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GEAP-13649
AEC RESEARCH AND
DEVELOPMENT REPORT
OCTOBER, 1970

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MASTER

DESIGN AND TESTING OF THE SEFOR FAST REACTIVITY EXCURSION DEVICE (FRED)

E. R. McKEEHAN

PREPARED FOR THE
U. S. ATOMIC ENERGY COMMISSION
UNDER CONTRACT AT(04-3)-540

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Prepared For The
U. S. Atomic Energy Commission
Under Contract AT(04-3)-540

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

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INTRODUCTION

1.1 General

This report describes Fast Reactivity Excursion Device (FRED) design and the results of development testing carried out for Southwest Experimental Fast Oxide Reactor (SEFOR).

SEFOR is a 20 MWt fast spectrum reactor fueled with $\text{PuO}_2\text{-UO}_2$ and cooled with sodium. SEFOR has characteristics similar to the large, soft spectrum fast breeder reactors fueled with mixed $\text{PuO}_2\text{-UO}_2$. Economic studies of these large power reactors indicate the potential for producing low-cost power. SEFOR is being used to obtain physics and engineering data at fuel compositions, temperatures, and crystalline states characteristic of power reactor operating conditions. SEFOR is particularly designed for the systematic determination of the Doppler coefficient of reactivity at temperatures up to the vicinity of fuel melting.

There are two parts to the SEFOR Project: (1) the design and construction of the reactor and (2) a related research and development program. Funds for the design and construction of the facility were provided by the Southwest Atomic Energy Associates (a group of seventeen-investor-owned utility companies located in the South and Southwest parts of the United States), together with the Karlsruhe Laboratory of The Federal Republic of Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the Research and Development Program. There are two phases to the Research and Development Program:

Phase I - Preoperational Research and Development

Phase II - The reactor test program after the start of reactor operation

This report describes work performed during Phase I of the Research and Development Program under Task 6.1 which is entitled Fast Reactivity Excursion Device (FRED).

FRED is a gas-actuated mechanism used for rapidly removing poison from the core to initiate reactor power excursions under controlled conditions. This device is used to carry out the transient testing phase of the experimental program. FRED is supported on the reactor vessel head at the center position by the positioner and drywell as shown in Figure 1. FRED is shown schematically in Figure 2. The method of actuating the mechanism is to supply argon gas to the expansion chamber where it acts over an annular area on the underside of the piston until the pressure has built up to approximately 100 psi. The expanding gas then lifts the piston from this annular area and exposes the complete underside area of the piston to the argon gas. This forces the piston up the guide tube until it is stopped at the upper end by a gas cushion which is controlled by a series of vent holes. After stopping at the upper end, the poison rod drops back into the core area. A detailed explanation of the methods of actuating the device, safety latches, switches and position indication are included in the latter sections of this report.

1.2 Design Objectives

The following are the design objectives for the FRED system:

- a. Core removal time: 90 msec (nominal)

This time was established as the nominal exit time under normal conditions of actuation. Subsequent tests showed a ± 5 msec random variation about the nominal value, with the accumulator charged to 1500 psia. The minimum exit time considering an accidental over-charging of the accumulator to the maximum pressure permitted by the pressure relief devices would be 80 msec.

- b. Stroke: 26 inches

This stroke includes half the core length plus one-half the length of the poison slug plus the extrapolated core length.

- c. Starting Position: Continuously Positionable Above Core Center
This capability permits FRED to be actuated from various points

FIGURE 1 - Fast Reactivity Excursion Device

FIGURE 2 - FRED Schematic

in the core above the core midplane to provide firings of different worths with the same poison slug. This is accomplished by using the positioner device.

- d. Position Indication: Discrete (start, mid-point, exit) and Continuous

The position indication system for FRED consists primarily of the lift-off switches at the start of motion, a magnetic proximity switch at the mid-point of the stroke and another magnetic proximity switch near the core exit. A continuous position indication system is also provided which uses a photoelectric system which senses changes between dark and light stripes on the actuator rod. The continuous position indication signal is recorded on a light beam oscillograph and is used in conjunction with position vs reactivity worth curve to arrive at a reactivity worth vs time curve for obtaining results for the experimental program. From a safety standpoint, the position switches are the only position indication system that is necessary to operate FRED.

- e. Poison Re-entry Into the Core After Firing

This provision gives an added margin of safety. In the unlikely event that the reflector control system failed to scram, the poison slug would drop back into the core to return the reactor to the power level at which it started.

- f. Maximum Slug Worth: 1.3\$

The maximum slug worth to be used in the experimental program will be established after the Doppler coefficient has been determined. One and three-tenths dollar has been established as the maximum slug worth that would be required (based on the expected Doppler coefficient of $T \frac{dk}{dT} = -0.0085$).

- g. Single Failure Criterion:

Multiple failures are required to cause FRED to misfire.

1.3 Summary and Conclusions

The primary objective of FRED design is to provide a reliable device that can rapidly remove a poison slug from the reactor core at a

predictable rate regarding the time and the desired conditions. To accomplish this objective, a pneumatically-actuated device was designed and extensively tested. This device has demonstrated reliable and reproducible performance and has many inherent safety features which are discussed in this section. In reviewing the design of the FRED and the reactor operations with the FRED, the following are the most significant items to be considered. Each item is referenced to a more detailed discussion in a later section of the report.

- a. The reactor will be loaded to 50¢ excess at 20 MW (Section 4.1).
- b. A system of checking slug worth each time by predetermined power level points (Section 4.2).
- c. The self-limiting characteristic of FRED limits the maximum potential exit speed (Section 3.1).
- d. The poison slug is allowed to drop back into the core area after having been fired out (Section 2.2).
- e. Three independent safety latches have been provided over the piston to prevent misfiring of the device (Section 2.3, No. 10).
- f. A groove in the piston prevents the safety latches from being withdrawn if the piston has contacted them (Section 2.3, No. 10).
- g. The pressure chambers of the device has rupture disks designed to relieve any over-pressurization (Section 2.3).

The above features make the device simple to operate with a minimum of single-check procedural controls and provides several inherent safety features.

SYSTEM DESCRIPTION

2.1 General

FRED is mounted on the positioner and drywell which is mounted on the reactor vessel head as shown in Figure 1. The drywell extends downward from the reactor vessel head into the center channel to a point approximately 15 in. below the core mid-point. The details of this drywell are given in Appendix A. The positioner is mounted on top of the drywell and provides a movable platform on which the FRED device is mounted. Figure 3 shows the positioner, which is basically a large acme thread lifting screw which may be raised and lowered by the rotation of the lifting nut through a bevel gear set. The vertical movement of the acme screw raises and lowers the complete device relative to the reactor vessel head. A detailed explanation of the positioner is given in Appendix B.

The function of the positioner is to move FRED out away from the core, so that the poison slug position will be outside the core. From this point, the device can be test fired without affecting the power level of the reactor.

The parts of FRED which move relative to the positioner device are the piston and the actuator rod to which is attached the poison slug. The piston is guided within the guide tube and stopped by gas in the gas cushion chamber. After firing, the piston-actuator rod, with a poison slug attached, drops back to its original in-core starting position after coming to a stop at the top of the cushion chamber.

2.2 Pneumatic System

A schematic of the pneumatic system is shown in Figure 2. The gas for actuating the device is supplied by a high pressure supply system located inside the reactor building, but away from the refueling cell. The transfer chamber is taken to the high pressure supply station and

filled to the prescribed pressure. This supply station has a regulator which is preset to limit the maximum pressure necessary to actuate FRED. After connecting the transfer chamber to the regulated high pressure supply, the valves are opened and the pressure in the transfer chamber equalizes to the regulator pressure setting. The transfer chamber has a pressure indicator for checking the pressure and a rupture disk for protection against over-pressurization.

After the transfer chamber has been filled, it is disconnected from the high pressure supply and moved to the refueling cell where it can be connected to the piping that passes inside the cell to the accumulator. When the system is ready for actuation, the transfer chamber is connected to the cell penetration outside the refueling cell wall. The inter-connecting valves are opened and the pressure allowed to equalize between the transfer chamber and the accumulator. This pressure equalization provides a check to assure that the proper pressures have been obtained in charging the transfer chamber. The accumulator has a pressure transmitter which is "read out" outside the refueling cell. In addition, the accumulator has a rupture disk to prevent over-pressurization. Once the accumulator has been charged to the proper pressure, the transfer chamber is disconnected and removed from the refueling cell wall. FRED is now ready for actuation.

With the mode switch in the excursion position, FRED is actuated in the following sequence: (1) The three independent safety latches which protrude into the guide tube to prevent the piston from moving up inadvertently are energized and (2) The three-way actuation valve between the accumulator and the expansion chamber is energized. The actuation valve which allows the argon from the accumulator to pass into the expansion chamber is energized thus causing the piston to move upward rapidly. When the piston reaches the upper end of the guide tube, the piston is stopped by a build-up of gas pressure which is also being vented off through vents in the upper end of the tube. The piston will consequently stop before reaching the top end of the tube, and return down the tube where it is cushioned by the collection of gas on the underside of the piston. This gas will leak out between the actuator shaft and the nozzle piece, thus providing a uniform cushioning action.

to allow the piston to settle back into the original position. The leakage path for this gas during the dropback period is shown in Figure 4.

After the piston has returned to its original position, the actuation valve and the safety latches are de-energized. The actuation valve in the de-energized position will vent the expansion chamber to the fueling cell atmosphere to prevent build-up of pressure in the expansion chamber.

The expansion chamber is provided with a rupture disk to protect it against excessive build-up of pressures which could change the characteristics of the device. This rupture disk is set to blow out at a pressure slightly higher than the normal pressure in this chamber during normal firings as shown in Figure 5.

2.3 Mechanical Description

FRED has been fabricated from Type 304 stainless steel except for the following components: (1) The latch plunger which extends into the tube is made of high strength tool steel (4140 heat treated). (2) The piston is made of low carbon steel so that it will actuate the magnetic proximity switches used for position indication. (3) The orifice piece was fabricated from Type 410 stainless steel and heat-treated to a Rockwell C of 35.

a. Transfer Chamber

The transfer chamber is a standard cylinder designed to the standards of the Compressed Gas Association. It has a liquid volume of 4.84 liters which approximately equals 297 in.³.

This cylinder is equipped with a rupture disk that will relieve the gas in the cylinder, should it be charged above 2200 psi. Due to the self-limiting characteristic of FRED, the ejection time would not decrease significantly if the transfer chamber were over-pressurized and the rupture disk failed to function.

b. Accumulator

The accumulator is fabricated from Type 304 stainless steel pipe and has a liquid volume of 70 in.³. Although this

FIGURE 4 - Drop Back Cushion

FIGURE 5 - FRED Parameters

vessel is excluded from the ASME pressure vessel code because of its small size, the stress levels were maintained at a level less than required by the code. Full penetration welds were used and dye-penetrant inspected following fabrication. As a final proof test, the chamber was hydro-statically tested to 2500 psi. This accumulator, as installed and shown in Figure 1, includes a rupture disk and a pressure transducer for remote read-out of the pressure. If the rupture disk were not used, no significant safety problem would be introduced since FRED has self-limiting characteristics as explained in Section 3.1. The rupture disk in the accumulator is designed to rupture at 1800 psi, 300 psi above the maximum expected operating pressure but below the maximum pressure that is available from the 2200 and 2500 psi high pressure supply. These rupture disks are accurate to within $\pm 6\%$ at the stated temperature.

c. Actuation Valve

This valve is a 28 Vdc, direct-acting, balance poppet three-way valve which, in the de-energized position, will vent the expansion chamber to the cell atmosphere. Energizing is required to open the accumulator to the expansion chamber.

d. Piping

The piping from the cell wall to the accumulator is 1/4-inch diameter Type 304 stainless steel tubing. From the actuation valve to the expansion chamber, a flexible reinforced rubber hose is used which allows for the positioner to raise and lower the complete FRED device and still allow for actuation of the device at any position.

e. Support Column

As shown in Figure 6, the support column is the bottom spool-piece which mounts on the positioner and provides a space for mounting the photoelectric light source and sensor. The expansion chamber is attached to the upper flange. The orientation of the photoelectric system is shown in View A-A of Figure 6.

f. Expansion Chamber

The expansion chamber is designed to 1100 psi with an expected pressure of less than 200 psi. This chamber is also equipped with a rupture disk of the same type as that used in the accumulator and in the transfer chamber. This rupture disk is designed to rupture at a pressure just slightly above the 200 psi normal peak pressure of the expansion chamber. This chamber has a calculated liquid volume of 50 in.³.

g. Nozzle and Orifice

The nozzle is mounted inside the expansion chamber and the orifice is mounted on top of the expansion chamber as shown in Figure 6. The nozzle and the orifice provide an annular flow area for gas to pass from the expansion chamber to the underside of the piston. When the piston is seated on the nozzle and orifice, the annular area of 1/2 in.² is the only area exposed to the gas pressure of the expansion chamber. After the piston has raised from the seat, the complete area of the underside of the piston is exposed to the gas which flows from the expansion chamber through this annular flow nozzle. The actuation shaft passes through the inside diameter of the nozzle. Labyrinth seal ring grooves are placed in the nozzle to lessen the leakage at high pressures and still allow leakage during the dropback of the piston, in which case the gas from under the piston leaks out through this path as shown in Figure 4. Located in the bottom of the orifice, below the piston, are two lift-off switches and a variable inductance sensor, as shown in Figure 6, View C-C. These devices are all used to indicate the action of the piston at lift-off. The lift-off switches provide the primary signal for start of motion, with the variable inductance device providing an analog signal to determine slight movements of the piston prior to actuation of the switches. This analog device is used only as an aid in reducing data relative to small initial movements of the piston, if such information is required. Each of the two lift-off switches contains two spring-loaded pins as shown in

Figures 6 and 7, which make contact with the piston thus using the piston to complete the circuit. The switches were fabricated specifically for FRED after prototype testing of FRED MODEL I. The signal from these switches is used in FRED interlocks as explained in Section 2.5.

h. Piston, Actuator Shaft and Poison Rod

The piston is fabricated from carbon steel as required to actuate the magnetic reed switches which are located outside the guide tube as shown on Figure 1. This piston has a rubber seal cushion attached to the bottom to cushion the piston and actuator shaft when the piston rests on the nozzle and orifice. A groove cut in the upper end of the piston (as shown in Figure 8) provides a place for the safety latches to catch so that they will not withdraw if the piston inadvertently raises and then the latches are energized. The piston is attached to the actuator shaft by a large nut which is safety-locked in place. To facilitate the handling of the poison rod assemblies during installation and removal, a fuel handle is machined on the upper end so that the half-ton hoist grapple can be used for handling.

The actuator shaft has a series of light and dark stripes. These stripes are used in connection with the photoelectric system to provide position indication during movement of the FRED. This position indication system is not necessary from a safety standpoint but is used for the reduction of test data and the determination of position vs time and thus reactivity vs time for a FRED test. The dark stripes are provided by machining a groove, approximately 0.020 in. deep, and 1 in. long as shown on Figure 9, in the actuator shaft followed by the application of a special high temperature paint (Thermalox) which provides a black surface. These stripes are at 1 in. intervals except three dark stripes three inches long to provide reference points to aid in data reduction. The poison rod and actuator shaft are shown in Figure 9. The poison sections are approximately 12 in. long and are filled with boron carbide. All poison slugs will be the same weight to

FIGURE 7 - Fast Reactivity Excursion Device - Piston Area

FIGURE 8 - Safety Latch Mechanism

FIGURE 9 - Actuator Rod & Poison Slug

within $\pm 1/2$ lb. Each poison slug will have the reactivity worth electro-etched on the outside surface for easy identification and checking.

i. Guide Tube

The guide tube mounts on the top end of the orifice and is held down by long studs which extend between the lower guide tube flange and the upper expansion chamber flange. These studs are designed to maintain a tight clamping force under all operating conditions of FRED. If under some unidentified accident conditions, 1500 psi were to be introduced into the expansion chamber and the piston did not lift and the rupture disk did not blow, these stud bolts would then act as springs by stretching, thus relieving the pressure. The guide tube has mounted on the wall the three independent safety latches which penetrate the wall and extend into the tube over the piston as shown in Figure 8. The internal surface of the guide tube is nitrided. No significant wear is expected, but it was believed that a reliable wear surface would be desirable. The cushion chamber is attached to the upper end of the guide tube.

j. Latches

The safety latches are shown in Figures 7 and 8. These latches are spring-loaded into the tube and each is energized independently by individual switches as shown in Figure 10. These latches also have limit switches on the latch plunger, which gives an indication of whether the plunger is in the tube or not. Any one of these latches is strong enough to prevent the piston from moving up the tube if FRED actuates without a latch being removed. If only one latch were extending into the tube, and the piston were actuated at the maximum pressure, some deformation of the bushing would be expected, but no failure would occur. As a further backup, the power supply rating for these three latches is not able to withdraw all three simultaneously even if they could be energized in that way.

FIGURE 10 - FRED Elementary Diagram

k. Cushioning Chamber

The cushioning chamber attaches to the upper flange of the guide tube with captive fasteners as shown in Figure 1. This cushion chamber has small holes drilled along the length to provide for the escape of gas above the piston as it moves up the guide tube. The area of venting decreases in such a way that the gas will build up and bring the piston to a stop prior to hitting the bumper pad in the end of the cushion chamber (as demonstrated by testing, see Section 5.2). After coming to a stop, the piston and actuator rod will drop back down the guide tube and gradually be slowed down by the gas pressure buildup below the piston. The gas below the piston will gradually leak out between the actuator shaft and the i.d. of the nozzle allowing the piston to come to rest in its original position.

2.4 Reactor Operations

The following explanation covers the intended use of various features designed into FRED and the positioner system.

2.4.1 In-Cell Handling

During periods when the reactor is shut down, it may be necessary to remove either the poison slug or the whole FRED, including the poison slug from the reactor head. For removal of the complete FRED, including the positioner and drywell, the captive bolts that attach the drywell to the reactor head (Figure 1) are disconnected, the hose between the actuation valve and the expansion chamber is disconnected, the coupling between the drive motor of the positioner and the positioner mechanism is disconnected. These, along with the removal of electrical connectors, allows for raising FRED, positioner and drywell by use of the multi-ton grapple which picks up the complete assembly by the grapple handle located at the upper end of the cushion chamber. The assembly is then raised and transported to a floor well where it is temporarily stored. For re-installation, the sequence is reversed.

In the case where it is necessary to change the poison slug only, the cushion chamber is removed by loosening the captive fasteners

which attach it to the upper end of the guide tube (Figure 6). After removal of the cushion chamber, the half-ton grapple can be lowered inside the tube and attached to the fuel handle which is located on the nut inside the piston (Figure 7). After the grapple is attached to the handle, the poison rod can be removed from the guide tube. Prior to this operation, the poison slug will be positioned outside of the core by moving the positioner to the upper limit of its stroke. When the poison rod is lifted out of the device by the half-ton hoist, the positioner must be lowered to provide clearance between the end of the poison slug and the upper end of the guide tube.

2.4.2 Test Sequence

As discussed under Safety Evaluation, Section 4.1, the reactor will be loaded to a maximum of 50¢ excess at 20 MW. This method of loading and the safety implications are discussed in Section 4.1. In preparing for a transient test, the poison slug is held above the core by the positioner. The reactor is then brought to a prescribed power level. When the poison slug is lowered into the core, a fine control rod will be raised to hold the power level constant.

2.5 Instrumentation

2.5.1 Safety System Interlocks

- a. An interlock is provided between the lift-off switches and the lowering or down direction of the positioner, so that the positioner cannot be lowered into the core unless the piston is seated on the lift-off switches.
- b. The actuation valve and latches are interlocked so that they can be energized only when the reactor mode switch on the main console is in the Excursion Mode.
- c. The actuation valve is interlocked to the latches so that all three must be withdrawn before the valve can be actuated.

2.5.2 Scram Delay

In the transient tests, scram will be delayed until 400 msec after the FRED is fired. The scram delay is necessary in order to

obtain adequate experimental data. The large error in the experimental determination of the Doppler coefficient that occurs as a result of an "early" scram is shown in Appendix VIII of GEAP-5576. Since the minimum error appears (Appendix VIII of GEAP-5576) to occur during the first 100 to 200 msec after complete FRED ejection (i.e., depending on the system speed, approximately 200 to 350 msec, after FRED is actuated) a 400 msec scram delay was selected. The transient analysis of the core was carried out with the 400 msec delay.

ANALYSIS3.1 Dynamic Analysis

A detailed analysis was carried out to determine the dynamic characteristics of the FRED for comparison with experimental test results. The configuration of the FRED used to develop the analytical model is shown in Figure 11. The following assumptions were made in carrying out the analysis.

1. The gas flow is adiabatic and reversible.
2. There is no gas leakage from the system.
3. There is no sliding friction between the piston and cylinder wall and between shaft and shaft seal.
4. The perfect gas law can be used to calculate the pressure in each chamber.
5. The work of lifting the piston is done by the gas in the low pressure chamber.
6. The gas compression in the cushion chamber is an adiabatic process.
7. Stagnation conditions occur in the expansion chamber.

With the above assumptions and the model shown in Figure 11, an analytical model was developed and then programmed for solution by digital computer. The equation of motion for this model was obtained by solving the following equation:*

$$\ddot{x}_p = \frac{\frac{m_3 R T_{03}}{V_{03} + A_3 x} - \frac{m_4 R A_4 T_{04}}{(V_{04} - A_4 x)} \left(\frac{l-x}{l}\right)^{k-1} - m_p g_c}{m_p \left(1 + \frac{R A_3^2 x_p}{C_p J (V_{03} + A_3 x)}\right)}$$

* Nomenclature is given at the end of the report, before Appendix A.

FIGURE 11 - FRED Analytical Model

This equation is arrived at by taking a force balance on the piston. The assumptions used neglect nonrecoverable losses and thus tend to produce faster withdrawal times than the experimental data, which are presented in Section 5 and shown in Figure 12. One method used to compare solutions of the above equation with experimental data was by plotting the time to travel 20 in. as a function of accumulator pressure. Plots of experimental and analytical results are shown on Figure 12. These lines (plots) have a characteristic equation of the form

$$t = BP_{01}^{-m}$$

where P_{01} is accumulator pressure, t is time to travel 20 in. and m and B are constants. The main difference between the experimental and analytical results is due to the effects of fluid friction, fluid loss coefficients and gas leakage, which are not included in the analytical model. If the losses were included, assuming constant coefficients, the analysis shows that the curves would be displaced in time but would be parallel to the curve as shown on Figure 12. (However, to provide a true representation of the fluid losses, the coefficients must vary with the flow rate.) It is important to note that the results of the analysis and the experimental data both show the same basic characteristics. Both show that the device has a self-limiting characteristic; they indicate that the sensitivity of the withdrawal time to increasing accumulator pressure in the region of FRED operation is small.

Thus an increase in accumulator pressure from 1500 psi to 2000 psi changes the withdrawal time from 90 msec to slightly over 80 msec. The variations of pressures in each chamber of the analytical model are shown in Figure 5 for an accumulator pressure of 1500 psi. These show that the peak pressure in the expansion chamber is under 200 psi.

3.2 Stress Analysis

A detailed stress analysis has been carried out on the various components of FRED. The loadings and pressures used in this analysis are well above those expected during operation of FRED. FRED was fabricated from tubular shapes of 1/4 in. wall thickness or larger and thus the tensile stress due to axial loading is small in all components. In the

FIGURE 12 - FRED Characteristics

case of the support column, the reactions due to FRED actuation creates less than 1000 psi of axial stress.

The following is a description of the loading and maximum stress in each component:

1. Accumulator

The accumulator is designed for 2000 psi at 150°F and is expected to be operated at 1500 psi and 130°F. It is fabricated of Type 304 stainless steel schedule-40 pipe sections. The maximum principal stress at the 2000 psi design pressure is 16,700 psi, which is less than one-half the yield strength of Type 304 stainless steel.

2. Support Column

The support column is the bottom piece of FRED, in which the photoelectric cells are mounted. Two types of loading occur at the lower flange.

- a. Bending loads due to side loads.
- b. Axial loads due to the piston reaction, or when the grapple picks up FRED, positioner, and drywell for removal from the reactor vessel head.

The maximum stress of 7800 psi occurs in the bolts due to the bending load assuming a 1/2 g side load which is more than twice the design earthquake load. The stress in the tube wall for this condition is 1090 psi. This stress is still well below the allowable yield stress. The upper flange of the support column has less loading than the lower flange, therefore, the stresses will be less.

3. Expansion Chamber

The primary loading of the expansion chamber is due to pressure build-up during the actuation of the FRED. The pressure build-up is shown in Figure 5 to have a maximum of under 200 psi. The design pressure for the expansion chamber was taken as 1100 psi with the following pessimistic assumptions. The accumulator must be overcharged to 2000 psi, instead of 1500 psi, and the piston must be seated tight enough so that no gas leaks out and thus

the pressure would build up or equalize at 1100 psi in the expansion chamber.

Under these conditions, the principal stress in the lower flange would be 23,400 psi. For normal operating conditions the stress will be about 1/5 of this, or under 5000 psi. The upper flange is loaded by the cushioning gas above the piston but assuming the same pressure loading, the maximum principal stress is 23,000 psi. As in the lower flange, the normal operating pressure would yield a stress less than 1/5 of the above stress. All of the above stresses are well below the yield strength of Type 304 stainless steel.

4. Cylinder

The cylinder loading is due to pressure build-up under the piston and in the expansion chamber. The load in the expansion chamber is transmitted to the lower flange of the cylinder by the orifice and as in the expansion chamber, the pressure used to calculate the loading is five times that expected in operation. The maximum principal stress in this flange due to the 1100 psi pressure is 24,000 psi which would be less than 5000 psi for normal operating conditions. The loading in the upper flange of the cylinder is due to pressure build-up during cushioning or axial loading when removing the FRED system from the reactor vessel head with the multi-ton grapple. The largest load is the pressure build-up during cushioning which is under 100 psi and produces an axial load of about 1250 lb., which results in a stress in the fasteners of 2650 psi.

5. Cushion Chamber

The loading in the cushion chamber is similar to that in the guide cylinder and since the flange sizes on each end of the cushion chamber and the wall thickness are the same size as the guide cylinder or larger, no additional analysis on this part is necessary.

6. Piston to Actuator Rod

The connection of the piston to the actuator rod is shown in

Figure 6. The loading at this joint is largest when the piston is being accelerated at the start of the stroke. The maximum pressure under the piston as shown in Figure 5 will be under 200 psi and will give a stress in the threaded section of the actuator rod of 3000 psi or about one-tenth of the yield strength of Type 304 stainless steel. The shear stress in the piston for this load is about 1800 psi.

7. Actuator Rod to Poison Rod

The joint for the attachment of the actuator rod to the poison slug is a threaded and pinned joint. Assuming that only the threaded portion is effective and that the axial load is 100 times the slug weight as compared to 25 g's expected, the stress in the threaded joint would be 4600 psi. The other stresses in the poison slug are small due to the thick cladding (minimum clad thickness is 0.1 in.).

3.3 Poison Rod Analysis

A detailed heat transfer analysis has been carried out on the FRED poison slug. The result of this analysis is given in Figure 12. The maximum rod condition will be 1\$ at 15 MW, which gives a clad temperature of 1370°F. If the emissivity of the drywell was only 0.75 instead of the 0.90 that was used in Figure 13, then the maximum clad temperature would be 1550°F. A special surface treatment was applied to the drywell in the core area to increase the emissivity to over 0.90.

The above heat transfer calculations were made assuming no natural convection in the drywell and no conduction along the length of the poison rod, and a uniform drywell temperature of 800°F. All of these assumptions tend to make the calculations conservative since the drywell should run between 700°F and 820°F and some conduction and convection along the length of the rod are to be expected.

FIGURE 13 - FRED Poison Slug Heat Transfer

SAFETY EVALUATION

4.1 Reactor Loading

For FRED tests the reactor will be loaded with enough fuel to provide 50¢ excess Δk at 20 MW operation. By limiting the excess Δk to 50¢, the maximum steady-state power level of 25 MW that will result following a transient test in which (1) the scram system fails, (2) FRED slug fails to drop back into the core, and (3) the reflectors must be in the completely raised position.

4.2 Verification of Poison Slug Worth

The worth of the poison slug to be used in each test will be verified in the following manner: First, the initial power level for the test (see Table 1) will be set with the poison slug out of the core. After stable conditions are achieved, the poison slug will be gradually lowered into the core, and a fine control reflector segment will be raised to just balance the reactivity effect by a rod-swapping technique. In this manner, reactor power and coolant temperatures will remain constant, and the required movement of the reflector segment will provide a direct measure of the worth of the poison slug.

4.3 Characteristics of FRED

One of the most important characteristics of the FRED, from a safety standpoint, is the self-limiting characteristic which limits the rate of reactivity insertion by the FRED. This characteristic was explained in Section 3.1 under Dynamic Analysis. This characteristic is illustrated in Figure 12 which is a plot of accumulator pressure vs time for 20 in. of travel. This curve shows that when the accumulator pressure is raised from 1500 psi to 2000 psi, the exit time decreased by less than 10 msec. Therefore, an accidental over-pressurization of the system would not cause a significant increase in the reactivity insertion rate. The possibility of over-pressurizing the system is very unlikely due to the burst disks and cross checks provided during the charging of the accumulator as explained in Section 2.1.

TABLE 1INITIAL POWER LEVEL FOR FRED TESTS

<u>Power Level for Test</u> (MW)	<u>Type of Test</u>	<u>Slug Size</u> (%)
0.1	Familiarization	0.4 0.7 0.85 0.95
10.0	Familiarization	0.4 0.7 0.85
5	Sub-Prompt	0.95
10		0.95
15 for $-.0085$ Doppler 12 for $-.005$ Doppler		0.95
0.1	Prompt	1.1 1.2 1.3*
5	Prompt	1.1 1.2 1.3*
10	Prompt	1.1 1.2 1.3*

* To be run only if $|T \frac{dk}{dT}| \geq |0.008|$

Another important characteristic of FRED is that it always drops back into the core area. This characteristic was provided so that the same amount of reactivity would be returned to the core as was removed. It takes approximately 1.5 sec. for the device to drop back into the core following initiation of the transient.

4.4 Actuation Sequence

The details of the actuation sequence are covered under Section 2.1. This section will cover those points which are additional cross checks to prevent errors from occurring. In preparing FRED for actuation, the transfer chamber is charged with argon gas from the high pressure source. To have this transfer chamber charged with the wrong pressure would take the following sequence of events. The transfer chamber would be attached to a pressure source where the maximum pressure would be 2500 psi. This pressure is regulated down to 2000 psi. If this regulator were not working, and the transfer chamber were charged to full 2500 psi, the rupture disk on the transfer chamber would rupture and relieve the pressure, thus it would require two failures; the regulator would have to malfunction and the rupture disk would have to fail to rupture. Now assuming that the transfer chamber were charged to 2500 psi, it would then be moved to the refueling cell wall and attached to the FRED charging line. Before the accumulator is charged, the pressure in the transfer chamber is checked again after which the valve is opened allowing the gas to equalize or fill the accumulator to 1900 psi. This pressure is then checked by the pressure transmitted on the accumulator, and also the rupture disk on the accumulator is set to relieve at 1800 psi. Thus, to have an over-pressurization of the accumulator would require not only malfunction of the pressure regulator, but in addition, the transfer chamber failure of the rupture, the pressure check of the transfer at the cell wall omitted or ignored, the rupture disk on the accumulator failing to function when the gas from the transfer chamber is allowed to equalize at the 1900 psi level and the pressure check from the accumulator pressure transmitter is omitted or ignored. As a result of all these errors, if FRED is then fired, the speed of the device would be approximately 83 msec instead of the planned 90 msec.

4.5 Protective Devices

FRED has been provided with various protective devices to protect against procedural errors during the operation of FRED. One primary example is the use of rupture disks which are provided in the expansion chamber, accumulator, and the transfer chamber. At each of these points these rupture disks will protect against any significantly higher pressures than planned.

The latches that extend into the guide tube wall above the piston provide protection in the event that the accumulator gas charge could somehow inadvertently be allowed to be released to the expansion chamber, thus causing the piston to move up at a time when it was not planned for. Although this might not be of any great significance due to the method of loading the reactor and the other safety points, these latches will absorb the energy from the rising piston and allow the gas to vent out back down the actuator rod until the piston settles back on the seat. Any one of these latches are capable of preventing the piston from moving up the guide tube. If only one latch were to be inserted in the tube and the peak pressure were to be applied, the latch would suffer some deformation but would not fail and allow the piston to move up the tube.

When FRED was installed in the reactor, a series of checkout tests were carried out with the device outside the core area by using the positioner. These tests verified the prototype tests carried out earlier and followed the procedures of charging and actuation as used in San Jose and to be used during reactor transient tests. Argon will be used in all test series.

TESTING5.1 Prototype Tests

A development program for FRED was conducted with a test model (Figure 13) which was prototypical of the FRED model installed in the reactor. The test model was designed so that various parameters could be varied to determine their effects on the travel time from start of motion to core exit of the slug. The parameters which were varied were flow areas, weight of moving parts, venting in guide tube, gas volume, chamber volumes, and pressure and type of gas.

The results of these tests provided information for establishing the reactor model parameter values to produce a minimum exit time of about 90 msec at the peak accumulator design pressure of 1500 psi. The results also provided a good indication of the reactor model dynamics. The basic dynamics characteristics are shown by the curves of 20-in. travel time versus accumulator pressure (Figures 14, 15, and 16).

To obtain a wide range of exit times, a means for pressurizing over the piston and in the expansion chamber, as well as in the accumulator, was incorporated in the test model. Initial tests showed the scheme to be unnecessary and thus only accumulator pressure was used in the firing sequence. The procedure for conducting a test with the test model was:

1. Pressurize the guide cylinder over the piston through the over-pressure gas supply line.
2. Pressurize the expansion chamber by opening both the fire valve and accumulator valve with the pressure control provided by a preset pressure regulator.
3. Close fire valve.
4. Continue to pressurize the accumulator to the desired pressure. (It is always higher than the pressure in the expansion chamber.)
5. Close accumulator valve.

FIGURE 14 - FRED Dynamics

FIGURE 15 - FRED Dynamics (Weight Test)

FIGURE 16 - Effect of Changing Gas

6. Start data-recording system.
7. Turn fire switch.
8. Stop data-recording system.

The piston motion starts about 30 to 50 msec after Step 7 and returns to the seal seat in 1 to 5 sec., after which the procedure may be repeated. Each data point on the curves in Figure 15 represents one test following the above procedure. Evaluation of the test results from the above performance tests showed that a reasonable range of exit times could be obtained by utilizing only the accumulator as a means of firing. This method has several advantages, the most significant one being that only one pressure is involved in setting up a test. With the design changed to firing with accumulator only, a series of design tests was conducted. These tests included varying the line size between the accumulator and expansion chamber, varying the weights of the moving parts, the type of gas used for the propellant, the volume of the expansion chamber, and the volume of the accumulator. Also included in these tests were variations in the venting conditions in the upper end of the guide tube. The above performance tests were carried out with a 1/2-in. line between the accumulator and the expansion chamber and using 32 lb. as the weight of the moving parts. To determine the effect of various weights, a 5 lb. weight was added, also a 10 lb. weight was added. These tests with a 1/2-in. line and a 1/4-in. line are shown in Figure 15. As in earlier tests, these were carried out using nitrogen as the propellant gas. In Figure 16, the effect of changing the propellant gas from nitrogen to argon is shown, as well as the effect of varying the weight. In Figure 17, the results of some of the venting tests are shown. Results are shown for no vents open to 2 vents open. It can be observed that the change had little effect on the time to travel 20 in.

Figure 15 and Figure 16 both have performance curves for a 47 lb. system weight and zero psig initial chamber gas pressure. The difference in the tests is that those charted in Figure 16 were performed using an orifice-and-nozzle-diameter different from those plotted in Figure 15. The nozzle enlargement produced about a 10 msec change in travel time.

FIGURE 17 - Effect of Changing Expansion Chamber Volume

A series of tests was carried out to determine the effect of varying the volume of the expansion chamber. The volume was reduced from 50 in.³ to 25 in.³ by using aluminum filler rings inside the chamber. The results indicate that ejection times are slightly shorter with the smaller expansion chamber volume, which would be expected since there would be less volume available for the gas to expand into and, thus, the propellant gas would have a shorter residence time in the expansion chamber. These volume change tests were also carried out with various vent conditions. As shown in Figure 17, the change in vent conditions had little effect on the exit times.

The instrument data for position indication of the FRED device and other parameters are shown in Figure 18. The record was made on a light-beam oscillograph. The upper trace is one which indicates switches switching in and out as indicated by step changes in voltage. The first switch (change in voltage) is the lift-off indication. Switches 1 and 2 are proximity switches which sense the travel of the piston as the piston passes by each switch. The second trace is from the photoelectric signal. This signal is obtained by striping the rod with alternate light and dark rings, as shown in Figure 19, and recording the change in voltage from a sensing head which senses the reflected light from a light source.

One light strip has been eliminated at three different positions on the shaft. This provides a method of orienting between the trace and the actual rod position at a given time. This is done at points corresponding to 5 to 8 in., 17 to 20 in., and 25 to 28 in. of travel from start of motion. The other three traces shown are from the pressure transducers that were used in the initial performance test.

5.2 Reactor Model Tests

All FRED reactor model parts were quality control checked for compliance with material, process and dimensional specifications. The accumulator was hydrostatically tested at a pressure of 2500 psi and 70°F, while the transfer chamber was hydrostatically tested at a pressure of 3000 psi and ambient temperature. The device is shown assembled on the positioner and ready for testing in Figure 20.

FIGURE 18 - Oscillograph Trace

FIGURE 19 - FRED Model I Arrangement

FIGURE 20 - FRED Reactor Model Test Setup

An initial series of tests were carried out to determine the actual accumulator pressure vs 20 in. travel time relationship for two different size connection hoses between the accumulator and the high pressure chamber. For these and the following tests, the device was modified by removing the rupture disks and using an argon cylinder attached directly to the accumulator. Also, the expansion chamber pressure was recorded throughout the testing so that a rupture disk could be installed that would relieve should the device become over-pressurized in actual reactor operation. For the initial series of tests, the 20 in. travel time was recorded for accumulator pressures ranging from 400 to 2000 psig for first a 1/4-in. diameter hose and then a 1/2-in. diameter hose. The results of this testing were compared with the analytical predicted results with favorable agreement. The 1/4-in. diameter hose was selected to continue testing. The results from the 1/4-in. diameter hose tests provided the desired performance from a physics and safety standpoint. The results of this testing are given on Figure 21.

A sample of the recordings taken for each test run is shown in Figure 18. The variables, which were recorded on a light-beam oscillograph, are from left to right:

- 1) Accumulator pressure
- 2) Expansion chamber pressure
- 3) Lift-off signal from the spring switches and proximity switches set to indicate 10 in. and 20 in. of travel
- 4) Position signal determined from a pattern of light and dark stripes on the poison rod
- 5) Lift-off signal determined from the Bentley-Nevada analog detector

There are two lift-off spring switches (Figure 22) mounted so that the piston makes contact with them in its resting position. The two spring switches were wired in series so that the first broken contact (piston lifting-off) would result in the lift-off signal. The Bentley-Nevada detector system is shown in Figure 23. The light-beam oscillograph records a high voltage signal when the piston is close to the detector and lowers as the piston raises.

FIGURE 21 - Reactor Model Tests with 1/2" and 1/4" Hose

GEAP-13649

FIGURE 22 - Lift-Off Switch

GEAP-13649

FIGURE 23 - Distance Detector

The second set of tests were carried out to determine if the piston would ever hit the bumper pad that is located in the upper end of the cushion chamber as shown in Figure 1. Two proximity switches were mounted approximately 2 in. and 12 in. below the bumper rod. Since the piston was made from carbon steel, the proximity switches could sense the piston if it passed by. Tests at accumulator pressures of first 1500 psig and then 2000 psig indicated that the piston did not reach the level of the first proximity switch which was 12 in. below the bumper pad. Verification that the proximity switches were operable was obtained by running the piston up by hand and observing the expected signals. Also, it was found in later tests, when the poison rod was tied down and the pressure in the expansion chamber was allowed to build up to maximum pressure before releasing the poison rod, that the piston still did not contact the bumper pad. This was concluded by audio observation of the tests and by inspecting the bumper pad after the tests.

It was also observed that on any test run, there was a definite gas cushioning effect as the piston settled back to its rest position after travelling up the cylinder. This was determined by observing the trace of the photoelectric-position signal at the end of the test run. The signal showed position changing very gradually with time when the piston approached its rest position.

Next, a series of 52-room temperature tests were carried out with positioner locations of near bottom and then mid-stroke at discrete accumulator pressures of 400 psi, 600 psi, 800 psi, 1000 psi, 1200 psi, 1500 psi, and 1600 psi.

This series of tests was repeated after enclosing FRED in a simulated reactor temperature environment. It was found that neither the temperature nor the positioner location had a significant effect on the accumulator pressure vs 20 in. travel time relationship as can be seen by comparing Figures 24, 25, and 26 which show the accumulator pressure vs 20 in. travel time relationship for three different conditions.

To complete the upper end of the possible accumulator pressure spectrum, a total of 12 more test runs were carried out at accumulator pressures of 1800 psig and 2000 psi with the positioner at bottom and

mid-point of stroke. Next, the transfer chamber was checked for volume (4.84 liters) and then installed in the line to simulate actual reactor operation. After installation was completed, check-out tests were carried out to determine what pressure relationship existed between the transfer chamber and the accumulator. The accumulator was pressurized by first pressuring the transfer chamber and then allowing the pressure to equalize between the accumulator and the transfer chamber. This sequence is depicted in Figure 27.

FIGURE 24 - FRED Test Results

FIGURE 25 - FRED Test Results

FIGURE 26 - FRED Test Results

CHARGING THE TRANSFER CHAMBER

FIGURE 27 - Charging Schematic

It was found that for a transfer chamber pressure of 800 psi the resulting accumulator pressure was 600 psi while for a transfer chamber pressure of 2000 psig the resulting accumulator pressure was 1500 psi.

This pressure ratio between the transfer chamber and the accumulator should be maintained in the actual reactor case since the same length of interconnecting tubing was used in this test as will be used in testing at the reactor site. If this relation is not repeated, then adjustments will be made in the transfer chamber pressure at the reactor.

Next, the following schedule of tests was conducted to better establish the accumulator pressure vs 20 in. travel time relationship for selected SEFOR operating points of 600 psi and 1500 psi accumulator pressure.

Accum. Pressure (psi)	Condition		Positioner Location (in. from bottom)	No. of Tests
	Heated	Rm. Temp.		
600		X	0.0	10
600		X	15.0	5
600		X	30.0	2
600	X		0.0	10
600	X		15.0	5
600	X		30.0	2
1500		X	0.0	10
1500		X	15.0	5
1500		X	30.0	2
1500	X		0.0	10
1500	X		15.0	5
1500	X		30.0	2

This series of tests was carried out by pressurizing the accumulator through the transfer chamber. A statistical analysis on the results obtained for the above tests yielded the following information.

Accum. Pressure (psi)	Mean Travel Time (msec)	Range for $\pm 3\sigma$ Deviation
600	144	133.5 to 154.5
1500	99	94.5 to 103.5

These travel times were measured using the lift-off switch and the proximity switch since these are the primary position indication methods that are to be used during reactor testing. The photo-electric system and

the analog lift-off signal were also used to provide additional information for the experimental program.

The results of all tests were plotted on a log-log graph of accumulator pressure vs 20 in. travel time and appear in Figure 28. The experimental data were analyzed on the computer program "CURFIT" to determine the best fit curve. The analysis yielded a hyperbolic function as the best fit curve based on a least-squares fit. The index of determination for this fit was calculated to be .975. A perfect correlation would yield a value of 1.0 for the index of determination. The asymptotic behavior of the hyperbolic function substantiates results in preliminary testing which exhibited a self-limiting characteristic for travel time. This self-limiting characteristic is more clearly shown in Figure 29 which is a linear plot of the hyperbolic function obtained for the experimental data from the computer analysis. The device, in actuality is even more self-limiting than indicated by Figure 29.

Some additional testing was carried out to substantiate the safety characteristics of the device by imposing some abnormal conditions. The following is a discussion of some of these conditions. The bottom of the test drywell was deflected from its normal position and held in the deflected position while tests were carried out at accumulator pressures of 600 psi and 1500 psi. The bottom of the drywell was deflected first 1/2 inch, then 1/2 inch, and then 3/4 inch in two opposite directions during the testing to determine what effect any misalignment of the drywell would have in the actual reactor case. No significant differences were noticed in the response of the device under these abnormal conditions. There were also three tests carried out with the safety latches in the "safe" position. In each case the safety latches were successful in holding the piston down and no detrimental effects were noticed when the safety latches were subsequently operated. These tests were run at both 600 psi and 1500 psi accumulator pressures. Some final tests were carried out to substantiate burst disk ratings. A series of rupture disks of different ratings were pressurized until they ruptured; both, by slow pressurization and by suddenly exposing a large volume of high pressure argon to the rupture disk. All of the rupture disks ruptured at a pressure which was within manufacturer specifications.

FIGURE 28 - FRED Reactor Model Test Results (for 196 tests)

FIGURE 29 - FRED Self-Limiting Characteristics

NOMENCLATURE

A	Area	ft ²
C _p	Constant Pressure Specific Heat	Btu/lbm-°F
F	Force	lb
g _c	Gravitational Acceleration	32.2 ft/sec ²
J	Heat Equivalent of Work	778 Btu/ft-lb
k	Ratio of Specific Heats	
ℓ	Length of Dashpot Chamber	ft
m	Mass	lbm
P	Pressure	psi
R	Gas Constant	ft-lbf/lbm-°F
t	Time	msec
T	Temperature	°F
w	Flow Rate	lbm/sec
W	Work	ft-lbf.
V	Volume	ft ³

Subscripts

0	Initial Conditions
1	Accumulator Conditions
2	Expansion Chamber Conditions
3	Low Pressure Chamber Conditions
4	Dashpot Conditions
p	Piston Conditions

APPENDIX A

DRYWELL

The drywell is shown in Figure A-1 and in cross section view in Figure A-2 of this supplement. This cross section view of the drywell shows the enlarged internal diameter at the upper end where the positioner screw extends down inside. Below this point the drywell narrows to the 1.380 in. internal diameter where the poison rod extends. The actuator rod is 1.25 and the poison slug is 1.315.

This drywell is designed to Section 3 (Nuclear Vessels) of ASME boiler and pressure vessel code. The portion of the drywell above reactor head which transmits the FRED reaction loads to the vessel head has been designed for 10,000 lb of force which is well above 1250 lb maximum which is expected. The bolts which attach the drywell to the head are captured fasteners and stretch bolts to absorb the energy due to the design basis accident. The heavy walls provide a greater or equivalent amount of shielding below the head to that in the fuel rods thus protecting the reactor head from activation.

FIGURE A-1 - Drywell - Detail

FIGURE A-2 - Drywell - Section View

APPENDIX BPOSITIONER DRIVE

The purpose of the positioner, as used with FRED, is to provide a means of moving the complete FRED System (mechanism and poison rod) into or out of the core area as a unit. The positioner drive is shown in Figure B-1 with FRED in place as installed in the reactor.

This device provides the capability for running transients of varying magnitude with the same poison slug (i.e., by positioning axially in the core) and, more importantly from a safety standpoint makes it possible to test FRED under environmental conditions with the poison slug portion outside the core area.

The position indication for this drive is displayed on the main control panel for reactor control. The position indication mechanism is a rotary counter attached to the input shaft of the positioner mechanism and transmitting its signal to a digital readout in the control room. The stroke of the positioner mechanism is 30 in. and the position indication readout provides four digit readout (i.e., 26.57 in.). The drive motor for the mechanism is a two speed motor to provide both slow and fast movement of the device during various testing phases. The fastest speed is 10 in./min and the slow speed is 2-1/2 in./min.

The upper and lower limit switches are the only items necessary to operate the system since the test firing will be carried out at the upper limit and in-core firings will be established by observing the power level. An additional feature of this device to aid in checking position indication is a scale and pointer that has been placed along one of the guide bars so that the position can always be verified by use of either the periscope or the in-cell TV system.

FIGURE B-1 - Fast Reactivity Excursion Device

The positioner without the drive motor is shown in Figure B-2. The rotation of the input shaft causes the bevel gear set to rotate the lifting nut since the bevel gear is keyed to the lifting nut. The rotation of the lifting nut causes the screw to move up or down. Rotation of the screw is prevented by the guide bars extending through the lifting platform guides.

The basic lifting mechanism is a 50,000 lb. lifting jack. The maximum load expected on the device is 1250 lb. which is imposed by the reaction when the FRED piston is expelled from the core. The critical loading mode occurs when FRED is fired in the raised position where the screw is loaded as a column extended the full 30 in. stroke above the positioner. This extreme condition still imposes very little load on the screw relative to its capacity since the minimum Euler critical column buckling load for this configuration is 500,000 lb.

The positioner drive was tested with the FRED system to determine proper operation at room temperature and at simulated reactor temperatures to establish any possible adverse effects that might come about due to mounting the device on the reactor head.

The materials that the positioner are fabricated from were chosen for the specific function for each piece. The outer case and exposed surfaces other than the screw are all Type 304 stainless steel. The internal parts are made of different material as required and are listed below.

<u>Component</u>	<u>Material</u>
Lifting Screw	4140 Alloy Steel (Nitrided)
Lifting Nut	Aluminum Bronze (Heat Treated)
Bevel Gear Set	4140 Alloy Steel (Heat Treated)
Bearings (All)	Alloy Steel (Heat Treated)

The screw jack mechanism is designed to operate without lubricants, but to improve operation, Molybdenum Disulfide was used on the lifting nut and screw, and a small amount of radiation-resistant grease will be applied to the surface of the bevel gear set.

The connection between the drive motor and the drive mechanism is made by a coupling which allows for misalignment between the shafts. If binding

were to occur in the mechanism, this coupling is designed to be the weak link in the system, so that it will fail without damaging other parts of the system. These tests were performed both at room temperature and at temperatures when the drywell was heated to 500°F. Over 200 cycles were carried out under these conditions, and no problems were encountered with the mechanism.

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