominal Slug Worth (cents)	Time to Lift-Off and Proximity Switches Relative to T ₀ Lift-Off Switch					
			Lift-Off Switch T ₀ (msec)	Lift-Off Switch T ₁ (msec)	Proximity Switch P ₁ (10 inches)		Proximity Switch P ₂ (20 inches)	
					Close (msec)	Open (msec)	Close ^a (msec)	Open (msec)
1	1	40	0.0	1.2	69.0	97.0	105.8	132.0
2	1	40	0.0	0.1	67.9	95.8	104.6	129.9
3	1	50	0.0	0.0	68.9	97.5	106.4	132.3
4	1	50	0.0	-0.3	69.2	97.9	107.0	133.2
5	10	40	0.0	0.0	68.8	97.3	106.1	132.0
6	10	40	0.0	-0.1	69.7	98.7	108.0	134.6
7	10	50	0.0	-0.5	68.3	96.7	105.6	131.5
8	10	50	0.0	-0.5	68.6	97.2	106.0	131.9

^a The listed value is the time to the first indication of P₂ closure.
The data show two, or sometimes three, "P₂ closure signals" at intervals of 0.3 msec.

Table 6-2
FRED POSITION-TIME DATA FROM SUBPROMPT CRITICAL TRANSIENT TESTS

Test	Initial Power (MW)	Nominal Slug Worth (cents)	Time to Lift-Off and Proximity Switches Relative to T ₀ Lift-Off Switch					
			Lift-Off Switch T ₀ (msec)	Lift-Off Switch T ₁ (msec)	Proximity Switch P ₁ (10 inches)		Proximity Switch P ₂ (20 inches)	
					Close (msec)	Open (msec)	Close ^a (msec)	Open (msec)
1	1	84	0.0	0.3	68.2	96.7	105.4	131.2
1A	1	80	0.0	0.8	68.2	96.3	105.2	130.8
2	2	97	0.0	0.4	67.9	95.9	104.7	130.2
3	2	97	0.0	0.3	68.4	96.8	105.5	131.0
4	5	97	0.0	0.0	68.2	96.6	105.3	130.9
5	5	97	0.0	0.6	68.1	96.4	105.1	130.6
6	5	97	0.0	0.3	67.9	96.3	105.0	130.5
7	10	97	0.0	0.2	67.7	95.9	104.7	130.3
8	10	97	0.0	0.5	68.0	96.1	104.7	129.9
9	10	97	0.0	1.0	68.8	97.4	106.4	132.3
10	10	97	0.0	0.9	69.0	97.8	106.4	132.2

^a The listed value is the time to the first indication of P₂ closure.
The data show two, or sometimes three, "P₂ closure signals" at intervals of 0.3 msec.

Table 6-3
FAMILIARIZATION TRANSIENT—TAPE LOCATION DATA

Test	Tape Numbers		Location of T ₀ on High Sampling Rate Tape ^a		Location of T ₀ on Low Sampling Rate Tape ^b
	High Sampling Rate	Low Sampling Rate	Record R	Word N	Record
1	—	132	—	—	697
2	41	139	56	141	1
3	CDM	141	51	135	51
4	73	143	59	132	49
5	24	114	52	219	52
6	DA5	53	57	162	57
7	47 ^c 111 ^c	129	51	105	51
8	93 ^c 115 ^c	126	55 ^d	69	55

^aThe relative times, t , in milliseconds on these tapes are determined from the following relation: $t = \frac{0.1}{3} [219(R-1)+N]$

^bOn these tapes, the time interval is 7.3 milliseconds per record.

^cTapes numbered 47 and 93 contain data for fission detector A (with a linear amplifier), and Tapes 111 and 115 contain data for fission detector B (with a logarithmic amplifier).

^dRecord 54 for Tape 93.

Table 6-4
SUBPROMPT CRITICAL TRANSIENT—TAPE LOCATION DATA

Test	Tape Numbers		Location of T ₀ on High Sampling Rate Tapes ^a		Location of T ₀ on Low Sampling Rate Tape ^b
	High Sampling Rate	Low Sampling Rate	Record R	Word N	Record
1	185 178 Log	184	59	198	59
1A	188	189	54	156	54
2	191	192	54	45	54
3	190	193	58	135	58
4	194	195	59	132	59
5	196	177	52	129	52
6	160	161	57	129	57
7	163	164	52	219	52
8	167	168	56	105	56
9	170	171	54	186	54
10	173A 148B	174	55	60	55

^aThe relative time, t , in milliseconds, on these tapes are determined from the following relation: $t = \frac{0.1}{3} [219(R-1)+N]$

^bOn these tapes, the time interval is 7.3 milliseconds per record.

Figure 6-7. Smoothed Data from U-238 Fission Channel A for Familiarization Transient No. 2

Figure 6-8. Comparison of Static and Dynamic Reactivities for Familiarization Transient No. 7

Figure 6-9. Comparison of Familiarization Test No. 7 Reactivities with Adjusted FRED Curve

of the same signal. The other set of tapes contains flux, flow, and temperature data (the signals from the wide range monitors [WRMs], numbered 1 and 2, are stored on DAS data channels 27 and 28) which have a time interval of 7.3 msec between successive samples of the same channel. This set also contains data from the FRED position signals (they have lower time resolution than the sets on the other tapes because of the lower sampling rate) and from time records.

The raw data from the WRMs which had no fluctuation, were used to evaluate the effect of using different numbers (N+1) of data points in the smoothing routine. It was found that use of up to seven data points caused essentially no difference between the raw and the "smoothed" data. As shown in Section 6.2.2, the smoothing characteristics depend on the product of the number of data points per set, and the time interval between samples. Since the U-238 fission detectors are sampled seventy-three times as often as the WRMs, the analysis indicated that up to $7 \times 73 = 511$ data point sets could be used in the smoothing of the fission detector data without distorting the true power signal during the familiarization transients. Because of the prominence of the 200 Hertz signal, 289 data point sets were used (for 200 Hz noise this corresponds to approximately the fifth zero of the T1 function) to minimize this particular noise signal. (See Section 6.2.2) The result of this smoothing on the raw data of Figure 6-1 is illustrated in Figure 6-7.

The reactivity feedback was small during the familiarization transients. The reactivity calculated using the measured "smoothed" power in the space independent reactor kinetic equation could thus be directly compared with that calculated (Section 6-5) from the static FRED reactivity worth versus position measurements, and the FRED position versus time measurements. All tests showed similar performance. A representative comparison is illustrated in Figure 6-8. This figure illustrates two effects. One is a time displacement of ~ 5 msec between the U-238 fission chamber data and the wide range monitor data. This is caused by the difference in response time for the two systems: about 10 to 20 μ sec for the fission chamber system, compared to about 10 msec for the WRM system. The other is a general agreement between the dynamic time dependent worth and that derived from the nontransient data. There is a 4% difference in reactivity between these two curves, however. This effect, which also occurred during the sub-prompt critical tests, should have little or no effect ($<4\%$) on the reactivity feedback effects inferred from the transient measurements. To further illustrate this difference, Figure 6-9 shows a modified curve obtained by increasing all non-transient reactivities by 4%. As illustrated, the modified curve and the "dynamic" time dependent reactivity curve show good agreement. For comparison purposes, the maximum FRED reactivity worths are tabulated for the different tests in Table 6-5.

Table 6-5
FAMILIARIZATION TRANSIENTS—SLUG WORTH
(Preliminary)

Test	Static Slug Worth (cents)	Worth from Transient Flux Data		
		WRM 2 ^a (cents)	U-238 Channel A (cents)	U-238 Channel B ^b (cents)
1	40.0	42.1	c	c
2	40.0	42.1	42.3	41.2
3	49.5	51.9	52.1	48.0
4	49.5	52.0	51.5	52.0
5	40.0	41.6	41.5	38.9
6	40.0	41.7	41.5	40.9
7	49.5	51.2	50.8	49.7
8	49.5	51.2	50.9	49.6

Note: All data were obtained using linear amplifiers except for U-238 Channel B in Tests 7 and 8, where a logarithmic amplifier was used.

^aWRM 1 exhibited drift during these tests, and the detector was replaced for subsequent transients.

^bThe low values for Channel B may be the result of incorrect current background corrections. This disparity was not observed in the subprompt transients where the current levels are higher, and thus less susceptible to changes in background.

^cU-238 data are not available for this test.

Possible reasons for this small difference include reflector-FRED rod interaction effects during the static reactivity versus position measurements, errors in the delayed neutron parameters or in the relative contribution* of the U-238 and Pu-239 delayed neutrons which would cause an error in the period versus reactivity conversion formula, or small errors introduced by the use of the space-independent reactor model to describe the actual results. All reactivity worths discussed in this report are dynamic worths unless otherwise specified.

In general, however, familiarization test results demonstrated agreement with the space-independent reactor kinetic calculational model and they demonstrated consistency and repeatability.

6.4 ANALYSIS OF THE SUBPROMPT CRITICAL TRANSIENTS

Eleven tests were performed that involved dynamic reactivity insertions of >50 cents, but <98 cents. These were classified under the heading of the subprompt critical transients. The first two tests (1 and 1-A) involved reactivity insertions of ≈80 cents from an initial power level of 1 MWt. The reactivity feedback was small during these experiments. The last nine tests involved reactivity insertions of ≈97 cents that resulted in appreciable reactivity feedback. The nine latter tests were used to determine the Doppler reactivity feedback effects, while the earlier tests were used, along with the familiarization transients, to check the equipment and the data analysis methods. The wide range monitors saturated at the high flux levels during test 1, and thus provided valid signals only for a portion of the transient. Test 1-A was performed with a slightly lower slug worth to provide valid WRM signals throughout the transient for comparison with the U-238 fission chamber signals. The WRM's saturated during the latter 97 cents transients; the two U-238 fission chambers were used with logarithmic amplifiers in tests 2 through 7.

Tests 8, 9, and 10, which were repeats of test 7, were used to test and calibrate the gamma chambers by comparison with the U-238 fission chambers. These chambers will be used in the subsequent super-prompt critical transients involving reactivity insertions in excess of 1 dollar. The super-prompt critical tests will result in flux level changes that cover several decades and two types of detectors will be used to record these changes. U-238 fission chambers will be used over the first portions of the transients, and gamma detectors will be used at the higher flux levels where the U-238 chambers may saturate. The DAS logic and components which control the switchover from the U-238 fission chambers to the gamma chambers and back again at pre-set voltage levels were also checked out during test 10.

The two tests (tests 1 and 1A) that were performed from an initial power of 1 MWt substantiated the results of the familiarization transients, including the ≈4% difference between the dynamic FRED worth and the values predicted from static test results. The reactivity derived from the flux monitors during the transient tests is compared with the predicted values in Figure 6-10, using the ≈4% reactivity adjustment indicated by the familiarization transients. As illustrated, the WRMs again (see Section 6.3) demonstrated the small time lag observed during the familiarization transients. The good agreement between the predicted reactivity curve for the 97 cents transients and that obtained from the fission chamber measurements during the subprompt critical transients is illustrated in Figures 6-11 through 6-13.

The flux data were smoothed and used in the space independent kinetic equation to determine the net reactivity in the same manner as for the familiarization transients. During these tests, especially the latter 97 cents transients, appreciable reactivity feedback occurred. The net reactivity, K_{net} , for these transients is composed of two terms; the FRED (and scram) reactivity, K_{in} ; and the feedback, K_{fb} , according to the following equation:

$$K_{net}(t) = K_{in}(t) + K_{fb}(t)$$

Since the net reactivity, $K_{net}(t)$, is determined from the power trace during the transient, the reactivity feedback can be readily determined from the above equation, provided the input (FRED or other) reactivity, $K_{in}(t)$ can be determined by some other independent means.

One method of determining the feedback would be to calculate an input reactivity, such as that shown in Figure 6-10, by combining the adjustment factor of approximately 4% (as indicated by the earlier familiarization transients) with the FRED position versus reactivity worth and position versus time measurements. These values would then be subtracted from the net reactivity measured during the transients. The resultant feedback could then be combined with the measured energy release, as determined from the integral of the power, to determine the feedback reactivity energy coefficient. Unfortunately, if there are errors in the determination of K_{in} or K_{net} , this method can introduce

*Use of the calculated inhour equation of Reference 3, rather than the one inferred from the zero power oscillator tests, would decrease the difference (see Reference 4) from 4 to 2%.

Figure 6-10. Comparison of Predicted and Measured Reactivity for Subprompt Test I-A

Figure 6-11. Time Dependent Reactivity During Subprompt Transient No. 2

Figure 6-12. Time Dependent Reactivity During Subprompt Transient No. 4

Figure 6-13. Time Dependent Reactivity During Subprompt Transient No. 7

significant errors in the feedback, since it is determined from the difference between two numbers which are very large, being of the order of 85 to 95 cents, compared to the feedback, which has a maximum magnitude of ~ 14 cents.

Another method, the one employed for the determination of the dependence of the feedback reactivity on the energy, avoids the potentially large errors introduced by the method described above. With this latter method, advantage is taken of the fact that the input reactivity is constant during the time interval following the complete ejection of the FRED from reactor regions of reactivity influence, but prior to reactor scram and prior to re-entry of the poison slug into the core. During this or any other time interval, the reactivity feedback may be expressed as a polynomial in energy, E , of the form

$$K_{fb}(t) = \sum_{j=1}^J a_j E^j(t)$$

where the energy, E , is determined from the recorded power (flux) data $P(t)$ according to the following expression

$$E(t) = \int_0^t [P(u) - P(0)] du$$

Since $K_{in}(t) = K_0$, a constant, on this interval the net reactivity can thus be expressed as

$$K_{net}(t) = K_0 + \sum_{j=1}^J a_j E^j(t) \quad t_0 \leq t \leq t_s$$

where t_0 and t_s define the time interval for which the input reactivity is constant after FRED ejection, but prior to scram and prior to the time the slug returns to the core region. A least squares fit of the above expression to the measured reactivity, and feedback data provides an estimate, K_0 , of the maximum FRED slug worth, and coefficients for the reactivity energy coefficient.

The coefficients, K_0 and a_1 , that were determined by fitting straight lines, $K_{fb} = K_0 + a_1 E$, to the net reactivity during the time interval between 140 msec and ~ 280 msec after FRED lift-off are summarized in Table 6-6. A representative comparison of the straight line fits and the data are shown in Figures 6-14 and 6-15. As illustrated, straight lines provide good fits to the data.

During the short time interval, ≤ 0.35 sec, after transient initiation and prior to scram, most of the heat and temperature changes are generated in the fuel. Smaller temperature changes occur in other materials as a result of direct gamma and neutron heating, and as a result of some small heat conduction from the fuel. The primary (~ 85 to 90%) component of the reactivity feedback is thus the fuel temperature prompt Doppler effect. The other components include reactivity effects due to fuel and cladding axial expansion, sodium density changes, and radial and axial expansion of the core, and its (non-fuel rod) constituents. Since the Doppler and non-Doppler effects cannot be experimentally separated during the transients, the non-Doppler components are calculated and the Doppler effect is then determined as the difference between the measured reactivity feedback and the calculated non-Doppler effects. To obtain estimates of the non-Doppler effects, the transient tests were simulated using the FORE II⁷ computer program. The predicted FRED reactivity, the previously⁴ measured or calculated non-Doppler reactivity coefficients, and an effective Doppler coefficient $T \frac{dk}{dT} = -0.0081$ were used as input to the program.

Figures 6-16 and 6-17 compare the calculated reactor power and energy release during the transient to the measured values for test 8. The reactivity insertion used for the calculated transient was 96.3 cents; subsequent analysis of the test results indicated a reactivity insertion of 96.6 cents. The measured scram reactivities were also used for the calculated transient. The close agreement between test data and calculated response is evident in the figures. The non-Doppler feedback effects are illustrated in Figure 6-18 as a function of energy for the 97 cents transients from an initial power level of 5 MW. These effects are approximately linear with energy release. The non-Doppler energy coefficients are approximately 12% of the total reactivity energy coefficient.

Subtraction of a constant 12% non-Doppler effect from the total measured energy coefficients listed in Table 6-6 gives the averaged measured Doppler coefficients in terms of the total energy produced. These are divided by the product of 0.932 (the fraction of the total energy produced that is released during the transient) and 0.943 (the portion of the total energy released which is absorbed in the fuel) to express the Doppler reactivity energy coefficients in terms of transient energy absorbed in the fuel. These are listed in Table 6-7 with the values that were calculated using an

Table 6-6
PRELIMINARY RESULTS OF SUBPROMPT CRITICAL TRANSIENTS

Test	Nominal Power (MW)	Maximum Slug Worth, K_0		Energy Coefficient ^a , a_1		Nominal Peak Power	
		Detector A (cents)	Detector B (cents)	Detector A (cents/MW-sec)	Detector B (cents/MW-sec)	Detector A (MW)	Detector B (MW)
2	2	96.6	96.6	-0.57	-0.56	80	85
3	2	96.7	96.5	-0.54	-0.58	85	80
4	5	96.4	96.5	-0.46	-0.45	140	150
5	5	96.6	96.6	-0.45	-0.45	150	150
6	5	96.9	96.8	-0.43	-0.44	160	160
7	10	96.6	96.7	-0.36	-0.37	260	250
8	10	b	96.6	b	-0.36	b	260
9	10	96.9	b	-0.34	b	270	b
10	10	b	b	b	b	a	b

^a These coefficients are defined in terms of the total energy produced during the transient.

^b The gamma detectors were used in these channels during tests 8 and 9 to compare their response with that observed on the fission chambers. In test 10 the computer switchover logic (see discussion in Section 5) from the fission to gamma chambers was checked out. The gamma detectors agreed with the fission chambers at the higher flux levels, but nonlinear current vs voltage relationships, and high (compared to the flux) background currents were observed at low power. These effects should not affect the superprompt region. The values from these detectors for tests 8, 9, and 10 were therefore less accurate and are not included in the table.

Table 6-7
COMPARISON OF DOPPLER ENERGY COEFFICIENTS

Power (MW)	Doppler Energy Coefficient ^a (cents/MW-sec)	
	Subprompt Tests	Calculated $T(dk/dt) = -0.0081$
2	-0.56 ± 0.08	-0.54
5	-0.45 ± 0.06	-0.45
10	-0.36 ± 0.05	-0.37

^a These coefficients are defined in terms of the total transient energy absorbed in the fuel.

Figure 6-14. Reactivity Versus Energy Data from Subprompt Tests 2, 4 and 7

Figure 6-15. Comparison of Reactivity Versus Energy for Subprompt Tests at 2 MW

Figure 6-16. Power Profile for 0.96\$ Transient from 10 MW

Figure 6-17. Energy Release from 0.96\$ Transient from 10 MW:

Figure 6-18. Calculated Ratio of Non-Doppler to Total Feedback for a 0.96\$ Transient from 5 MW

effective Doppler T_{dT}^{dk} of -0.0081 . The reactivity-energy coefficients for a Doppler coefficient, T_{dT}^{dk} , of -0.0081 were calculated using the computer program WEDOP. ⁷ The program calculates the fuel temperature rise resulting from the energy addition assuming no heat losses from the fuel rod and assuming all the energy is deposited in the fuel. The total core Doppler reactivity change associated with the temperature rise is calculated using a power-squared weighting of the local reactivity effects. The Doppler reactivity change divided by the energy added during the transient yields a Doppler energy coefficient in terms of transient energy absorbed in the fuel which can be compared to the measured values adjusted to also be relative to the energy deposited in the fuel.

The presently estimated standard deviation in the measured transient Doppler energy coefficient is $\pm 14\%$. This deviation is composed of the following parts (combined as the square root of the sum of the squares of the individual standard deviations).

1. $\pm 5\%$ uncertainty (one sigma) in energy released ($\int [P(u) - P(o)] du$) due to a $\pm 5\%$ uncertainty in absolute initial power as indicated by heat balance data,
2. $\pm 10\%$ additional uncertainty in the energy release as a result of uncertainties in the leakage and background corrections (from the decay of Neptunium formed from U-238 capture) to the measured currents from the U-238 fission chambers,
3. $\pm 4\%$ uncertainty in absolute reactivity,
4. $\pm 7\%$ uncertainty introduced by approximately $\pm 50\%$ uncertainty in the calculated non-Doppler corrections which constitute 12% of the measured reactivity change.

Comparison of the measured and calculated transient Doppler energy coefficients in Table 6-7 shows that the best value of the Doppler coefficient, T_{dT}^{dk} , is -0.0081 , in agreement with the previous static and oscillator test results. As shown below, the estimated standard deviation in the value of the Doppler temperature coefficient, T_{dT}^{dk} , obtained from the transient tests is $\pm 17\%$ to $\pm 18\%$. This compares with the $\pm 17\%$ deviation for the static and oscillator tests reported in reference 4.

The standard deviation in the value of T_{dT}^{dk} , as determined from the transient tests, may be estimated as follows:

Let A be the Doppler constant defined by $A = T_{eff} \frac{dk}{dT}$

where T_{eff} is the effective core average absolute fuel temperature, and dk/dT is the change in Doppler reactivity per unit temperature change. Then, since $dE = MCdT$, the equation for A becomes

$$A = T_{\text{eff}} M C \frac{dk}{dE}$$

where dE is the energy deposited in the fuel, M is the fuel mass, and C is the fuel heat capacity.

By defining $\eta = dk/dE$ as the Doppler energy coefficient, and by assuming uncorrelated errors, the standard deviation σ_A in A may be obtained from the following expression:

$$\left(\frac{\sigma_A}{A}\right)^2 = \left(\frac{\sigma_{T_{\text{eff}}}}{T_{\text{eff}}}\right)^2 + \left(\frac{\sigma_C}{C}\right)^2 + \left(\frac{\sigma_\eta}{\eta}\right)^2$$

where σ_X denotes the standard deviation in X .

At 10 MW the calculated core average fuel temperature is $\sim 1400^\circ\text{F}$ at an average sodium temperature of 760°F . For essentially no uncertainty in sodium temperature, and a $\pm 15\%$ uncertainty (see reference 2) in the fuel temperature rise above the sodium, the value $\sigma_{T_{\text{eff}}}/T_{\text{eff}}$ is thus $0.15 (1400-760)/(1400 + 460) = 0.05$.

At the lower power levels the fuel temperature rise, and thus its contribution to the over-all uncertainty is smaller. The estimated standard deviation in heat capacity is $\pm 10\%$ and, as indicated above, the estimated standard deviation in the measured energy coefficient is $\pm 14\%$. Use of the above relation shows that the estimated standard deviation in the Doppler coefficient $T \frac{dk}{dT}$ determined from the sub-prompt critical transient tests ranges from $\pm 17\%$ at 2 MW to $\pm 18\%$ at 10 MW.

6.5 FAMILIARIZATION SLUG STATIC CALIBRATION TEST RESULTS

The reactivity worth of the FRED familiarization slug was measured as a function of axial position by moving the slug with the FRED positioner. The maximum static worth of the slug (with the positioner in its lowest position) was 49.5 cents. The maximum reactivity insertion rate for this slug was determined from the worth vs. position measurements, and distance vs. time data, to be 6.6\$/sec.

The reactivity worth of the FRED familiarization slug was measured as a function of axial position. These measurements were combined with position versus time measurements to generate the reactivity worth as a function of time.

The worth versus position measurements were made with a calibrated fine reflector as the FRED rod was lowered by increments into the core, and they were repeated as the rod was withdrawn. Static equilibrium was attained after each change in the FRED position. The measurements were performed at low power with a constant coolant temperature of 750°F .

The actual worth versus position data are tabulated in Table 6-8. The two measurements at each axial position were averaged to give the worth versus position data tabulated in Table 6-9 and plotted in Figure 6-19. Averaged position versus time data for a FRED test firing with an accumulator pressure of 1385 psi (at or near maximum pressure) are illustrated in Figure 6-22.

The FRED slug can be fired from any initial position in the core. The distance versus time characteristics are independent of the initial position. The reactivity change as a function of FRED slug displacement is dependent on the starting slug position. The total reactivity change for a firing of the familiarization slug can vary between a maximum of 49.5 cents for a starting position of zero (positioner at lowest position) to a minimum of ~ 0 cents for a starting position ~ 25 inches (poison slug out of the core).

The data in Figures 6-19 and 6-22 were used to generate FRED worth versus time curves for two initial positions: 0.0 inch, and 4.0 inches. The zero and 4 inch starting positions correspond to the nominal 50 cent and 40 cent transients called for in the experimental program. The FRED reactivity worth - time characteristics for these different initial starting conditions are illustrated in Figure 6-20.

6.6 FRED STATIC CALIBRATION - SUBPROMPT CRITICAL SLUG

The reactivity worth of the FRED slug to be used for the sub-prompt critical transient tests was measured as a function of axial position in the core. The maximum static worth at zero inches was 97 cents. A positioner shim as installed to limit the lower position to 0.7 inch. This limited the maximum dynamic worth to 97 cents. Measured position versus time characteristics of the FRED rod were combined with reactivity versus position data to estimate the reactivity worth as a function of time. The maximum reactivity insertion rate obtained from these data is 13.9\$/sec.

Table 6-8
FAMILIARIZATION SLUG REACTIVITY WORTH MEASUREMENTS

FRED Position ^a (inches)	Reflector No. 3		Reflector No. 8		Relative FRED Worth ^(b) (cents)
	Position (cm)	Worth (cents)	Position (cm)	Worth (cents)	
29.69	34.38	45.06	0.41	-0.43	0.27
24.69	34.38	45.06	1.03	0.01	0.71
19.64	34.38	45.06	5.20	3.33	4.03
17.64	34.38	45.06	8.08	6.01	6.71
15.64	34.38	45.06	11.70	9.85	10.55
13.64	34.38	45.06	15.46	14.36	15.06
11.64	34.38	45.06	19.60	20.01	20.71
9.64	34.38	45.06	22.77	24.74	25.44
7.64	34.38	45.06	26.00	29.82	30.52
5.64	34.38	45.06	29.14	35.03	35.73
3.64	34.38	45.06	32.12	40.29	40.99
1.64	34.38	45.06	34.84	45.26	45.96
0.00	34.38	45.06	36.72	48.75	49.45
1.64	34.38	45.06	34.87	45.31	46.01
3.64	34.38	45.06	32.15	40.34	41.04
5.64	34.38	45.06	29.25	35.21	35.91
7.64	34.38	45.06	26.15	30.06	30.76
9.64	34.38	45.06	22.88	24.91	25.61
11.64	34.38	45.06	19.27	19.53	20.23
13.64	34.38	45.06	15.59	14.53	15.23
15.64	34.38	45.06	11.59	9.72	10.42
17.64	34.38	45.06	7.84	5.78	6.48
19.64	34.38	45.06	4.71	2.90	3.60
24.69	34.38	45.06	0.41	-0.43	0.27
29.69	34.09	44.52	0.41	-0.43	-0.27

^a Indicated position from full-in. At an indicated position of 0.0 inch, the lower tip of the B₄C column in this slug is estimated to be 6.0 inches below the core midplane.

^b Relative to an average value at the completely out position (29.69 inches) of zero.

Table 6-9
FAMILIARIZATION SLUG WORTH vs POSITION

FRED Position ^a (in.)	Average Measured ^b Worth (cents)	FRED Position ^a (in.)	Average Measured ^b Worth (cents)
0.00	0.00	13.64	34.31
1.64	3.47	15.64	38.97
3.64	8.44	17.64	42.86
5.64	13.63	19.64	45.64
7.64	18.81	24.69	48.96
9.64	23.93	29.69	49.45
11.64	28.98		

^a Indicated position above the core midplane. At an indicated position of 0.0 inch, the lower tip of the B₄C column in this slug is estimated to be 6.0 inches below the core midplane.

^b Relative to zero at the completely inserted position (0.00 inch). Average values obtained from last column of previous table.

Figure 6-19. Static Reactivity Worth Versus Position Measurements for Familiarization Slug

Figure 6-20. Familiarization FRED Time Dependent Reactivity Inferred from Static Tests

The reactivity worth of the FRED subprompt critical slug was measured as a function of axial position in the core. The measurements were performed by moving a calibrated fine reflector segment to compensate reactivity changes introduced as the FRED rod was lowered by increments into the core. The measurements were repeated as the rod was withdrawn from the core. Static equilibrium was attained after each change in the FRED position. The measurements were performed at low power with a coolant temperature of about 740°F.

Measurement data are recorded in Tables 6-10 to 6-12. The data were averaged to give worth versus FRED position data as tabulated in Table 6-13 and illustrated in Figure 6-21.

Averaged position versus time data obtained from test firings during the familiarization and subprompt critical transients are tabulated in Table 6-14 and are illustrated in Figure 6-22.

The FRED slug may be fired from any initial position in the core. The displacement versus time characteristics of the FRED rod are independent of its initial position. However, the amount of reactivity inserted is dependent on the starting position of the slug, and varies between a possible maximum of > 97 cents for a starting position of zero to a minimum of zero for a starting position of ~25 in.

The data in Figures 6-2 and 6-22 were used to calculate the time dependence of the reactivity changes occurring for slug firings from initial positions of 0.7, 2.85, and 3.5 in. These starting positions correspond to sub-prompt transients involving estimated (from the static data) reactivity insertions of 93.0, 80.5, and 76.5 cents, respectively. The time dependent behavior of these slugs are illustrated in Figure 6-23.

Illustrated in Figure 6-24 are curves obtained by increasing the reactivity values of Figure 6-23 by 4%. These modified curves, which have maximum slug worths of 96.5, 84.0, and 79.7 cents, respectively, are in good agreement, as shown in Section 6.4, with the values calculated from the measured transient flux values.

Table 6-10
FRED SLUG ACTIVITY WORTH MEASUREMENTS
Data Set 1

FRED Position (in.)	Reflector No. 3		Reflector No. 8		Core Temperature (°F)	Relative ^a FRED Worth (cents)
	Position (cm)	Worth (cents)	Position (cm)	Worth (cents)		
29.68	29.53	36.27	0.50	-0.37	742.7	-0.03
0.01	29.53	36.27	62.65	96.35	742.7	96.69
2.00	29.53	36.27	55.90	84.88	742.7	85.22
4.00	29.53	36.27	49.27	72.70	742.8	72.99
29.68	29.45	36.13	0.40	-0.44	742.2	0.03

^a Relative to an average value at the completely out position (29.7 inches) of zero at a constant temperature. Reactivity corrections for the small temperature changes were made with a reactivity coefficient of -0.54 cent/°F.

Table 6-11
FRED SLUG REACTIVITY WORTH MEASUREMENTS
Data Set 2

FRED Position (in.)	Reflector ^a No. 8		Core Temperature (°F)	Relative ^b FRED Worth (cents)
	Position (cm)	Worth (cents)		
29.68	10.00	7.98	748.0	0.00
24.68	10.00	7.98	747.7	0.16
20.68	12.25	10.47	748.9	2.00
17.68	16.64	15.90	748.8	7.49
15.69	20.67	21.57	748.6	13.27

^a Reflector No. 3 was maintained at a constant position of 27.00 cm (worth = 31.84 cents).

^b Relative to an average value at the completely out position (29.7 inches) of zero at a constant temperature. Reactivity corrections for the small temperature changes were made with a reactivity coefficient of -0.54 cent/°F.

Table 6-12
FRED SLUG REACTIVITY WORTH MEASUREMENTS
 Data Set 3

FRED Position (in.)	Reflector ^a No. 8		Core Temperature (°F)	Relative ^b FRED Worth (cents)
	Position (cm)	Worth (cents)		
29.70	10.00	7.98	735.6	0.00
25.00	9.87	7.85	735.6	-0.13
19.99	12.84	11.16	735.8	3.07
17.99	15.98	15.03	736.0	6.83
15.99	19.83	20.34	736.3	11.98
13.99	24.48	27.40	736.2	19.09
11.99	29.75	36.08	736.5	27.61
10.00	35.35	46.20	736.0	38.00
8.00	41.34	57.54	736.2	49.23
5.99	47.64	69.61	736.0	61.41
4.00	54.23	81.90	736.0	73.70
2.00	61.22	94.00	735.7	85.96
0.00	68.65	105.60	736.1	97.35
2.02	61.24	94.04	735.9	85.89
4.01	54.24	81.92	735.9	73.77
6.00	47.55	69.44	735.9	61.29
8.01	41.18	57.23	735.2	49.46
9.99	35.26	46.03	735.4	38.15
12.01	29.46	35.58	735.1	27.87
14.00	24.21	26.98	735.1	19.27
16.00	19.43	19.76	735.3	11.94
18.01	15.63	14.58	735.2	6.81
20.01	12.57	10.84	735.3	3.02
22.00	10.56	8.58	735.2	0.81
26.00	9.48	7.44	735.1	-0.27
29.69	9.74	7.71	735.1	0.00
25.99	9.47	7.42	734.9	-0.19
24.00	9.55	7.51	734.7	0.01
28.00	9.55	7.51	734.8	-0.04

^a Reflector No. 3 was maintained at a constant position of 22.95 cm (worth = 25.07 cents).

^b Relative to an average value at the completely out position (29.7 inches) of zero at a constant temperature.
 Reactivity corrections for the small temperature changes were made with a reactivity coefficient of -0.54 cent/°F.

Table 6-13
SUBPROMPT SLUG WORTH vs POSITION

FRED Position (in.)	Averaged ^a Measured Worth (cents)	FRED Position (in.)	Averaged ^a Measured Worth (cents)
0.0	0.0	17.7	.89.5
2.0	.11.3	18.0	.90.2
4.0	.23.5	20.0	.94.0
6.0	.35.7	20.7	.95.0
8.0	.47.7	22.0	.96.2
10.0	.58.9	24.0	.97.0
12.0	.69.3	25.0	.97.1
14.0	.77.8	26.0	.97.3
15.7	.83.8	29.7	.97.0
16.0	.85.1		

^a Relative to zero at the completely inserted position (0.0 inch). Maximum spread in data = ± 0.4 cent.

Table 6-14
AVERAGED FRED TIME-POSITION DATA

Distance (in.)	Time from Lift-off (msec)			Average from A Tests
	Familiarization Tests	Subprompt Tests 1 through 4	Subprompt Tests 5 through 10	
0	0	0	0	0
1	20.6	20.7	20.6	20.6
2	29.1	29.1	28.8	29.0
3	35.3	35.6	35.5	35.5
4	41.5	41.1	40.8	41.1
5	46.3	—	—	46.3
8	60.4	60.2	59.3	60.0
9	64.3	64.0	—	64.1
10	—	68.1	67.8	68.0
12	—	76.3	75.9	76.1
13	79.9	—	—	79.9
14	83.4	83.3	83.7	83.5
15	86.7	87.2	87.2	87.0
16	—	90.8	90.9	90.9
17	94.6	—	—	94.6
20	105.6	104.9	105.5	105.3
21	—	108.5	108.4	108.4
22	—	112.2	112.4	112.3
25	123.1	122.9	122.7	122.9
28	133.8	134.0	133.7	133.8

Figure 6-21. Static Reactivity Worth Versus Position Measurements for Subprompt Slug

Figure 6-22. FRED Position Versus Time Behavior Measured During Transient Tests

Figure 6-23. Subprompt FRED Time Dependent Reactivity Inferred from Static Test Data

Figure 6-24. Subprompt FRED Time Dependent Reactivity

7. SEFOR SAFETY AUDIT AND LICENSING

The objectives of Safety and Licensing in relation to SEFOR are to: (1) provide an independent safety audit of SEFOR operations, (2) provide support in assessing safety significance of reactor operations, the experimental program, and modifications to the reactor system, and (3) handle licensing efforts - special reports required by license, malfunction reports, and Technical Specification Changes.

Three malfunction reports were sent to the AEC-DRL concerning:

1. Malfunction of the primary drain tank venting system which occurred during preparation for a scheduled fuel surveillance on May 8, 1971,
2. malfunction of two, safety system, mercury wetted relays discovered during the performance of a routine monthly surveillance test on May 23, 1971. The relays were associated with the high flux trip on WRM number 3 and the power supply breaker for the main secondary coolant system pump winding, and
3. malfunction of a time delay relay in the emergency power supply for the main primary pump. This malfunction, which did not affect normal reactor operation, was discovered during routine data collection on June 10, 1971 when the reactor was operating at criticality (zero power).

Nine safety evaluations were completed for:

1. Sodium system temperature during fuel surveillance operations,
2. Operation requirements to minimize reactor vessel head bolt stresses,
3. Measured dynamic slug worths being approximately 3% greater than the static slug worths for the FRED familiarization and subprompt transient slugs.
4. Modification Request No. 702 - Gas Meter for Reactor Cover Gas Usage Determination,
5. Modification Request No. 731 - Improved Control for the Pump-Around-Pump,
6. Modification of the Refueling Cell for Emergency Crane Retrieval,
7. Modification Request No. 752 - WRM Picoammeter Protection,
8. Modification Request No. 745 - Reactor Vessel Backup Seal, and
9. Use of Water for Cooling the Concrete Drill.

The following series of reports were sent to the AEC-DRL to complete the report required by the Technical Specifications for Core I.

Report	Date Submitted
Results for Core I of Power Ascension and Conventional Oscillator Tests to 20 MWt	June 18, 1971
Results of the Balanced Oscillator Experiments for Core I	July 14, 1971
Results of the Familiarization and Sub-Prompt Critical Transients for Core I	July 16, 1971

A report was submitted to the AEC-DRL on May 28, 1971 to document the analysis of the reactor head bolt stresses which had been previously discussed with the DRL at meetings in Bethesda, Maryland, on March 24, April 27, and April 28, 1971. The report also provides the bases for corrective action - a reduction in bolt preload, and a reduction in the allowable rate of sodium temperature change.

The seventh meeting of the Safety Review Committee was held at the site on June 8, and 9, and a site safety audit made on June 10, and 11.

8. SEFOR SUPPORT

The Plant Engineering effort is a supporting function to the SEFOR Facility. During May the reactor was operated and the subprompt transient tests were completed. The subprompt transients included reactivity insertions of 97 cents. During June and July the reactor remained shutdown for the annual containment leak test along with modification and maintenance activities.

8.1 VESSEL HEAD SEAL

During the later part of June, installation of a backup seal to the reactor vessel head seal "O" rings was completed. The design of the backup seal provides a backup to the existing reactor "O" ring seal for the purpose of minimizing reactor cover gas leakage.

The seal is shown schematically in Figure 8-1. The backup seal provides sealing in two locations: one, in the annular gap between the vessel support skirt and outer head; two, annular space between each of the forty-eight bolt holes in the outer head. Sealing capability for these components is provided by elastomer "O" rings. Details of the sealing arrangement are shown in Figure 8-2.

The backup seal is made up of a seal face ring which is seal welded to the outer head and follows closely the shape of the vessel support skirt. A backup ring above the seal face ring confines an o-ring in a controlled volume compression. The "O" ring is confined between the seal face ring, the backup ring, and the vessel support skirt. Compression of the "O" ring is achieved by forcing the backup ring downward with set screws located in the ring segment components.

The outer head studs, spacers and nuts are enclosed in containment caps (Figure 8-3). The caps rest on retainer ring segments (Figure 8-4) held down to the outer head by the stud nuts. The containment cap and retainer are sealed by elastomer "O" rings.

The design conditions for the O-ring elastomer seals are:

Temperature	Time
500°F	100 hours
450°F	4000 hours
Pressure	
30 psig internal	

The design of the head seal "O" rings allows for replacement periodically following extended periods of operation.

The design, fabrication, and installation of the head seal was performed in accordance with ASME Code, Section III for Class B vessels. All welds were designed and inspected in accordance with the requirements for Class B vessels. All welds were made with welders qualified to Section IX of the ASME Code. A pneumatic test was applied to the containment caps and the completed seal assembly. In addition, a reactor vessel cover gas leakage test was performed and satisfactory results were achieved.

8.2 CRANE RETRIEVAL

Procurement of components and installation of the crane retrieval system was completed during the June/July outage. This system is described in detail in reference 2. Some delay occurred in coring holes in the refueling cell walls when reinforcing bars were encountered in line with the holes.

Adjustments in alignment of the core hole and modification to the penetration sleeves was accomplished to avoid cutting any of the reinforcing bar.

8.3 ADDITIONAL SUPPORT

Additional engineering activities were completed during the report period as follows:

1. A modification to the one-half ton refueling cell grapple was designed which would assure proper operation of the slack cable load limit interlock.
2. Recommendations were made concerning installation of auxiliary air blast cooler door bearings.
3. Recommendations were made concerning the design requirements, materials, and fabrication for a hold-up volume to be installed in the radiation monitoring system piping.
4. A reactor head bolt surveillance plan was completed covering periodic visual, dimensional, dye penetrant, and ultrasonic examination of the reactor vessel outer head bolts.
5. A replacement "T" bar grapple handle for the refueling cell ten crane was fabricated.
6. An improved design for the installation of reactor vessel head surface thermocouples was completed.
7. Procurement of the replacement axial-fan argon blower was completed when the unit was received at the site.
8. Work was initiated on the development of an overall quality assurance program plan for the SEFOR Facility.

Figure 8-1. SEFOR Reactor Vessel

Figure 8-2. SEFOR Backup Seal Installation

(1) MAT'L
SA-419 TYPE 304 OR
SA-182 TYPE F304

Figure 8-4. Reactor Vessel Head Seal Segment

9. SEFOR OPERATION

9.1 EXPERIMENTAL PROGRAM

9.1.1 Transient Detectors

After identification and quantification of the noises appearing in the signals from the transient fission detectors during the Familiarization and SubPrompt Transient Test series, extensive tests and checks were performed to locate and eliminate the sources of these noises. From these tests, it was concluded that the transient fission chambers were susceptible to mechanically induced low frequency noise or "microphonics" of approximately 200 Hz excited by the Nitrogen Blowers. The two spare unirradiated transient fission detectors were returned to the vendor for correction and modification.

Between subprompt tests 3 and 4, both fission chambers were replaced by the newly modified chambers. The 200 Hz noise which had been a problem with the premodified chambers was greatly reduced in the modified ones. Provisional Test Procedure 54, Gamma Background Measurement, was performed on both old and modified chambers to determine what correction might be needed in the data analysis for induced background.

In the continued effort to determine and correct any 60 Hz pickup, the High Voltage and signal leads inside the N₂ zone were encased in grounded conduit. External to the N₂ zone, the signal leads from the penetrations to the amplifiers were also enclosed in grounded conduit. A careful re-review of all leads and connections disclosed a section of wiring in the calibration box (in conjunction with the amplifiers) which was nonshielded triaxial cabling. This section of wiring was replaced with grounded and shielded wiring.

A review showed that the transient detector system was grounded at the amplifiers which are located inside the reactor containment, close to the reflector drive cell. The system was also grounded at the Data Acquisition System (DAS). These two grounds were at slightly different ground potential, which induced a low level ground loop current when the two grounds were connected. The major equipments grounded to both grounds are 60 Hz which would cause any ground loop current to be 60 Hz.

Several direct ground loop paths were discovered in the High Voltage Power supplies to the detectors located in the transient amplifier cabinet. The incoming AC has an AC ground which results in ground loop noise irrespective of whether the high voltage supplies are on.

The elimination of the ground loop was accomplished by removing the capacitors in the AC ground from the power supplies, and then electrically isolating the transient amplifier cabinet, grounding the system only at the DAS. Preliminary testing, using the oscilloscope, indicates that this solution reduces the 60 Hz noise a factor of 4 to 6. More exhaustive testing, when the transient amplifier modifications have been completely installed, is planned to verify the reduced noise level.

An additional noise content, about 2000 Hz, was observed in early system checkout. During the familiarization and subprompt testing, it was possible to filter this noise with on-hand 5 kHz filters and not compromise the needed system response. The superprompt transients, however, require the maximum system response (10-16 kHz band width) and high frequency noise filtering is no longer practical.

In the diagnostic investigation, it was discovered that most of the high frequency noise appeared to be induced in the signal cable from the amplifiers to the DAS. When a graphite impregnated co-axial cable was substituted for the old signal cable, most of the ~2000 Hz noise disappeared.

Since this discovery, all the old signal leads for both fission and gamma detectors have been replaced with RG 598/U, graphite impregnated coaxial cable.

9.1.2 Transient Amplifiers

One transient amplifier was returned to the vendor for modification to improve the temperature sensitive zero drift, and the low current, nonlogarithmic, current-voltage characteristic. The modified amplifier was returned to the site with parts, and instructions to modify the remaining four amplifiers.

After the subprompt transient tests the amplifiers were modified and checked out. The temperature sensitive zero drift appeared to be much improved. The low current, nonlogarithmic, current-voltage characteristic was greatly improved, as can be seen by the representative comparison in Figure 9-1, which illustrates a before-and-after modification current-voltage characteristic.

9.1.3 Transient Testing

The subprompt transient testing was completed during the reporting period. Tables 6-2 and 6-6 summarize the subprompt tests performed.

Figure 9-1. Transient Amplifier Current Voltage Characteristics

The first subprompt transient test was performed on May 8, 1971 at 1120. This test was a nominal 84 cents transient from 1 MW. The transient fission detectors had one channel (channel B) in the linear mode with a 5 kHz filter installed and one channel (channel A) in the log mode with a 5 kHz filter installed.

Subprompt transient test 1A was performed as a repeat of subprompt transient number 1 to investigate an apparent disagreement in subprompt transient test 1 data between the static worth of the slug and the dynamic worth. In test 1, the dynamic worth was ~4 percent higher than the static worth. Prior to subprompt transient test 1A, the slug was recalibrated by both period measurement and rod swapping. There was good agreement of the results of the two methods, both confirming the static worth as measured earlier by the rod swapping technique. The higher dynamic worth was also present in test 1A.

Subprompt transient test 2 was performed with the slug partially withdrawn above the normal firing position to reduce the static worth to 0.93 dollars. As before, the nominal dynamic worth was approximately 4 percent higher (0.97 dollars) than the static value. The lower limit switch was adjusted, and a mechanical stop was added to the FRED mechanism which positively prevented the slug from being lowered to a position which would result in a static slug worth greater than 0.93 dollars. The subprompt test series was completed with this mechanical stop installed.

The initial power level on tests 2 and 3 were increased to 2 MW from 1 MW in order to bring the initial power level output further onto the logarithmic portion of the amplifier current-voltage characteristics.

An additional test was performed from 10 MW steady state to provide additional data on transient instrumentation cross calibration as described later.

9.1.4 Transient Instrumentation

During the course of the subprompt tests, some transient instrument connections were varied to provide cross calibration and some instruments were modified to improve the signal. Table 9-1 summarizes the instrumentation status for the individual tests: Normal instrument connections are defined as follows:

DAS High Sensitivity Channel A — Fission Chamber A (with 5 kHz filter)

DAS High Sensitivity Channel B — Fission Chamber B (with 5 kHz filter)

DAS Low Sensitivity Channel A — Gamma Chamber A

DAS Low Sensitivity Channel B — Gamma Chamber B

Visicorder — SEFOR Energy Probe (through Sanborn amplifier)

Visicorder — SEFOR Energy Probe (through Sanborn amplifier)

Test No. 10 Connections — Same as Test No. 7. Also, automatic switching was set up which allowed the DAS to record DAS High Sensitivity Channels A and B (fission chambers) below about 20 MW, and DAS Low Sensitivity Channels A and B (gamma chambers) above 20 MW.

Channel A — Log Mode

Channel B — Log Mode

Sanborn Amplifiers — Gain Setting of 10

On Test No. 2, The Sanborn amplifiers saturated. The gain was reduced for the next test.

On Test No. 3, the 5 kHz filter was removed from Channel A in an attempt to reduce a "ringing" high amplitude noise. The signal was much improved. The cause of the "ringing" which was peculiar only to Channel A was not established. The Sanborn amplifier gain of 3 was found to be too low. The gain was returned to 10 as in Test 1A.

Prior to Test 5, a buffer amplifier was installed between the DAS and the amplifier for each gamma channel to correct for an impedance mismatch. Checkout showed that an earlier loading problem was corrected by the modification.

For Test 8, gamma chamber A was connected to the DAS high level Channel A in order to compare gamma chamber A with fission chamber B. (DAS low sensitivity channels A and B were not recorded during tests 1 through 7 due to limitations of the system to record only 2 channels).

For Test 9, gamma chamber B was connected to DAS high sensitivity channel B in order to provide a comparison between gamma chamber B and fission chamber A.

Table 9-1
SUBPROMPT TRANSIENT TEST DETECTOR CONNECTIONS

Test No. 1	Connection — Normal Channel A — Log Mode Channel B — Linear (100 V/ma) [Sanborn Amplifier x 10]
Test No. 1A	Connection — Normal Channel A — Linear Mode (100 V/ma) Channel B — Linear Mode (100 V/ma) Sanborn Amplifiers — Gain Setting of 10
Test No. 2	Connections — Normal Channel A — Log Mode Channel B — Log Mode * Sanborn Amplifiers — Gain Setting of 100
Test No. 3	Connections — Normal, except 5 kHz filter removed from Channel A Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 3
Test No. 4	Connections — Same as Test No. 3. Both fission chambers were replaced with modified chambers Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 10
Test No. 5	Connections — Same as Test No. 4 Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 10
Test No. 6	Connections — Same as Test No. 5 Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 10
Test No. 7	Connections — Same as Test No. 6 Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 10
Test No. 8	Connections — Same as Test No. 7, except gamma chamber A instead of fission chamber A was connected to DAS High Sensitivity Channel A Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 10
Test No. 9	Connections — Same as Test No. 7, except gamma chamber B instead of fission chamber B was connected to DAS High Sensitivity Channel B Channel A — Log Mode Channel B — Log Mode Sanborn Amplifiers — Gain Setting of 10

* Sanborn amplifiers were used in the Energy Probe circuits from this test on.

Test 10 was the first test with automatic switching from fission chambers to gamma chambers during the transient. In the test, fission chamber output was recorded up to about 20 MW, then the circuitry switched to record the two low sensitivity channels (gamma chambers). Switching occurred in the reverse direction during the power decay after the scram.

The voltage levels were initially selected so that switchover should occur at about 70 MW, but switch-over was premature in the actual test. The reason for this premature switching is being investigated.

When the reflector drive cell was opened to install the low sensitivity transient detectors (gamma), one of the wide range monitor (WRM) detector pairs which had been exhibiting a tendency to drift slightly was replaced. After the systems were returned to normal, calibration of all the WRMs, transient fission detectors and the transient gamma detectors was performed to 19 MW(t) and back to zero power with points at 2, 5, 10, 15 and 19 MW(t).

A variety of calibration data was taken in both linear mode and log mode. The calibration data acquired is as follows:

Fission Chambers

Linear Mode

- 1) Gain — 100 volts/milliamperere
Sanborn Amplifier - x 10
5 kHz filter installed
- 2) Gain — 100 volts/milliamperere
Sanborn Amplifier - x 10
5 kHz filter removed

Log Mode

- 1) Sanborn Amplifier - x 1
5 kHz filter installed
- 2) Sanborn Amplifier - x 1
5 kHz filter removed

A similar sequence was performed for the gamma chambers, and after the buffer amplifier was installed to correct an impedance mismatch, (see earlier discussion) the proper functioning of the gamma chambers was demonstrated.

9.1.5 Special Activities

A special test involving the application of temperature sensitive paints to the FRED subprompt slug was performed to determine the clad temperature versus reactor power. Preliminary results indicated the initial power for the subprompt transients should be limited to maintain acceptable FRED cladding temperatures. Subsequent transient initial power levels were limited to 10 MW.

At the completion of the subprompt transient test series, the measured worth of the prompt slug was 1.17 dollars at the same elevated position (0.7 inches) as the subprompt tests.

The core excess reactivity had to be increased prior to the high power subprompt transients because of the higher negative worth of the subprompt slug relative to the familiarization slug. This was achieved by replacing a stainless steel rod located under a through-head port (W3.0S2.0E) with a standard fuel rod. This change increased the excess reactivity at 20 MW with 700°F inlet temperature by 0.24 dollars to 0.41 dollars. The new assembly is designated Assembly I-K.

Earlier plans called for measuring the reactivity worth of the subprompt FRED poison slug, returning the slug to California for adjustment and then returning the slug for full calibration. This procedure was necessary due to the extremely narrow limit imposed by the Technical Specifications and program requirement— 96.5 ± 1.5 cents. The slug was sent to California during the previous reporting period after its total worth had been measured at 101 cents. The subprompt transient slug was returned after poison location adjustment had been made. A reactivity verification was made of its adjusted worth which resulted in a measured value of 97 cents.

Prior to the initiation of the subprompt transient testing, a mechanical check of FRED — test firing the assembled FRED with the slug out of the core and the reactor secured — with the subprompt slug was performed and the results analyzed. A number of firings were completed to verify performance. Test results are listed in Table 9-2. The mean ejection time (time for 20 inches of travel) is about one millisecond faster than the 50 cents familiarization ejection time, i.e. 105.6 msec versus approximately 104.6 msec, which is attributable to the weight difference between the two slugs.

The evaluation of the pilot irradiation of the fission rate measurement, test procedure 11-11, indicated that the fluence would have to be reduced about a factor of 3 to 5 to avoid excessive track density. The actual irradiation was performed on May 3, 1971 with the power level reduced to 20 watts with an irradiation time of an hour and one half. The solid state track records (SSTR) were prepared and were counted at the University of Arkansas. The data are being evaluated, but the preliminary results indicate that some form of surface contamination may have been present on the source foils. This effect is being evaluated.

Work continued on the preparation of the Core II procedures. The status is as follows:

Test Procedure	Status
Reactor Noise and Subcritical Multiplication Measurements in Core I, TP VII-1	Approved
Replacement of BeO Tightener Rods with Stainless Steel Rods, TP I-A.1 (Core II)	Approved
Reactor Noise and Subcritical Multiplication Measurements in Core II, TP I-A.2 (Core II)	Approved
Material Worth Measurements, TP I-B.1 (Core II)	Drafted
Reflector Worth Measurements, TP I-B.2 (Core II)	Out for Review
Oscillator Rod Calibration, TP I-C.1 (Core II)	Out for Review
Zero Power Transfer Function, TP I-C.2 (Core II)	Out for Review
Reflector Worth Measurements (550°F and 760°F), TP I-D.3 (Core II)	Drafted
Conventional Oscillator Test, TP II-2	Drafted
Static Test, TP KK-4 (Core II)	Drafted

9.1.6 Fuel Surveillance

Fuel surveillance was performed following the first subprompt transient at 1 MW, 0.8 cents; 2 MW, 0.96 cents; 5 MW, 0.96 cents; and 10 MW, 0.96 cents; and after completion of the subprompt tests. Results of the measurements are compared with pre-irradiation measurements in Table 9-3. Length and diameter measurements are recorded in inches deviation from the nominal drawing dimensions. Bow is recorded as total indicator reading during rotation, representing twice the actual bow. Pellet column lengths are as measured from the transmission gamma scan.

All changes in fuel rod features are small relative to the allowable changes, and are roughly equal to the repeatability of the measuring device.

In order to prevent stress cycling of the fuel clad due to thermal shock, insertion of fuel into the reactor has been limited to temperature differences between the clad and coolant of 300°F. Removal of fuel from the reactor does not present the same thermal shock problem and no temperature difference limits have been imposed. To perform fuel surveillance, these limitations were adhered to operationally by cooling the entire coolant system to approximately 400°F before fuel was returned to the reactor. Fuel surveillances resulted in many heat-up and cool-down cycles which were very time consuming.

Table 9-2
FRED PREOPERATIONAL MECHANICAL CHECK
SUBPROMPT SLUG
April 23, 1971

Test	t	t	Pressure	
	Visicorder (msec)	Calcomp (msec)	Gage (psig)	Panel 29 (psi)
1a	100.8	100.8	1365	1420
2b	101.0	99.9	1390	1450
3b		101.2	1400	1460
4b	103.5	102.8	1350	1400
5b	103.5	102.4	1400	1450
6	105.2	104.5	1320	1380
7	104.0	103.5	1380	1440
8	104.6	103.7	1390	1450
9	106.5	105.8	1310	1360
10	105.0	104.0	1400	1440
11	105.0	103.9	1390	1450

^a Nitrogen used in test firing.

^b Nitrogen-argon mixture used in firing, progressing to pure argon in this sequence.

During the fuel surveillance after the first subprompt (80 cents) transient, tests were conducted to determine if a fuel rod could be heated in the vacuum distillation station to 750°F and then returned to the reactor before the temperature difference between fuel rod and reactor sodium exceeded 300°F when the reactor sodium temperature was approximately 600°F. If this were possible, fuel surveillance would not require complete cool-down and heat-up and attendant time consumption at the 10°F/hr rate. The results of this test demonstrated that the transfer could be made within all the prescribed limits, if the sodium temperature was at 575°F. In the future, all fuel surveillance removals and reinsertions are planned to be done at the elevated temperatures to speed this operation.

All the fuel surveillances performed during the subprompt transients were performed by this mode of operation.

Receiving inspection of the 126 new and re-worked fuel rods received from Nuclear Fuel Services (NFS) was completed. The following defects were noted:

Defect	Quantity
Helium Leak at Room Temp	7
Upper gas plenum too short	3
Top hole and bottom slot misaligned	1
Helium leak at 800°F	25
Weld defects as determined by x-ray	5
Possible weld defects	2

The first eleven rods tabulated above were returned to NFS for repair. The remaining rods are stored at SEFOR until negotiations for repair are completed.

Table 9-3
SUBPROMPT TRANSIENT TEST FUEL SURVEILLANCE RESULTS

	Pre-Irradiation	1 MW 0.8 Dollars	2 MW 0.96 Dollars	10 MW 0.96 Dollars
Rod A02				
Temperature-Corrected Length (in.)	-0.008	-0.028	-0.032	-0.034
Temperature-Corrected Diameter (in.)	+0.0030	+0.0037	+0.0037	+0.0038
Bow Spiral (in.)	0.016	0.030	0.028	0.020
Bottom Pellet Column Length (in.)	21-3/8	21-3/8	21-5/16	21-3/8
Top Pellet Column Length (in.)	13-15/16	13-15/16	21-3/8	13-15/16
Rod 807				
Temperature-Corrected Length (in.)	-0.006		—	-0.025
Temperature-Corrected Diameter (in.)	+0.0035		+0.0039	+0.0039
Bow Spiral (in.)	0.019		0.019	0.021
Bottom Pellet Column Length (in.)	21-7/16		21-7/16	21-7/16
Top Pellet Column Length (in.)	14		13-15/16	14
	Pre-Irradiation	5 MW 0.96 Dollars	End of Tests	
Rod A16				
Temperature-Corrected Length (in.)	-0.007	-0.033	-0.033	
Temperature-Corrected Diameter (in.)	+0.0030	+0.0039	+0.0039	
Bow Spiral (in.)	0.008	0.042	0.040	
Bottom Pellet Column Length (in.)	21-1/2	21-7/16	21-7/16	
Top Pellet Column Length (in.)	13-15/16	13-15/16	14	
Rod 806				
Temperature-Corrected Length (in.)	-0.001	-0.018	-0.040	
Temperature-Corrected Diameter (in.)	+0.0035	+0.0038	+0.0035	
Bow Spiral (in.)	0.016	0.020	0.019	
Bottom Pellet Column Length (in.)	21-3/8	21-3/8	21-7/16	
Top Pellet Column Length (in.)	13-15/16	14	14	

9.2 OPERATIONS AND MAINTENANCE

Reactor Operation Statistics

	Current Month June 14—July 18, 1971	Current Quarter April 18—July 18, 1971	Total to Date July 18, 1971
Hours Critical (hr)	2.3	172.5	2,941
Power Generated (MWh)	0	793.9	20,385
Startups	1	34	486
Scrams	0	20	143 ^b
Operating Efficiency ^a (%)	22.8	39.6	39.2

^aThis represents the percent of time that the reactor complex was available for performance of the test program, or work necessary for the operation of the reactor, such as normally scheduled License Test Procedures. The accountability is to the nearest full day.

^bTwenty-one scrams have been intentional, for FRED tests.

The reactor outage that was initiated on March 14, 1971 to investigate the loading on the reactor vessel outer-head studs from differential movement of vessel flange and head during temperature changes of the primary coolant was terminated on April 29, 1971, when authorization to resume operations was received from DRL. Recalibration of the subprompt critical FRED plug was interrupted by a malfunction of the positioner motor drive gear reductor. A new gear reductor was installed and the lubricant was changed to heavyweight oil to improve the lifetime of the gears. Following the nominal 0.8 dollars transient test from 1 MW, operation was delayed by the necessity to investigate and remove a partial restriction in the Primary Drain Tank vent line, a requirement for readjustment of one of the polyphase directional relays on the Primary Pump Power Supply, and replacement of a reflector scram solenoid valve.

Subprompt transient tests were resumed and were interrupted, again, to correct two malfunctions of mercury-wetted relays in the safety system, and to perform measurements of the FRED slug temperature by the use of temperature sensitive paints.

Following subprompt test No. 4 (0.96 dollars from 5 MW) operation was interrupted to correct instabilities in the input electrometers in the Wide Range Monitors. The instabilities were created by excessive input currents during the previous transient tests or from diagnostic tests to determine the limits of operation for the electrometers. By the replacement of the electrometers and the addition of an input current limiting circuit, the instabilities were eliminated and the transient testing proceeded. Following subprompt test No. 8 (0.96 dollars from 10 MW) a malfunction of the Main Primary Pump Motor Generator DC exciter circuit was corrected. The subprompt test series was completed and the reactivity worth of the superprompt slug was measured.

An outage to perform the annual containment leak checks and to accomplish plant modifications and maintenance was initiated on June 15, 1971. Significant modifications involve the installation of a reactor vessel outer-head back-up seal, and an emergency crane retrieval system. Inner and outer containment leak checks were completed. The leakage rate from the inner containment was well within the limits, and the leakage from the outer containment was essentially zero. All modifications and maintenance activities were accomplished. Pressure leak test of the back-up seal and a leak rate re-test of the inner containment were initiated.

The two cold traps removed from the primary sodium system in November 1969, were cut open and examined in an argon atmosphere. The blockage of flow through the traps had been caused by the compression of the stainless steel mesh upward to 1/3 to 1/2 of its height and the deposition of oxides on and around the mesh. Photographs of the interior of the traps and samples for chemical analyses were taken. The total quantity of residue (sodium plus sodium oxide) in each trap was determined.

126 fuel rods received from the vendor were visually and dimensionally inspected, and helium leak checks were performed at ambient temperatures and at 700°F. The shipment consisted of 104 new, 19 repaired, 2 unrepaired fuel rods, and one UO₂ dummy rod. Eleven fuel rods were returned to the vendor because of deviations from specifications.

A total of 196 equipment malfunctions were corrected, distributed as follows:

Mechanical	58
Electrical	60
Instrumentation	78
Total	196

The more significant malfunctions included:

- Reactor building pressure controller
- Positioner motor gear reductor
- Primary pump motor generator poly phase directional relay
- Safety system relays
- Primary pump control circuit line delay relay
- Wide range monitor input electrometers
- Freon compressor valves and springs
- Freon unit leaks
- Trace heaters and volt pacs
- Primary drain tank vent line
- Breathing air compressor seal
- Argon compressor oil seal
- Argon supply high velocity check valve
- M G set pillow block bearing
- Reflector limit switch
- 480 V transformer insulator spacers
- Reflector scram solenoid limit switch
- Refueling all T V camera

A total of 44 plant and equipment modifications were completed, including the following significant items:

- Refuel cell crane emergency retrieval system
- Reactor vessel outer-head back-up seal
- Transient fission chamber cable conduit
- Wide range monitor input current protection
- Valt-pac 3-phase neutral return to load center
- Half-ton grapple slack cable fix
- Safety system jumper panel
- Improved control — Pump-around-pump
- Boron carbide shield — Transient fission detectors
- Reactor vessel head surface thermocouples
- Transient flux detector system ripple reduction
- Excursion mode time delay measurement equipment
- Programmed flow reduction and time delay
- IFA reference junction monitor and alarm
- Area lighting
- Refueling cell inter-comm.
- Energy probe wide band amplifiers
- High velocity check valves position indication

Gamma-ray spectrometry measurements of fission gas components of the reactor cover gas were made routinely during the experimental testing. The results continue to indicate levels of xenon and krypton commensurate with tramp uranium in the system.

Routine environmental surveys were conducted to verify that no environmental radioactivity increase attributable to reactor operation occurred.

REFERENCES

1. McKeethan, E. R., "Design and Testing of the SEFOR Fast Reactivity Excursion DEVICE [FRED]", GEAP-13649, Oct. 1970.
2. SEFOR Development Program 28th Quarterly Report, February-April 1971, GEAP-10010-28, May 1971.
3. Noble, L. D., and Wilkinson, C. D., "Final Specifications for the SEFOR Experimental Program", GEAP-5576, January 1968.
4. Nobel, L. D., et al., "SEFOR Core I Test Results to 20 MW", GEAP-13702, April 1971.
5. Power, B. J., Hagen, R. N., and Johnson, S. O., "SPORT - A System for Processing Reactor Transient Data on the IBM-7040 Computer", IDO-17078, July 1965.
6. Wylie, C. R., Jr., "Advanced Engineering Mathematics", McGraw-Hill, New York, 1960.
7. Fox, J. N., et al., "FORE-II - Computational Program for the Analysis of Steady State and Transient Reactor Performance", GEAP-5273 September 1966.
8. Berman, D., and Wilkinson, C. D., "Weighted Doppler Analysis Code WEDOP", GEAP-5543, July 1967.

CONTRIBUTORS

The following persons contributed to the work performed on the SEFOR Research and Development Program during the quarter ending July 31, 1971.

SEFOR Operations

J. Arterburn
Q. Baird (PNWL)
R. Becker
M. Johnson
W. Kozik
Y. Lu
R. Meyer
W. Oosterkamp (Karlsruhe)
M. Plummer
B. Sarma
N. Nielson

E. Craig
S. Derby
B. Farwell
T. Gleason
J. Haar
K. Johnson
P. Hallila
E. McKeethan
F. Rally
H. Stock
W. Tachiki
R. Wilson
F. Young

Other Contributors

K. Beecher
K. Cohen
L. Fidrych
P. Greebler
E. Olich
R. Pflasterer

Task 6—Reactivity Controls Required for Experimentation

E. McKeethan
W. Tachiki
N. Wallace
F. Young

Task 9—Fuel Fabrication

E. Aitkin
D. C. Allen
D. Bishop
T. Brownell

Task 10—Startup Testing

M. Audoux (Karlsruhe)
S. Derby
G. Kussmaul (Karlsruhe)
L. Noble
A. Raberain (Karlsruhe)

Task 11—Transient Tests

H. Butz
S. Derby
M. Kelley
G. Kussmaul (Karlsruhe)
L. Noble

SEFOR Safety Audit and Licensing

J. Cole
K. Hikido
R. Meyer
F. Rally
N. Hockford
G. Kussmaul (Karlsruhe)
C. Russell
L. Noble
J. Punches
J. Whalen
W. Whitling

SEFOR Support

G. Brynsvold
J. M. Day
L. Franckx
G. Kruger
E. McKeehan
L. Nemeth
F. Young

DISTRIBUTION

Division of Technical Information Extension U. S. Atomic Energy Commission P. O. Box 62 Oak Ridge, Tennessee	15	Power Reactor Development Company 1191 First Street Detroit, Michigan 48226	1
Director Research and Development Division U. S. Atomic Energy Commission Richland Operations Office P.O. Box 550 Richland, Washington 99352	1	Project Manager FFTF Project Pacific Northwest Laboratory Richland, Washington 99352	5
Mr. G. Vendryes Cen Saclay Boite Postale 2 Gif-Sur-Yvette (S et O) France	10	Chief, Fuels and Materials Branch DRD&T, USAEC Washington, D. C. 20545	1
Dott, Ing. F. Pierantoni CNEN Viz Mazzini 2 Bologna, Italy	4	Assistant Director for Reactor Projects Division of Reactor Licensing DRD&T, USAEC Washington, D. C. 20545	1
Chief Fuel Fabrication Branch DRD&T, USAEC Washington, D. C. 20545	1	Director Los Alamos Scientific Laboratory Los Alamos, New Mexico 87544	3
Mr. F. W. Lewis, President Louisiana Power and Light Company 142 Delaronde Street New Orleans, Louisiana 70114	1	Dr. John C. Woodhouse 21 Woodbrook Circle Wilmington, Delaware 19803	1
Mr. R. C. Green, President Missouri Public Service Co. 10700 East 50 Highway Kansas City, Missouri	1	Senior Representative U. S. Mission to EURATOM Communities c/o U. S. Embassy Brussels, Belgium	3
Mr. L. J. Cucullu, President New Orleans Public Service Inc. 317 Baronne Street New Orleans, Louisiana 70160	1	General Directorate Research and Training EURATOM 51-53 Rue Belliard Brussels, Belgium Attn: A. DeStordeur	10
Mr. B. S. Jeffrey, President Kansas Power and Light Company 808 Kansas Avenue Topeka, Kansas 66601	1	Mr. F. H. Coughlin, Chairman of Board Central Louisiana Electric Co., Inc. P. O. Box 111 Alexandria, Louisiana 71301	1
Mr. J. Robert Welsh Chairman of the Board Southwestern Electric Power Company P.O. Box 1106 Shreveport, Louisiana 71102	1	Mr. John Stewart, President The Central Kansas Power Company 111 East 11th Street Hays, Kansas 67601	1
		Mr. Reeves Ritchie, President Arkansas Power and Light Company Ninth and Louisiana Street Little Rock, Arkansas 72203	1

GEAP-10010-29

Mr. J. T. Jones, President The Empire District Electric Co. 602 Joplin Street Joplin, Missouri 64802	1	USAEC Office of RDT Site Representative 310 DeGuigne Drive Sunnyvale, California 94086 Attn: J. Levy	2
Mr. Harold E. Mortimer Vice President Assistant to Chairman of the Board Gulf States Utilities Company P. O. Box 2951 Beaumont, Texas 77704	1	Director Liquid Metals Information Center P. O. Box 309 Canoga Park, California 91305	1
Gesellschaft fur Kernforschung m.b.H. Projekt Schneller Bruter 75) Karlsruhe, Germany Postfach 947	10	Mr. S. Golan, Project Manager 1000 MWe LMFBR Follow-On Study Atomics International P. O. Box 309 Canoga Park, California 91304	2
Mr. C. F. Edwards, Vice President Western Power Division Central Telephone & Utilities Corp. P. O. Box 170 Great Bend, Kansas	1	Mr. M. W. Croft, Project Manager 1000 MWe LMFBR Follow-on Study The Babcock & Wilcox Company 5061 Fort Avenue P. O. Box 1260 Lynchburg, Virginia 24505	2
Director, Contracts Division U. S. Atomic Energy Commission San Francisco Operations Office 2111 Bancroft Way Berkeley, California 94704	2	Director, LMFBR Program Office Argonne National Laboratory South Cass Avenue Argonne, Illinois 60439	1
F. W. Thalgott Associate Director, Idaho Division Argonne National Laboratory Box 1096 Idaho Falls, Idaho 83401	1	Asst. Director for Plant Engineering DRD&T, USAEC Washington, D. C. 20545	2
Director, Argonne National Laboratory 9800 South Cass Avenue Argonne, Illinois 60439	2	Asst. Director for Reactor Engineering DRD&T, USAEC Washington, D. C. 20545	2
Chief, Reactor Physics Branch DRD&T, USAEC Washington, D. C. 20545	1	Brookhaven National Laboratory Associated Universities, Inc. Upton, Long Island, N. Y. 11973 Attn: Dr. C. H. Raseman	1
Mr. C. C. Czeschin, President Arkansas-Missouri Power Company 104 South Fifth Street Blytheville, Arkansas 72316	1	Project Manager Special Projects Branch DRD&T, USAEC Washington, D. C. 20545	1
Mr. T. Flynn Ebasco Services, Inc. 2 Rector Street New York City, 6, N. Y.	1	Mr. G. W. Evans, President Kansas Gas and Electric Company 201 North Market Street Wichita, Kansas 67201	1

GEAP-10010-29

Mr. L. F. C. Reichle Ebasco Services, Inc. 2 Rector Street New York 6, New York	1	Dr. W. P. Staker, Project Manager 1000 MWe LMFBF Follow-On Study Combustion Engineering, Inc. P. O. Box 500 Windsor, Connecticut 06095	2
Mr. R. B. Wilson, President Mississippi Power and Light Company Electric Building Jackson, Mississippi 39205	1	Mr. C. A. Anderson, Project Manager 1000 MWe LMFBF Follow-On Study Westinghouse Electric Corporation Advanced Reactors Division Waltz Mill Site P. O. Box 158 Madison, Pennsylvania 15663	2
Mr. Ray W. Call, President Missouri Utilities Company 400 Broadway Cape Girardeau, Missouri 63701	1	Mr. L. W. Fromm, Manager 1000 MWe LMFBF Follow-On Study Project Building 208 Argonne National Laboratory 9800 South Cass Avenue Argonne, Illinois 60439	2
Mr. W. A. Parker, President Oklahoma Gas and Electric Company 321 North Harvey Street Oklahoma City, Oklahoma 73101	1	USAEC Scientific Representative United States Embassy, Box 40 FPO New York, N. Y. 09510	1
Mr. D. J. Tuepker, Chairman Public Service Company of Oklahoma 600 South Main Street Tulsa, Oklahoma 74102	1	United States Atomic Energy Commission Region II - Division of Compliance Suite 818 230 Peach Tree Street, NW Atlanta, Georgia 30303	1
Chief, Liquid Metal Project Branch DRD&T, USAEC Washington, D. C. 20545	1	Dr. Knox M. Broom, Jr. Nuclear Specialist Middle South Services, Inc. Post Office Box 61000 New Orleans, Louisiana	1
Asst. Director for Nuclear Safety DRD&T, USAEC Washington, D. C. 20545	1		