EOCR CONTROL ROD AND DRIVER FUEL
HYDRAULIC TESTS

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Further information on the EOCR, its core and control rods is contained in:

IDO-16820, "Experimental Organic Cooled Reactor Safety Analysis Report", G. H. Hanson, General Editor and Coordinator. (In press - December 1962),

and in internal reports and drawings of the Fluor Corporation and Atomics International. Of these the following are available through the usual channels:

NAA-SR-Memo 5514, "Structural Analysis of the Fuel Element Box and Fuel Plates".

NAA-SR-Memo 5373, "Thermal-Hydraulic Analysis of the EOCR Core".

Drawing 5942-EOCR-601-MS-22, "Control Rod Drive Assembly - EOCR".

Drawing 5942-EOCR-601-MS-26, "Control Rod Assembly - EOCR".

Drawing 5942-EOCR-601-MS-27, "Driver Fuel Assembly".

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L. J. Harrison

S U M M A R Y

The EOCR prototype control rod, control rod drive and driver fuel assembly were extensively tested in 500°F Santowax and 132°F water. These tests not only established the operating characteristics of these assemblies but also revealed a number of deficiencies in the various components. The modifications required were tested to establish the satisfactory performance of the modified components.

Flow versus pressure differential measurements were performed on the driver fuel and the control rod. These measurements were also performed on various sized orifices in both assemblies to facilitate final orifice sizing when the final physics and heat transfer calculations have been completed.

Scram insertion time curves were obtained for a variety of control rod configurations and test conditions. These curves not only established the scram insertion reliability of the control rod but also provided the basis for performing a control rod force analysis.

Included in this report are descriptions of the control rod, control rod drive and driver fuel assembly together with descriptions of their method of operation.

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I. Introduction

The Experimental Organic Cooled Reactor incorporates a number of unique design features. Some of the features are included in the control rods, the control rod drives, and the driver fuel assemblies. To establish the operational characteristics and the operational reliability of these components, a hydraulic test facility was designed and constructed at NRTS Central Facilities.

The basis for the design of the EOCR Hydraulic Test Facility was the simulation of the conditions at which these three components would operate. To this end the component test vessel is in essence a twelve in. diameter section of the reactor pressure vessel centered on either a control rod or a driver fuel assembly position, extending from above the control rod drive to below the bottom head. In this vessel all of the mechanical and hydrodynamic characteristics of the reactor are duplicated. This includes the location and size of the grid plate, spiders and vessel heads, the direction of flow, the physical properties of the test media, etc. The test components themselves were built in accordance with the design of the reactor components.

Approximately one half of the test program was completed using Santowax as the test medium with water being the test medium for the remaining tests. Upon completion of these tests, the original test facility was dismantled with all of the loop components other than the piping and the surge tank being reused in a new facility. This facility, which is being built adjacent to the reactor, will use Santowax as the medium to test components, experimental and production, which are to be inserted into the reactor.

II. Description

A. Main Test Loop

1. General Description

The test facility is located in Building 656 at the NRTS Central Facilities and occupies the northwest section of this building; Fig 1 presents a flow diagram of the test facility. Below is a brief description of the main test loop followed by a detailed description of the various loop components.

The circulating pump discharge line divides into two lines with one line going to the loop cooler and the other line going to the loop heater. A pressure relief valve located on the heater inlet line discharges into an atmospheric, unheated relief tank. The discharge lines of these two units join to form the test vessel inlet line. This line is connected to the surge and storage tank via secondary piping. The test vessel outlet line returns to the circulating pump suction with the flow metering orifice plate in this section of line. The surge and storage tank is connected to the pump suction via secondary piping.

2. Circulating Pump

The test facility circulating pump is a single-stage vertically-split centrifugal refinery pump with a cantilevered impeller and a capacity of 1,200 gpm at 200 ft TDH. The bearing box, stuffing box and frame are water cooled. A double row of packing is used with a lantern ring between each row. Each row of packing has lead covered packing on the outside with graphite impregnated asbestos packing in the middle. The pump is driven by a 100 hp, 440 volt motor at 1,800 rpm.

Fig 1 EOC

3. Heater

The loop heater, which is located outside the west wall of the building, is an oil-fired 350,000 BTU/hr unit of the vertical, circular, all-radiant type. The radiant coil consists of eight passes of vertical 6 in. tubes connected at the top and bottom by welded 180° return bends. The bottom return bends rest in cast saddle-type supports which are designed to distribute the stress uniformly throughout the return bends; the weight of the coils is thus carried on the heater floor. The refractory on the walls and floor is cast in place, without joints, being supported by special V-shaped anchor clips securely welded to the heater shell. The heater controls are automatic with a manual pilot. The upper-limit setpoints are on high tube-wall temperature and high organic discharge temperature.

4. Cooler

The loop cooler has a natural convection cooling capacity of 250,000 BTU/hr and a design rating of 450 psig at 650°F. The cooler is located on the outside west wall of the building with 8 in. valves for inlet and outlet service. The inlet valve is a globe valve through which manual control of the flow rate is exercised. The cooler is made up of six 3 in. fintubes 6 ft long with 357 sq ft of cooling area per tube; these tubes are manifolded at both ends. The cooler is equipped with a drain line and a nitrogen purging system.

5. Test Vessel

The control-rod test vessel is a 32 ft long section of 12 in. nominal diameter extra strong seamless carbon steel pipe which is ASME certified for 400 psig service at 850°F. Fig 2 shows a sectional view of the test vessel with the control rod and control rod drive-unit

at the rod zero position. The vessel extends from above the roof of the building down into a pit below the floor level. It has 8 in. 600 lb flanges for inlet and outlet connections and machined face top and bottom flanges for ring-type joint heads. The top and bottom heads are of the same material and thickness as EOCR vessel heads. The top head is $14 \frac{5}{8}$ in. thick with a 4.005 in. hole drilled through the center for rod-drive unit installation. The drive is housed in a cupola located on top of the building. The bottom head is $9 \frac{5}{8}$ in. thick with a 1.754 in. hole in the center for the seat switch push-rod bellows and seal assembly.

The heavy arrows in Fig 2 indicate the flow path of the test medium. The test medium enters the vessel below the grid plate, flows downward and makes a 180° turn through the boot orifices. It then flows up through the fuel and poison sections and out the slots located in the poison section above the poison plates. A very small amount of the test medium leaks past the aluminum-bronze seal shoes and flows upward between the boot and fuel section. The test medium then flows upward through the test vessel and exits through the nozzle located near the upper end of the test vessel.

The control rod assembly is supported in the test vessel by a grid plate of the same thickness as the EOCR grid plate. The assembly is centered by the two spiders, one radially adjustable and the other stationary, which are connected to the grid plate by four tie rods. The grid plate bolts to a grid support platform which is welded to the inside of the test vessel. The grid plate has the boot bolted to it and the snubber is screwed into the lower end of the boot. The grid plate hold-down bolts are tightened by a 20 ft long Allen wrench

which is inserted and withdrawn by means of a mobile crane. This same crane is used to remove and install the complete rod assembly or only the control rod portion.

Referring to Fig 2 again for a detailed view of the test vessel components, the boot, bolted to the grid plate, is a guide for the fuel section. Also it directs the test medium flow through the orifices and into the fuel section. The fuel section is bolted to the poison section which is screwed onto the control rod guide tube. Screwed into the guide tube is the latch extension which contains the scram spring and the latch hook.

The control rod drive unit is bolted to the top head and the seal tube and latch extend down through the head into the test medium to make contact with the latch hook. The seal tube contains a push rod connected to the armature of the magnet for the latching and releasing of the rod from the latch mechanism. The magnet carriage is raised and lowered by means of two Acme screws which are driven through a gear train by the drive motor.

6. Surge Tank

The surge and storage tank for the test facility is a 117 cu ft capacity horizontal tank rated at 400 psi at 550^oF by ASME code. It is used to store the test medium while the system is shutdown and as a pressure surge absorber while the system is running. The surge tank is also used for charging new Santowax into the system and for pressurizing the system while operating. Nichrome wire heaters cover the outside of the tank and three (30 KW each) electric immersion type heaters are used for heating the organic prior to filling the system. Three thermo-

couples, one installed in a thermowell and two attached to the vessel shell are used for temperature indication. The rupture disk mounted on top of the surge tank is vented to the atmosphere above the roof. All system drain lines enter the surge tank through a manifold system at the top and the tank is vented to atmosphere by opening a manual vent-valve or a motor operated valve in the vent line. A 4 in. valve on the bottom of the test vessel is used for filling the test loop and remains open for pressure surge absorption. Another 4 in. valve in the secondary piping permits circulation through the surge tank with or without the test vessel isolated.

7. Instrumentation

a. Flow

The test loop flow rate is measured by an orifice plate in a horizontal run of 8 in. pipe with straight pipe for fifteen diameters upstream and nine diameters downstream of the plate. The orifice is square-edged and installed between flange-tap orifice flanges. Impulse lines run from the flange taps to a differential pressure cell with a pneumatic output of 3-15 psi for a 0-100 in. water differential across the orifice. The pneumatic signal is sent simultaneously to a mercury manometer and a transducer which transmits a signal to an electronic recorder for visual control and recording. A thermostatically controlled electric capsule heater (200 watts) is cemented to the d/p cell body to keep its temperature above 325°F. Steam tracing, Thermon heat transfer cement and insulation cover all the Santowax filled impulse lines to maintain fluid conditions.

b. Temperature

System temperatures are measured using iron-constant-an thermocouples and are recorded on a 24 point electronic recorder. Eight of the thermocouples are mounted in thermowells with the balance of the 42 thermocouples fastened to the system piping by welding or by use of Thermon heat transfer cement. The temperature of the test medium was manually controlled with the alarm setpoint on the recorder 100°F above the test temperature.

c. Level

A pressure differential system for measuring the surge tank level was initially installed but due to deficiencies failed to operate properly and was removed from service. The system had two pipes going into the top of the surge tank, one ending just inside the top of the tank while the other ran to the bottom of the tank. Nitrogen flowed through each leg at a pressure which maintained the same flow through both legs. The differential between the inlet pressures in the two legs was measured by pneumatic output differential pressure cell. The cell output was converted to an electrical signal by a transducer and an electronic recorder converted this signal to a height of water reading. This reading was converted to the volume of Santowax in the tank.

A capacitance probe was used for the last portion of the Santowax tests. The capacitance of the probe was a function of the height of the Santowax on the probe. The capacitance was electronically converted to inches of Santowax in the tank.

During the water tests a gage glass is used for the surge tank level indication.

d. Pressure

The test loop pressure is maintained by the surge tank pressure. The surge tank is manually pressurized to 100 psig. This is the approximate reactor outlet pressure and, since the surge tank is connected to the test vessel outlet, this is also the test vessel outlet pressure. The inlet pressure is a function of the flow rate through the vessel and the particular unit being tested.

The surge tank pressure is measured by a pressure gage mounted on the top of the tank and an electronic output sensing element which is connected to a pressure recorder. The recorder is in turn electronically connected to a motor operated valve which opens when the pressure reaches the setpoint. This unit was installed to be compatible with the nitrogen-purge level system which continually bled nitrogen into the surge tank.

Pressure gages are mounted on the system to read the pump suction and discharge pressures and the test vessel inlet and outlet pressures.

e. Control Rod Drive Console

The control rod drive console contains all the instrumentation for the control rod and drive. A Veeder-root digital read-out unit gives the position of the drive unit in hundredths of an inch. The Veeder-root unit is driven off the top of one of the Acme screws in the drive. At this location the mechanical motion is converted to electrical signals. The magnet contact light indicates whether or not the control rod is latched to the drive unit. The console also contains indicating lights for the upper limit, lower limit and rod zero positions.

The rod drive is raised and lowered with a three-way, pistol grip, spring return switch. Raise and lower lights indicate the direction of rod travel. An ammeter shows the motor current.

The magnet power is supplied by a transistorized power supply which has a 0 to 50 volt range. The magnet power is cut off either by pushing the scram button or by shutting off the power supply. An ammeter and voltmeter indicate the magnet operating power.

A key switch shuts off all the power to the console.

f. Scram Circuit

The scram circuit used during the control rod testing is identical to the magnet switch circuit designed for the reactor. Referring to Fig 3, the circuit contains four main transistors, Q_1 , Q_2 , Q_3 , and Q_4 . Transistors Q_1 and Q_2 pass the magnet current, and transistors Q_3 and Q_4 are used to actuate the magnet-current cutoff.

Transistors Q_3 and Q_4 are held in cutoff by the application of +25 volts to their bases, while transistors Q_1 and Q_2 are held in saturation by the application of -25 volts to their bases. In the saturated state, transistors Q_1 and Q_2 will conduct the magnet current necessary to hold the control rod.

When scram switch SW1 is pushed, the bases of transistors Q_3 and Q_4 go negative, driving Q_3 and Q_4 into saturation, which raises the voltage on the base of transistors Q_1 and Q_2 to +25 volts and drives them to cut off. When transistors Q_1 and Q_2 are cut off they no longer conduct the magnet current, and the magnet releases the armature which, in turn, releases the control rod from the drive.

Fig 3 Scram Circuit

The counter emf produced by the collapsing field of the magnet is shunted through diode CR3 which is connected across the magnet coil. Diodes CR1 and CR2 protect transistors Q_1 and Q_2 from reverse voltage.

B. Test Loop Auxiliary Systems

1. Seal Coolant System

Pressurized water in a closed loop is used to cool the nozzle assembly of the control rod drive immediately above the top head. A 3 hp motor drives a water-cooled turbine pump to deliver water at 5 gph to the seal area. The seal coolant cooler, a heat exchanger, is used to cool the water returning from the seal or to preheat the water to 250°F. This is the temperature of the boiler feed water which is to be used in EOCR for

seal cooling. The seal coolant surge tank was used as a working reservoir and to pressure the system to 30 psig at the pump suction.

2. Nitrogen Systems

There are three nitrogen systems associated with the test facility which are used for pressurizing and purging various loop components. These systems were: (1) the seal coolant surge tank pressurizing system, (2) the test loop surge tank pressurizing system (3) the test loop purge system. Standard 220 scf nitrogen bottles are used as the nitrogen supply and the pressure regulators are conventional manually set units.

The test loop nitrogen purge system is used to force the organic out of the various sections of loop piping into the surge tank via the organic drain lines when the loop is shut down. The various branches of the nitrogen purge system entered the main loop piping through double block and bleed valve clusters.

3. Organic Drain System

At the end of each test program all organic is drained into the surge tank for storage. Drain lines of 1/2 in. schedule 80 iron pipe are used to connect various sections in the test system to the surge tank. These drain lines are steam traced and insulated with 1 1/2 in. preformed insulation to prevent freezing of organic in the lines. Valves at both ends of the drain lines were opened and nitrogen pressure of 200 to 300 psi was applied in the proper section of the test system. The operator listens to the flow of organic through the manifold at the entrance to the surge tank. When organic stops flowing, both ends of the drain line are shut off and a new line from some other part of the system is opened.

After the draining of the system is completed the valve on the bottom of the test vessel is opened to check for complete drainage.

4. Steam Generator and Tracing System

All of the main loop piping, secondary piping, pressure impulse lines, drain lines and vent lines associated with the test facility are steam traced with high pressure steam supplied by a portable generating unit. This unit is rated at 15 boiler horsepower and supplies 150 psig steam. The oil fired steam generator is placed in service prior to loop startup to preheat all of the loop piping. The pressure in the receiver automatically controls the generator operation to maintain the temperature of the steam trace lines at 365°F during loop operation.

The steam trace lines are 1/4 in. iron and copper tubing strapped to the lines. Thermon heat transfer cement and insulation cover all the lines. The condensate is pumped back to the steam generator hot well.

C. Test Data Instrumentation

1. Flow Versus Pressure Differential

The test data flow rates are measured with the orifice in the main piping. During the water tests this system is supplemented by a manometer filled with 2.95 sp.gr. oil. This manometer is connected to a separate set of taps in the orifice flange. The readings of the two flow measurement systems are compared throughout the test programs to assure proper flow rate measurement.

The pressure differentials across the various test components are obtained in the following manner: hypodermic pressure impulse lines are attached to the test piece at the points of interest. These lines are brought out of the test vessel through Conax fittings in the

high pressure couplings at the top and bottom of the test vessel. Fig 2 presents several typical pressure impulse lines. Outside the test vessel the hypodermic tubing is connected to lines in one of the two bundles of stream-traced and insulated lines which run between the test vessel and the special heated differential pressure panel. A total of 12 high pressure and 12 low pressure lines are available. Inside the panel the impulse lines are connected to either a high pressure or a low pressure manifold through a double block and bleed valve cluster. The pressure differentials are then read on one of two direct reading differential pressure cells which are connected to the manifolds. The ranges of the cells are 0 to 15 psi and 0 to 50 psi. Thermostatically controlled capsule heaters maintain the cells at 325°F.

All of the valves in the differential pressure panel are installed in double block and bleed clusters. Each bleed valve is connected to a drain manifold so that all sections of piping in the panel as well as the pressure impulse lines can be purged of any trapped gas.

Two finned, thermostatically controlled, electric heaters together with two steam lines maintain the temperature of all the piping at approximately 325°F to prevent freezing of the Santowax. The outside covering of the differential pressure panel is rigid insulation.

Nitrogen purge lines are connected to each manifold to purge the Santowax from any or all of the lines if desired.

2. Rod Position Indicator System

The control-rod-position versus time-after-scram is determined utilizing two frequency-modulated, high-temperature coils mounted on the outer poles of a common "E"-shaped core. The two coils are parts of a bridge circuit and form two arms of the circuit.

The coil assembly is mounted on an adapter and inserted in a thimble which is mounted in a test vessel nozzle. Fig 4 presents a pictorial view of this system. The thimble faces an armature strip which is mounted on the poison section of the control rod. The one inch wide stainless steel armature strip has a row of $3/16$ in. square mild steel buttons mounted flush on each outside edge, with the buttons in each row set on one inch centers and the two rows offset one-half inch; each row of buttons faces one of the two coils. As the control rod moves, a mild steel button replaces the stainless steel in front of one of the coils, changing both the coil reluctance and the coil current. The coils are wired into the bridge circuit such that the current change in one coil increases the circuit current while the change in the current in the other coil decreases the circuit current. A trace of the current passing through the bridge circuit is then made on a Visicorder strip chart; Fig 5 presents a typical Visicorder chart. The current trace

Fig 4 Pictorial View of "E" Core

Fig 5 Typical Visicorder Chart

obtained when the rod is moving approximates a sine wave with 360° of the cycle representing one in. of rod travel.

On the Visicorder chart there are other traces which indicate when the scram button is pushed and released, when the magnet contact switch is opened, and when the seat switch is actuated. Parallel to all of these traces is a 60 cps sine-wave trace which is used to determine the various time intervals. The data provided by these traces give a complete time history of an EOCR Test Facility scram.

The Visicorder chart presented in Fig 5 shows a magnet release time of 40 milliseconds and a 9 in. scram insertion accomplished in 265 milliseconds.

D. Special Test Equipment

1. Latch Test Facility

The special latch test facility is located in a small temporary building outside the main building. This building contains a stand on which the drive unit is mounted and a small pit in which the latch test weight container travels. A special control box located in the building is wired into the drive circuit so that the drive can be raised or lowered and the latch mechanism engaged and scrambled from the site of the latch tests. Fig 6 presents a view of the test facility.

The test vessel is a 12 in. section of 12 in. pipe which is filled with the desired test medium. Three thermostatically controlled immersion heaters maintain the test medium at the desired temperature; insulation covers the test vessel during high temperature tests. During certain tests particulate matter is added to the test medium with a motor driven stirrer used to maintain uniform particulate concentration throughout the test medium. The latch hook to be tested is screwed

Fig 6 Special Latch Test Facility

into the bottom of the test vessel and the latch test weight is bolted to the bottom of the test vessel. The latch test weight can be varied from 86 to 885 lbs using lead shot and lead bricks as weight. During an actual test, the test vessel and weight is latched to the drive, raised approximately one inch and then scrambled. Using this procedure the entire latch mechanism remains immersed in the test medium.

2. Magnet Test Facility

A special magnet-test facility was built to test the holding power of the magnet at various conditions, with the magnet separated from the drive. Fig 7 presents a view of this facility. The magnet, either with or without the carriage, is mounted on a platform suspended from a crane. Various combinations of carriage material, air gap and radial location of the armature in the magnet have been tested. The desired test weights are added to measure the magnet pick up and drop off current. The same magnet power supply is used for these tests as is used in the control rod drive console at the test facility.

3. Scram Spring Calibration Assembly

An assembly was fabricated to determine the spring constant of the scram spring. The assembly consisted of a weight platform mounted on a cylinder which mates with the top of the scram spring cage. This calibration unit is used in conjunction with the scram spring assembled into the control rod and latch hook extension.

E. Control Rod

1. General Description

The EOCR control rod assembly is made up of four subassemblies which are mechanically joined together and held in place by lock washers. Starting at the upper end of the rod these subassemblies are:

Fig 7 Special Magnet Test Facility

(1) the control rod and latch extension, (2) the guide tube, (3) the poison section, and (4) the fuel section which is occasionally referred to as the fuel follower. Fig 8 presents drawings of these four subassemblies.

The latch and rod extension assembly is a 4 in. diameter cylindrical section 57 in. in length containing the scram spring and the latch hook. The upper end of the scram spring cage, the unit extending out the top of the rod extension, mates with the lower end of the drive unit. The Acme thread joint on the lower end of this assembly screws into the guide tube.

The guide tube is a 4 in. O.D. and 3 in. I.D. tube which is 90 in. in length. Its upper and lower ends have right and left hand Acme threads respectively which screw into the latch extension and the poison section respectively.

The poison section, with a round-to-square transition as its upper end, is a 4 in. square stainless steel box with the poison plates riveted to the inside of the box. A tie-bolt running through the center of the poison section screws into a spider-nut on top of the fuel section.

The fuel plates are housed inside a 4 in. square stainless steel box. The snubbing of the control rod after a scram is accomplished by the snubber piston, attached to the lower end of the fuel section, entering the snubber cylinder. Positive stopping of the control rod is accomplished by the stop ring on the snubber piston. The fuel section travels inside of a guide boot with a clearance of 0.062 in. on all four sides. Fixed seal shoes located on the lower end of the fuel section prevent excessive leakage of organic through this annulus.

EOCR CONTROL ROD SUBASSEMBLIES

Fig 8 Control Rod Subassemblies

Fig. 9 presents a foreshortened view of the control rod assembly together with the guide boot, snubber piston and seat switch push rod assembly. The flange on the upper end of the boot bolts to the grid plate and the lower end of the boot contains the inlet orifices. These orifices are sized to provide adequate but not excessive coolant flow through the individual control rods. The snubber cylinder, which is screwed into the bottom of the boot, terminates in an extension which reaches down to the reactor bottom head and houses the seat-switch push-rod. This extension terminates in the seat-switch seal bellows shroud; there is a 1/2 in. gap between this shroud and the bottom head. When the control rod is seated on the stop ring, the snubber piston has actuated the seat-switch via the seat-switch push rod which acts through the seal bellows. The seat-switch is located on the bottom of the reactor bottom head. Fig 10 presents a sectional view of the bottom head seal plug assembly.

2. Scram Spring

The EOCR control rod scram spring is made of 88 coils of 0.312 in. diameter Inconel X wire with the coil having an O.D. of 3.062 in. and an I.D. of 2.438 in. Its free length is 60 in., its maximum working length is 48 in. and its minimum working length is 30 in. The design spring rate is 6.00 lbs per in. at 850°F and 7.66 lbs per in. at 70°F. At reactor operating conditions the cocked spring will have a force of approximately 200 lbs. The lower end of the scram spring pushes against the lower end of the latch hook extension and the upper end of the scram spring pushed against the scram spring cage. The top of the scram spring cage pushes against the latch cam retainer, the lowest component

Fig 9 Control Rod and Boot Assembly

BOTTOM HEAD SEAL PLUG ASSEMBLY

Fig 10 Bottom Head Seal Plug Assembly

of the drive mechanism, when the control rod is latched to or within 18 in. of the drive. When the control rod is scrammed, the spring expands 18 in. before the cage separates from the drive unit and moves as an integral part of the control rod.

3. Poison Section

The EOCR control rod poison section, which has an overall length of 77.25 in. and an active length of 37.75 in., contains not only the poison plates but also the coolant outlet slots. The four outlet slots, 2 in. by 10 in., are located immediately above the poison plates with an inverted pyramidal flow deflector located above the slots. The 1/4 in. thick poison plates have a stainless steel covering over the two major sides of a boron-stainless matrix; the matrix contains one per cent boron-10. The prototype poison section contains dummy poison plates made of stainless steel. The poison plates are riveted to the stainless steel box at three elevations with a 0.100 in. gap between the plates and the box for coolant flow. The lower ends of the poison plates are undercut and extend below the bottom of the poison section box into the top of the fuel section box to decrease neutron flux peaking in this region. Fig 11 presents a detailed view of the poison and fuel sections.

4. Fuel Section

The EOCR control rod fuel section which has an overall length of 72.3 in. including the snubber piston, contains 26 fuel plates 38.500 by 3.488 by 0.030 in. Each plate has a 0.005 in. cladding over a 0.020 in. thick UO_2 -stainless steel cermet matrix which is 36 in. long. The prototype fuel sections contain dummy fuel plates made of stainless steel. The plates are free to accomodate thermal expansion in all three

Fig 11 Control Rod Poison and Fuel Section Details

dimensions and guided by slots in the side plates and by the spacer combs located at the upper and lower ends of the plates. The plates are held in place in the stainless steel box by retainer bars which are attached to the insides of the side plates. A cellular web plate runs through the center of the fuel section parallel to the fuel plates and is plug welded to the side plates of the assembly to strengthen the assembly.

The snubber piston screws into a lenticular brace near the lower end of the fuel section and is guided by a second lenticular brace at the lower end of the section.

5. Snubber Piston and Cylinder

The 24 1/4 in. long stainless steel snubber piston extends 15 1/4 in. below the lower end of the fuel section enclosure box with a plug welded retaining pin preventing the piston from unscrewing. The first 3/4 in. on the lower end of the piston is chamfered at a 15° angle. The next 7.225 in. of the piston is very slightly tapered with the minor diameter, adjacent to the taper, being 1.235 in. and the major diameter being 1.250 in. The remaining 3.025 in. below the stop ring has a diameter of 1.250 in. When the control rod assembly is seated it is supported by the 3/4 x 2 1/8 in. diameter stop ring which rests on top of the snubber cylinder. Fig 12 presents a view of the snubber piston and cylinder with the rod in the seated position.

The snubber cylinder is essentially a 12 x 2 in. cylinder with a 1.255 in. diameter opening at the upper end of the cylinder. The face of this opening is made of stellite to reduce the wear on the opening. As the snubber piston enters the cylinder, the fluid in the cylinder is forced out through the narrow annulus between the piston and the cylinder opening. The energy required to force the fluid out of the cylinder

Fig 12 Control Rod Snubber Piston and Cylinder

is supplied by the kinetic energy of the rod resulting in the rod slowing down significantly before the stop ring seats.

F. Control Rod Drive

1. General Description

The EOCR control rod drive mechanism consists of an 8 in. diameter, in-line, double Acme screw mechanism which positions the control rod through a high-temperature sliding seal. Fig 13 presents a fore-shortened view of the drive mechanism. The ball detent latch mechanism, located on the organic side of the seal, holds the control rod against a cocked scram spring. The control rod is released by cutting off the current to the magnet which in turn releases the latch.

At the upper end of the drive is a service plate in which four amphenol connectors are mounted. The drive motor power and the various instrumentation signals are transmitted through these connectors from the drive to the control rod drive console. Immediately below the service plate is the drive motor and speed reducing gears unit which is mounted on the upper end of the housing which encloses and supports the drive mechanism.

Between the drive mechanism and the reactor is the nozzle assembly which contains the high temperature sliding seal assembly and cooling coils. Fig 14 presents a sectional view of the nozzle assembly. The seal is made up of two sets of Inconel-asbestos packing with a lantern ring between the two sets. A seal drain is provided for the organic which leaks through the first set of packing. If desired, the lantern ring could be pressurized with nitrogen to decrease the leakage rate. The cooling coils are located on the outside of the nozzle assembly in the seal area. Other reactor seals associated with the drive are the latch

Fig 13 Control Rod Drive Assembly

NOZZLE ASSEMBLY

Fig 14 Control Rod Drive Nozzle Assembly

seal bellows, the soft iron gasket between the nozzle mounting flange and the top head, and the silicone rubber "O" ring between the lower seal retainer and the nozzle.

2. Drive Mechanism and Housing

The mechanism is driven by a 1/6 hp, three phase, induction, 860 rpm, 440 volt motor with an integral magnetic-release spring-setting brake and a 34:1 gear reducer. The output shaft of the gear reducer is connected to a center drive gear by a socket coupling. This center gear drives and synchronizes the two Acme screws through drive pinion gears attached to the top of the Acme screws. A Veeder-root remote digital readout unit is operated off the top of one Acme screw in the eight control rod drives. This unit is supplemented by a potentiometer operating off the top of the other Acme screw in the four regulating rod drives.

The rotary motion of the Acme screws is converted into vertical motion by the aluminum-bronze Acme nuts which are mounted on the bottom of the carriage. The resultant vertical speed of the drive, both insertion and withdrawal, is 6.6 in. per minute. Also mounted on the bottom of the carriage is the seal tube which carries 73 per cent of the latch hook load; the other 27 per cent is carried by the armature push rod. The Acme screws are hung from double row angular-contact bearings which are mounted in the upper bearing plate. Radial bearings mounted in the lower bearing plate maintain the Acme screw alignment. The upper and lower bearing plates are both mounted on the drive housing; the alignment of the entire mechanism is provided by this housing. Four access plates, two opposite each screw at the upper and lower ends of the housing, are provided for inspection and maintenance.

The housing also supports the push rods for the upper-limit and the rod-zero-limit switches. On each threaded push rod is a stop-nut

which is actuated by the carriage. Located on the upper and lower ends of the respective push rods are cams which actuate the limit switches. Continuous adjustment over the 24 in. range provided on each limit switch push rod is accomplished by removing a locking screw or bracket and turning a knob on the end of the push rod.

Each switch station consists of two hermetically sealed micro-switches which operate off a common leaf actuator. By connecting the two switches in series, switch failure protection is provided; by connecting the two switches independently, two different control functions are provided at different voltages if desired.

3. Magnet

The EOCR control rod drive magnet, 3.875 in. in diameter by 7.663 in. long, is mounted on the carriage with the armature captive between the magnet and carriage. Fig 15 presents a view of the magnet mounted on the carriage. The magnet coil is made of 2,452 turns of No. 19 wire on a slotted, mild steel bobbin. The bobbin, as well as the magnet core and the armature shaft, are slotted to affect minimum hysteresis when the magnet current is cut off and the armature is released. The magnet core, 1.50 in. in diameter, is fixed in position and extends through the top 5 in. of the center of the bobbin. The armature is made up of two concentric cylindrical sections one of which is 0.625 in. long with the same diameter as the magnet body and the other cylinder is approximately 2.2 in. long with the same diameter as the magnet core; this latter cylindrical section travels inside the bobbin. An air gap of 0.003 in. exists between the magnet core and the armature shaft. The large diameter section of the armature seats against the face of the magnet when the control is latched to the drive.

Fig 15 Control Rod Drive Magnet Assembly

Upon cutting off the magnet current, the armature drops 0.300 in. away from the magnet. The armature is prevented from dropping further by a shim between the armature and the carriage. The push rod is attached to the armature thus it falls as an integral unit with the armature resulting in the latch mechanism releasing the control rod.

The magnet contact switch, which is mounted on top of the magnet, is actuated by a small push rod which runs through the magnet core and operates off the armature. This switch is identical to the other micro switches in that the switch station consists of two switches operating off a common leaf actuator. The two switches can be wired in series or in parallel.

The carriage is made of carbon steel with an aluminum-bronze sleeve lining the magnet cavity. This sleeve is to prevent shunting the magnetic field through the carriage and thus reducing the effectiveness of the magnet.

4. Latch Mechanism

The EOCR control rod drive latching mechanism is composed of the following major components: the latch hook, five latching balls, the ball cage, the latch cam and the push rod guide assembly. Fig 16 presents a photograph of these components together with all the other components which are an integral part of the latching mechanism. In its operating condition, the latching mechanism is divided into three separate sub-assemblies; the control rod assembly, the push rod assembly and the seal tube assembly.

The control rod assembly in the latching mechanism is limited to the latch hook. It is screwed into the latch hook extension and from there down into the remaining rod assembly. The latch hook

Fig 16 Latch Assembly Components

is made of Rex M-2 tool steel hardened to Rockwell C 58/66 in the latching area.

The push rod assembly, that portion of the drive mechanism which moves during the latching and releasing, is assembled in the following manner: the bellows assist spring is place over the seal bellows, the upper end of which is welded to the seal tube and the lower end of which is welded to the armature push rod guide assembly. The bellows assist spring retainer is screwed onto the guide assembly until the 1/4 in. diameter holes in the two pieces line up. This action compresses the spring 0.4 in. The guide pin is inserted through these two components with the latch cam guide also mounted on this pin. The ball cage is screwed onto the seal tube prior to inserting the pin and assembling the latch cam guide. The latch cam is screwed onto the latch cam guide and held in place with a double dent lock washer. The latching balls are mounted in the ball cage prior to assembling the latch cam.

The bellows assist spring is made of hardened Inconel X wire 0.25 in. in diameter wound in eleven coils with a free length of 3.9 in. The seal bellows is made of stainless steel with special flanges welded on each end of the bellows. The guide assembly is a stainless steel unit which screws into the armature push rod inside the seal tube. The bellows assist spring retainer, the guide pin, the lock washer and the latch cam guide are also made of stainless steel. The latch cam is made of SAE M-2 tool steel hardened to Rockwell C 60/66. In the latched position, the latching balls are held in place by the internal latch cam face which has a 15° taper. When the latch releases, the balls fall radially outward onto a 45° face which is above the 15° face. The latching balls are 5/8 in. diameter Carbaloy #44-A balls.

The seal tube assembly, that portion of the drive mechanism which remains stationary during the latching and releasing, is assembled in the following manner: after the bellows assist spring and retainer have been installed the ball cage is screwed onto the seal tube and locked in place with a double dent lock washer. After the latch cam, guide and latching balls have been installed the latch cam retainer is screwed onto the bottom of the ball cage and locked in place with a double dent lock washer.

The ball cage is made of SAE M-2 tool steel hardened to Rockwell C 60/66. The five latching ball holes are countersunk to prevent the balls from dropping into the center of the cage. The guide pin travels the slot in the ball cage. The latch cam retainer is that part of the drive which mates up with the scram spring cage to compress the scram spring.

5. Latch and Scram Sequence

Figs 17 and 18 present the control rod latching and scram sequences. In view A the drive and the control rod are about to mate and begin compressing the scram spring. In view B the drive and control rod have mated and the scram spring is almost completely compressed. In view C the carriage is at the "rod zero" position. This is the position at which, when the control rod is latched to the drive, the drive first begins to lift the control rod from its seated position. At this position in the sequence under consideration the bottom of the guide assembly has come in contact with the top of the latch hook and the bellows assist spring has been compressed 0.175 in. Since the magnet is not strong enough to overcome the bellows assist spring and pull the armature onto the magnet, the magnet must be driven down an additional 0.125 in. to

Fig 17 Control Rod Latching Sequence

Fig 18 Control Rod Scram Sequence

the "lower limit" to bring the armature in contact with the magnet. In view D the drive mechanism is at the lower limit position with the armature on the magnet with the latch closed and the magnet contact switch is closed.

In view E the drive has been raised back up to the rod zero position resulting in the latching balls being firmly seated against the latch hook ready to raise the control rod. In view F the rod is being withdrawn. In view G the rod has been scrambled and the latch hook has been released and is moving away from the drive. To affect the release, the push rod assembly has dropped 0.300 in. In this view the lower end of the scram spring is forcing the rod down while the upper end of the scram spring is pushing on the drive mechanism through the top of the scram spring cage.

G. Driver Fuel Assembly

1. General Description

The driver fuel assembly consists of three sub-assemblies: the fuel section, the center extension section and the top extension section. The fuel section is fastened to the center extension section by means of a captured tie rod which runs through the center of the extension piece and screws into the top of the fuel section. The top extension in turn is fastened to the center extension by means of a captured tie rod which runs through the center of the extension piece and screws in the top of the center extension. Fig 19 presents a pictorial view of the assembly.

The assembly is held in place in the test vessel by the end box which mates into the grid plate, by the guide fins which fit into

Fig 19 Driver Fuel Assembly

holes in the spiders and by a spring loaded monitor hold-down tube which mates into the orifice plate in the top of the assembly.

The Santowax enters the assembly through the fuel section end box. After flowing through the fuel section and center extension, a portion of the Santowax leaves the assembly through slots at the lower end of the top extension; the remainder of the Santowax leaves through the orifice plate at the upper end of the top extension. The orifices and slots are sized to provide each fuel assembly with adequate but not excessive coolant flow.

The test facility monitor tube contains only a pressure impulse line whereas the reactor monitor tubes also contain thermocouples. Fig 20 presents a pictorial view of the reactor monitor hold-down tube assembly. In the reactor the differential pressures across the orifice plates is measured to provide constant monitoring of the flow rates through the fuel assemblies.

2. Extension Tubes

The center extension tube section is a 4 in. O.D. x 3.5 in. I.D. x 116 in. long stainless steel tube. The 4 in. x 6 in. box on its lower end fits into the top of the fuel section. The extension is provided with a set of lifting lugs for handling purposes.

The top extension section is a 4 in. O.D. x 3.5 in. I.D. x 110 in. long stainless steel tube. The two sets of guide fins provided on this section fit into the openings in the spiders to prevent bowing and vibration of the assembly. The four slots in the lower end of this section, which are either rectangular in shape or 1/4 in. diameter holes, are provided to facilitate natural convection cooling of the fuel section during reactor shutdown. During reactor shutdown, the level of the organic at times is below the orifice plate.

Fig 20 Monitor Tube Hold Down Assembly

The removable stainless steel orifice plate is bolted to the upper end of the extension. This circular plate has a large hole in the center to accommodate the monitor tube. The outer portion of the plate contains the orifice holes. Normally there are eight orifice holes whose size depends on the flow requirements of the particular assembly

3. Fuel Section

The drive fuel section, which has an overall length of 58 in. is made up of two fuel sub-assemblies. Each 3 in. x 4 in. sub-assembly contains 28 fuel plates with one dummy plate in the center. This cellular plate is welded to the end plates of the stainless steel box to provide additional strength to the 4 in. span. Fig 21 pictorially presents the details of the fuel section. The fuel plates are free to accommodate thermal expansion in three directions. The plates are held in place by grooves in the box side plates, by spacer combs at the upper and lower end of the plates, and by rectangular retainer bars at the lower end of the plates. Each plate has a 0.005 in. stainless steel cladding over a 0.020 in. thick UO_2 stainless steel cermet matrix which is 36 in. long. The prototype fuel section contains dummy fuel plates made of stainless steel.

The two sub-assemblies are joined together at their lower end by the end box and at their upper end by a tie bar. The center extension tie bolt screws into this bar. A 1/2 in. gap exists between the two sub-assemblies and is filled with Santowax moderator in the reactor.

Fig 21 Driver Fuel Section Details

III. Loop Operation

A. Loop Startup

The following is a generalized procedure for the startup of the EOOR test loop:

1. Place the steam generator and the steam tracing system in operation checking for any system malfunction. Also turn the steam into the circulating pump stuffing box to heat the pump.
2. Heat the Santowax in the surge tank to approximately 450°F.
3. Heat the tubes in the organic heater to approximately 550°F.
4. If any flanges in the system have been broken during the shutdown, pressure check at 100 psig that section of the loop containing the flange or flanges.
5. Check the loop vent valves and lines for solidified Santowax.
6. Check the position of all the drain valves and nitrogen purge valves to be sure they are closed.
7. Place the seal coolant system in operation.
8. Turn the circulating pump shaft by hand to be sure the impeller is free.
9. Pressurize the surge tank to 100 psig.
10. Open all of the 8 in. gate valves to their fully open position minus one-half turn. Open the flow control globe valve two turns. Fully open the 4 in. gate valve which isolates the surge tank from the pump suction allowing the loop to fill with Santowax.
11. Vent the gases from the loop as it fills with Santowax.
12. Shut off the steam to the stuffing box and turn on the cooling water to the stuffing box.

13. Start the pump and check the vents for accumulated gas.

At this stage the loop is in operation and the test program can commence.

B. Control Rod Drive Adjustments

All of the adjustment procedures required for the EOGR control rod and drive mechanisms are presented in maintenance instructions for the EOGR control rod drives.

C. Test Data Procurement

1. Flow vs Pressure Differential

During any given control rod or driver fuel assembly test the following procedure is used in procuring flow versus pressure differential data. The test loop flow rate is adjusted over the range of interest in 50 gpm steps. At each flow rate the various pressure differentials are measured and the data recorded. The reliability of the data is established by plotting the data prior to shutting down the loop. If unreliable data is obtained, the necessary corrective action, e.g., purging the impulse lines, is taken and the data procurement repeated.

While using water as the test medium, the flow rate measurements obtained from the two independent measurement systems are compared at each flow rate. This procedure assures correct flow measurement.

2. Scram-Insertion Time

The following procedure is used in procuring the control rod scram-insertion time data. The Visicorder is checked to assure proper operation of all the traces while attaining the desired flow rate, temperature, pressure and rod position. When all of the conditions are correct, the Visicorder is started and, as soon as the Visicorder chart reaches full speed, the scram button is pushed. As soon as the

rod ceases moving, the Visicorder is shut off. The Visicorder normally does not operate more than five seconds.

The Visicorder chart is allowed to develop and the data reduced in accordance with the requirements of the particular test.

D. Insertion and Removal of Test Pieces

The insertion and removal of all test pieces from the test vessel is accomplished by means of a mobile crane. Upon completion of any given control rod test, the following procedure is used to remove the test piece. The reverse procedure is used to insert a test piece.

By means of a mobile crane, the top and side panels are removed from the cupola on the roof of the building. The drive unit is unbolted from the top head and moved to the test stand beside the building. The top head is unbolted from the test vessel and moved to the building roof. The grid plate is then unbolted using the 20 ft long Allen wrench and the pressure impulse lines are disconnected at the top of the test vessel. The test assembly is then removed from the test vessel and laid horizontally on a trailer for the necessary modifications. Two large "I" beams are bolted to the test assembly to prevent excessive bowing of the assembly while it was being lowered to a horizontal position. Fig 22 presents a photograph of the test assembly without the "I" beams suspended from the mobile crane boom. In this photograph the control rod is mounted in the grid plate and spider assembly.

IV. Test Commentary

The EOCR Test Facility was placed in operation in March, 1961. During the first three months the major effort was devoted to overcoming

Fig 22 Test Assembly Suspended from Mobile Crane Boom

system deficiencies, with instrumentation presenting the main problem. Also during this period the first control rod problems were encountered. After the control rod had been in 500°F Santowax for a relatively short period of time, the fuel-follower would be galled by, and become seized in the boot. Therefore, a new fuel-follower and a new boot were ordered with the clearance between these components increased by 50 per cent.

During June, 1961, it became apparent that the control rod was not seating after being scrambled at high flow rates from its fully withdrawn position; the distance between the seat and the control rod was a function of the flow rate through the rod. After the rod had ceased falling, it could be raised or lowered by raising or lowering the organic flow rate. A significant change in the flow rate was required to move the rod, however. This dead-band performance indicated a significant mechanical friction force acting on the rod. This problem was thought to have been solved by lowering the position of the coolant outlet ports in the control rod by approximately 9 ft thus reducing the pressure differential across the rod. After this change, flow vs pressure differential data were obtained which appeared to be correct. The next three months were devoted to the problems encountered with the magnet and the latch mechanism while awaiting the arrival of the new fuel-follower and boot. Upon the arrival of these components, qualitative tests were conducted with some quantitative data obtained. These data, as well as data obtained during subsequent tests, were not in agreement with the data obtained earlier and were not repeatable during the various tests. In particular, the pressure differentials appeared to increase chronologically. Repeatable data were finally obtained during two consecutive

tests performed in December, 1961; these data were in good agreement with the calculated values. However, during these two tests the control rod would not seat when scrambled at flow rates which produced control rod seating during the previous tests.

It appears that during the majority of these earlier control rod tests high- and low-coolant flow rates were being indicated by the instrumentation. Exhaustive calibration checks were made on the instrumentation during the various tests without ever indicating instrumental errors. Analyses did not reveal any significant change in the chemical composition or physical properties of the organic test medium during the test program. Also, there was no indication of temperature or sediment stratification in the test vessel which, if present, might explain the test anomalies. The only apparent explanation for the anomalies encountered was the buildup of gas in the orifice impulse lines between the Santowax and the experimental sealant used in the differential pressure cell. The impulse lines were not purged when the experimental sealant was used.

The only reproducible data obtained with Santowax are those obtained during December, 1961. Additional Santowax data were not obtained because weld failures forced suspension of operation of the test loop using Santowax as the test medium.

Operation of the test loop was resumed in February, 1962, following the removal of the Santowax residue from the system. Treated water was then used as the test medium; refer to Section V, the following section, for a discussion of the use of water as the test medium. During the next five months reliable data were obtained in the following areas:

- (1) Control rod flow rate vs pressure differential
- (2) Boot orifice flow rate vs pressure differential
- (3) Driver fuel flow rate vs pressure differential
- (4) Driver fuel orifice flow rate vs pressure differential
- (5) Control rod scram-insertion time as a function of flow rate

Also, considerable effort was devoted to determine the modifications necessary to obtain a control rod configuration which would insert satisfactorily and reliably upon being scrambled at high flow rates. Another area which received considerable effort was the determination of the forces acting upon the control rod.

The test loop was disassembled in July, 1962, with all components other than the piping and the surge tank being reused in a test facility being built adjacent to the reactor. This new facility will use Santowax as the test medium and will be used to confirm the experimental results obtained in water. The new facility also will be used to test at reactor conditions all the components which are to be inserted into the reactor.

In summation, the quantitative and qualitative test results reported herein were acquired over a considerable period of time and were acquired using two different test media. Based upon these results the control rod, the control rod drive and the driver fuel assembly should perform satisfactorily in the EOCR.

V. Operation With Water

A. Justification

The justification for operating the test loop with water in place of Santowax OMP as the test medium is the fact that the same Reynolds number can be obtained with either test medium.

The Reynolds number is the dimensionless product: velocity x hydraulic diameter x density/viscosity. For a given Reynolds number the hydrodynamic characteristics of a system are determined regardless of the magnitude of the four factors whose product is the Reynolds number⁽¹⁾. For the system under consideration (the EOCR control rod), the hydrodynamic characteristics of interest are the pressure losses across the various components and the control rod scram-insertion time.

The same Reynolds number is obtained with either test medium in the following manner. The hydraulic radius remains unchanged since the same geometrical configuration, i.e., the control rod, is used and the fluid velocity remains unchanged by operating at the same flow rate. Thus the ratio of the two remaining factors also must remain unchanged. The reciprocal of this ratio is the fluid viscosity divided by the fluid density and is commonly known as the kinematic viscosity of a fluid. By operating with water at the proper temperature, the kinematic viscosity of the water is equal to the kinematic viscosity of Santowax OMP at the desired test temperature.

Fig 23 graphically presents the kinematic viscosity of water and Santowax as a function of fluid temperature. From this figure it can be seen that the kinematic viscosity of Santowax OMP, i.e., zero per cent HB Santowax, at 500°F is 5.5×10^6 ft²/sec. Water has the same kinematic viscosity at 132°F. Consequently the pressure differential data and the scram-insertion time data obtained using 132°F water at any given flow rate is equivalent to the same data obtained using 500°F Santowax OMP.

Fig 23 Kinematic Viscosity of Water and Santowax
vs Fluid Temperature

Fig 24 graphically presents pressure differential vs loop flow data obtained using the two different test media as well as the calculated values. These data are for compatible, and in some cases equal, Reynolds numbers. The calculated values for the test vessel differential are slightly higher than the measured values. This is attributable to the uncertainty in calculating the permanent pressure loss across the boot orifices. This uncertainty is in turn attributable to the peculiar geometry of these orifices. The four streams of fluid passing through the orifices converge upon one another immediately inside the orifices and then make a 90° turn. The calculated values, particularly the calculated pressure differentials across the fuel and poison sections, reproduce the measured values accurately enough to establish the reli-

Fig 24 Control Rod and Test Vessel
 Pressure Differentials vs Loop Flow

ability of the measurements. These data thus demonstrate the reliability of using the Reynolds number as the basis for applying pressure differential data obtained in a water system to a Santowax system.

Fig 25 graphically presents control rod scram-insertion-time curves at four different test conditions and two different Reynolds numbers. Data points are not included because they all fall on the curves shown. The 700-gpm Santowax data and the 550-gpm water data were obtained at the same Reynolds number. The flow rates are not the same because the Santowax temperature is 575°F, requiring adjustment of the 132°F water flow rate to obtain the desired Reynolds number. These two rod-insertion-time curves are not identical, but the difference is attributable to the scram spring being 15 per cent stronger at the lower temperature, thus giving the control rod greater inertia resulting in faster and greater insertion.

Fig 25 Prototype Control Rod Scram Insertion Curves,
1 in. Boot Orifices

The 540 gpm Santowax data and 450 gpm water data were obtained at approximately the same Reynolds number. As in the case above, the water flow rate had to be adjusted and the difference in insertion curves is attributable to the scram spring being stronger during the water test.

These two pairs of control rod insertion-time curves thus demonstrate the reliability of using the Reynolds number as the basis for applying rod-drop-time data obtained in a water system to a Santowax system.

B. Pre-Operational Requirements

Prior to operating the test loop with water as the test medium, three requirements had to be met: (1) the Santowax had to be removed from the system, (2) provisions had to be made to treat the water in the system to avoid rust formation and (3) provisions had to be made to dissipate the circulating pump heat input.

Removing the Santowax entailed draining the surge tank into the pressure relief tank and removing the Santowax from the sections of piping which were known to be filled with solidified organic. Also, it entailed disassembly and solvent cleaning of the differential pressure cells and pressure impulse lines. Presumably any free pieces of solid Santowax could be water flushed into the surge tank or into the bottom of the test vessel for removal prior to testing. After this flushing was attempted, it was found that the organic residue in the system had acted as a highly viscous fluid and slowly flowed over the pipe walls coating the entire system with a thick film of Santowax. This occurred even though the water temperature was kept below 150°F. The Santowax was finally completely removed from the system by circulating solvent through the system for several hours.

The second and third requirements were satisfied by a single system. This system injects cold water into the main loop during operation while the warm water is purged from the system. The seal coolant pump, which is not required for the lower temperature loop operation, is used as the injection pump with a water treatment drum connected to its suction. Highly concentrated solutions of sodium chromate are mixed in this drum and fed to the injection pump along with cold raw water. Periodic analyses are carried out on the loop water and the concentrated chromate feed rate adjusted to maintain a 1,000 ppm concentration. The injection and purge lines contain manometers which are used to maintain equal flow rates. The normal rates during operation are 6 gpm. With the system it is possible to maintain the water temperature to within 2° of the desired 132°F value.

VI. Qualitative Test Results

A. Initial Component Deficiencies

1. Control Rod Drive

a. Drive Mechanism

The prototype drive mechanism was disassembled and reassembled approximately twelve times during the course of the test program. Each time the drive was disassembled the various components were inspected for wear or deformation, or both. Four deficiencies were noted. The first time the threaded stainless-to-stainless joint between the armature push rod and seal bellows guide assembly was unscrewed, the joint was found to be galled and to have seized. This deficiency has been overcome by using an adequate amount of high temperature anti-seize compound on this joint.

The second deficiency was the twisting of the drive seal bellows during the assembly or disassembly of the drive. Fig 26 presents a photograph of a severely twisted bellows with its seal tube end sheared off. Usually the twisting occurred when the bellows was partially exposed, thus the damage can be detected by inspection in this case. However, the bellows can also be twisted if the ball cage is not firmly locked in place and is turned slightly. This results in the bellows being twisted via the guide pin. In this case, however, the damage cannot be readily detected. The bellows deformation in itself may not be serious, but it could result in the failure of the bellows much sooner than normal; the bellows are rated at 2,000 cycles. If a seal bellows failed in the reactor the Santowax could be forced up through the annulus between the push rod and the seal tube reaching the armature. If the Santowax solidified, as it undoubtedly would, the armature could not drop away from the magnet making it impossible to release the control rod from the drive.

Any twisting which occurs is the result of incorrect procedures and can be overcome by following proper procedures. Since the seal bellows can be easily twisted, this problem will exist whenever maintenance work is being performed on the latching mechanism. In light of the consequence of a bellows failure, it may be prudent to modify the ball cage locking device to obtain more positive locking of this component.

The third deficiency was the crushing of the magnet contact switch and the magnet electrical cord holder. These components were crushed when the upper limit switch stop nut was raised to its maximum elevation and the drive raised to its maximum elevation. This results

Fig 26 Drive Seal Bellows Twisted and Sheared

in the two components being driven into the bottom of the upper bearing plate. To eliminate the possibility of crushing these two components, the travel of the upper limit stop nut must be restricted by at least two inches. It may also be prudent to provide positive stopping of the carriage as a backup in case of limit switch failure.

The fourth deficiency is the ability of the drive to pull the control rod completely out of the boot if the upper limit stop nut is improperly adjusted. As soon as the seal shoes are raised out of the boot, all coolant flow through the control rod stops. In the reactor this situation would be quite serious. If a control rod was withdrawn out of the boot and then scrambled, the rod may not go back into the boot and could end up in a very awkward position. This deficiency could be overcome by positively restricting the travel of the upper limit stop nut or the carriage, or both, as long as the present boot is in service.

The ease of disassembly and reassembly of the drive assembly could be increased by drilling and tapping the upper and lower bearing plates and the housing plate for the temporary installation of handling lugs during maintenance operations.

b. Latch Mechanism

The ball-detent latch mechanism as originally designed was deficient in that the latch hook did not release promptly after approximately 25 latch and release cycles. As the number of these cycles increased, the failure rate increased until it was impossible to release the control rod from the drive.

The failure to release promptly apparently occurred in the following manner. In the process of a normal latch release with the original latch hook, the design of which is shown in Fig 27, the rod

SECTION "A"

Fig 27 Latch Hook - Original and Modified Designs

was supported for a brief time interval on the sharp corner at the top of the radial latching area. During this time interval, the Hertz stress on the sharp corner exceeded the hook yield stress, resulting in deformation of the corner. After this process had been repeated several times, five flat surfaces approximately 45° from vertical had been worn on the corner, one where each ball traveled. While a ball was on this worn surface, the force vectors between the latch hook and the latch cam were directly opposed to one another through the center of the ball. The latch cam was prevented from falling by the balls which roll towards the center of the latch hook, thus tending to lift the latch cam; the balls at all times rest on the ball cage. Markings which have appeared on the vertical face and top tapered section of various latch hooks strongly support the conclusion that the balls behaved in the above manner.

By establishing a 0.080 in. radius on the corner which was being deformed, the contact area on this corner was increased, resulting in a decrease of the Hertz stress to less than the yield stress of the hook. Fig 27 presents views of the original design of the latch hook and the modified design.

c. Magnet

As originally designed, the magnet was deficient in that the time required for the release of the armature was approximately 200 milliseconds as compared with a specified value of 50 milliseconds. To decrease the release time, the following modifications were made to the magnet: (1) a 0.003 in. air gap was established between the magnet and the armature, and (2) the coil bobbin, the armature core and the

magnet core were slotted to reduce hysteresis. These modifications resulted in obtaining the specified armature release time.

After the modified magnet was incorporated in the drive assembly and placed in service, the number of spurious armature releases increased many-fold. It was subsequently found that much of the magnetic flux was being shunted through the carbon steel magnet mounting carriage. Upon replacing this carriage with an aluminum carriage, the spurious releases were eliminated.

The above mentioned trouble has also been eliminated by modifying the carbon steel carriage so as to incorporate an aluminum bronze sleeve between the carriage and the magnet. The modified prototype magnet and carriage as well as three production drive assemblies have performed satisfactorily. Each of the EOCR production carriages have an aluminum bronze sleeve between it and the magnet.

2. Control Rod

a. Poison Section

The prototype poison section was deficient in that some of the rivets which attached the poison plates to the stainless steel box were sheared. After the poison section had experienced approximately 1,200 scrams, it was found that all six rivets in two poison plates and four rivets in a third poison plate had been sheared. This deficiency has been overcome by doubling the rivet diameter.

b. Fuel Section

The prototype fuel section was deficient in that, at operating temperature, there was not sufficient clearance between the fuel section and the boot, resulting in galling and seizing of the two components. When these two components were out of the test medium and

cool, there was adequate clearance on all sides. Apparently the 500°F operating temperature produced distortion of either one or both of the components. To overcome this deficiency, the clearance between the carbon steel boot and the second prototype fuel section was increased from 0.040 in. to 0.062 in. on all sides. It was these components, having this larger clearance, which were successfully utilized in all of the control rod tests discussed in section VI, B.

Fig 28 presents a photograph of some of the galling which occurred on the outside of the original fuel section enclosure box.

A second deficiency in the original fuel section was associated with the stellite pads on the lower end of the fuel section. The indications were that this material had contributed to the galling of the boot. The stellite pads were replaced first by graphite and then by aluminum bronze shoes which were spring loaded and rubbed on the boot to restrict the leakage between the boot and the fuel. This modification eliminated the galling but resulted in an additional drag force acting on the control rod. The magnitude of the drag force was such that it significantly reduced the scram-insertion time at high flow rates. The final design has aluminum bronze shoes brazed onto the lower end of the fuel section with a nominal 0.009 in. clearance on all four sides.

A third deficiency came to light only after the 112 lb ballast had been added to the control rod assembly. At zero gpm flow rate, the seating impact velocity of the control rod was excessive. To reduce this impact velocity the minor diameter on the snubber piston taper was increased and the distance between the minor diameter and the major diameter was decreased with length of the piston having the major diameter being increased. This modification resulted in an acceptable impact velocity.

Fig 28 Galled Prototype Control Rod Fuel Section

The spider bolt on the upper end of the original fuel section was improperly welded to the fuel box with one web breaking loose from the box. This is a matter of quality control on the part of the fabricator as much as it is a design deficiency.

c. Guide Boot

The comments in the preceding section with regard to the clearance between the fuel section and boot and the galling and seizing of the components apply in this section. In addition, the material of construction for the guide boot was changed from stainless steel to carbon steel to further reduce the probability of galling.

c. Bottom Head Seal Plug

Two deficiencies were noted in the original bottom head seal plug arrangement. The first deficiency was noted the first time the bellows shroud was lifted off the bellows. Apparently the cavity between these two components was filled with liquid Santowax and, as the shroud was being lifted, a vacuum formed inside the shroud resulting in the bellows being pulled upward. The bellows was permanently damaged and had to be replaced. To overcome this deficiency four large holes were drilled in the upper portion of the shroud.

The second deficiency was the galling which occurred between the stainless steel push rod and its tool steel bushing. This galling became so serious that the push rod eventually had to be driven upward after the control rod had been raised off its seated position. In the test facility this deficiency was overcome by increasing the clearance between the two components. For reactor service, the material of construction of the bushing was changed to cast iron.

e. Other Components

Deficiencies were noted in two other areas, the latch extension and the weight of the assembly, during the course of the test program. The latch extension and the control rod extension screw together and are locked in place with a double-dent lock washer. Above the male threads in the latch extension is a cylindrical section which is not relieved from the thread diameter. The clearance between this cylindrical section and the rod extension is quite small, 0.0015 in. minimum, and resulted in galling and seizing of the two stainless steel components. During the greater part of the test program these two components were cut apart and welded together whenever it was necessary to remove or install the scram spring. This deficiency could be overcome simply by increasing the clearance between these two components in the area under consideration.

During the course of the test program it was found that satisfactory control rod scram-insertion was not being obtained at high flow rates. One of the modifications made to the rod to overcome this deficiency was to add a 112 lb ballast to the control rod. This modification increased the weight of the control rod assembly from 410 lbs to 522 lbs; the weight in Santowax or water was increased from 358 lbs to 456 lbs. The ballast was a piece of bar-stock steel located in the guide tube. It was held in place by a large pin which passed through one of the original coolant outlet ports with the pin bolted in place.

3. Driver Fuel Assembly

Two deficiencies were noted in the prototype driver fuel assembly. The first was the top of each extension tube being out-of-round. This was caused by the guide fins being welded onto the extension

tubes after the ends had received their final machining.

The second deficiency was in the sizing of the orifices and slots. The sizes recommended did not produce the desired flow rates. The final sizing of the orifices and slots has not been made pending the completion of the final physics and heat transfer calculations.

B. Modified Component Results

1. Control Rod Drive

a. Drive Mechanism

The prototype EOCR control rod drive mechanism, consisting of some 425 separate items, performed satisfactorily and reliably throughout the test program with certain exceptions noted in the preceding section. The drive has been operated the equivalent of traveling from zero to 36 in. and back to zero in. in excess of fifteen hundred times. The drive motor has been started and stopped approximately 20,000 times. Based on MTR-ETR experience, these tests are equivalent to approximately ten years' trouble-free operation of the control rod drive and to at least two years' trouble-free operation of the regulating rods. It was necessary, of course, to periodically lubricate the Acme screws; "Moly-Sulfide" spray lubricant was used.

One of the specific requirements of the drive motor was to start and stop 20 times per minute for three consecutive minutes without overheating. Upon subjecting the assembled motor to this service, the motor temperature rose less than five degrees.

The Veeder-root control rod drive position indicating system performed satisfactorily and reliably throughout the test program. Occasionally, phantom images appeared in the readout unit when the amphenol connector was not properly attached to the drive unit. Periodic

adjustment of the transmitting unit was also required.

b. Latching Mechanism

The modified ball detent latching mechanism performed satisfactorily and reliably throughout the test program. No malfunctions were experienced in 1,126 consecutive latch and release cycles carried out at operating conditions ranging from 380°F to 800°F and from 300 to 660 gpm indicated Santowax flow rates. Table I tabularly summarizes these tests. The indicated flow rates were probably in error at times. The performance is, however, valid over the range of indicated flow rates. There was approximately an equal number of latch and release cycles experienced at unrecorded conditions in Santowax and water test media. Again no malfunctions were experienced.

The modified latching mechanism also performed satisfactorily and reliably during extensive testing under adverse conditions. This testing program was conducted in two phases. The first phase involved subjecting the mechanism to 900 latch and release cycles with the test medium being 500°F Santowax containing 5,000 ppm fine grit material; approximately 10 ppm particulate is expected in the reactor. The mechanism was subjected to an additional 800 cycles in the above medium to which was added 5,000 ppm sand. These tests were performed in the latch test facility.

The second phase of this program involved releasing the mechanism after it had remained static in high particulate content test medium for an extended period of time. The test medium was 500°F Santowax containing 2,000 ppm impurities consisting of iron oxide, graphite and mica; the time periods ranged from one to ninety hours. The various

TABLE I

DISTRIBUTION OF EXPERIMENTAL ROD DROPS OVER SPECIFIED CONDITIONS OF
COOLANT FLOW RATES, COOLANT TEMPERATURES, AND INITIAL ROD POSITIONS

October 4 through December 11, 1961 - With Prototype Components

Coolant Flow Rate, gpm**	Rod Position at Scram, inches	Santowax Temperature, °F					
		380	400	500	600	650	800
300	2	5		7		3	3
	18		2	15			
	36	9	5	16	4	7	5
350	2						
	18	48					
	36		3	1	4	1	
400	2	5		7		4	2
	18			115			
	36	9	4	118	5	15	3
450	2						
	18		13	26			
	36		3	2	4	1	
500	2	5		16*		5	3
	18		50	94			
	36	9	9	20	4	10	6
550	2						
	18		44	24	9		
	36		3	2	19	7	
600	2	5		7		5	3
	18		60	55			
	36	9	5	30	7	10	6
660	2	5		7		5	3
	18		15	32			
	36	9	9	15	1	10	9
Total		118	225	609	48	83	43

*Includes two scrams each at 6 in., 12 in., 24 in., and 30 in.

**The flow rates may be in error but the range indicated is valid.

Total scrams at 2 in.	-	97
Total scrams at 6 in.	-	2
Total scrams at 12 in.	-	2
Total scrams at 18 in.	-	593
Total scrams at 24 in.	-	2
Total scrams at 30 in.	-	2
Total scrams at 36 in.	-	428
Total scrams		1126

latch components were coated with 0.002 to 0.020 in. of high temperature resistant paint and the tests repeated. No malfunctions were experienced during these tests. Additional results are reported in IDO-16775.

c. Magnet

The modified magnet performed satisfactorily and reliably throughout the test program. The magnet did not overheat, did not experience any spurious armature releases and did not give any indication of potential malfunction. The holding strength of three production magnets in the drive assemblies have been checked and found to be satisfactory.

2. Control Rod

a. Poison Section

The prototype poison section performed satisfactorily and reliably during approximately 2,500 scram cycles except for the weak poison plate support rivets; this deficiency has been corrected with approximately one-half of the scrams performed after the modifications. The operating conditions for 1,126 scrams are presented in Table I. The indicated flow rates were probably in error at times. The performance, however, was valid over the range of indicated flow rates. There was no deformation of the stainless steel box or of the threaded joints which fasten the poison section into the control rod assembly. No dimensional changes were noted in the poison section after it had experienced the above scrams as well as some 100 temperature cycles, each of which covered a range of approximately 500°F.

b. Fuel Section

A non-fueled prototype fuel section has performed satisfactorily and reliably during 2,200 scram cycles. Of these, 1,126 were

performed under the operating conditions presented in Table I. The indicated flow rates were probably in error at times. The performance is, however, valid over the range of indicated flow rates. This prototype section was dimensionally checked before the above 1,126 scrams were experienced, after 1,000 scrams were experienced, and at the completion of the study. No significant dimensional changes were detected. Also, there was no evidence of interference between the prototype fuel section and the guide boot.

The aluminum bronze seal shoes have performed satisfactorily and reliably during all of the scrams. The wear on the four shoes was even and not excessive. No shoe damage was experienced while removing or inserting the fuel section through the spiders. The leakage past the shoes is not excessive. Details of the leakage measurements are presented in Section VII, G.

The snubber piston exhibited signs of surface wear on the eleven in. long cylindrical section, but the wear had reduced the piston diameter less than 0.001 in. This reduction is not significant in that the piston experienced at least 20 times as many scrams as will be experienced by a piston in the reactor. The stop ring on the snubber piston exhibited no sign of deformation of any nature. Also, there was no sign of deformation of the brace into which the snubber was screwed and no sign of deformation of the stainless steel box where this brace was attached.

c. Guide Boot

A carbon steel guide boot which is identical to the guide boots fabricated for the EOCR performed satisfactorily and reliably during 2,200 scram cycles cited in the preceding section. There was no indication of interference between the guide boot and fuel section.

d. Bottom Head Seal Plug

The seat switch push rod performed satisfactorily and reliably during the test program. There was no indication that the rod

was experiencing excessive wear, was tending to hang up or was being deformed.

The modified bottom head seal plug performed satisfactorily and reliably during the test program. There was no indication of seal bellows or bellows-assist-spring malfunction.

e. Other Control Rod Components

The snubber section performed satisfactorily and reliably during approximately 2,500 scrams. There was no indication of deformation or wear on the face where the stop ring of the snubber piston seats, on the snubber orifice through which the snubber piston travels, or on the body of the snubber piston.

VII. Quantitative Test Results

A. Flow vs Pressure Differential Data

1. Control Rod

a. Fuel & Poison Sections

Experimental and calculated values for the flow versus pressure differential across the fuel and poison sections are presented graphically in Fig 24. Although only a few data points are shown, literally hundreds of data points were obtained, all of which fall on or adjacent to the line shown. The pressure differential across the entire control rod is essentially equal to the differential across the fuel and poison sections. The differential between the outlet ports in the poison section and the outlet of the vessel is less than the accuracy of the measurements.

The position of the control rod had no effect on the flow rate through the rod at any given pressure differential.

b. Boot Orifices

Flow versus permanent head loss, psi, data has been obtained for six different boot orifices sizes. These data are presented graphically in Fig 29. Data points were obtained with both 132°F water and 500°F Santowax test media.

Pressure differential values were calculated for the 0.797, 1.000 and 1.250 in. diameter boot orifices and were found to be slightly higher than the measured values. The difference, which approaches the accuracy of the measurements is attributable to the uncertainty in calculating the permanent head loss across the boot orifices. This uncertainty is in turn attributable to the peculiar geometry of the orifices. The four streams of fluid passing through the orifices converge upon one another immediately inside the orifices and then make a 90° turn. The calculated values reproduce the repeatable measured values accurately enough to establish the reliability of the data.

Fig 30 presents the total loop flow rate as a function of the boot orifice diameter. All of these data were obtained at a test vessel pressure differential of 40 psi with the test medium being 132°F water. The seal shoes were restricted to 4.106 in. square thus the leakage past the seal shoes is included in the values presented.

The reactor boot orifices will be sized to obtain the 40 psi reactor pressure differential flow rates as determined by the heat transfer calculations. The final physics and heat transfer calculations have not been completed thus the final boot orifice size determination has not been carried out.

c. Test Vessel

The test vessel pressure differential at any given test

EOCR BOOT ORIFICE PERMANENT HEAD LOSS VS. TOTAL FLOW THROUGH THE ORIFICE, 132°F WATER AND 500°F SANTOWAX OMP

Fig 29 Boot Orifice Flow vs Pressure Differential

EOCR TEST LOOP FLOW RATE
Vs.
BOOT ORIFICE DIAMETER

Fig 30 Test Loop Flow Rate vs Boot Orifice Diameter

condition is equal to the sum of the differentials across the boot orifices and the fuel and poison sections. The test vessel pressure differential curve shown in Fig 24 is a graphic example. The data points presented for the test vessel flow versus pressure differential are measured values rather than values obtained by addition. The same values can be obtained by taking the sum of the orifice differential and the fuel and poison sections differential. Minor discrepancies are sometimes encountered but these are within the accuracy of the measurements.

2. Driver Fuel

a. Fuel Section

Experimental and calculated values for the flow versus pressure differential across the assembled driver fuel section are presented graphically in Fig 31. The solid straight line presents the calculated values and the broken lines cover the range of measured values. The pressure differential considered in both the calculations and measurements is the test vessel inlet pressure minus the pressure at the monitor tube. Thus the differential includes the losses across the end boxes and extension tubes as well as the fuel plates.

b. Monitor Tube

Experimental and calculated values for the 40 psi vessel pressure differential flow rate versus monitor tube pressure differential are also presented in Fig 31. The solid curved line presents the calculated values and the $\odot$'s present the measured values. The flow rates in this particular case are the flow rates through the driver fuel assembly with 40 psi test vessel differential. The monitor tube pressure differential is the pressure at the monitor tube minus the test vessel outlet pressure.

EOCR DRIVER FUEL ASSEMBLY
PRESSURE DIFFERENTIAL Versus TOTAL FLOW RATE

NOTE: Water temp. 132°F.

Monitor tube pressure differential equals
tube pressure minus vessel outlet pressure.

Fuel section pressure differential equals
vessel inlet pressure minus monitor tube pressure.

Fig 31 Driver Fuel Assembly Flow vs Pressure Differential

After the final flow requirements have been determined and the final orifice and slots sizes have been determined, individual flow versus monitor tube pressure differential graphs will have to be empirically determined. During reactor operation these curves will be utilized to determine the flow rate through each driver fuel assembly. If a driver fuel assembly becomes totally or partially obstructed for any reason, the flow rate through the assembly will decrease resulting in a decrease in the monitor tube reading.

c. Orifices

The flow rate through a prototype driver fuel assembly at an overall pressure differential of 40 psi was measured with various combinations of orifice and slot sizes. The results of these measurements are graphically presented in Fig 32. From this figure the orifice and slot sizes required for the various driver fuel positions can be selected in accordance with the flow rate requirements.

The reliability of these data was established by comparing the difference between the inlet pressure and the monitor tube pressure with the calculated differential. At 700 gpm the measured differential was 15.5 ± 1.0 psi and the calculated value was 15.8 psi. The larger variations existed when a large orifice area was combined with a small slot or when a small orifice area was combined with a large slot. Only under these circumstances does the pressure differentials across the upper extension tube vary significantly from the average value.

d. Test Vessel

The test vessel pressure differential at any given test condition is equal to the sum of the differential across the fuel section

Fig 32 Driver Fuel Flow vs Orifice Area

and across the orifices and slots. During the experimental program these three differentials were measured and found to have the expected relationship.

B. Leakage

1. Control Rod

The leakage flow of a control rod is defined as the flow through the square annulus between the control rod fuel section and the boot plus the presumably small flow between the grid plate and the grid support plate. The leakage in the reactor should be essentially equal to the leakage in the test facility.

The leakage was precisely determined in the MTR-ETR flow test facility. The test medium was 132°F water, the fuel section and boot were mounted horizontally and the fuel section was centered by means of small spacers. The fuel section was plugged so that all of the measured flow was leakage flow.

Three shoe configurations were tested at two rod elevations, the rod seated and the rod at the 36 in. position. The three configurations were: (1) the shoes fully expanded against the boot, (2) the shoes retracted to the 4.106 in. dimension, and (3) the shoes completely removed from the fuel section.

Fig 33 graphically presents the results of leakage measurements. Table 2 presents the most significant leakage rates at a control rod pressure differential of 15 psi, the approximate maximum operating condition differential.

The leakage with the rod at 36 in. is higher because the length of the leakage annulus is reduced from 42 in. to 6 in.

EOCR CONTROL ROD LEAKAGE Versus CONTROL ROD PRESSURE DIFFERENTIAL

NOTE: Water temp. = 132°F.

Fig 33 Control Rod Leakage

TABLE II

EOCR Control Rod Leakage Flows (gpm) at 15 psi Rod ΔP

<u>Configuration</u>	<u>Rod Position</u>	
	<u>0 Inches</u>	<u>36 Inches</u>
Shoes expanded	11 gpm	16 gpm
Shoes retracted to 4.106 inches	35 gpm	44 gpm
Shoes removed	62 gpm	96 gpm

The leakage measurements performed at the EOCR Hydraulic Test Facility essentially agree with the above data. Since the flows measured with shoes in place are equal to or less than the accuracy of the EOCR Facility measurements, the MTR-ETR Facility data is used for all leakage considerations.

In all other sections of this report the leakage flow is included in the flow rates mentioned.

2. Driver Fuel Assembly

The leakage flow of a driver fuel assembly is defined as the flow between the grid plate and the lower end box of the fuel section plus the flow between the grid plate and the grid support plate. This leakage is assumed to be 20 gpm or less and is included whenever the flow rate is mentioned.

C. Control Rod Scram-Insertion-Time

1. Operating Condition Data

During the course of the test program an exceedingly large number of control rod scram-insertion-time curves were obtained using various rod configurations and test conditions. To avoid overburdening the report with non-essential data, the data presented herein were ob-

tained with the final modified control rod configuration, i.e., the configuration presently scheduled for reactor operation, using 132°F water as the test medium. Fig 34 graphically presents these data at flow rates ranging from 0 to 750 gpm. These data do not include the magnet release time which was measured to be 0.04 seconds. These data will be repeated with 500°F Santowax to fully evaluate the effects of the higher temperature and change in test medium. Curves will also be obtained at a number of higher and lower operating temperatures.

The effect of higher or lower operating temperatures as well as the effects of higher or lower viscosities and densities of the operating fluid can be evaluated in the following manner: the Reynolds number is calculated for the flow rate, temperature and physical properties being considered. A flow rate of 132°F water is then calculated from this Reynolds number and the scram-insertion-time curve for this flow rate can be obtained from Fig 34. If the water flow rate is a value other than those presented, the desired curve can be readily extrapolated in most cases. This curve then is approximately equal to the curve which would be obtained at the non-test conditions being considered. The temperature effect on the scram spring can be a significant factor. Section V of this report presents data which illustrates this effect.

The scram-insertion-time operating parameters were determined by the safety analysis study. This study resulted in the requirement that the first seven in. of the scram-insertion be accomplished in 1.29 seconds to avoid hazardous operating conditions during the two rod withdrawal at startup accident. Details of this analysis are presented in IDO-16802, "EOCR Safety Analysis Report". From Fig 34 it can be seen that this insertion is accomplished in 0.28 seconds at 700 gpm, once the

EOCR PROTOTYPE CONTROL ROD
SCRAM INSERTION ROD POSITION
Versus
TIME AFTER MAGNET RELEASE

Fig 34 Scram Insertion Curves

rod has been released. The normal release time measured during the test program was 0.04 seconds. If a conservative release time of 0.06 seconds is used, the total scram-insertion time of 0.34 seconds is obtained.

Based on the experimental data obtained with the prototype control rod, the probability that a control rod in the reactor will fail to meet the above scram insertion requirement is 0.003 at a 95 per cent confidence level.

2. Force Analysis

Considerable effort was devoted to the establishment of a mathematical model of the forces acting on the dynamic control rod. The successful formulation of this model permitted assigning quantitative force values to the various test modifications affected on the control rod and the prediction of the control rod behavior when a given force was added to or removed from the control rod.

The force analysis has been reported in IDO-16802, "EOCR Safety Analysis Report", with the significant results of the analysis listed below.

1. The fully expanded spring loaded seal shoes rubbing on the boot produced a frictional drag force 75 to 100 lbs greater than the drag force that exists when these shoes are restricted to a dimension which is less than the internal dimension of the boot; 4.106 in. was the restricted dimension used. At high flow rates the drag force which exists with the latter shoe configuration is less than 50 lbs. These forces are more prominent at the higher flow rates where the net downward force is low.

2. To evaluate the magnitude of potential frictional forces which may be added to the control rod during operation, one edge of the

number two spider, the first spider above the guide boot, was offset $1/8$ in. from the corresponding edge of the guide boot. This modification resulted in the 36 in. scram insertion time at 700 gpm increasing from 1.21 seconds for the aligned components to 1.26 seconds. Comparison of the two scram insertion time curves shows the increase in friction force to be 10 to 15 lbs.

3. A frictional drag force of approximately 50 lbs acts on the expanding scram spring. This force is apparently the result of the outer diameter of the spring coil rubbing on the scram spring cage. Wear marks on the prototype scram spring confirm that this rubbing does exist. This frictional force is apparent in the mathematical model only at high flow rates when the net downward force is low.

4. The friction force acting on the rod is independent of the mass of the rod.

5. The friction force action on the control rod is decreased as the flow rate is increased. The magnitude of this change has not been precisely established but it does not appear to be a large change.

There are two facts which give credence to this last phenomenon. The first fact is graphically presented in Fig 35. Herein the calculated and emperical data for the time of the first 16 in. insertion of a 36 in. scram-insertion are plotted as a function of flow rate; 16 in. was chosed to avoid the snubber piston effect. Two different rod configurations are evaluated, the seal shoes fully expanded and the seal shoes retracted to the 4.106 in. position; the scram spring was not utilized in either case. In each case the emperical times are less than the calculated times at flow rates greater than 450 gpm indicating the frictional force acting on the rod is decreasing as the flow rate is increasing.

EOCR PROTOTYPE CONTROL ROD
SCRAM INSERTION TIME FROM 36in. TO 16in. Versus
FLOW RATE

Note - 132°F Water No Scram Spring

Fig 35 Scram Insertion Times

The second fact is that the retracted seal shoes rub less on the boot at 700 gpm than they do at 300 gpm. This was determined by polishing the seal shoes with fine emery paper, scrambling the rod once at the desired flow rate and then inspecting the markings on the shoes.

This decrease in friction with increased flow is apparently due to a hydrodynamic phenomenon called Bernoulli centering. At high fluid velocity through the boot the highest static pressure exists adjacent to the boot walls resulting in the fuel section being forced away from the boot walls.

VIII. Appendix

A. Hydraulic Calculations

The hydraulic calculations performed in conjunction with testing of the EOGR control rod and driver fuel assembly were of two types, pressure loss across orifices and pressure loss across fuel plates and extensions. These calculations were utilized in establishing the reliability of the experimental data. Listed below are samples of each of the two types of calculations. The remaining calculations are similar.

1. Sample Orifice Loss Calculations

Problem: What is the permanent head loss across the boot orifice?

Condition: One in. boot orifice - 485 gpm Santowax 0%
HB, 500°F.

$$\text{Solution: } V_2^2 - V_1^2 = C_o^2 2g_c \Delta P / \rho$$

$$V_1 = 1.8 \text{ ft/sec}$$

$$V_2 = 49.5 \text{ ft/sec}$$

$$\begin{aligned} \text{NRe} &= DV\rho/\mu = (0.166) (49.5) (57.4)/ \\ &3.17 \times 10^{-4} = 1.5 \times 10^6 \end{aligned}$$

$$D_e = 0.166 \text{ ft}$$

$$C_o = 0.61$$

$$\Delta P = 40.9 \text{ psi (temporary loss across the orifices)}$$

$$\text{Orifice area/boot area} = 0.05$$

$$\text{Per cent permanent head loss} = 93\% \text{ of temporary loss}$$

$$\text{Permanent head loss} = 38 \text{ psi}$$

The permanent head loss due to the change in the direction of the fluid flow prior to entering the orifices is negligible.

The permanent head loss due to the four streams of fluid converging inside the orifices and turning upward is assumed to be one velocity head with the velocity being the average of the orifice velocity and the boot velocity. This loss equals 4 psi.

$$\text{Total permanent head loss} = 42 \text{ psi.}$$

2. Sample Fuel Plate Loss Calculations

Problem: What is the permanent head loss across the fuel plates in the driver fuel section?

Condition: 485 gpm Santowax 0% HB, 500°F

$$\text{Solution: } \Delta P = \rho / 2g_c (144) \times Q^2 / A^2 \times (N_v + \Sigma K)$$

$$N_v = f L/D = \text{number of velocity heads}$$

$$\Sigma K = \text{number of velocity heads}$$

$$K = \text{entrance and exit loss coefficients}$$

$$\Delta P = 7.240 \times 10^{-3} / A^2 \times (N_v + \Sigma K)$$

$$\text{Entrance loss, } A = 0.002 \quad K = 0.14$$

$$\Delta P = 0.17 \text{ psi}$$

$$\text{Exit loss, } A = 0.079 \quad K = 0.002$$

$$\Delta P = \text{essentially zero}$$

$$\text{Fuel plate friction loss, } NRe = 4.15 \times 10^4$$

$$f = 0.022 \quad L/D = 191.5 \quad \Delta P = 4.89 \text{ psi}$$

Loss across two spacer combs, A = 0.069
K = 0.106 ΔP = 0.32 psi
Total ΔP = 5.38 psi

B. Effect of Fuel Plate Film on Pressure Differential

One of the operating problems which may be encountered is the formation of a film on the fuel plates. In an effort to evaluate the effect of such a film, the flow rate versus pressure differential for three film thicknesses were calculated. The results of the calculations are presented in Fig A-1. For calculational purposes it was assumed that the fuel plates were covered with a uniform film of the stated thickness.

To evaluate a given film thickness in terms of control rod scram-insertion time the following procedure is followed. For any given situation, i.e., film thickness and boot orifice size, the flow rate at which the sum of the two differentials, orifices and fuel and poison sections, equals 40 psi is determined from Figs 29 and A-1. From Fig 24 the film-free flow rate is determined which has the same fuel and poison section pressure differential as does the fouled sections under the situation being considered. The scram insertion time for this latter flow rate is then determined from Fig 34. This time will be approximately equal to the scram insertion time of the situation under consideration.

In the case of the driver fuel assemblies, the monitor tube pressure differential and the individual calibration curves will give a direct reading of the flow rates through the driver fuel assemblies at all times. If a significant film formation occurs, a direct reading of the decreased flow rate or rates will be available.

EOCR CONTROL ROD FUEL & POISON SECTION

FLOW RATE Versus PRESSURE DIFFERENTIAL

500°F SANTOWAX OMP
(CALCULATED VALUES)

Fig A-1 Calculated Flow vs Pressure Differential

C. Major Modifications Proposed

Several major modifications to the control rod design were proposed and considered during the course of the test program. At the present time none of the modifications are being considered for reactor use. Below is a brief presentation of two of the modifications.

The most unique modification proposed was a system whereby the reactor outlet pressure was imposed on the bottom face of the control rod assembly. This system would eliminate the pressure differential force which tends to lift the assembly. This pressure balance would be accomplished by means of sliding seals and special pressure channels. Phillips EOCR Design Engineering is preparing a conceptual design of this system.

A second modification considered was an air-assist scram mechanism. This system entailed the installation of a pressurized air cylinder between the reactor top head and the drive mechanism. This cylinder would provide sufficient scram insertion force to overcome a 40 psi pressure differential acting upward on the control rod assembly.

D. New Flow Test Facility

The new EOCR Flow Test Facility is presently under construction adjacent to the reactor building. This permanent facility should be operational prior to reactor criticality.

The FTF is basically the same as the original test facility with a significant number of improvements incorporated into the design. The general layout of the facility together with the hydrostatic testing and 100 per cent radiographing of the loop piping will result in a much safer facility. A monorail crane inside the building enclosure will be utilized to insert and remove test pieces from the test vessel thus eliminating the hazards and scheduling problems associated with the old

mobile crane method. The plant auxiliaries such as nitrogen, steam and new coolant will be provided by the reactor utility systems thus providing greater capacity and increased reliability for these systems. Additional safety is also provided in the fire hazard area by the presence of a sprinkler system and the use of Class I, Division II electrical equipment. All the general purpose electrical equipment is installed in the control room which is positively pressurized with outside air.

All of the components from the original facility are being reused with the exception of the surge tank and the piping. A new surge tank was required for the increased system capacity. The new surge tank is heated with steam tracing rather than electric immersion heaters. New piping is being installed throughout the facility.

In addition to the original test vessel, a special test section will be installed in which individual fuel sections, both control rod and driver fuel sections, can be hydraulically tested. This testing arrangement will facilitate more rapid testing of the components to be used in the reactor. This special test section will also be designed to handle any future prototype components, such as power fuel prototypes, which may be tested in the reactor as well as capsule and in-pile tube experiments.

Two items which existed in the original test loop have been deleted. These are the fin-tubed cooler and the nitrogen pressurized draining method. The fin-tubed cooler was deleted in that the pipe rupture which forced the cessation of Santowax testing in the original loop occurred in the cooler loop. Also, it was found that rapid cooling of the test medium was seldom required.

Gravity draining of all the loop piping is to be utilized

throughout the FTF. A few small sections will have to be drained into 55 gallon drums rather than into the surge and storage tank.

R E F E R E N C E

- (1) R. B. Bird, et al., "Transport Phenomena", New York,
John Wiley & Sons, 1960.

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