SETBACK TESTS TO DETERMINE THERMAL TRANSIENTS AND CONTROL PERFORMANCE - ENRICO FERMI REACTOR

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ABSTRACT

This report presents results of setback tests conducted on the Enrico Fermi reactor at thermal power levels of 50 and 75 Mw. Setbacks at each power level were initiated manually, and by temperature and power, to determine thermal transients, setback system operation, and performance of reactor controls.

Recordings obtained in the tests have furnished values of the thermal transients and the magnitude of the power of the setbacks for conditions of the test. Satisfactory control of the reactor in setback was verified.

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FOREWORD

This is one of a series of reports on the low-power (up to 1 Mwt) and high-power (up to 200 Mwt) nuclear testing of the Enrico Fermi reactor. The Nuclear Test Program is planned, directed and evaluated by Atomic Power Development Associates, Inc. (APDA). The tests are conducted by Power Reactor Development Company (PRDC). The reactor proper is owned and operated by PRDC. The steam generators and electrical generating facilities are owned by The Detroit Edison Company (DECo.)

Many individuals have contributed to the nuclear testing of the Fermi reactor. Listed below are those, exclusive of the authors, who made significant contributions to the work described in this report.

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SUMMARY

Power setback tests were conducted at power levels of 50 and 75 Mwt with operation of two and three coolant circuits, respectively. Three types of setback were performed at each power level. The first setback was initiated manually, with run-in of the regulating rod being one basic setback increment of approximately 20-sec at a rod speed of 5.35 in./min. The second and third setbacks were initiated automatically on power level and temperature level, and were performed in that order.

The automatic setbacks were obtained by placing the power or temperature setback point slightly over the steady-state value for the specific test power level, and then slowly raising the reactor power until a setback was initiated upon reaching the set point. At both 50 and 75 Mwt the resulting power setback consisted of two consecutive increments, having an overall duration of 40 sec. The speed of the regulating rod during the increment was constant at the nominal setback rate of 5.35 in./min. The temperature setbacks consisted of a three-increment setback at 50 Mwt with a duration of 60 sec, and a four-increment setback at 75 Mwt with a duration of 80 sec. As found to be the case for the power setbacks, the regulating rod movement in the temperature setbacks was executed in consecutive increments, with no interruption being evident in the recorded trace of rod position.

In all setback tests at 50 and 75 Mwt the response of the setback control circuit was found to be rapid and the regulating rod movement was smooth. No spurious scrams were incurred, demonstrating satisfactory coordination of setback with the scram system. Transients were insignificant in the temperature of the reactor outlet sodium, reactor inlet sodium, steam generator inlet sodium, steam generator outlet sodium, and the steam temperature, with no instability occurring in plant control.

I. PURPOSE OF TESTS

The purpose of the setback transient tests was to determine: (1) the thermal transients that occur as a result of a setback; (2) that the settings of the temperature setback and temperature scram have been properly coordinated; and (3) that the setback rate and duration are compatible with the system dynamics.

Setback is an action whereby negative reactivity is introduced by insertion of the regulating rod in discrete increments to maintain temperature or power level below a set limit. Setback can be initiated automatically or manually. The control parameters for the automatic setback are reactor sodium outlet temperature (TE-201) and power range neutron flux.

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II. GENERAL DESCRIPTION OF THE ENRICO FERMI REACTOR¹

The Fermi reactor and its associated structures are shown in perspective in Fig. 1. The reactor is contained in a stainless steel reactor vessel sealed at the top by a rotating shield plug which supports the control mechanism, the fuel subassembly holddown mechanism, and the fuel subassembly handling mechanism. The reactor vessel is surrounded by borated and plain graphite neutron shielding material which is contained inside the primary shield tank. The reactor is of the fast-breeder type, cooled by sodium and operated at essentially atmospheric pressure. The maximum reactor power obtainable with the first core loading (core A) is 200 Mwt.

The core and blanket are located in the lower reactor vessel and consist of 2.65-in. -square subassemblies containing the fuel pins and blanket rods. The core and blanket subassemblies are arranged to approximate a cylinder about 80 in. in diameter and 70 in. high. The core, which is contained in the central portion of the core subassemblies, approximates a right cylinder 31 in. in diameter and 31 in. high; it is axially and radially surrounded by the breeder blankets. The fuel in the first core loading consists of zirconium-clad pins containing U-10 w/o molybdenum alloy with the uranium enriched to 25.6 w/o U-235. The blanket is depleted U-3 w/o molybdenum alloy.

The reactor cross section, shown in Fig. 2, indicates the placement of individual components within the lower reactor vessel. There is a total of 149 central lattice positions used for core and inner radial blanket subassemblies and operating control and safety rods, all of which are supplied with sodium coolant flowing upwards from a plenum which is fed directly from the discharge of the primary sodium pumps. Owing to the large pressure drop across this region, through which flows about 90 per cent of the total sodium, the subassemblies located in it require downward mechanical restraint in addition to their own weights, to prevent ejection from the lower support plates. This restraint is supplied by the holddown mechanism.

The lattice positions surrounding the inner radial blanket comprise the outer radial blanket area and, when filled with outer radial blanket subassemblies, form an annular region whose top and bottom are at the same elevation as the top and bottom of the inner radial blanket. Surrounding the outer radial blanket are lattice positions used for steel subassemblies which provide thermal and neutron shielding. The lattice positions occupied by outer radial blanket and shielding subassemblies are supplied with sodium coolant from a low-pressure plenum which is fed from the primary sodium pumps through throttle valves. The force produced by the pressure drop acting on these subassemblies is less than their weight so that no holddown is required.

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FIG. 1 PERSPECTIVE VIEW OF REACTOR

FIG. 2 REACTOR CROSS SECTION

Control of the reactor is accomplished by two operating control rods and seven safety rods. All the rods are of the poison type, containing boron carbide (B_4C) in which the boron is enriched in B-10. One operating control rod is for regulating purposes and the other is for shimming; they have maximum reactivity insertion rates of about 2/3 cent/sec and 1 cent/min, respectively. Together, they provide a total of 92 cents of reactivity to compensate for temperature override, burnup, and operating flexibility. The seven safety rods, which are located around the core about 7 in. from its vertical centerline, provide a shutdown reactivity of over 8 dollars. During reactor operation, the safety rods are poised just above the axial blanket section of the core so that they can be rapidly inserted into the core if necessary for scram, or driven in at the rate of 10 ft/min. The safety rods provide the shutdown during refueling operations.

The plant is designed for manual approach to criticality and low-power operation, and for either manual or automatic plant loading in the power range. Plant loading is determined by the reactor, not by system demand.

Heat produced in the reactor is removed by three primary coolant loops contained within the reactor building. Flow in the primary coolant system is upwards through the core and blanket into a large plenum region designated the upper reactor pool. Because the primary sodium is radioactive, its heat is transferred by three intermediate heat exchangers within the reactor building to three nonradioactive secondary sodium loops, and, finally, to three once-through steam generators in the steam generator building. Here steam is produced to operate the turbine in the adjacent turbine house.

III. EXPERIMENTAL APPARATUS AND EQUIPMENT

An understanding of reactor control and overall system operation requires knowledge of plant instrumentation employed for the principal plant parameters. To secure accurate test data it was necessary to properly utilize the circuit of a detector, and in some cases even provide special auxiliary circuitry to prevent loading which would alter the signal voltage and upset normal operation of the circuit. In recognition of these facts, this section presents information on the detectors of main interest in these tests, their main functions, and a brief account of the signal-handling circuitry employed to obtain the signal recording. The signal parameters recorded during these tests are listed in Table 1 which shows the scale spans used for the strip-chart recorders.

A. DETECTORS

Brief descriptions of the detectors of concern in these tests and their physical locations and plant functions are presented below. Locations of the temperature detectors in the heat transport system are illustrated schematically in Fig. 3.

1. Reactor Outlet Temperature (TE-201 and TE-217)

The temperature detector used to sense reactor outlet temperature is a resistance thermometer having a time constant of 6.07 sec (Ref. 2). One such detector is provided in each of the three 30-in. reactor outlet pipes; mounting is in a well-type arrangement. These detectors are given the designation TE-201, followed by a number representing the coolant circuit number. The TE-201 detectors are used in the reactor control system, reactor setback system, and the feedwater flow control system. To avoid impairing the normal control functions of the detector, connection of the strip-chart recorder was made at the output of the demodulator. The demodulator provided a low source impedance and thereby prevented introduction of reading errors due to loading by the input circuit of the recorder.

The detectors designated TE-217 (followed by a number representing the coolant circuit number) are sheathed thermocouples located in thermowells in the 30-in. reactor outlet pipe. The time constant of the basic detector is about 1 sec. These detectors have been installed as back-up for the TE-201 detectors, and are specifically intended to be replaceable. The TE-217 detectors are located nearer the reactor proper than are the TE-201 detectors, and they are inside the primary shield tank, while the TE-201 detectors are outside the primary shield tank but inside the secondary shield wall.

TABLE 1 - RECORDER SCALE SPANS USED DURING
SETBACK TESTS AT 50 Mwt AND 75 Mwt

<u>Parameter</u>	<u>Recorder Span</u>	
	<u>50 Mwt</u>	<u>75 Mwt</u>
TE-115-9	500-800 F	500-800 F
TE-201-1D	500-700 F	NR *
TE-201-2	NR *	500-700 F
TE-201-2D	500-700 F	NR *
TE-201-3	NR *	500-700 F
TE-209-2	500-550 F	500-600 F
TE-217-2	NR *	500-700 F
TE-301-2D2	500-550 F	500-550 F
TE-308-2	500-700 F	500-700 F
TE-601-2	500-700 F	500-700 F
Neutron Flux (Electrometer)	$0-3 \times 10^{-5}$ amp	$0-3 \times 10^{-5}$ amp
Regulating Rod	+ 19 in. to - 1 in.	+ 19 in. to - 1 in.
Shim Rod	+ 19 in. to - 1 in.	+ 19 in. to - 1 in.

* Not recorded

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**FIG. 3 SCHEMATIC DIAGRAM OF RESISTANCE TEMPERATURE DETECTOR LOCATIONS
IN THE FERMI REACTOR HEAT TRANSPORT SYSTEM**

A stainless steel guide tube (3/8-in. OD) connects the thermowell and the thermocouple installation port. The guide tubes for TE-217-1 and TE-217-3 are about 12 ft long, and have two 60-deg bends; the offset in this line also is about 2-1/2 ft. It was evident from the response of TE-217-2 during the 20-Mwt and 67-Mwt scram tests that the thermocouple was not properly seated in the thermowell.³ The thermal lag of TE-217-2 has been found to be about four times that of TE-217-3. The seating problem is probably the result of an accumulation of dirt in the thermowell.

2. Core Outlet Temperature (TE-115)

Fifty-five thermocouples are provided in the Fermi reactor to monitor the coolant outlet temperatures of the core subassemblies. These thermocouples have junctions grounded to the sheath (contact only, not welded) for a fast response of about 1 sec. The junctions have become ungrounded in several of the TE-115 thermocouples in the course of normal operations because of a difference of coefficients of linear expansion of the sheath and conductor materials. The response of an ungrounded thermocouple could be of the order of 5 sec. Mounting inside the holddown finger is such that the thermocouple is close to the conical cavity which seats on the subassembly handling head. These sensors are given the designation of TE-115.

The TE-115 detectors are used in the reactor safety system and core temperature automatic scanner and alarm. Core outlet temperature signals from four TE-115 thermocouples control bistable multivibrators which feed the 2-out-of-4 AND gate logic circuit in the safety system. The AND gate is connected in a manner such that two "unsafe" signals must be present before an "unsafe" signal is applied to the scram logic OR gates, scrambling the reactor.

3. Steam Generator Sodium Inlet Temperature (TE-308)

The TE-308 is a resistance-type temperature detector mounted in a thermowell in the 18-in. pipe of the inlet piping system to the steam generator. More specifically, the detector location is in the region of the "T" connection in the 18-in. pipe which divides the steam generator inlet sodium flow to the two 12-in. inlet nozzles of the steam generator. The time constant of this sensor is about 25 sec. The detectors are given the designation of TE-308.

The TE-308 detectors have no control functions, but provide information to an indicator in the control room. A pneumatic retransmitter is used to drive the indicator. A separate bridge circuit was provided to obtain a signal from the resistance thermometer detector (RTD). A suitable scale factor was set up for the recorder by means of the recorder gain adjustment.

4. Steam Generator Sodium Outlet Temperature (TE-301)

The steam generator outlet sodium temperature is used as one of the basic signals in the feedwater control system to establish a demand signal for feedwater flow. Emergency feedwater flow also is controlled by the steam generator sodium outlet temperature. The TE-301 detector, as originally provided in the outlet piping of the steam generator, is a resistance thermometer located about 1-1/2 ft from the bottom of the steam generator vessel. Response of the detector is estimated to be 2.5 sec. Early in the reactor test program it was observed that flow-channeling of relatively hot sodium along the walls of the sodium outlet piping of the steam generator was producing erratic and high readings of TE-301 because of poor mixing at this point. To obtain a better temperature signal, thermocouples were installed in thermowells about 75 equivalent pipe diameters downstream from the original TE-301 detector location. Three thermocouples have been provided in each loop and carry the designations D, E and F. The response of the basic thermocouple is about 1.5 sec.

5. Reactor Inlet Temperature (TE-209)

The reactor inlet temperature detector designated as TE-209 is located in the 6-in. standpipe. The TE-209 temperature detector is a resistance thermometer identical to the TE-201 detector which has a time constant of 6.07 sec.

6. Water-Steam Temperature (TE-601)

The TE-601 is a resistance-type temperature detector thermowell, mounted in the outlet pipe of the steam generator. The TE-601 is the same type as the TE-308, having a time constant of 25 sec. The water-steam temperature signal is used in the reactor program controller and plant recorders and indicators.

7. Neutron Flux

The neutron flux detector for measuring and monitoring reactor power was provided as separate apparatus, independent of the reactor safety system and control instrumentation. The detector utilized was NE-116, a B-10 lined, compensated ion chamber (Reuter-Stokes, Inc.). Installation of the detector is in neutron-counter tube No. 5, the location of which is illustrated in Fig. 3 of Ref. 4. Output of the ion chamber is read on an electrometer (Keithley Instruments Inc. Model 415) located in the control room. A coaxial cable approximately 250 ft long interconnects the ion chamber and the electrometer. The time constant of the neutron flux measuring instrumentation is of the order of 10 msec.

B. SIGNAL CONDITIONING CIRCUITS AND ADJUNCTIVE APPARATUS

Since a readily available signal was not existent in some cases to record a plant parameter, a special bridge circuit had to be provided for some RTD's to enable their operation and calibration; the basic circuit is shown in Fig. 4. To simulate a temperature signal, the variable resistance is set to a value which corresponds to the RTD resistance. Special care was required with some detectors to prevent upsetting the normal operation of the circuit by recorder loading or by an accidental short circuit which could impair or otherwise alter the detector output signal. Inasmuch as the output of the TE-201 detectors has important control functions, the output of each TE-201 detector recorded was taken at the output of the demodulator where the circuit impedance is low. An available spare TE-301 detector already in the system was placed into use for the tests. The TE-209 detector utilized was temporarily diverted from its normal function in the safety rod withdrawal interlock circuit. A signal from the TE-601 detector was obtained from the retransmitting slidewire of the plant recorder into which the detector normally works. The TE-301 signal was obtained at the output of a load-isolating (low output impedance) amplifier.

The circuits of the resistance thermometer detectors are shown in Figs. 5a, 5b and 5c in block diagram form; the circuit for the TE-301 thermocouples is shown in Fig. 5d.

Adjunctive apparatus and equipment employed in the setback tests consisted of the following major items:

- Eight-channel strip-chart recorders having a minimum response of 50 cps, and containing suppression and span calibrating provisions -- used for recording the system parameters such as temperatures, regulating rod position, and neutron flux.
- Millivolt box -- used for simulating the output of a thermocouple.
- Four-arm resistance bridge circuits, equipped with a battery power supply for excitation of the bridge -- used for simulating an RTD during recorder calibration, and to provide the required bridge circuitry for operation of RTD's TE-209 and TE-308, apart from their respective plant recorders.

C. OPERATING CONTROL RODS

Two operating control rods are employed in the reactor. They are on opposite sides of, and 2-1/2 in. from, the vertical centerline of the core. Reactivity adjustments for start-up, power level changes, and burnup compensation are made by means of the operating control rods. Then two rods are raised and lowered at different rates, corresponding to approximately

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FIG. 4 BRIDGE CIRCUIT FOR RESISTANCE THERMOMETER DETECTORS

FIG. 5 TEMPERATURE DETECTOR SIGNAL CIRCUITS

1 cent/sec for the regulating rod, which is used for start up and control, and 1 cent/min for the shim rod. The essential function of the shim rod is to position the regulating rod so that it normally operates within ± 2 in. of its reference position. During reactor operation, the shim rod is adjusted as necessary to keep the regulating rod in that range. The stroke of both rods is approximately 20 in. for the first core loading.

In the full-in position of the regulating rod, the poison section, which is 10 in. long and located at the bottom end of the rod assembly, is located such that it is 3 in. below the center plane of the core. This is called "zero position" for the regulating rod and the shim rod. Since the vertical dimension of the core is 32-25/32 in., the lower end of the poison section is located approximately 1/2-in. above the upper end plane of the core when the rod is fully retracted.

D. THE SETBACK SYSTEM

A portion of the reactor safety system is designated as the setback system. The function of the setback system is to reduce the reactor power when a parameter has reached an established limit, but not with the severity of a scram. Setback is a comparatively gentle action in which power is reduced by discrete amounts until the high parameter level causing the setback is brought within the established limit. Setback can be initiated automatically or manually.

The parameters which initiate setback automatically are the reactor outlet sodium temperature and neutron flux in the power range. Associated with each channel is an alarm which is set to trip somewhat below setback level. Limits for the 200-Mwt program have been 110 per cent of the parameter values at nominal full power for the setback trips and 105 per cent for the alarm trips.

Circuitwise, setback is accomplished by removal of the reactor control channel signal (whether on automatic or manual control) from the regulating rod drive and the substitution of a fixed a-c voltage to drive the regulating rod into the reactor at a fixed speed for a discrete period. After this period, which is determined by the setback cycle timer, the setback initiating relay is automatically reset and, if the parameter limit condition still exists, another setback is introduced, etc., until the abnormal condition clears. The duration of one setback period is 20 sec, and the regulating rod insertion rate during the setback period is approximately 5.35 in./min.

The automatic setback circuit receives a total of six channels of information, as follows:

- Three safety system power range nuclear channels instrumented with detectors NE-108, NE-109 and NE-110.

- Three reactor sodium outlet temperature channels instrumented with detectors TE-201-1, TE-201-2, and TE-201-3.

Signals from the TE-201 bistable trip units are fed to a two-out-of-three logic network. Outputs from the logic network feed into an OR gate designated as the setback mixer. Similarly, outputs from the flux channel bistable trip units are fed to a two-out-of-three logic network which feeds into the OR gate. Thus, under normal operation, when two of three temperature signals exceed the set limit or when two of three neutron flux signals exceed the set limit, each of the bistable trip units fed by these channels produces an output signal representing this condition. This signal causes the logic network to supply, in turn, a signal to the OR gate which energizes the relay controlling the setback timer circuit. In addition to initiating the setback action, the relay energizes an alarm and starts a counter which indicates to the operator the number of setbacks which have occurred. When the setback condition is cleared, the drive motor of the regulating rod is disconnected from the setback system and connected to the reactor manual control system; thus, after a setback the regulating rod and the shim rod positions are fixed, except for operator action or further setback. A pushbutton is provided on the operating console for the operator for manual execution of a setback.

IV. EXPERIMENTAL PROCEDURES AND PLANT CONDITIONS

The test procedure specified setbacks to be performed at 25 and 60 per cent of full power, with the plant operating on two and three coolant circuits, respectively.² The tests were performed for manual and automatic control modes. Control of feedwater, however, was manual in each case, and pressure in the steam-feedwater system was constant at 950 psia.

The essential operations in the setback tests for the condition of the reactor and feedwater controls in the manual mode were the following:

- The setback trip points for temperature and power were set as required. The setting for temperature was 658 F and for power it was approximately 50 Mwt.
- The power of the reactor was increased according to established operating procedures to obtain levels of outlet temperature and power which were slightly below the setback trip points.
- The setback counter was set at zero.
- The regulating rod was withdrawn until setback occurred; responses of the parameters of main interest were recorded.

The essential operations in the setback tests for the condition of the reactor in the automatic mode and the feedwater control in the manual mode were the following:

- The reactor power was adjusted, as required, to obtain a reactor outlet temperature (TE-201) about 15 F below the temperature setback trip point. The power trip point was set at 110 per cent of nominal test power in all of the tests in the automatic mode.
- The reactor was placed in manual control, and the temperature set point was set at 10 F above the setback trip point.
- The setback counter was set at zero.
- The reactor was switched to automatic control to obtain a setback; responses of main parameters of interest were recorded.

The scram trip points for all setback tests were set at 120 per cent of the nominal test power level. It was necessary to deactivate the interlock

which prevents the use of automatic reactor control if the temperature set point is more than 5 F above the actual outlet temperature of the reactor.

The sodium flow rates of the primary and secondary loops during the setback tests are listed in Table 2.

TABLE 2 - SODIUM FLOW RATES IN PRIMARY AND SECONDARY HEAT TRANSPORT SYSTEMS DURING MANUAL, POWER, AND TEMPERATURE SETBACK TESTS AT 50 Mwt AND 75 Mwt

	<u>Sodium Flow Rate, lb/hr x 10⁶</u>	
	<u>50 Mwt</u>	<u>75 Mwt</u>
<u>Primary System</u>		
Circuit No. 1:		
14-in. Pipe	2.750	2.550
6-in. Pipe	0.275	0.390
Circuit No. 2:		
14-in. Pipe	2.750	2.600
6-in. Pipe	0.255	0.390
Circuit No. 3:		
14-in. Pipe	-0.400	2.700
6-in. Pipe	0.255	0.395
<u>Secondary System (18-in. pipe)</u>		
Circuit No. 1	2.650	3.200
Circuit No. 2	2.830	3.050
Circuit No. 3	-	3.100

V. EXPERIMENTAL RESULTS AND ANALYSIS

A. RESULTS

The setback tests were performed as described in Section IV. Commentaries on the recordings are presented in this Section to provide accurate insight into the parameter responses following the setbacks and to document the data obtained. The information is divided into three subsections according to the type of setback. The commentaries include parameter steady-state values immediately prior to the test, as well as their values after level-off following the setback.

1. Manual Setback

a. Regulating Rod

In both the 50- and 75-Mwt tests the manual setback was executed with a 1.2-in. inward movement of the regulating rod over a period of 18 sec, corresponding to a displacement rate of 4 in./min. The initial position of the regulating rod was 7 and 7.4 in. for the 50- and 75-Mwt tests, respectively.

b. Shim Rod

Throughout the 50-Mwt test the shim rod position remained constant at 3 in., whereas in the 75-Mwt test the shim rod position was constant at about 3.6 in.

c. Neutron Flux

In the 50-Mwt test the initial value of the neutron flux, as read on the electrometer, was 1.32×10^{-5} amp (39.4 Mwt). As a result of the setback, the neutron flux reading decreased monotonically from the initial value to the final value of 0.78×10^{-5} amp (23.3 Mwt) in about 280 sec. In the 75-Mwt test, the initial flux reading was 2.1×10^{-5} amp (62.6 Mwt). Upon setback, the reading decreased to the final value of 1.2×10^{-5} amp (35.8 Mwt) in about 275 sec.

d. Core Outlet Temperature (TE-115)

At 50 Mwt, the initial reading of TE-115-9 was 650 F, and at 75 Mwt the reading was 656 F. Following the setback, the reading dropped to its level-off value in about 500 sec. The level-off value in the 50-Mwt test was 593 F, whereas in the 75-Mwt test the level-off value was 596 F.

e. Reactor Outlet Temperature (TE-201 and TE-217)

Leading up to the manual setback, TE-201-1 and TE-201-2 read 602 F at 50 Mwt. Following the setback, the readings dropped off monotonically toward the level-off value. After about 500 sec, TE-201-1 and TE-201-2 reached their level-off values of 572 F and 574 F, respectively.

At 75 Mwt, the readings of TE-201-2 and TE-201-3 were approximately 606 F. Upon setback, the readings dropped off monotonically, leveling off at about 576 F in approximately 500 sec.

A transport delay of about 15 sec was noted between the start of the setback and the beginning of the RTD responses.

In the 75-Mwt test TE-217-2 was recorded, but the response of the detector was exceedingly slow. The decay time for TE-217-2 from the initial value of 590 F to the level-off value of 564 F was about 1200 sec. The discrepancy in reading relative to TE-201-2 and slow response of the detector are attributed to poor seating of the thermocouple in its thermowell.

f. Reactor Inlet Temperature (TE-209)

At 50 Mwt, the reactor inlet temperature TE-209-2 was 529 F up to the instant of initiation of the setback. Following the setback, and after a transport delay of about 100 sec, the temperature dropped off monotonically to the final value of 524 F in about 630 sec.

At 75 Mwt, TE-209-2 was 512 F up to the instant of setback. Temperature drop-off began about 90 sec after initiation of the setback, with level-off at 510 F in 320 sec. The transport lag of the TE-209-2 response was approximately 140 sec.

g. Steam Generator Sodium Inlet Temperature (TE-308)

At 50 Mwt, after a transport delay of about 100 sec, TE-308-2 dropped off monotonically from 560 F to 542 F in 270 sec. At 75 Mwt, the drop-off was from 566 F to the final value of 542 F.

h. Steam Generator Sodium Outlet Temperature (TE-301)

The recorded trace of TE-301-2D2 exhibited a wide band having an amplitude of 10 F peak-to-peak, apparently due to a 60-cycle pickup. The sensor circuit was not operative, as no change in position was noted in the recorded trace following the setback.

i. Water-Steam Temperature (TE-601)

In both the 50- and the 75-Mwt tests the water-steam temperature TE-601-2 remained essentially constant at 534 F before and after the setback.

j. Feedwater Flow

In the 50-Mwt test, feedwater flow was not recorded. In the 75-Mwt test, the feedwater flow was about 0.96×10^5 lb/hr/loop up to the instant of initiation of the setback and to about 75 sec beyond this point. At 75 sec, the feedwater flow was cut to 0.92×10^5 lb/hr/loop, and finally, at about 450 sec, the flow was cut to 0.86×10^5 lb/hr/loop.

2. Power Setback

a. Regulating Rod

In the 50-Mwt test, the regulating rod position was held constant at + 5.2 in. up to the instant of start of the regulating rod withdrawal leading to the power setback. The regulating rod was withdrawn manually, to raise the power and initiate setback, from the + 5-in. position to the + 9.4-in. position in 75 sec. At the + 9.4-in. point, setback occurred, running the rod in a ramp function to the + 6-in. position in about 40 sec, corresponding to a rate of 5.8 in./min.

In the 75-Mwt test, the regulating rod was withdrawn at a relatively constant rate a distance of 1.6 in. over a period of 700 sec. The rod withdrawal rate then increased to obtain an additional 2.4-in. withdrawal in approximately 30 sec. Upon reaching this position, the power setback occurred, causing the rod to be driven inward a distance of 3.8 in. in 40 sec, corresponding to a rate of 5.70 in./min.

b. Shim Rod

Shim rod position in the 50-Mwt test was + 3 in., whereas in the 75-Mwt test the rod had a position of +3.6 in.

c. Neutron Flux

In the 50-Mwt test, as the regulating rod was being withdrawn toward initiation of the power setback, the electrometer reading increased from the initial value of 1.32×10^{-5} amp (39.4 Mwt) to 1.65×10^{-5} amp (49.2 Mwt), at which point the power setback occurred. Upon setback, the neutron flux diminished monotonically, with the final electrometer reading of 0.99×10^{-5} amp (29.5 Mwt) being reached in 385 sec.

In the 75-Mwt test, simultaneously with the withdrawal of the regulating rod over a period of 700 sec, the electrometer output increased from 1.2×10^{-5} amp (35.8 Mwt) to 1.8×10^{-5} amp (53.6 Mwt). At the 700-sec point, the neutron flux rose rapidly, and 30 sec later the electrometer output was 2.31×10^{-5} amp (69.0 Mwt). At this point the power setback occurred, causing the neutron flux to drop off monotonically, with level-off at 1.29×10^{-5} amp (38.5 Mwt) in 295 sec after occurrence of the peak.

d. Core Outlet Temperature (TE-115)

Simultaneously with the withdrawal of the regulating rod, leading up to the setback in the 50-Mwt test, the core outlet temperature TE-115-9 increased as a ramp function from 593 F to 671 F. After occurrence of the setback, TE-115-9 dropped off monotonically to the final value of 620 F in about 350 sec.

In the 75-Mwt test, TE-115-9 rose smoothly from 599 F to 638 F over a period of about 700 sec. At 638 F, TE-115-9 began a rapid rise, reaching 668 F in 30 sec. At this point the temperature began to decay, dropping to the final value of 605 F in about 350 sec.

e. Reactor Outlet Temperature (TE-201 and TE-217)

In the 50-Mwt test, TE-201-1D and TE-201-2D were recorded. Before the setback, the steady-state readings were 566 F and 572 F, respectively. In response to the rapid withdrawal of the regulating rod leading up to the power setback, TE-201-1D and TE-201-2D rose to 598 F and 604 F, respectively, in about 140 sec after start of the setback. After peaking at 140 sec, the reading dropped off to 582 F and 588 F, respectively, for TE-201-1D and TE-201-2D in about 360 sec.

Responses in the 75-Mwt test were as follows. Over a period of about 700 sec, TE-201-2 and TE-201-3 increased from about 576 F to 600 F. In response to the fast run-out of the regulating rod leading up to the setback, the readings of TE-201-2 and TE-201-3 peaked at about 612 F, approximately 35 sec after the peak in the electrometer (neutron flux) reading. Following the setback, TE-201-2 and TE-201-3 dropped off monotonically to about 580 F in about 380 sec.

Readings of detector TE-217-2, a thermocouple, were recorded along with TE-201-2 and TE-201-3 in the 75-Mwt test, but poor response was obtained, apparently because of poor thermal contact between the thermocouple and its thermowell.

f. Reactor Inlet Temperature (TE-209)

At 50 Mwt, the reactor inlet temperature was 523 F prior to movement of the regulating rod. In response to the rod withdrawal and the

ensuing setback, TE-209-2 peaked broadly at 529 F about 200 sec after the setback. Following the peak, TE-209-2 diminished monotonically to 525 F in 500 sec.

At 75 Mwt, TE-209-2 rose from 520 F and peaked broadly at 524 F about 95 sec after the peak in the neutron flux reading. Following the setback, TE-209-2 diminished smoothly to the final value of 520 F in about 450 sec after the peak in the neutron flux.

g. Steam Generator Sodium Inlet Temperature (TE-308)

In the 50-Mwt test, TE-308-2 increased slowly from 540 F to 560 F, with the latter being reached at the time the regulating rod withdrawal rate was increased to cause a power setback. About 95 sec after the peak in neutron flux, TE-308-2 peaked broadly at 564 F and then diminished smoothly to 544 F in about 340 sec.

At 75 Mwt, TE-308-2 first increased slowly from 542 F to 558 F, with the latter being reached at the instant of the power setback. About 95 sec after start of the setback, a slight rise to 562 F was noted, and the temperature diminished thereafter to a level-off value of 546 F in about 340 sec after the setback.

h. Steam Generator Outlet Temperature (TE-301)

As described under Section V-A-1-h, detector TE-301-2D2 was defective, and no readable signal was obtained in either test.

i. Water-Steam Temperature (TE-601)

In both tests, the reading of TE-601-2 was constant, with 520 F and 532 F being read for the 50-Mwt and the 75-Mwt tests, respectively.

j. Feedwater Flow

Feedwater flow was not recorded in the 50-Mwt test. In the 75-Mwt test, the recorded response was as follows. Up to the setback and about 230 sec beyond the instant of its initiation, the feedwater flow was constant at 0.9×10^5 lb/hr/loop. At the 230-sec point, the feedwater flow was reduced to 0.8×10^5 lb/hr/loop.

3. Temperature Setback

a. Regulating Rod

The steady-state position of the regulating rod in the 50-Mwt test was about + 7 in. In the approach to the setback, the regulating rod was

withdrawn approximately 1 in. over a period of 340 sec. Upon setback, the regulating rod was driven to the 3-in. position in approximately 60 sec, corresponding to a rate of 5 in./min.

In the 75-Mwt test, the regulating rod was first withdrawn from the + 5.6-in. position to the + 7.6-in. position over a period of approximately 2130 sec. At the 7.6-in. position, a temperature setback occurred, running the regulating rod back into the core a distance of 6.6 in. in a period of 80 sec, corresponding to a rate of 4.95 in./min.

b. Shim Rod

In the 50- and 75-Mwt tests, the shim rod position was left in a constant position at + 3.0 in. and + 3.7 in., respectively.

c. Neutron Flux

The electrometer reading during steady-state conditions at 50 Mwt was 1.32×10^{-5} amp (39.4 Mwt). Over about 350 sec, leading up to the setback, the neutron flux reading rose from 1.32×10^{-5} amp to 1.59×10^{-5} amp (47.5 Mwt), at which point the temperature setback occurred. In about 185 sec, the neutron flux decayed smoothly from 1.59×10^{-5} amp to the steady-state value of 0.45×10^{-5} amp (13.4 Mwt).

At 75 Mwt, the electrometer reading during the steady-state conditions leading up to the setback was 2.1×10^{-5} amp (62.6 Mwt). Over about 350 sec the electrometer reading increased from the steady-state value to 2.4×10^{-5} amp (71.5 Mwt), at which the temperature setback occurred. Upon occurrence of the setback, the electrometer reading dropped off rapidly, but smoothly, undershooting to 0.45×10^{-5} amp (13.5 Mwt) in about 200 sec and then rising and leveling off at 0.6×10^{-5} amp (17.8 Mwt) in about 330 sec.

d. Core Outlet Temperature (TE-115)

At 50 Mwt, over a period of about 350 sec leading up to the temperature setback, the core temperature TE-115-9 slowly rose to 677 F from the steady-state value of 650 F. Upon setback, the temperature dropped rapidly, but smoothly, from the 677 F maximum value to the level-off value of 575 F in about 225 sec.

In the 75-Mwt test, TE-115-9 rose over a period of approximately 210 sec from the steady-state value to 680 F, at which point the setback occurred. (The steady-state value was not determinable from the recording, as the temperature was already increasing when recording was begun.) Upon setback, TE-115-9 dropped rapidly, but smoothly, from 680 F to the level-off value of 560 F in about 200 sec.

e. Reactor Outlet Temperature (TE-201 and TE-217)

In the 50-Mwt test, TE-201-1D and TE-201-2D were at their steady-state value of approximately 598 F up to about 330 sec before the setback. Over a period of 330 sec the temperature rose from 600 F to 616 F, at which point the setback occurred, causing the detector readings to drop off smoothly to the final value of 566 F in about 220 sec.

At 75 Mwt, the TE-201-2 and TE-201-3 temperatures rose from approximately 600 F to 626 F as the regulating rod was withdrawn. Upon setback, the reading of TE-201-2 and TE-201-3 dropped off smoothly, reaching the final value of 554 F in 390 sec; the recording was terminated at this point.

Detector TE-217-2 was recorded during the 75-Mwt test, but as stated in Section III-A-1, this detector was unresponsive.

f. Reactor Inlet Temperature (TE-209)

An increase in TE-209-2 from 528 F to approximately 530 F was noted in the recorded trace at 50 Mwt, with the peak occurring about 110 sec after start of the setback. Level-off at 526 F was noted 150 sec after the peak readings.

In the 75-Mwt test, TE-209-2 decreased from 528 F to 515 F in 390 sec following start of the setback; at the 390-sec point the recording ended.

g. Steam Generator Sodium Inlet Temperature (TE-308)

At 50 Mwt, TE-308-2 increased from the steady-state value of 558 F to 566 F, the latter occurring about 90 sec after the setback. Beyond the peak, TE-308-2 dropped off to the final value of 550 F in about 245 sec after the start of the setback.

In the 75-Mwt test, TE-308-2 rose from about 570 F to 578 F, the latter occurring approximately 100 sec after start of the setback. After attaining the peak value, the temperature dropped off smoothly toward an unknown level-off value, reaching about 530 F in 340 sec, at which point the recording ended.

h. Steam Generator Sodium Outlet Temperature (TE-301)

As described under Section V-A-1-h, detector TE-301-2D2 was defective, and no readable signal was obtained in either the 50-Mwt or the 75-Mwt test.

i. Water-Steam Temperature (TE-601)

No change occurred in the recording of TE-601-2 in either the 50- or the 75-Mwt test.

j. Feedwater Flow

Feedwater flow was not recorded in the 50-Mwt test. In the 75-Mwt test, the feedwater flow was constant at 0.9×10^5 lb/hr/loop up to the setback and about 230 sec beyond its initiation. At the 230-sec point, the feedwater flow was slowly reduced, reaching 0.78×10^5 lb/hr/loop about 360 sec after initiation of the setback.

B. ANALYSIS

The approximate maximum transients and their time durations which occurred during the tests are listed in Table 3. These were determined by a cursory method of applying the following formula to determine the "actual" temperature change of a transient over an approximately straight segment of the temperature response recording.

$$\Delta T_s = \Delta T_t \left(\frac{T_1}{\Delta t} + 1 \right)$$

where,

ΔT_s = the "actual" temperature change, F

ΔT_t = measured temperature change, F

T_1 = time constant of the resistance change, sec

Δt = time duration of the temperature change, sec

To obtain the above expression, the time constants of the strip-chart recorder and signal processing circuit were considered to be zero.

1. Setback Responses

a. Manual Setback

The manual setback performed at each test power level consisted of one setback period. As read on the recorder chart, the setback duration was 18 sec and the regulating rod velocity was 5 in./min. These values, being somewhat lower than the nominal values of 20 sec and 5.35 in./min, are attributed to some extent to data reduction error; some of the difference may be due to the motor voltage setting of the setback circuit,

TABLE 3 - MAXIMUM THERMAL TRANSIENTS DERIVED
FROM RECORDINGS OF SETBACK AT
NOMINAL POWERS OF 50 Mwt AND 75 Mwt

<u>Parameter*</u>	<u>Nominal Power, Mwt</u>	<u>No. Coolant Circuits</u>	<u>Rate-of- Change, F/sec</u>	<u>Approx. Duration of Transient, sec</u>
(A) <u>MANUAL SETBACK</u>				
TE-201-1D	50	2	-0.19	80
TE-201-2D	50	2	-0.19	80
TE-209-2	50	2	-0.025	160
TE-308-2	50	2	<-0.10	60
TE-201-2	75	3	-0.26	70
TE-209-2	75	3	-0.025	160
TE-308-2	75	3	-0.10	100
(B) <u>POWER SETBACK</u>				
TE-201-1D	50	2	-0.12	50
TE-201-2D	50	2	-0.12	50
TE-209-2	50	2	<-0.01	50
TE-308-2	50	2	<-0.10	60
TE-201-2	75	3	-0.65	20
TE-209-2	75	3	<-0.01	50
TE-308-2	75	3	<-0.10	60
(C) <u>TEMPERATURE SETBACK</u>				
TE-201-1D	50	2	-0.35	85
TE-201-2D	50	2	-0.35	85
TE-209-2	50	2	-0.04	80
TE-308-2	50	2	-0.18	80
TE-201-2	75	3	-0.42	80
TE-209-2	75	3	-0.04	80
TE-308-2	75	3	-0.20	100

* No data for two detectors; TE-301-2D2 was inoperative
and TE-601-2 showed no perceptible change.

which is adjustable. Precise voltage setting, however, is not a critical requirement.

Setback action upon manual command was prompt, and movement of the regulating rod was smooth. The level-off power readings after setback were about 23.3 Mwt and 35.8 Mwt for the 50- and 75-Mwt tests, respectively. No sign of instability was noted in any of the principal plant parameters. Decays were monotonic for reactor outlet temperature (TE-201), reactor inlet temperature (TE-209), steam generator sodium inlet temperature (TE-308), and steam generator sodium outlet temperature (TE-301). The rate-of-change and duration of the thermal transients occurring in the manual setbacks at 50 and 75 Mwt are presented in Table 3(A).

While reasonably good correlation between the inserted negative reactivity and the power coefficient has been obtained for the 50-Mwt test, poor correlation is noted for the data of the 75-Mwt test. The latter case is attributed to incorrect recorder scaling of the channel in which the rod position was recorded. The cause of the scaling error is unknown.

b. Power Setback

Each setback action consisted of two periods having a duration of 40 sec in the power setbacks executed at 50 Mwt and 75 Mwt.

In the 50-Mwt test, reactor power was raised to 49.2 Mwt to obtain the setback. As a result of the setback, reactor power was reduced to approximately 29.5 Mwt.

In the 75-Mwt test, reactor power was raised to 69 Mwt to initiate the setback. The result of the setback was a reduction of reactor power from that level to approximately 38.5 Mwt.

As in the case of the manual setbacks, no instability was noted in any of the plant parameters as a result of the power-produced setbacks. Decay of the TE-201, TE-209, TE-308, and TE-301 temperatures was monotonic. The rate-of-change and duration of the thermal transients which occurred in the power setback tests are presented in Table 3(B).

Poor correlation is noted between the inserted negative reactivity and the power coefficient in the data of the power setback tests. As stated in Section V-B-1-a above, the poor correlation is attributed to incorrect recorder scaling.

c. Temperature Setback

In the temperature setbacks, a three-period setback having a duration of 60 sec was obtained in the 50-Mwt test and a four-period setback having a duration of 80 sec was obtained in the 75-Mwt test.

To perform the 50-Mwt test, reactor power was advanced from 39.4 Mwt to approximately 47.5 Mwt to obtain the setback, producing an increase in TE-201-1 and TE-201-2 readings from 600 F to 616 F. Following the setback, the temperature dropped monotonically to 566 F.

In the 75-Mwt test, reactor power was advanced from 62.6 Mwt to approximately 71.5 Mwt to obtain the setback, producing an increase in TE-201-1 and TE-201-2 readings from somewhat over 600 F to 626 F. Following the setback, the temperature dropped off to 554 F.

As in the manual and power setback tests, no instability was noted in any of the plant parameters as a result of the temperature incurred setbacks. Decay of the TE-201, TE-209, TE-308, and TE-301 temperatures was monotonic. The rate-of-change and duration of the thermal transients which occurred in the temperature setback tests are presented in Table 3(C).

Poor correlation is noted between the inserted negative reactivity and the power coefficient in the data of the 50-Mwt temperature setback test. As stated in Section V-B-1-a, this result is attributed to incorrect recorder scaling.

VI. CONCLUSIONS

The setback tests have demonstrated fast response of the setback control circuit and smooth regulating rod operation. In the power and temperature setbacks where two or more basic setback periods were incurred, the setback actions were essentially consecutive, i. e., no significant interruption of regulating rod motion over the total period was observed. Transients in the principal plant control parameters resulting from the setbacks were well below tolerance limits and no operating instability was encountered. No spurious scrams were experienced as a result of setback action. In view of the satisfactory setback circuit operation and the moderate level of the temperature transients demonstrated by the setback tests, protective system performance at higher reactor power levels is expected to be in accordance with established performance requirements.

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