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AEC RESEARCH AND DEVELOPMENT REPORT

PERFORMANCE OF HWCTR SAFETY ROD AND CONTROL ROD DRIVE SYSTEMS

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DU PONT

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PERFORMANCE OF HWCTR SAFETY ROD AND CONTROL ROD DRIVE SYSTEMS

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October 1965

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CONTRACT AT(07-2)-1 WITH THE UNITED STATES ATOMIC ENERGY COMMISSION

ABSTRACT

The Heavy Water Components Test Reactor (HWCTR) is a pressurized, D_2O reactor that has 18 control rods and six safety rods, each driven by an electric motor through a rack and pinion gear train. Racks, pinions, and bearings are located inside individual pressure housings which penetrate through floating ring labyrinth seals. The drives are mounted on the top head of the reactor vessel. Safety rods have electromagnetic clutches and drop into the reactor when it is scrammed. The reliability and performance of the rod drives were very good, from initial critical on March 3, 1962, to termination of operation on December 1, 1964. Seal leakage was well within design limits. Inspection of seals and control rod parts showed no evidence of deposit buildup or stress corrosion cracking of type 17-4 PH stainless steel components. The accident potential of the system is acceptably low.

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PERFORMANCE OF HWCTR SAFETY ROD AND CONTROL ROD DRIVE SYSTEMS

INTRODUCTION

This report is a record of the performance of the control rod and safety rod drive systems during three years of operation of the Heavy Water Component Test Reactor (HWCTR). This information is of special interest because the drive systems contain parts made from 17-4 PH stainless steel, which had earlier given rise to problems in other reactors.[1] The accident potential of the system is analyzed and conclusions are made concerning the reliability of the drives and operating experience.

The HWCTR is designed to test natural uranium fuel assemblies, up to ten feet long, at powers and exposures expected in full scale power reactors. The HWCTR is a helium pressurized reactor, cooled and moderated with D_2O. The maximum power is about 70 MW and design pressure is 1500 psig at 315°C. The reactor was designed and constructed by E. I. du Pont de Nemours and Company for the U. S. Atomic Energy Commission under Contract AT(07-2)-1. It is located at the Savannah River Plant, Aiken, South Carolina. The reactor and containment building are shown in Figure 1. A complete description of the reactor facility is given in reference 2.

The HWCTR was operated for the U. S. Atomic Energy Commission by the Du Pont Company from March 1962, to December 1964, as part of the development program for power reactors cooled and moderated with D_2O. Operation was terminated and the facility placed in standby condition when this USAEC program was redirected toward D_2O reactors that are organic cooled.

SUMMARY AND CONCLUSIONS

During the three years of operation of the HWCTR, none of the abnormal actions of the control and safety rods ever prevented the reactor from shutting down promptly or involved adding reactivity at an unsafe rate. Requirements of the HWCTR Technical Standards and the AEC Technical Specifications for the HWCTR were met at all times.

Parts of the control and safety rod system operated abnormally on fifty-nine occasions. For the purpose of this report, the word abnormal is all inclusive; for example, it includes such faults as cracked plastic cover plates and minor difficulties in latching a rod. On only three occasions did a control or safety rod fail to insert completely into the

reactor core and these three occurred during the first two weeks of reactor operation while tests were being made with the reactor subcritical. Fifty-four percent of the difficulties occurred during the initial test period for the reactor. Thirty-seven percent of the difficulties occurred during nuclear operation of the reactor. Design changes and improved preventive maintenance programs corrected all deficiencies.

In April 1963, and December 1964, rod drive assemblies and shaft seal assemblies were removed for inspection. Very little wear was found and no deposits or foreign matter were found in the close-fitting seal rings. Parts fabricated from 17-4 PH stainless steel showed no stress corrosion cracking.

Seal leakage at pressures of 1000 to 1200 psig was satisfactory. Leakage collected from the low pressure end of the seal was about 0.3 lb per hour per seal.

Table I summarizes the rod system difficulties from March 3, 1962, to December 1, 1964.

TABLE I

Summary of Difficulties with HWCTR Rod Drive System

Number of operating difficulties		59
Mechanical	18	
Electrical	31	
Others	10	
Number of difficulties during nuclear operation		22 (37%)
Number of difficulties during initial test period		32 (54%)
Total safety rod drops		~1800
Failures to drop within time limits		11
Too slow	8	
Incomplete drop (stuck)	3	

DETAILS

DEVELOPMENT OF ROD SYSTEMS

DESCRIPTION OF ROD DRIVES

Drives for the twelve individual control rods, six central cluster control rods, and six safety rods are directly above the reactor. Each of the individual control and safety rod drives is attached to an individual rack drive housing. The drives for the six central cluster control rods are attached to a common rack drive housing. The top drive platform serves as a maintenance platform for the drives, and provides support for the four jacks used to lift the reactor head. The central cluster rack drive housing is guided by the platform when the reactor head is lifted. Each rack drive housing is held in alignment by a sliding-key connection to the central cluster rack drive housing. These connections allow differential thermal expansion of the housings.

The entire rack drive housing is 20 feet 8-13/16 inches long and consists of a stainless steel drive housing welded at the top and bottom to two sections of two-inch stainless pipe. The bottom section terminates at a flange that is bolted to the reactor head. The top section is flanged to allow removal of the rack. The vertical housings are shown in Figure 2. A cross section of the reactor is shown in Figure 3. The rack, pinion, snubbing springs, and bearings are in the housings; all other drive components are outside the housings.

Latches for gripping the control and safety rod poison sections are at the lower end of each rack assembly; the latch actuating mechanism, a trapped-nut translating-screw type, is in the upper end. The nut has gear teeth machined across its outside face so that latching and delatching can be done by a special tool inserted through a flanged access port above the drive motor. Each rod must be individually delatched before the reactor head can be removed.

The rack drive pinion gear is spline-coupled to the pressure seal shaft. One end of the seal housing is bolted to the rack drive housing and the other is bolted to the 45° bevel gear housing. The seal contains 10 pairs of Stellite and Monel labyrinth rings, a stainless steel shaft, a stainless steel low pressure bushing with neoprene O-rings, and a high pressure Stellite lantern ring. A 45° bevel gear is bolted to the low pressure end of the shaft. Figure 4 is a photograph of the seal components, and Figure 5 is a sectional view of the seal assembly.

The seal is a controlled-leakage seal. Filtered heavy water at 30°C is forced into the high pressure lantern ring from an overhead seal head storage tank. Because the tank is vented to the reactor gas space, seal water supply is at a constant head. The difference in elevation between the seals and the head tank is about 43 feet. The seal water leakage path is split; part of the flow goes into the reactor through the drive housing and the remainder goes down the shaft through the pressure breakdown seal rings. This leakage is collected in the main D_2O storage tank at a pressure of 10 inches H_2O.

The seal head tank is supplied from the purification collection tank by a positive displacement triplex reciprocating pump. The seals thus receive only filtered heavy water.

The bevel gear on the low pressure end of the seal shaft mates with the gear on the lower end of the limit switch assembly. The limit switch assembly is a traveling-nut, fixed-screw type, with the shaft serving as an actuating screw and the main drive member. Upper and lower travel limit switches are actuated by the traveling nut. A safety rod drive assembly is illustrated in Figure 6.

The gear motor, which drives the pinion, is bolted to its rack housing and is connected to the limit switch assembly with a flexible coupling. It is a 208-volt AC motor with two-speed windings and an electric brake. The control rod motors are wired for 1140 rpm and 580 rpm operation. The control rod slow speed winding is energized from a variable frequency generator that gives a rod speed from 0.25 fpm to 1.25 fpm. On high speed, the rack speed is 2.5 fpm. The safety rod motors have only the high speed winding connected and are always driven at 2.5 fpm.

A flexible coupling connects a shaft extension of the gear motor to a position-indicating synchro transmitter. The synchro actuates a digital readout indicator in the control house. Only the control rod drives are equipped with the position-indicating system, because safety rods are used only in the up or down limit positions.

Safety rod drives contain a clutch assembly between the gear motor and limit switch assembly. This assembly contains a magnetic clutch that is deenergized to effect a gravity-fall scram, and an overrunning mechanical cam clutch that allows the motors to drive the safety rods in if they do not drop freely. When the reactor is scrammed, the safety rods drop 9-1/2 feet after the clutch is automatically demagnetized; the control rods drive automatically into the core.

REACTIVITY WORTH OF ROD SYSTEM

The lattice arrangement for the HWCTR is shown in Figure 7. The 24 driver elements are on a circle with a 20-inch radius. Each driver assembly consists of a fuel tube, a housing tube, and a burnable poison target in the center of the tube. Inside the driver ring, the ring of 12 control rods is evenly spaced on a circle with a radius of 15.5 inches. All 12 rods are 1.25-inch-OD stainless steel that contains about 1.0% natural boron by weight. The test region contained a central control rod cluster surrounded by 12 test elements on a 7-inch triangular lattice spacing. The central control cluster contained six rods similar in construction to the outer control rods. The six safety rods are 1.25-inch-OD tubes of 1.0% boron stainless steel, spaced evenly on a circle of 12-inch radius.

The average worth of a single control rod was 0.017 k in the normal driver-test lattice. The 12 ring control rods were worth 0.20 k. The worth of the central control cluster was 0.025 k. Under normal operating conditions, the maximum rate at which reactivity could be added by control rod motion was 0.0005 k/sec. This rate was attained during the simultaneous withdrawal of two ring control rods (normally paired together) at the maximum rate of 2.5 ft/min from their position of maximum reactivity worth. This ramp k input was used in the safety analysis that established the scram set points of the automatic safety circuits.

The worth of the six safety rods was 0.09 k. The safety rods were normally withdrawn two at a time at a maximum speed of 2.5 ft/min. The maximum rate of reactivity addition during safety rod withdrawal was 0.0004 k/sec. Drive power to the control rods was interlocked such that all safety rods had to be fully withdrawn before the control rods could be moved. With the safety rods withdrawn, Technical Standard requirements at the HWCTR required a minimum shutdown margin of greater than 1% $(\Delta K/K)_{eff}$; this margin was always greater than 4% $(\Delta K/K)_{eff}$ for all HWCTR charges.

DESIGN CONSIDERATIONS

The Engineering Department of the Du Pont Company designed the rod drive units; starting in the latter half of 1957. A motor-driven rack and pinion type of drive was preferred because it had been proven reliable, and it was compatible with space restrictions in the cluster rod drive package.

In July 1958, the concept of top-located drives was selected. The major consideration was the fact that in a bottom-located, gravity scram concept, the irradiated rod follower section would be driven down below the reactor, and would create a serious shielding problem. Other advantages of top-located drives are simplified design and maintenance requirements, and the ability to remove a drive assembly without draining the reactor. A disadvantage is the necessity of delatching all rods to remove the reactor head.

Because there was no information available at that time as to the practicality of hydraulic snubbing of the safety rods, an inertial wheel was designed and provision was made for its possible inclusion. This inertial wheel would decrease the acceleration of the safety rod and rack when scramming, so that a mechanical spring could be employed for complete snubbing. This assembly was later eliminated from the design when tests proved the feasibility of hydraulic snubbing which protects the reactor internal elements in the event of breakage or accidental delatching of a control rod.

The pressure breakdown, floating ring labyrinth seal was designed to duplicate closely the type of seal in use on existing rod drives. To make it a self-contained assembly, completely interchangeable on all HWCTR rod drives, it was further refined to include its own bearings. This concept of driving through a seal into the pressure housing permitted the use of less exotic materials than would be required for a canned drive.

Modular design, incorporating interchangeable subassemblies, was used wherever possible. The safety rods, control rods, and cluster control rods vary only in minor details. Motors, couplings, clutches, limit switch assemblies, bevel gears, and seals are completely interchangeable. Because 24 drives were required, castings were used as much as possible. Maximum use was made of commercially available parts.

DEVELOPMENT TESTING

To obtain data for the final design, a developmental testing program was initiated in January 1959. The program was divided into two categories: rod latch testing and hydraulic snubbing.

Latching Tests

The latch proposed for the final design was a pivoting finger, sliding actuator-button type. Two variations of the design were considered. The first consisted of three gripping fingers, a finger housing, and an actuating button and rod. The second design included a secondary protective housing into which the fingers and finger housing retracted after delatching, and a spring to impart return motion. As the additional parts in the second design made it more liable to malfunction, the reliability of the two mechanisms was tested. The nonretracting latch is shown in Figure 8.

The five-year design-life of each safety and control rod was estimated as 1000 and 1500 complete cycles, respectively. A satisfactory latch mechanism should thus survive without malfunction at least 3000 cycles of: enter rod — latch — apply load — relieve load — delatch — leave rod.

There was no malfunction or failure of either latch design during extensive testing that included 52 days of exposure to water flow at 260°C in an autoclave. Both designs were in a similar condition at the end of the tests. The nonretracting latch was chosen for the final design because it contained fewer parts than the retracting type.

Drop Tests

When a scram occurs, the safety rods are dropped 9/1-2 feet by de-energizing the magnetic clutch. A dashpot at the lower end of the guide tube was believed to be the most simple way to decelerate the rods at the end of the fall.

Tests were conducted to prove the feasibility of hydraulic snubbing and to obtain design data. High speed motion pictures were taken to record drops so that deceleration and impact could be observed. Drop times of about three seconds and smooth deceleration were achieved with the following features: 1) a combination orifice and drain hole at the bottom of the guide tube; 2) a three-foot dashpot section at the lower end of the guide tube, 0.060-inch larger than the safety rod; 3) water exit holes just above the dashpot section; and 4) an Inconel spring at the bottom of the tube to absorb the final impact. The lower section of the guide tube is shown in Figure 9.

PROTOTYPE FABRICATION AND TESTING

Prototype testing was necessary to: 1) demonstrate complete operability and dependability before accepting the drives for installation; 2) demonstrate scram times under precisely duplicated reactor conditions; 3) confirm that required cooling water flow would be achieved; 4) determine the effect of 315°C operating temperature on critical internal parts.

The prototype fabrication and testing were subcontracted to Alco Products, Incorporated. They fabricated all drive components except the gears, racks, rollers, and shaft seals; these parts were purchased separately. Photographs and measurements were taken of subassemblies and parts that were expected to wear.

Two prototypes were tested between July and December 1959. The complete test facility was designed and built by Alco. Du Pont furnished a concept layout of an autoclave that duplicated the internal configuration of the HWCTR. Except for preliminary cold cycling, all testing was carried out under the maximum expected reactor operating conditions of 315°C and 1500 psig, and with water circulation through the rods. To minimize corrosion, chlorine and oxygen contents of the test loop were held to maximum limits of 2.0 and 0.7 ppm, respectively. Nitrogen instead of helium was used for pressurization.

The safety rod drive was disassembled and inspected after 500 cold cycles. Some minor design changes were made as a result of galling and binding.

Hot testing was then started and continued for 1500 cycles. Binding occurred on four occasions, but was attributed to excessive eccentricity of the guide tube. Scrams were made on 497 cold cycles and 600 hot cycles. Wear and corrosion rates at the conclusion of the tests were considered satisfactory.

The control rod assembly was tested for 100 cold cycles and 2900 hot cycles, with only minor electrical difficulties. The condition of all parts, except the pinion, was satisfactory at the conclusion. Although pinion wear was excessive during the test, a control rod pinion showed no significant wear after three years of reactor operation.

The average seal leakage rate during the tests was 2.7 pounds per hour per seal. Total seal water consumption was 3.8 pounds per hour per seal. Leakage experienced during reactor operation was considerably different; see "Seal Performance," page 16.

Drop times of 95 scram tests were recorded. The average drop time was 1.57 seconds. Scram times in the reactor are discussed in "Safety Rod Scram Times," page 18.

After completion of all testing, the two units were disassembled and shipped to the Savannah River Plant where they were installed on the reactor after overhaul and replacement of worn parts.

OPERATING EXPERIENCE

There were 59 instances of component failures or abnormal operation in the rod drive system during the three-year history of the facility. None of these prevented or inhibited the reactor from shutting down promptly or involved adding reactivity at an unsafe rate. As shown previously in Table I, page 2, 63% of the problems were discovered during routine checking or planned inspections of the rod systems, and 54% occurred during the early stages of testing the new reactor. Many of the problems reported in this section in no way prohibited normal movements of the rod drive; for example, failure of console position indicators or cracked plastic casings on limit microswitches. The detailed treatment of each component failure, regardless of consequence or potential, serves to show the excellent performance of a system that contained many thousands of mechanical and electrical components.

Difficulties are listed in Tables II, III, IV, and V. Mechanical component failures are listed in Table III, and electrical component failures are listed in Table IV. Table V itemizes those malfunctions or failures involving parts of the system other than drive components, such as guide tubes and control rods.

Table II lists those incidents shown in Tables III, IV, and V, which occurred during nuclear operation of the reactor. This category comprised 22 out of 59 of the total incidents; ten of these occurred during the low power (<10 kw) test period following initial criticality in March 1962.

The malfunctions listed in Table II are divided into six types: (1) uncontrolled rod motion, (2) lack of rod motion on demand, (3) intermittent stops in rod motion, (4) reverse rod motion, (5) slow rod motion, and (6) lack of rod position indication at console. None of the incidents involved the scram feature of the safety rod system or, except in one instance, the ability of the control rods to drive in automatically if an automatic scram had been received. This instance, item 4, involved a single control rod whose slow speed motor had been miswired during a preceding shut down such that the direction of motion was reversed. The problem was discovered immediately after attaining criticality when control rod motion is switched from fast to slow speed and each individual rod is tested.

The only other two instances that involved the addition of reactivity to the system occurred once during the initial-critical test and once a few days subsequent to that test (Table II, item 1). In each case, the safety rod control switch failed so that the switch contacts were left in their demand position during an incremental

TABLE II

Rod Drive System Malfunctions During Nuclear Operation

Description of Problem	Rod No.	Date	Cause
(1) Single rod drove in or out of reactor uncontrolled	CR-3 CR-1	3/3/62 3/7/62	Bakelite cam on individual rod drive control switches failed under turning force on switch
(2) Rod(s) failed to move on demand signal from console	All	3/29/62	Cluster rod master drive relay failed. Insulation breakdown.
	Various CR's	3/62	Silicone grease, applied by vendor, in circuit breakers on rod drive distribution panel caused shorts. All switches replaced 3/30/62.
	All CR's	1/4/63	When rods switched to slow speed after attaining critical, no rods could be driven. All slow drive switches found turned off.
(3) Intermittent electrical faults in relay coils, switches, or wiring caused momentary stops in rod drives	Various CR's on 6 occasions	3/62 5/62	Inadequate auxiliary relay coils. All coils replaced in May 1962.
	CR-5,11	6/18/64	Rod pair momentarily failed to move on demand during power ascension. Cleared after energizing several times.
	CR-1,7 8,9,10	11/26/64	Intermittent drive interruptions while at power. Relay contacts cleaned and trouble corrected.
(4) Control rod direction reverse from console demand	CR-4	1/4/63	When rods switched to slow speed after attaining criticality, CR-4 motion found to be reverse from demand. Wiring to slow speed motor had been reversed during previous shutdown.
(5) Rod driving slower than normal	CR-6 CR-4	12/2/62 12/3/62	High motor currents during rod withdrawal on slow speed. One motor bearing rough but not frozen. Intermediate fiber gear showed slight wear.
	CR-4 CR-6	11/18/63 11-23-63	Intermittent high motor currents and slower drive than other rods. Near end-of-exposure life on rods. Rods were slightly bowed when discharged.
(6) Failure of rod position indicators at console	CR-3 CR-12 CR-2 CR-6	6/23/64 6/25/64 7/64 9/22/64	Synchrotransmitters failed. Cause was not determined.

out-motion of the rods. No real safety hazard was involved in either case because the total worth of a single safety rod (about 0.015 k) was so much smaller than the shutdown margin at the instant of the two events (about 0.10 k and 0.13 k, respectively). In both cases, a manual scram was initiated immediately upon the advent of uncontrolled motion. Details of the switch failure are in "Electrical Failures," page 13.

MECHANICAL FAILURES

There were 18 mechanical failures of rod drive components. Table III shows that six occurred in March and April 1962. The first two items in the table were caused by personnel errors. Safety rods 2 and

TABLE III

Rod Drive Component Mechanical Failures

Description	Rod No.	Date	Remarks
(1) Broken or bent latch fingers and latch actuator rod	SR-2 SR-3	3/3/62 3/3/62	Rack scrammed without an attached rod. Fingers replaced.
	SR-5	4/5/64	Fingers left in closed position when driving down to latch.
	SR-3	6/1/64	Rack dropped from upper limit during delatch operations.
(2) Seal spacer galled on seal shaft	SR-2	3/17/62	Seal improperly assembled.
(3) Backup roller and rack galled Roller not rotating freely on shaft	SR-2	3/29/62	Unknown substance caused binding between roller and stud. Roller and stud replaced. Rack smoothed with file.
	SR-5	4/7/64	Unknown.
(4) Deformation of safety rod clutch shaft caused clutch to bind	SR-4 SR-5	3/10/62 4/7/62	Shaft size and hardness not sufficient for load. Stronger shafts installed.
(5) Actuating cam on limit switch broken	SR-3 SR-4 SR-5	8/20/62 9/8/62 9/8/62	Under-strength cam. Limit switch improperly adjusted. Stronger cams installed.
(6) Cracked safety rod cam clutch	SR-2 SR-4 SR-5 SR-2	9/20/63 11/18/63 12/63 3/19/64	High impact loads and lack of adequate radii in clutch keyway.
(7) Binding in reduction gear assemblies or motor bearings	CR-6 CR-4	12/2/62 12/3/62	High motor currents during rod withdrawal on slow speed. One bearing rough but not frozen. Intermediate fiber gear showed slight wear.

3 (SR-2 and SR-3) were not latched properly prior to the initial-critical experiment. The reactor was made critical and the rods were scrammed a number of times before the delatched condition was discovered. The scram tests caused the damage described in the tables; the latch fingers and actuator rods were replaced.

Personnel errors are believed to be responsible for three other mechanical failures, items 2 and 3 of Table III. The seal shaft galling was caused by improper assembly of the seal and prevented the rod from dropping completely into the reactor core. It is probable that lubricant was improperly applied to the backup roller and stud. In the reactor atmosphere it became sticky and prevented the roller from rotating freely on the stud. Galling between the rack and roller resulted.

On March 10, 1962, the clutch shaft seized and prevented SR-4 from dropping completely into the reactor during shutdown testing (item 4). The motor drove the rod in. It was subsequently determined that the shaft had been deformed by the clutch cams and was below specifications for hardness. The same condition in SR-5 was revealed during an inspection on April 7, 1962. All six clutch shafts were replaced with larger, stronger shafts in May 1962. A cam clutch rated at 150-ft-lb torque was also installed to replace the original 65-ft-lb clutch. Subsequent performance of these new components was satisfactory.

When the broken cam on the limit switch was discovered on August 20, 1962, it was replaced with a cam having a thicker, stronger actuating lip. Inspection of the remaining five units on September 8, revealed two more cracked cams. All five cams were then replaced with newly designed cams. Improper safety rod limit switch settings contributed to the cam failures. The control rod switches were set properly, and the original cams on the control rods were satisfactory.

In late 1963, several rods failed to drop freely (item 6). Investigation revealed that the overrunning cam clutch, used to drive in a rod that fails to fall, was cracked through the race at the base of the keyway. This point was suspected to be a location of high stress concentrations because the keyway was cut with virtually no radii in the corners. A crack of this type is believed capable of jamming the clutch and preventing free fall of the rod.

Replacement clutches with 0.020 to 0.025-inch radii in the keyway corners were installed upon advice from the vendor that these keyways should have a significant radii.

After the cracked clutch was discovered in March 1964, in a unit that had a 0.025-inch radius keyway, the practice of driving the safety rod rack down onto the latch holdup tool was suspected of causing high impact loads and resultant cracks. To rectify this situation, latches were no longer driven onto the holdup tools but were manually lowered, even though the operation was time consuming.

In August 1964, all clutches with 0.025-inch radii that had been in service since March 1964, were inspected after driving the racks down onto holdup tools 25 times. No cracks were observed. The clutches were than loaded with a static torque, and four of the six failed. At the same time, new clutches with 0.060-inch radii were tested in the same fashion, and none failed. The 0.060-inch radii clutches were installed and no failures occurred thereafter, even though the practice of driving racks onto holdup tools was resumed.

ELECTRICAL FAILURES

Thirty-one electrical failures that caused abnormal rod drive operation are listed in Table IV according to type of failure. Each of the components failed or caused trouble several times. Twenty-one of these failures occurred during the initial two-month testing period.

Three of the switch failures (Table IV, item 1) caused rods to drive out of the reactor. The fourth caused a rod to drive in. Two of these failures occurred during nuclear operation and are listed in Table II. The switches that failed were a double block selector type employing a spring return. Turning the control knob in one direction or the other turned a Bakelite* cam that depressed one contact shaft and allowed the other to rise. Due to the heavy spring in the assembly, enlarged knobs were used to operate the switches. These enlarged knobs permitted excessive torque to be exerted on the cam. With no mechanical stops in the switch, it was possible to turn the cam past its normal end point and break it. Failure of the cam in this manner left the cam in the failed position and hence the switch contacts in the last position demanded. The rod drives could only be stopped by scramming or turning off the power. All of the switches were replaced with switches employing metal cams with mechanical stops. Replacement was completed on March 30, 1962, and no more failures occurred.

Clutch coil failures (Table IV, item 2) in 1962 were caused by excessive voltage to the coil. Resistors were inserted in the circuits to reduce the voltage to design value. As a backup, a coil with a higher temperature class of insulation was successfully tested and was available for use. Shorting occurred twice again in 1964, but the cause was not determined.

* Trademark of Bakelite Corporation for organic polymers.

TABLE IV

Rod Drive Component Electrical Failures

Description	Rod No.	Date	Remarks
(1) Broken rod drive control switch cam	CR-3 CR-1 SR-4 CCR-5	3/3/62 3/7/62 3/22/62 3/23/62	Bakelite cams could not withstand turning force on switch. Switches were replaced on 3/30 with metal cammed switches.
(2) Shorted or grounded safety rod clutch coils	SR-3 SR-3 SR-2 SR-3 SR-5 SR-2	3/21/62 4/18/62 7/25/62 8/14/62 5/11/64 8/24/64	Failures in 1962 caused by excessive voltage applied to coils. 1964 failures were from insulation breakdown due to age or defect, cause not established.
(3) Relay coil or contact failure	All CCR	3/29/64	Insulation breakdown in cluster rod master drive relay.
	CR-3	3/5/62	Insulation breakdown in motor starter overload relay.
	SR-4	3/17/62	Open in relay coil for safety rod circuit interlock.
	SR-4 CR-6	3/62	Silicone grease applied by manufacturer caused shorts in rod drive circuit breakers. All switches replaced March 30.
	SR-5 and 6 others	3/3 to 4/6/62	Cases on seven up or down limit microswitches cracked during assembly of housing cover. Switches modified to prevent damage.
	Various CR's	3/62 to 5/62	Inadequate insulation on auxiliary relay coils. All coils replaced in May 1962.
	CR-5 and 11	6/18/64	Poor or dirty contacts on control rod drive switches. Switches energized several times and fault stopped.
	CR-1,7, 8,9,10	11/26/64	Motor power interlock relay contacts cleaned and trouble corrected.
(4) Failure of rod position indicators at control console	CR-3 CR-12 CR-2 CR-6	6/23/64 6/25/64 7/64 9/22/64	Synchro-transmitter failures, cause not determined.
(5) Loose or incorrect wiring	CR-4	1/4/63	Wiring to slow speed motor winding reversed during shutdown work.
	All	7/4/64	Disconnected wire found in scram relay reset circuit.

Circuit breakers, relay coils, and poor contacts gave erratic and unreliable service during the initial testing period. Thirteen of the fifteen failures listed in Table IV, item 3, occurred in March and April 1962. Replacement units supplied by the vendors gave satisfactory service.

Cracked microswitches were discovered on April 6, when the limit switch was disassembled to lubricate the guide. Although the crack extended almost completely around the switch case, the case had not come apart and the switch had operated satisfactorily. The switches were cracked in either of two ways: (1) at the time the limit switch was assembled, the contact button struck the side of the actuating cam and was cracked when the limit switch case cover was tightened; or (2) during the time the safety rod switches were adjusted upward too far, the contacts did not have a sufficient overtravel. To allow easier assembly of the limit switch, the contact buttons were rounded off. The practice of moving the switches up was discontinued in April 1962, and after that time no failures occurred.

OTHER MALFUNCTIONS

Malfunctions or failures involving parts of the system other than rod drive components are shown in Table V. During the first month of nuclear operation, the scram drop times of SR-5 and SR-6 were consistently faster than those of the other four rods. Absence of the rod support spring at the bottom of the guide tube was suspected as the cause. SR-5 and its upper and lower guide tubes were discharged for examination. Although the rod, upper guide tube, and support spring assembly were in satisfactory condition, the lower end fitting that attaches to the lower guide tube was loose. The guide tube for SR-6 was in a similar condition. The end fitting was not inserted far enough into the flared Zircaloy guide tube to make a good joint. This poor fit provided an extra opening for the escape of D_2O from the snubbing section of the guide tube and thus resulted in fast drop times.

All ring control rod and safety rod guide tubes were then discharged and X-rayed to determine the amount of contact. Eleven had unsatisfactory contact; the end fittings were repaired to provide adequate contact and a strong joint. The fittings were also machined to provide the same amount of rod insertion.

A second set of guide tube failures occurred in April 1964.[3,4] These were detected when safety rod SR-5 dropped into the reactor too rapidly on a routine test during shutdown. A few days later, SR-4 also dropped too rapidly. Four of the guide tubes were found to be either split open or broken and split. The failures were at the necked-down transition section in the Zircaloy tubing. The cause of the failures was believed to be high stresses induced in the thin wall tubing during hydraulic snubbing of a safety rod.

The tubes were replaced with spares which operated satisfactorily until termination of reactor operation. In addition, a further replacement set of guide tubes with a modified transition section (necked-down area leading into the hydraulic snubbing section) was ordered. The transition section was lengthened from about 1/4 inch to one inch so that rod deceleration would be less abrupt, thus reducing the hydraulic snubbing forces. As a result of intervening work between the original and replacement orders, an improved Zircaloy that was less susceptible to hydrogen embrittlement arising from corrosion of the Zircaloy was used for the replacements.

Replacement of the bowed rods (Table V, item 3) with unexposed rods eliminated the binding difficulty. Cause of the bowing, whether from long use, radiation induced, or a combination of the two, was not resolved.

TABLE V

Malfunctions and Failures Not Involving Drive Components

Description	Rod No.	Date	Remarks
(1) Insufficient engagement between guide tube and end	SR-5 SR-6	3/20/62	End fitting on lower guide tube loose, thus partially negating hydraulic snubbing.
(2) Broken lower guide tubes	SR-5 SR-4 SR-6 SR-2	4/2/64 4/7/64 4/11/64 4/11/64	High hydraulic snubbing forces.
(3) Binding of rod(s) in lower guide tube	CR-4 CR-6 CCR-3 CCR-4	11/18/63 11/23/63 1,2,3/64 2/15/64	When raised manually, rods bound in first four feet at certain orientations. Inspection showed slight bow in rods. As rods were near maximum exposure life, cause thought to be related to exposure.

SEAL PERFORMANCE

The performance of the 24 seals was very satisfactory. The only case of seal failure was due to improper assembly (a spacer galled and seized the shaft).

Seal leak rates for operation at pressures of 1000-1200 psig and reactor temperatures of 200-250°C are listed in Table VI. The average seal out-leakage to the low pressure system was 0.3 lb per hr per seal.

Circuit breakers, relay coils, and poor contacts gave erratic and unreliable service during the initial testing period. Thirteen of the fifteen failures listed in Table IV, item 3, occurred in March and April 1962. Replacement units supplied by the vendors gave satisfactory service.

Cracked microswitches were discovered on April 6, when the limit switch was disassembled to lubricate the guide. Although the crack extended almost completely around the switch case, the case had not come apart and the switch had operated satisfactorily. The switches were cracked in either of two ways: (1) at the time the limit switch was assembled, the contact button struck the side of the actuating cam and was cracked when the limit switch case cover was tightened; or (2) during the time the safety rod switches were adjusted upward too far, the contacts did not have a sufficient overtravel. To allow easier assembly of the limit switch, the contact buttons were rounded off. The practice of moving the switches up was discontinued in April 1962, and after that time no failures occurred.

OTHER MALFUNCTIONS

Malfunctions or failures involving parts of the system other than rod drive components are shown in Table V. During the first month of nuclear operation, the scram drop times of SR-5 and SR-6 were consistently faster than those of the other four rods. Absence of the rod support spring at the bottom of the guide tube was suspected as the cause. SR-5 and its upper and lower guide tubes were discharged for examination. Although the rod, upper guide tube, and support spring assembly were in satisfactory condition, the lower end fitting that attaches to the lower guide tube was loose. The guide tube for SR-6 was in a similar condition. The end fitting was not inserted far enough into the flared Zircaloy guide tube to make a good joint. This poor fit provided an extra opening for the escape of D_2O from the snubbing section of the guide tube and thus resulted in fast drop times.

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A second set of guide tube failures occurred in April 1964.[3,4] These were detected when safety rod SR-5 dropped into the reactor too rapidly on a routine test during shutdown. A few days later, SR-4 also dropped too rapidly. Four of the guide tubes were found to be either split open or broken and split. The failures were at the necked-

This rate is much less than that determined for the prototype. The total inleakage, however, of 7.1 lb per hr per seal up to April 1963 was about twice as great as that of the prototype. In the period between May and November 1963, total seal supply dropped to 77 lb per hour. Thus, total inleakage was reduced to 3 lb per hour per seal. The reason for this apparent decline in seal consumption was attributed to recalibration of the measuring rotameter. Out-leakage remained at 0.3 lb per hour per seal.

TABLE VI

Seal Leakage Rates, lb/hr

Total seal outleakage	7.1
Average seal outleakage per seal	0.3
Smallest outleakage of any seal	0.1
Total seal inleakage to reactor	171.0 - 77.4
Average seal inleakage to reactor per seal	7.1 - 3.2

At the maximum rod drive speed of 2.5 fpm, the seal shaft speed is 7.67 rpm, or a rubbing velocity of 1.25 fpm. During scrams, the peak shaft velocity reaches 400 fpm. Lubrication is provided only by the leakage of D_2O.

The seals of control rods 4 and 6 were inspected in April 1963, to determine the extent of wear, corrosion, crud buildup, and stress corrosion cracking. Seal parts are exposed to D_2O at 25 to 30°C. The seal shafts, seal rings, lantern rings, bushings, and rack drive pinion shaft were measured. There was from 0.0001-inch to 0.0007-inch wear on the shafts. Dimensions were unchanged on the other parts (excessive wear of the pinion was noted during prototype tests). The shafts and seal rings were very clean and no deposits were found. Only very light wear marks were observed. There was no corrosion on any of the sealing surfaces. Photographs of the inspected seals are shown in Figures 4, 12, and 14.

In December 1964, after termination of reactor operation, the seal from control rod 9 was disassembled and inspected. Again, the shaft and seal rings were very clean and there were no deposits. From these inspections it is concluded that no corrosion or crud buildup occurred in the seals.

SAFETY ROD SCRAM TIMES

To provide the protection required by the Technical Standards, the safety rods must be inserted 90% into the core within 1.50 seconds of receipt of a scram signal. In approximately 1800 safety rod drops (300 scrams), there were only three occasions when a safety rod did not fall completely into the core. On all three occasions, the reactor was subcritical prior to the drop. However, even on these occasions, technical requirements for negative reactivity were met and shutdown would have occurred had the reactor been critical because only five of six safety rods are needed to shut down the reactor. The causes of two of these failures were discussed in "Mechanical Failures," page 11. The third case occurred prior to the initial-critical on March 3, 1962, and the cause was not established. After sticking initially, the safety rod was driven out and scrammed many times without further difficulty.

Drop Time Measurements

Two types of problems were encountered in measuring the time required for 90% insertion to ensure that the safety rods dropped fast enough to meet the fast shutdown requirements. Because position indicators were not installed on the safety rods, an electronic counter was attached whenever drop time measurements were desired. To time the fall, the upper and lower limit switch relays were used to actuate the counter or recorder. The first measurements, made just prior to the initial reactor startup, showed that the total drop time (100% insertion) was not a good indication of the shutdown capabilities of the safety rods. The times were between 1.72 and 2.60 seconds; however, a considerable proportion of the time was required for the last one to two inches of travel.

Springs at the bottom of the guide tube absorb the final shock of the fall. When the rod drops freely, it is slowed only by mechanical and hydraulic friction for the first 6-1/2 feet. However, in the dashpot section, the rod is decelerated almost to a stop by the time it hits the spring. The motor, through the overrunning clutch, then drives the rod to the bottom limit, compressing the spring about an inch. The time required for this is variable and quite sensitive to small differences in limit switch settings.

To eliminate measuring this "dead" time, the bottom limit switches were at first adjusted up from one to two inches for measurements. Because the rods accomplish their nuclear functions when they reach 90% insertion, this technique was permissible. However, to obtain proper latching, it was then necessary to lower the switches after each measurement. Not only was this time consuming, but these adjustments caused switch failures (see "Electrical Failures," page 13).

Although the logical solution was to measure or record electronically the actual time for 90% insertion, no readily accessible means existed for obtaining a signal from the drives. Motion pictures were made of one of the accessible gears in the drive train. From the movies, time-displacement curves were constructed for all rods. These curves showed that only 54% of the total drop time was required for 90% insertion and that driving the last two inches required 30% of the time.

Additional drop tests were made at various moderator temperatures and flow conditions to determine their effect on scram times. Total drop times for temperatures up to 250°C are shown in Figure 18. Rod displacement and velocity curves are shown in Figure 19. The average time required for 90% insertion was 1.16 seconds at 25°C, and 1.08 seconds at 240°C. The maximum acceleration achieved was from 0.8 to 1.3 g.

Time-displacement measurements were needed periodically because the drop characteristics of the rods could be altered by wear of rod drive parts, corrosion buildup, and other factors. Because the procurement and processing of data from the motion pictures was very time consuming, a system including high speed potentiometers to provide an accurate method of recording the time-distance relation was designed. The potentiometers were coupled to the limit switch bevel gear, and the voltage output was fed to a high speed electronic recorder. Only two units were fabricated. They were used one at a time when the reactor was shut down. Periodic measurements were made to ensure that the safety rods continued to furnish the necessary scram protection.

Drop times were measured once per week for the first two months of reactor operation while the low power physics studies were conducted. After this period of satisfactory performance, operation at significant power levels commenced and the interval between tests was increased to a month. After six months of operation, the measurement interval was changed to twice a year. In addition, measurements were required whenever any part of the drive train was physically disturbed.

Difficulties in Meeting Scram Time Specifications

During tests conducted while the reactor was shut down, safety rods failed to drop into the reactor within specified limits on eight occasions. Cam clutches cracked on three occasions and the rods were driven in, rather than dropping in freely. Inadequate lubrication of the limit switch actuator nut guide, and galling of the rack backup roller, each slowed a rod once. In the other instances, maladjustment or drifting of the limit switch setting was at fault.

Adjustment of the upper and lower switches was difficult. Individual Microswitches were adjusted up and down by rotating thumbscrews that projected through the cover plate of the housing. The total available adjustment was worth 6-1/4 inches of rack travel for each switch. To move the rack setting one inch required 0.040 inch of switch movement, equivalent to 1-1/3 rotations of the thumbscrew. The adjusting thumbscrew had a locking nut. Moving this nut had the undesirable effect of moving the Microswitch a small amount. Each time rod drive components were removed or installed, the switches had to be reset to give the correct amount of travel. The settings were verified by actual measurement of rack travel from the top flange of the drive housing. This required depressurization of the reactor and the resultant waste of helium and D_2 gas.

Except for these eight occasions, drop time specifications were always met. The other individual components of the drive never caused the rods to be too slow.

ACCIDENT POTENTIAL

A recent report on the experience with control rod systems at 96 AEC-licensed reactors evaluated their performance by examining two capabilities: (1) the ability of a system to shut down a reactor promptly when a condition arose that could damage the reactor, and (2) the ability to limit the rate of reactivity addition so that fuel temperature increases did not exceed the heat-transfer capability of the reactor cooling system.[5] The problems were divided into four types: (1) stuck rods that delayed scrams, (2) difficulties with latching and control mechanisms, (3) instrument circuit problems, and (4) materials problems. Other reports[1,6,7] on reactors with rod system components and materials similar to those in the HWCTR dwell in greater detail on problems of type 1 and 4.

The accident potential of the difficulties with the HWCTR rod system has been compared to similar problems reported in the above references. As stated previously, none of the difficulties experienced with the HWCTR system ever prevented the reactor from shutting down promptly or involved adding reactivity at an unsafe rate.

STUCK RODS OR ROD DRIVES

One of the six safety rods failed to insert completely into the core on three occasions during tests while the reactor was shut down. On eight occasions, the drop time of a safety rod was in excess of its specified limit. There were 14 instances in which the seal, other rotating mechanical parts, or the rod itself caused or was suspected of binding or sticking. In all but two of these 25 instances, the problem was diagnosed and corrected. In these two exceptions, the problem did not persist long enough for study.

The accident potential of the abnormal movement of one or two rods during a shutdown condition is small because the worth of a single rod in the HWCTR control system is small compared to the total shutdown margin.

The worths of rods in the HWCTR control system are 0.017 k for a control rod, 0.025 k for all six cluster control rods, and 0.015 k for a safety rod, all of which are small compared to the total shutdown margin of 0.13 k.

The accident potential of abnormal rod movements during nuclear operation is severely restricted by choosing scram set points for all automatic safety circuits such that a ramp input of 5×10^{-4} k/sec is arrested before the heat flux of any fuel assembly exceeds 70% of the burnout heat flux. This reactivity increase corresponds to the movement of two rods at fast speed and at the point of maximum worth.

The only parts in the HWCTR system that are considered susceptible to troubles similar to those described in reference 6, and that have the potential, though remote, for negating more than one rod at the same time are the shaft seal which might stick or jam, and the rod, which might bow.

Seal performance, discussed on page 16, has shown that this design is essentially trouble free. As the seal supply water is taken directly from the effluent of the purification system, which keeps the maximum particle size to about 10 microns, crud buildup has not been a problem. The seal parts, shown in Figures 4, 12, and 14, were free from crud and corrosion when they were removed from the reactor in April 1963, and in December 1964, after one and three years of operation, respectively.

Rod bowing, discussed on page 16, caused an individual rod to drive slowly on four occasions. In each case, the bowing appeared to be associated with a radiation-induced damage near the end of the useful life of the rod, although this was not difinitely established. Because the safety rods were not in the neutron flux during operation, they had no effect on the prompt shutdown of the reactor. The small reactivity worth of a single control rod and the practice of using fresh control rods for each driver cycle provided adequate protection against this accident potential.

LATCHING AND CONTROL MECHANISMS

About 40% of the mechanical and electrical malfunctions and failures reported previously (pages 11 and 13) were concerned with latching and control mechanisms. Because the drives for the control and safety rods are mounted on the reactor vessel head, and latching and delatching operations take place with the reactor shut down with all rods inserted fully into the core, the nuclear accident potential is nil. Subsequent to the latching problem that occurred during the initial critical test (Table III, item 1), each latch-rod joint was inspected after each latch operation with a borescope inserted through an opening in the reactor head. In addition, after attaining criticality but before raising power, the nuclear response of each control and safety rod was tested by movement of the rod.

Only one of the electrical control failures reported previously (page 9) affected the ability of a rod to scram automatically. This instance involved a wiring error that reversed the direction of a single control rod. During the first month of nuclear operation, failures of rod drive control switches caused a single control rod to drive out in three instances and to drive in on one occasion. All rod drive switches were replaced with switches of a better design and no more failures occurred. The remaining control failures prevented the normal movement of a rod but did not inhibit the automatic scram feature.

INSTRUMENT CIRCUIT PROBLEMS

Difficulties associated with the instrumentation in the scram circuits have not been discussed previously in this report. Redundancy of independent scram instruments, e.g., four high level flux monitors, two log-N period monitors, two low pressure monitors, interlocks to prevent removal of more than one of two or two of four instruments without an automatic scram, and procedural control of required on-line instrumentation successfully prevented this type of problem from invalidating the safety function of a type of instrument.

MATERIALS PROBLEMS

In December 1960, failure of type 17-4 PH stainless steel control rod parts was reported in the Dresden Nuclear Power Station of the Commonwealth Edison Company.(1) These parts were fabricated by the Atomic Power Equipment Department of the General Electric Company.

Similar parts of the same material were also being fabricated for HWCTR at that time by the General Electric Company. The problem was studied in detail with the Dresden reactor operator and the vendor. Seventeen parts in each HWCTR rod drive unit made with 17-4 PH stainless steel were exposed to D_2O or D_2O vapor and helium. The temperature ranged from 250°C at the latch fingers to 30°C at the seal parts.

It was concluded that the material to be used must be aged at 1100°F, and then fabricated by techniques that would keep parts free of residual stresses. These procedures were expected to provide a satisfactory combination of strength, corrosion resistance, wear, and galling resistance under HWCTR operating conditions. The moderator water conditions are listed in Table VII. A test program was conducted at the Savannah River Laboratory and the conclusions were confirmed. Great care was taken to ensure that all 17-4 PH stainless steel control rod and safety rod parts used in HWCTR were properly heat treated and fabricated.

TABLE VII

HWCTR Moderator Conditions

pD	10.4-11.0
Chlorides	0.1 ppm
Oxygen	0.014 ppm

The possible results of the failure of type 17-4 PH parts were analyzed; it was concluded that only four of the 17-4 PH parts in the rod drive could prevent rod insertion. The complete analysis is given in Appendix A.

To obtain further assurance that the parts were not cracking, one control rod drive and two seals were inspected in April 1963, and another control rod drive and seal assembly were inspected in December 1964. The 17-4 PH parts, together with type 304 parts, were inspected with dye penetrant. No cracks were found. Photographs of the inspected parts are shown in Figures 10 to 17.

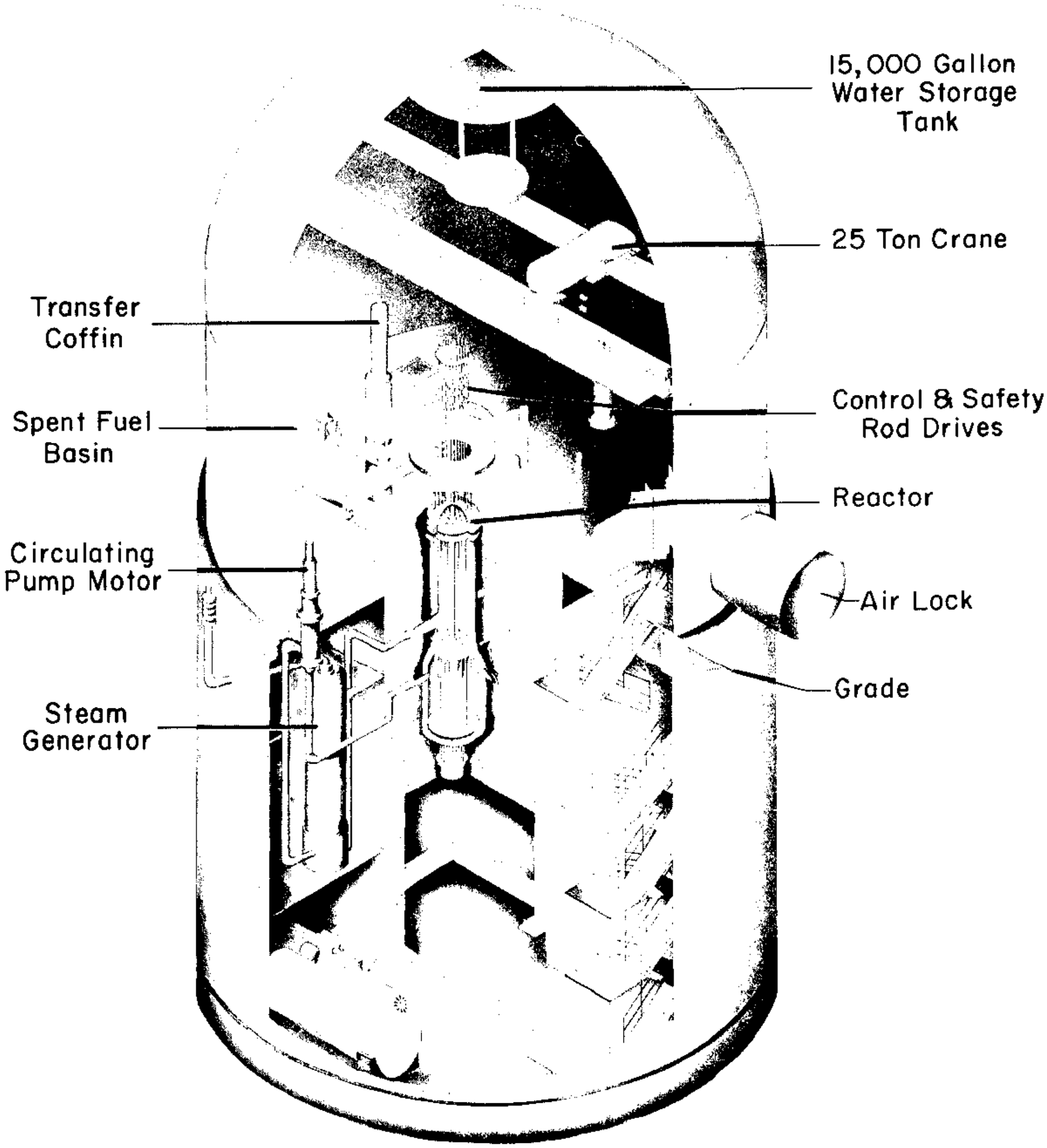


FIG. 1 THE HWCTR CONTAINMENT BUILDING

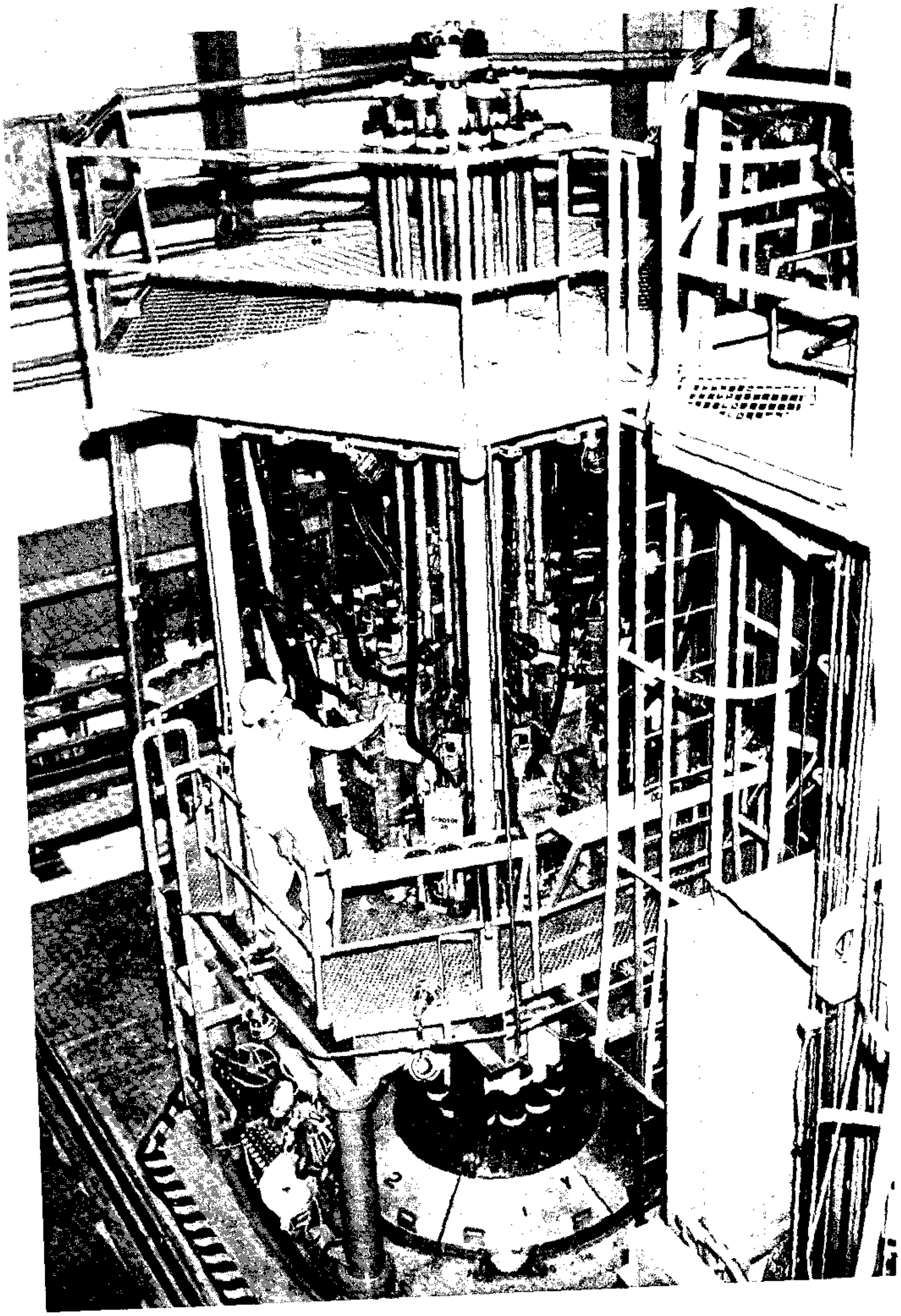


FIG. 2 THE DRIVE MECHANISMS FOR THE CONTROL AND SAFETY RODS

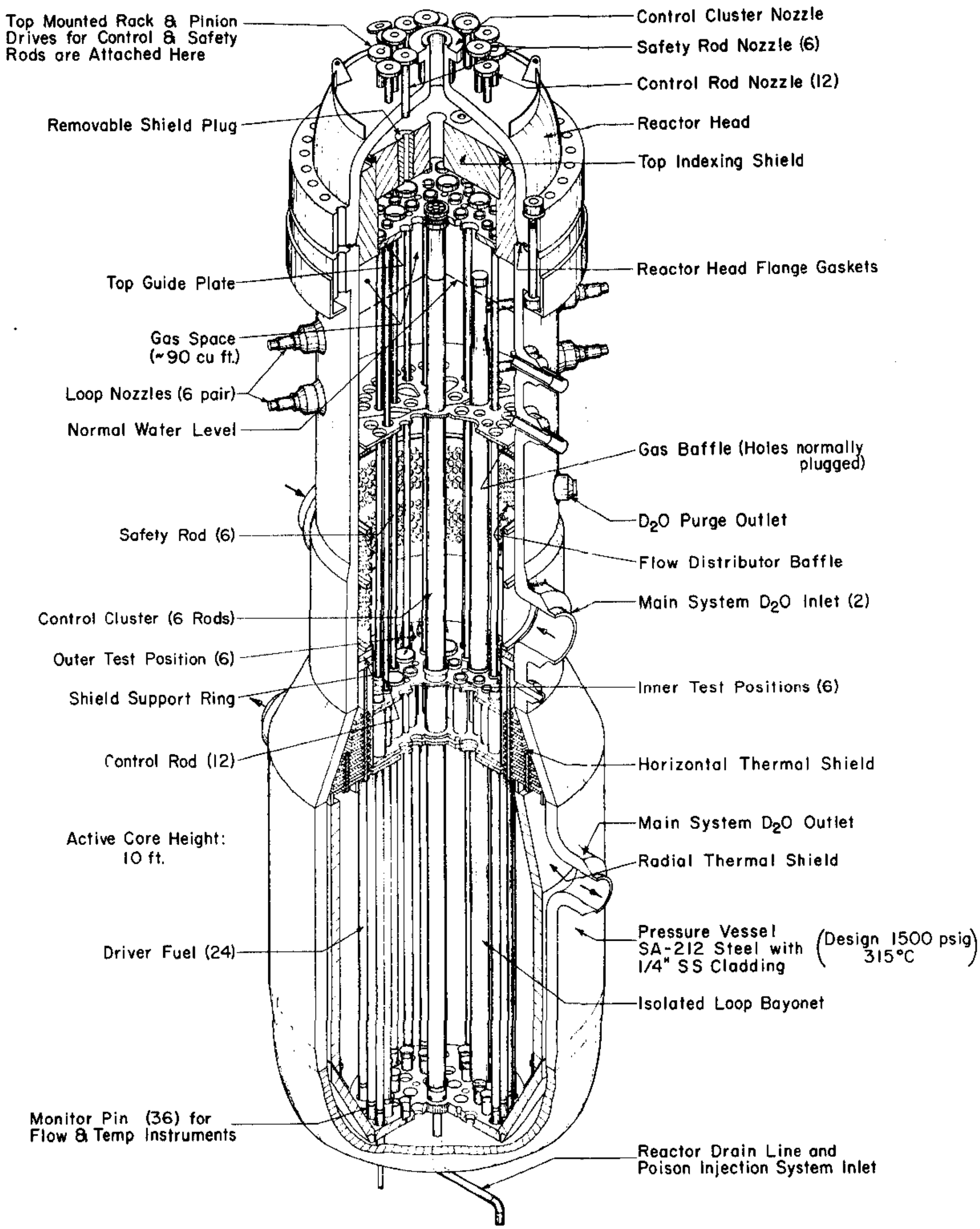


FIG. 3 CROSS-SECTIONAL VIEW OF THE REACTOR VESSEL

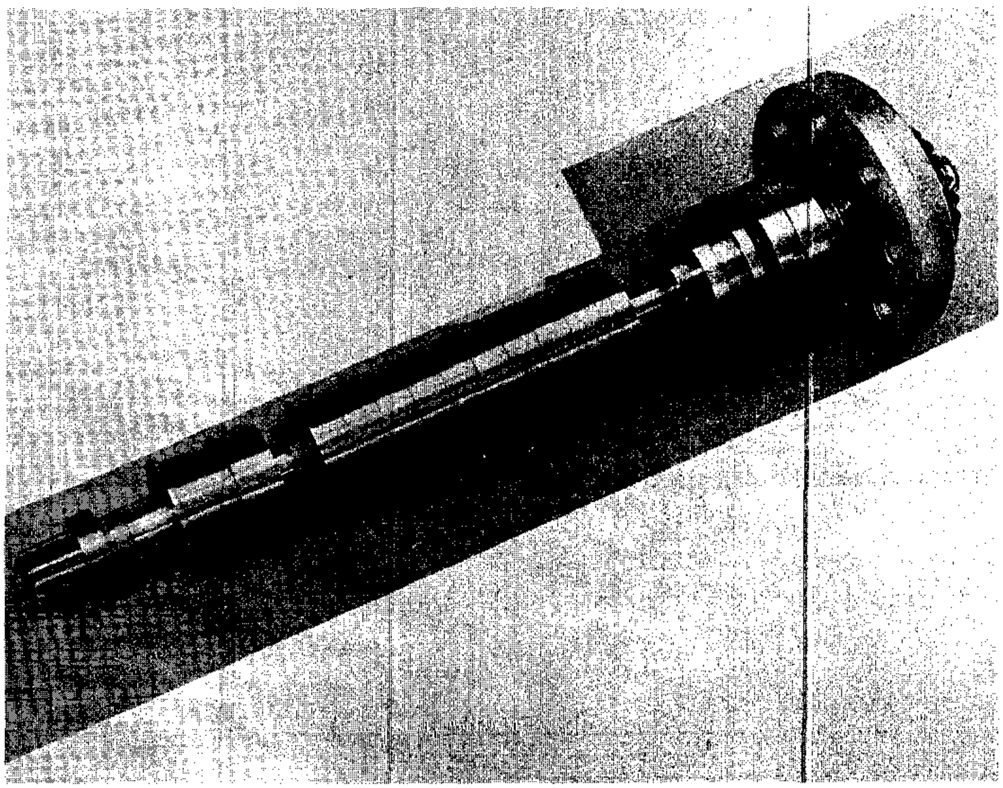


FIG. 4 SEAL SHAFT ASSEMBLY AFTER ONE YEAR OF SERVICE

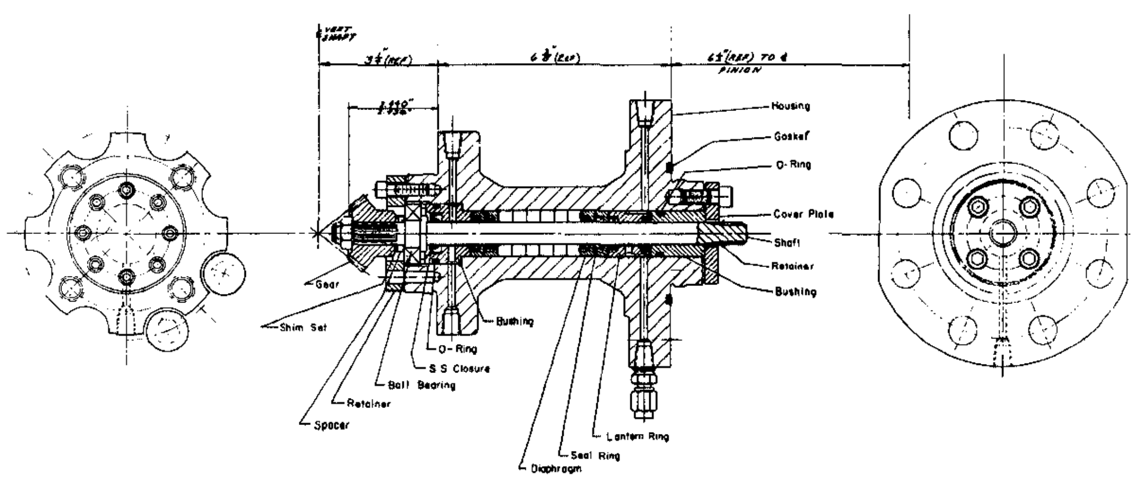


FIG. 5 CROSS-SECTIONAL VIEW OF SEAL ASSEMBLY

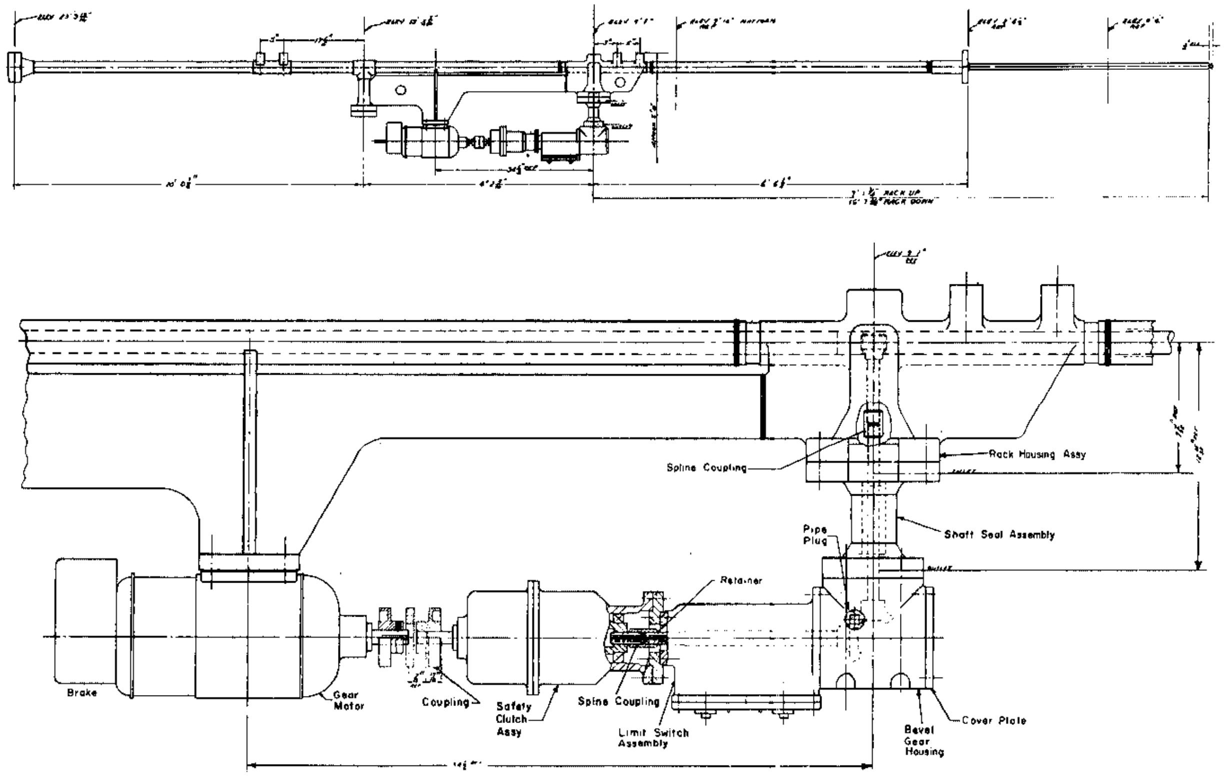


FIG. 6 SAFETY ROD DRIVE ARRANGEMENT

● 12 TEST POSITIONS

Diameter

Six outer positions	5.3 inches
Six inner positions	3.5 inches
Length	10 feet

Typical test fuel assemblies are tubes and rods of natural or slightly enriched uranium or uranium oxide clad with Zircaloy-2 or -4.

● 24 DRIVER FUEL POSITIONS

These positions can also be used as test positions.

Diameter	3.5 inches
Length	10 feet

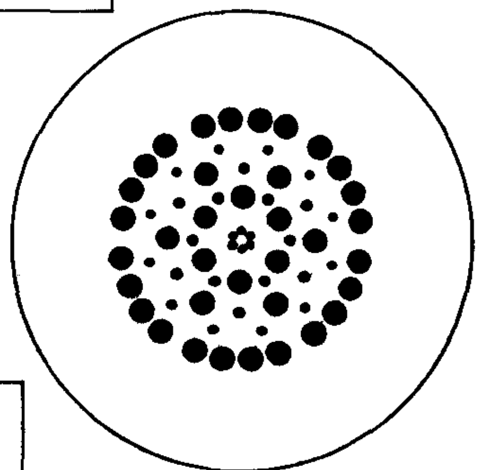
Typical driver fuel is tubular with cross-shaped target pieces and has the composition:

Core	9.3 wt % enriched uranium (108 g U^{235}/ft) in zirconium
Cladding and Housing	Zircaloy-2
Target	304 stainless steel with 0.36 wt % natural boron (0.60 g boron/ft)

Design burnup is 40% of the 22.9 kg of U^{235}.

• 6 INSTRUMENT POSITIONS

Diameter	1.0 inch
Length	10 feet



Approximate diameter of core: 77 inches

18 CONTROL RODS

Size

Diameter	1-1/4 inches
Length	9 feet 10-7/8 inches

Composition

● 17 black rods	304 stainless steel with 1.05 wt % natural boron
○ 1 gray rod	304 stainless steel

○ 6 SAFETY RODS

Size

Diameter	1-1/4 inches
Length	9 feet 10-7/8 inches
Composition	304 stainless steel with 1.05 wt % natural boron

FIG. 7 LATTICE ARRANGEMENT OF HWCTR

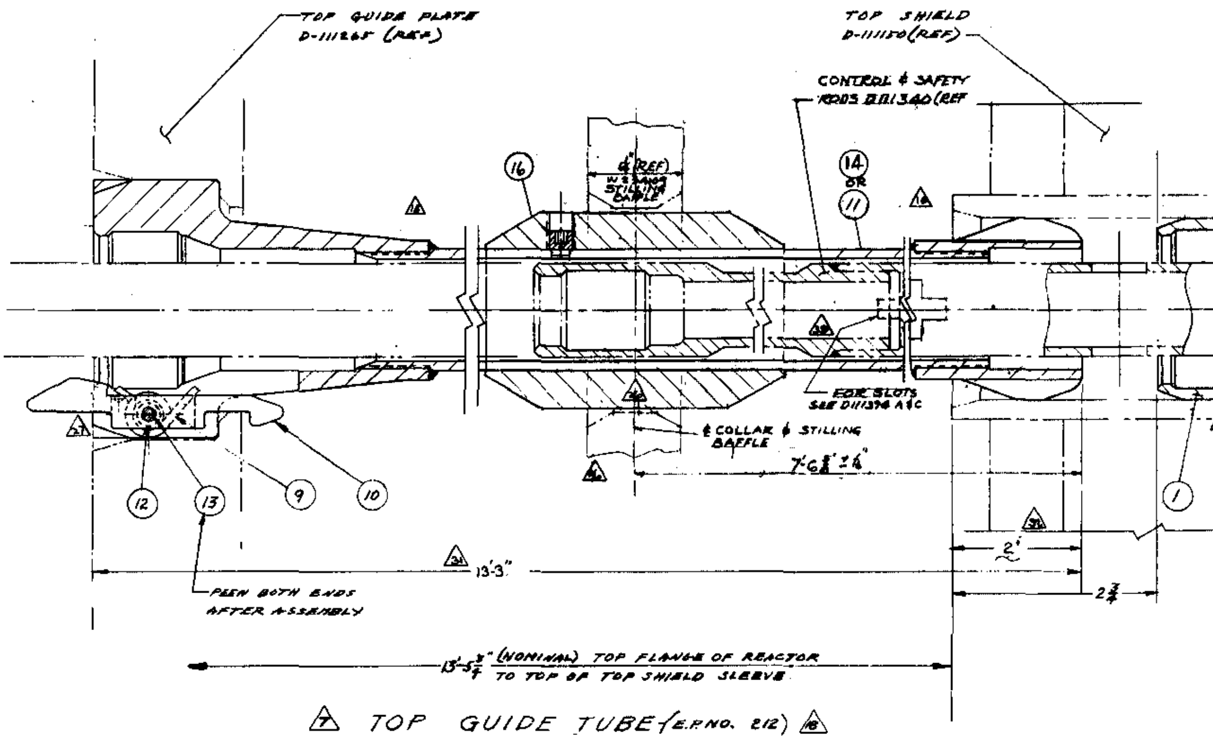
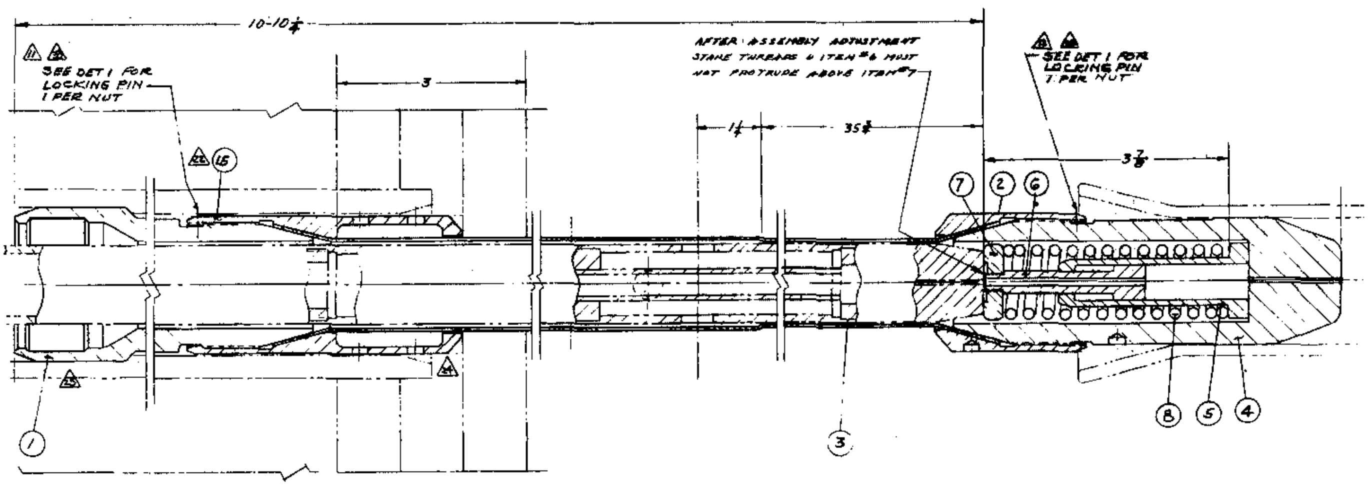


FIG. 8 CONTROL AND SAFETY ROD LATCH ARRANGEMENT



ROD SHOWN IN LOWER
ELECTRIC LIMIT STOP POSITION

FIG. 9 BOTTOM OF GUIDE TUBE

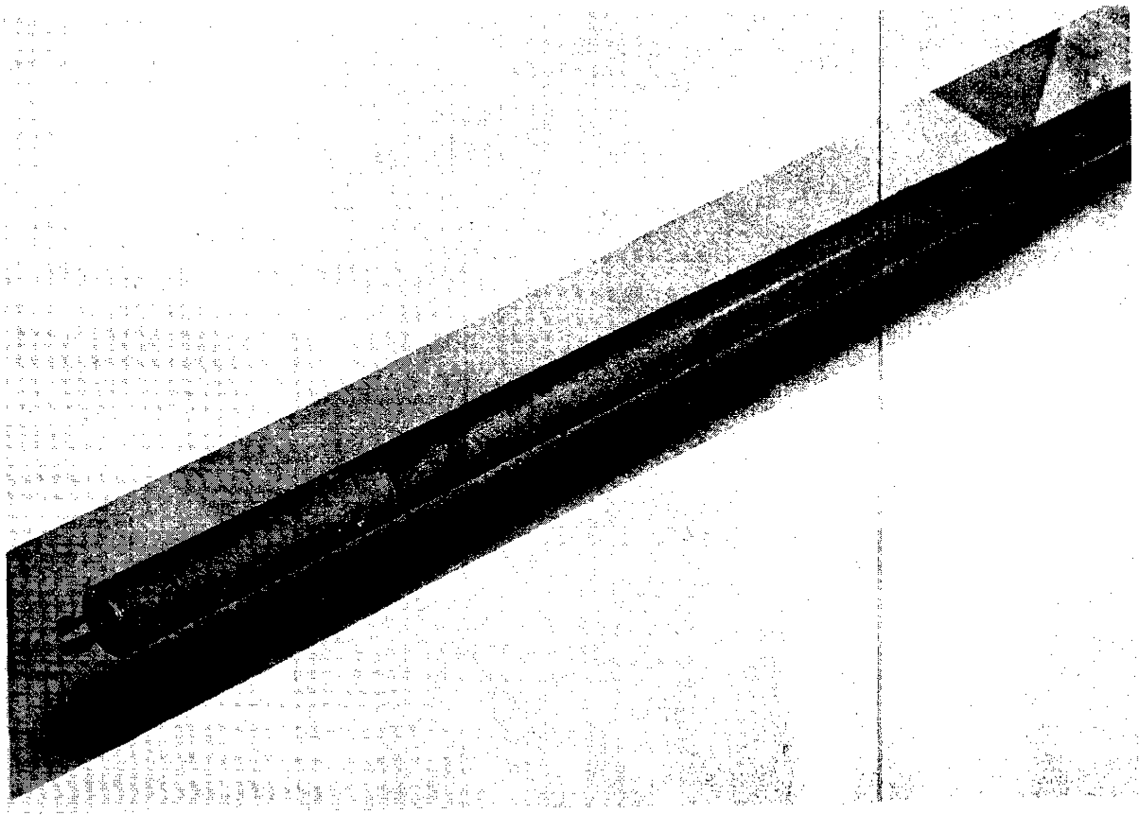


FIG. 10 LATCH END OF RACK AFTER ONE YEAR OF SERVICE

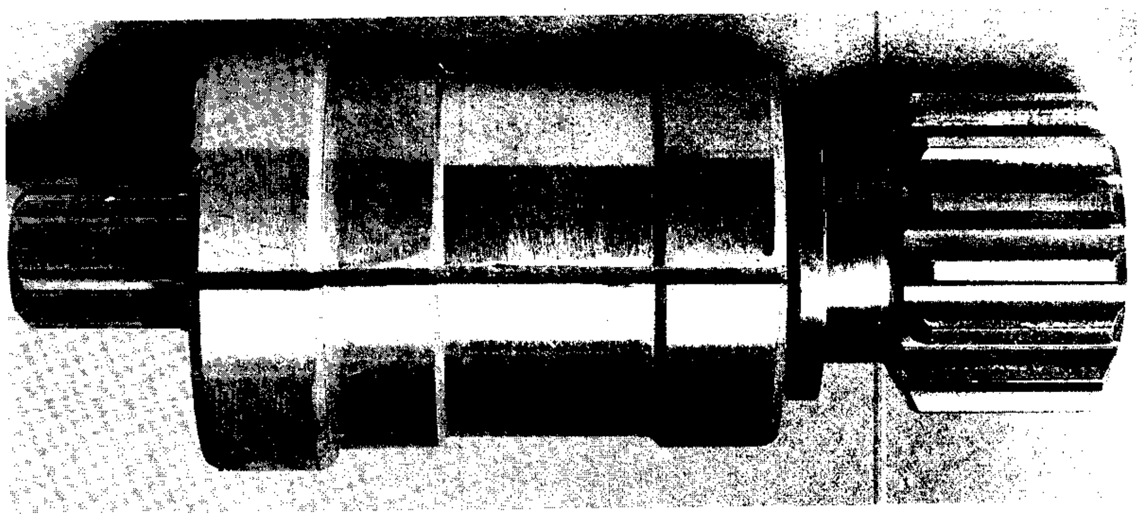


FIG. 11 RACK PINION AFTER ONE YEAR OF SERVICE

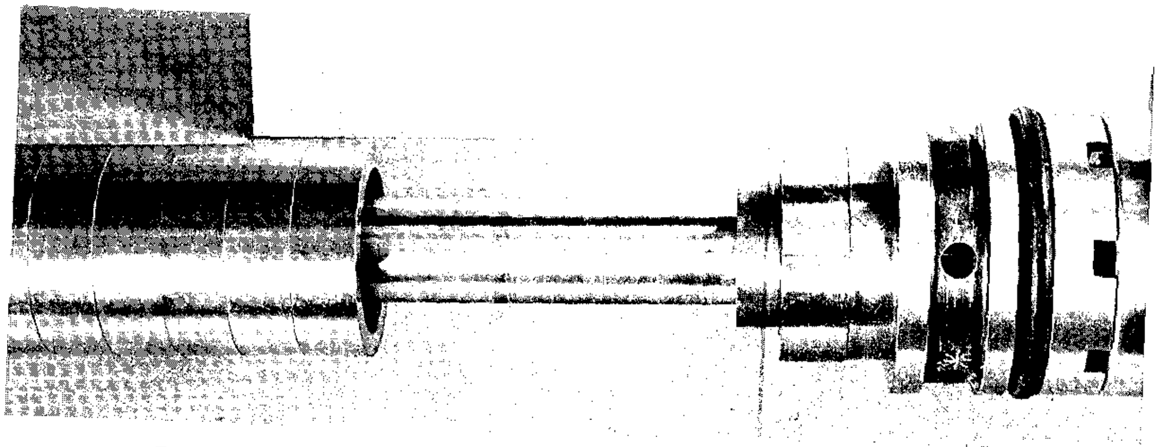


FIG. 12 SEAL SHAFT AND RINGS AFTER ONE YEAR OF SERVICE

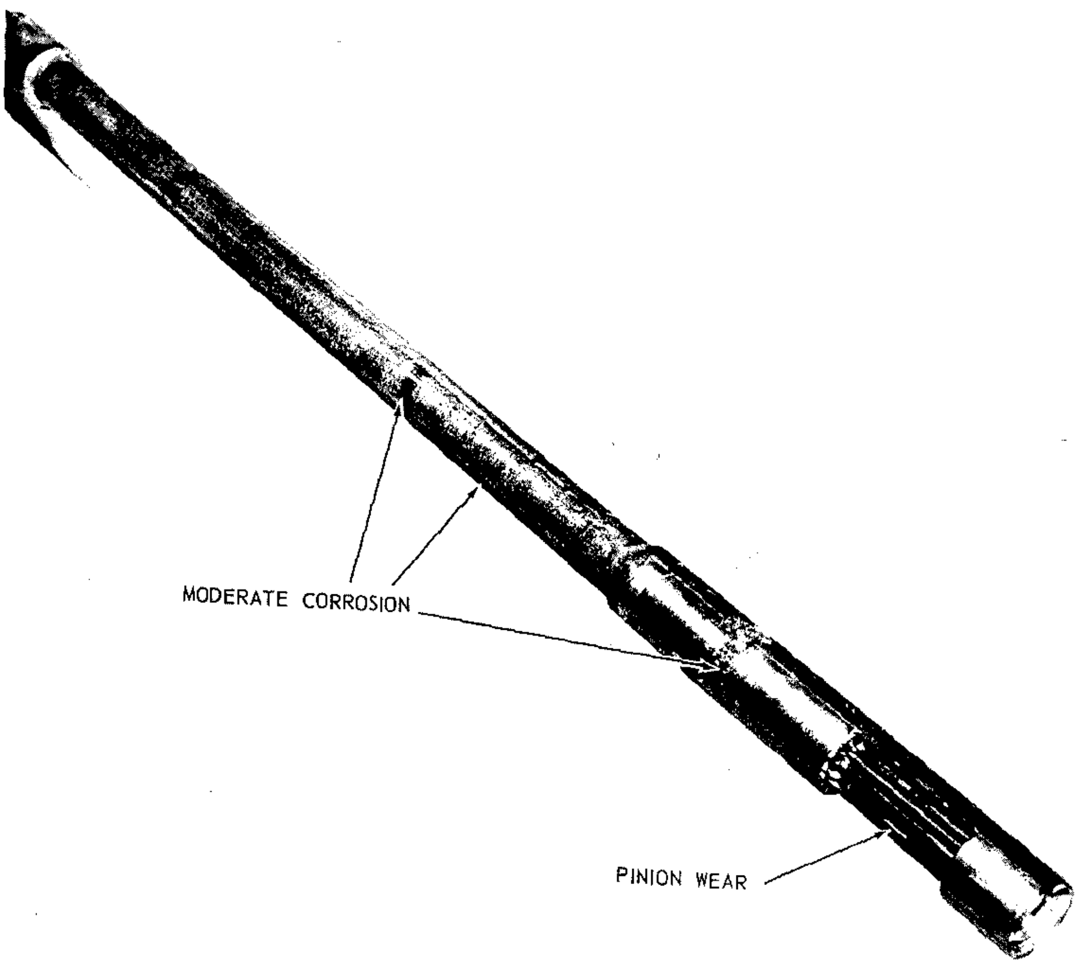


FIG. 13 RACK UPPER EXTENSION AFTER ONE YEAR OF SERVICE

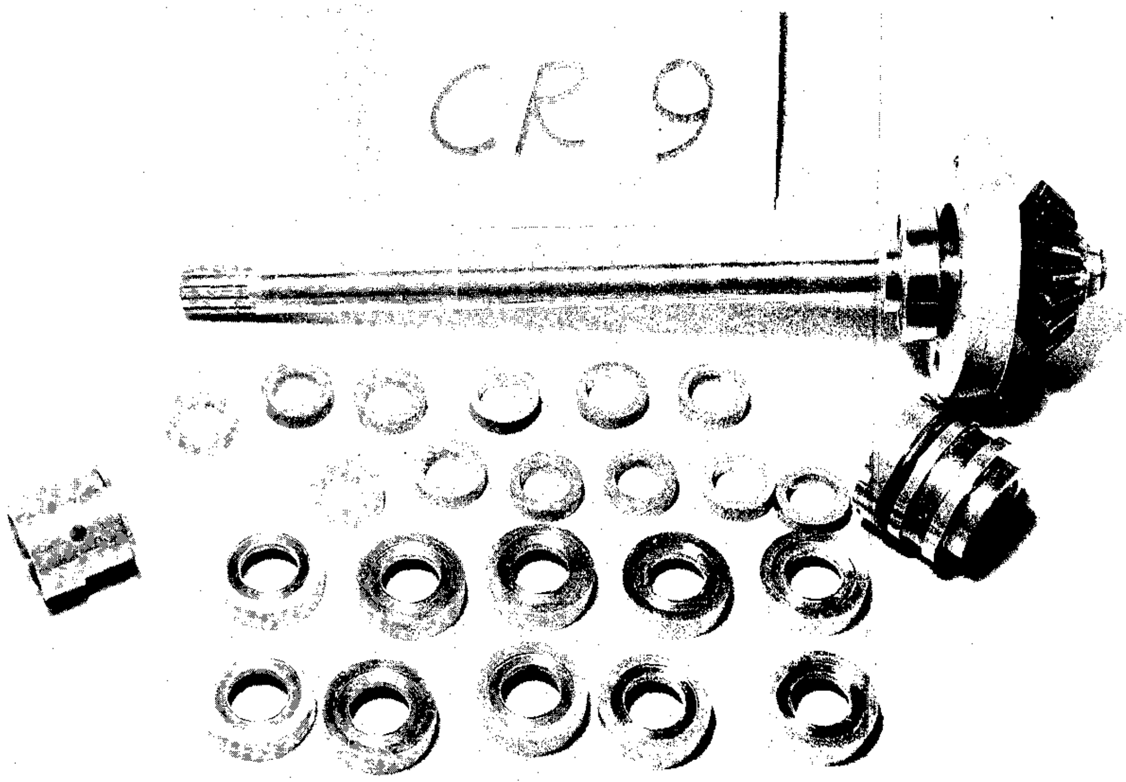


FIG. 14 SEAL COMPONENTS AFTER ONE YEAR OF SERVICE

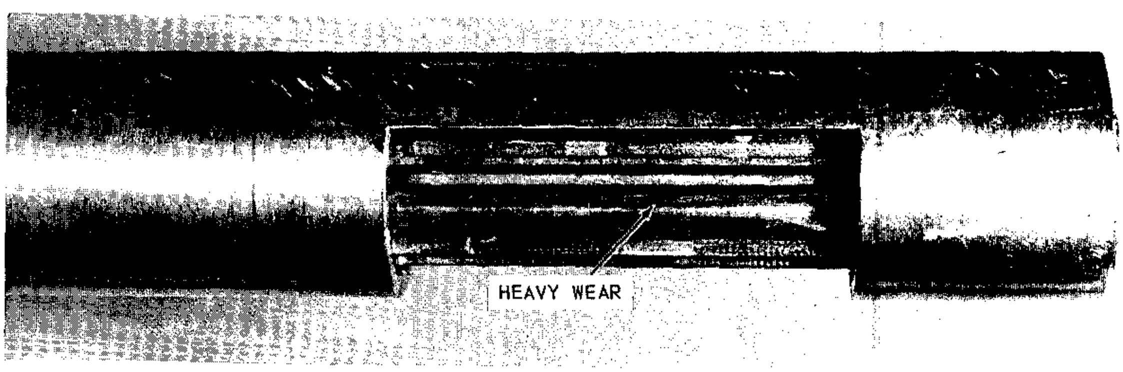


FIG. 15 DELATCH PINION AFTER ONE YEAR OF SERVICE

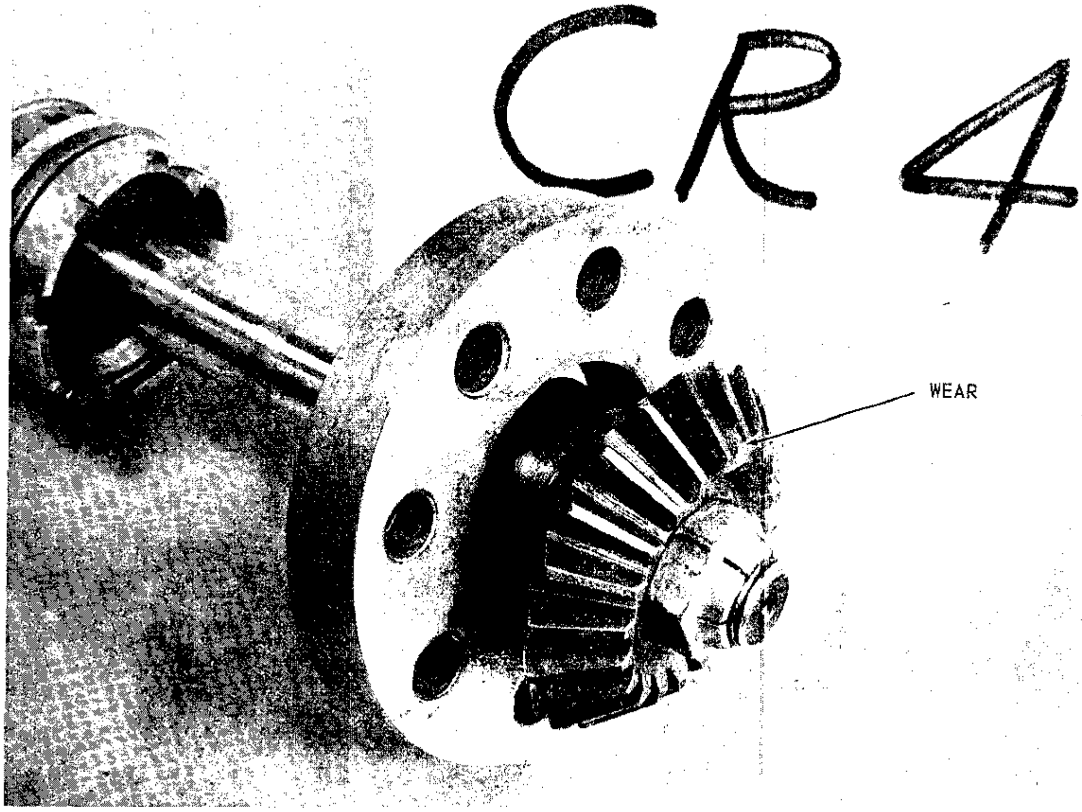


FIG. 16 BEVEL GEAR AFTER ONE YEAR OF SERVICE

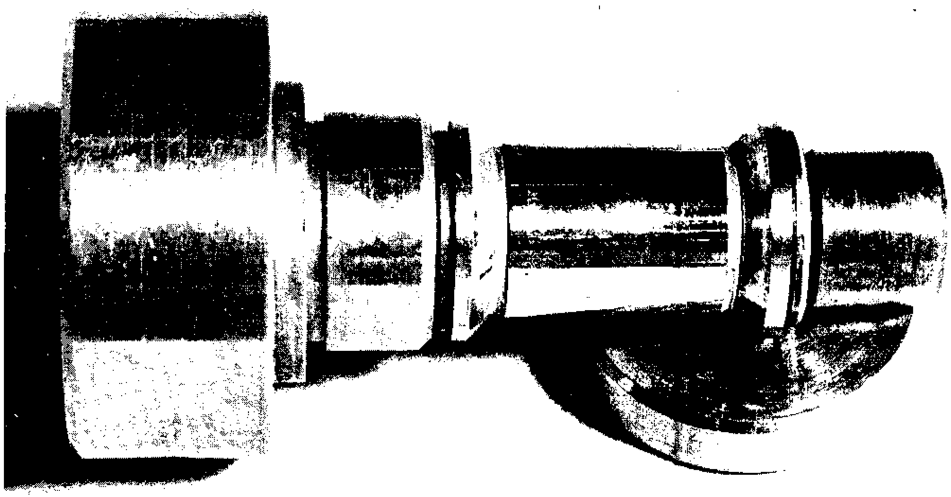


FIG. 17 BACKUP ROLLER AND STUD AFTER ONE YEAR OF SERVICE

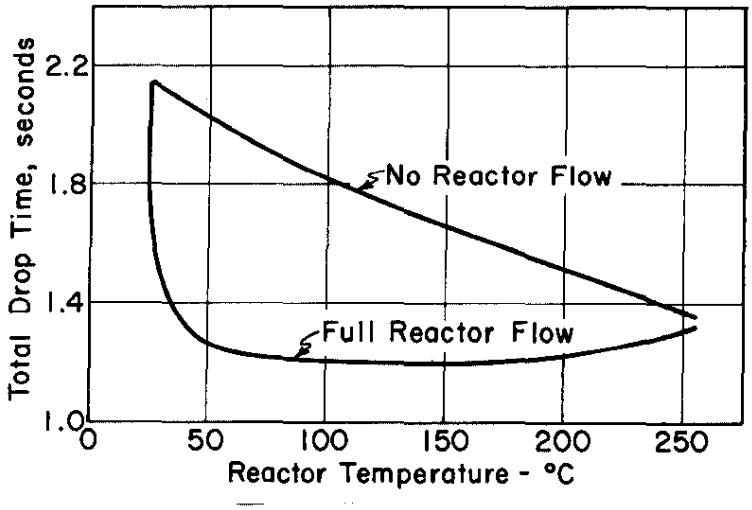


FIG. 18 SAFETY ROD DROP TIMES AT VARIOUS MODERATOR TEMPERATURES

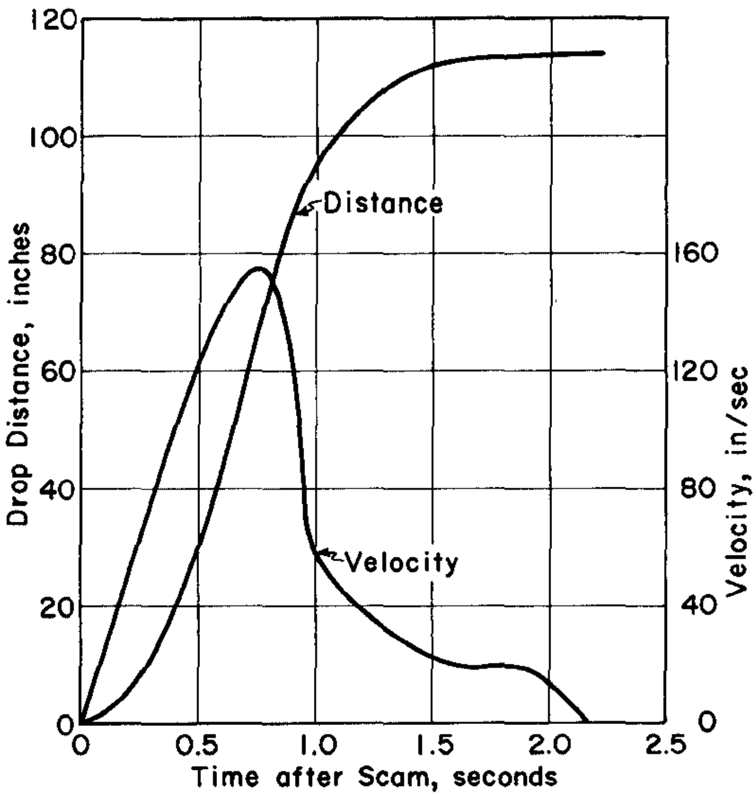


FIG. 19 SAFETY ROD SCRAM CHARACTERISTICS FOR 30°C MODERATOR TEMPERATURE

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APPENDIX

POSSIBLE RESULTS OF STRESS CORROSION FAILURE – TYPE 17-4 PH ROD DRIVE COMPONENTS

Safe reactor control is the prime requirement of the rod system; therefore, classification of the 17-4 PH parts was based on the possible consequences resulting from failure. A part is classified critical if its failure could prevent rod insertion in some manner. A description of the critical and noncritical parts is given below.

CRITICAL PARTS

Roller Stud

The roller stud is the shaft on which the rack backup roller runs. It is only remotely conceivable that a certain mode of failure might cause the rack to jam, thus preventing rod motion.

Pinion

The pinion engages the rack, transmitting motion to the rod. Failure of the pinion would probably cause the rod to drop into the reactor core, but there is a small possibility that it could jam the rod, preventing movement.

Rack

The rack attaches to and supports the weight of the rod. Failure of the rack would have the same possible consequences as failure of the pinion.

Washer

The washer takes the thrust loading of the pinion. There is a slight probability that failure could cause the rack to jam, but only if a piece of the washer falls into an unfavorable location.

NONCRITICAL PARTS

Spline Coupling

The spline coupling is a part of the drive train from the motor to the rack. Failure would cause the rod to drop into the reactor core.

Seal Bushing

The bushing is a spacer in the shaft seal housing. Failure would have no unfavorable effect on rod insertion.

Seal Shaft

The shaft is part of the drive train. Failure would cause the rod to drop into the reactor core.

Spacer

The spacer holds the end of the roller stud. Failure would have no unfavorable effect on rod insertion.

Delatch Rod

The delatch rod uncouples the control or safety rod from the rack. Failure would prevent normal delatching but would have no adverse effect on rod motion.

Spring Housing

The spring housing holds the upper limit spring. Failure would result in loss of energy absorption at the upper limit of rod travel, if the limit switch failed. There would be no effect on rod insertion.

Plug

The plug holds the roller stud in place against reactor pressure. Most types of failure would result in a slight leakage of reactor blanket gas, but in the unlikely complete loss of thread engagement, the roller stud could be blown out resulting in serious but not catastrophic leakage and reactor pressure reduction.

Upper Extension

The upper extension delatches the rod from the rack. Failure would have no effect on rod motion, but would prevent normal delatching.

Latch Finger

The latch fingers attach the rod to the rack. Failure would drop the rod into the reactor core.

Delatch Pinion

The delatch pinion delatches the rod from the rack. Failure would prevent normal delatching, but would have no effect on rod insertion.