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AMF ON-POWER REFUELING SYSTEM FOR A CANDU-TYPE REACTOR

PROTOTYPE REFUELING HEAD FINAL DEVELOPMENTAL REPORT

DECEMBER 1964

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FINAL DEVELOPMENTAL REPORT

for

AMF ON-POWER REFUELING SYSTEM

PROTOTYPE REFUELING HEAD

December, 1964

AMF ATOMICS

A Division of
American Machine & Foundry Company
York, Pennsylvania

FINAL DEVELOPMENTAL REPORT
TO THE
UNITED STATES ATOMIC ENERGY COMMISSION
SAVANNAH RIVER OPERATIONS OFFICE
FOR THE
AMF ON-POWER REFUELING MACHINE
PROTOTYPE REFUELING HEAD

December, 1964

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FINAL DEVELOPMENTAL REPORT
TO THE
UNITED STATES ATOMIC ENERGY COMMISSION
FOR THE
AMF ON-POWER REFUELING MACHINE
PROTOTYPE REFUELING HEAD

INTRODUCTION

This report presents a synopsis of the work performed by AMF Atomics, a division of American Machine and Foundry's Advanced Products Group, under contract number AT(38-1)-233 with the United States Atomic Energy Commission, Savannah River Operations Office, for the development of on-power refueling equipment.

The objective of the overall activity was to design, fabricate and test a prototype on-power refueling head suitable for operation with a CANDU-type heavy-water moderated reactor. The machine would facilitate loading and unloading natural uranium fuel in rod-bundle form from a reactor operating under full power.

The work accomplished was part of a cooperative program between the USAEC and the Atomic Energy of Canada, Limited, and was administered by the Savannah River Operations Office of the USAEC.

The scope of this report is to document the developmental design, fabrication and testing of the Prototype Refueling Head as achieved under Tasks III, IV and VI of the project work program (revised September 1962).

Significant points of concept development are covered completely in Task I Completion Report (AMF-388-TR-2, dated July 1962). Component Feasibility Test Report (AMF-388-TR-1, dated February 1962) covers work performed under Task II of the project work program. Design, manufacture and test of the Adapter Valve is covered in Adapter Valve Development Report (AMF-388-TR-3, dated February 1963).

The report is presented in four chapters. Chapter I, Refueling Head Design, deals with the development period between the establishment of the concept to the initiation of component fabrication. Chapter II, Manufacturing, is concerned with the fabrication and assembly of the refueling head hardware. This chapter is further supplemented by photographs of the assembled equipment installed in the test facility. Chapter III, Refueling Head Testing, covers all phases of refueling head testing and is augmented by appropriate data samplings and illustrations. Chapter IV, Conclusions and Recommendations, outlines the conclusions drawn from program experience and recommends those areas in which refinements may be made on future devices of similar purpose.

To acquaint the reader with the basic system requirements and to outline the reactor parameters, there follows a description of the reference reactor for which the system was designed.

The requirements are discussed in two categories. The first category will describe the reactor in consideration of its physical arrangement and refueling modes, the second will describe the reactor components and building limits with which the refueling system must be compatible.

REACTOR ARRANGEMENT

The reactor is shaped like a right-ended cylinder and is arranged with pressure tubes on the horizontal axis. The reactor proper is located in the calandria vault at ground level. Each reactor face opens into a refueling vault in which refueling and reactor maintenance are carried out. Adjacent to each refueling vault are refueling machine maintenance rooms. (See figure 1).

AMF REFUELING VAULT EQUIPMENT

Figure 1.

REACTOR SYSTEM

The reactor is provided with two heavy-water circuits, and an enclosure with a recirculating, conditioned atmosphere. One of the heavy-water circuits is the high-pressure/high-temperature primary coolant circuit, used to extract heat from the reactor fuel and to generate steam in the boilers. The other heavy-water circuit is the low-pressure/low temperature moderator circuit, the principal parts of which are: the calandria, the dump tank, and a cooling circuit. A helium atmosphere is used above the heavy water in the tanks of this circuit.

The reactor vessel, or calandria, is a horizontal, cylindrical tank roughly 20 feet in diameter by 17 feet long containing 306 horizontal tubes passing from end-to-end and rolled into the end plates. Passing through the calandria tubes, but separate from them, are 306 pressure or coolant tubes in which resides the reactor fuel. See figure 2. Both the calandria tubes and the pressure tubes are made of Zircaloy. The rest of the calandria is made of austenitic stainless steel. Immediately below the calandria is the dump tank with a capacity greater than the calandria. The two vessels are connected by a large neck and separated by the dump ports. The dump ports are shaped so that a gas/liquid interface exists at the bottom of the calandria. This permits gas pressure in the dump tank to support the heavy-water moderator in the calandria. When the gas pressure above the liquid in the calandria and dump tank are equalized by interconnection, the moderator falls into the dump tank.

The high-pressure primary circuit is contained in four overhead manifolds. Heavy-water coolant is supplied to fuel channels in the reactor at 480°F from two cold headers. The working pressure in these headers is 1460 psig. Heavy-water coolant leaves the reactor channels at 560°F and is collected in two hot headers. These hot and cold headers, known as the reactor headers, are horizontally disposed

FIGURE 2

at an elevation above the calandria. The reactor fuel-carrying channels in the region of flux, consist of Zircaloy tubes, extended at each end by steel end fittings. The Zircaloy tube is expanded into the end fittings by rolling. The end fittings pass through and are supported by structures known as end shields at each end but separate from the calandria. The outer ends of both end fittings are fitted with closures which can be removed by fueling machines to facilitate the insertion and removal of fuel in the channel. Heavy-water coolant is supplied and removed from the channel by radial connections on the end fittings. Individual feed pipes at each end conduct the heavy water between the end fittings and the reactor headers.

The reactor fuel, in the form of bundles, consists of 19 parallel, cylindrical elements, spaced apart for cooling, making an assembly 19.5 inches long. The bundles pass freely through the 3-1/4 inch bore of the fuel channels. The uranium oxide fuel material is contained in Zircaloy sheaths within a Zircaloy structure. The contents of a fuel channel are a closure plug and a shield plug at each end, and twelve fuel bundles. The length of channel in the reacting region corresponds to the length of 10.1 bundles.

Associated with the primary circuit are the sampling tubes. A sample of the coolant from each fuel channel is taken from a connection on its outlet feeder pipe and delivered to a monitoring station. Separate sample tubes are used for each channel. The samples are monitored by a scanning arrangement to detect fission-product activity to determine if any channel bears defective fuel sheaths. The temperature of the coolant leaving each fuel channel is also measured. Equipment is provided in each supply feeder for measurement of the inlet flow to each channel and a valve or other means is incorporated to adjust the flow to the requirements of the channel. The flow adjustment is intended primarily for establishing the initial distribution of coolant in the channels but, if necessary, readjustments can be made as required.

The primary circuit is the major source of concern with regard to heavy-water leakage, which may be an economic factor, or an operational inconvenience, because of the contained activity. The moderator circuit may also have losses but this circuit is cold and at low pressures. The major part of the primary circuit, where leaks would be expected, is housed in the reactor vault, and all leakage in this region is recovered. Outside the reactor vault, all connections on the primary or moderator circuit are either welded or double sealed with provisions for leakage collection from the interseal space. Similarly, valve stems and pump shafts are fitted for leakage collection from an interseal space. In this way it is anticipated that leakage of D_2O to the atmosphere in the building will be negligible in operation.

REACTOR VAULT

The reactor vault consists of three separate vaults, the calandria vault and two fueling machine vaults. The reactor vault is divided by heavy-concrete walls and end shields. These dividers separate the two refueling vaults from the centrally located calandria vault. The calandria and dump tank are situated in the calandria vault. The fuel channel ends are accessible to the fueling machines working in refueling vaults to replace reactor fuel.

Personnel may enter the machine vaults during reactor shutdown periods for maintenance work on the end fittings or other reactor components. The radiation level will be relatively high and working conditions will not be ideal, but the advantage of direct access can be claimed. The enclosure is lined with steel designed to contain an atmosphere with heavy-water humidity. All penetrations through the lining are sealed to prevent loss of the enclosed atmosphere, or contamination, by in-leakage, of surrounding air with ordinary water humidity. The reactor headers are within the reactor vault. The remainder of the large piping, valves, pumps, and boilers of the primary circuit are outside the enclosure. The moderator circuit is outside

the vault excepting those pipes which necessarily connect with the calandria or dump tank.

The atmosphere in the reactor vault is CO_2 . This has the advantage over air in that nitric acid does not form in the irradiated gas, and active argon is not produced. The absence of argon activity facilitates personnel access. For major maintenance work, the CO_2 can be purged and replaced with air.

The vault cooling circuits for the CO_2 are designed to remove excess humidity and recover heavy water which enters the atmosphere from minor leaks in those portions of the heavy-water circuits within the vaults. A purification circuit is provided to remove any air which gets into the CO_2 atmosphere, either in connection with purging and filling or from the transfer of equipment, such as the fueling machines, to and from the vaults through air locks.

The concrete which forms the calandria vault is protected from thermal and radiation damage by steel thermal shields. These air-cooled layers of steel are located on the inner concrete face, outside the vault liner. When air cooling is inconvenient and shield replacement possible, portions of the thermal shield may be water cooled. Some active argon will be produced in the thermal shield-air cooling circuit. This is a recirculating circuit with a normally continuous purge to the stack. The concrete behind the thermal shields is cooled by embedded pipes carrying water in a recirculating cooling system. This system is called the biological-shield-cooling circuit.

REACTOR CONTROL

Reactivity in the reactor is controlled in a number of ways. These are: control of moderator level, control of the position of solid absorber elements, control of the position of enriched fuel elements (boosters), and control of the concentration of poison dissolved in the moderator. The proposed solid absorber and enriched elements are in vertical assemblies housed in through-tubes which pass between lattice positions

and extend above and below the calandria. Four absorber elements, in two sites, and eight enriched or booster assemblies in four sites, are planned. The elements may be withdrawn to reside one above and one below the calandria at each site. The planned soluble poison, used during occasional transient periods of excess reactivity, is cadmium sulphate. It will be removed by ion exchange for normal operation. The primary method of keeping available reactivity matched to demand is by daily refueling, replacing spent fuel with new fuel as required. The margin of excess reactivity normally carried (other than the booster elements) will be very small.

Two methods of stopping the reactor are provided. Emergency shutdown - viz., trip - will be by dumping the moderator. This action will be requested when supervisory or protective instrumentation senses a situation which is potentially hazardous enough to require prompt corrective action. A less drastic action, set-back, will be invoked on occasions when the situation requires correction, but where speed is of no importance. This applies in most cases where the parameter, which has gone beyond a permitted range, is thermally dependent on reactor power. In a set-back, the moderator level is lowered at a controlled rate to take the reactor power down to about 2 percent neutron power in 100 seconds. Once the fault condition has been removed, following a trip or set-back, the reactor can be brought back up to full power provided the elapsed time is not too great. The reactivity reserve provided by the booster elements permits the resumption of full power within 25 minutes. This requires starting of the moderator pump within 15 minutes in cases of trip where all the moderator has been dumped.

FUELING

All 306 reactor channels are physically identical and use the same fuel. For considerations of physics and fueling rates, the reactor is divided radially in two zones. The center zone embraces

roughly one-fifth of the channels. In this zone, the fuel is subjected to a greater total irradiation than that of the outer zone. This gives a flux distribution which is somewhat flattened in the radial direction. Fuel in the inner zone will have a two-year residence time in the reactor. The residence time for fuel in an outer channel depends on the position of the channel, and ranges from under two years for the innermost to about three years for the outermost channels. During its stay in the reactor, the fuel advances in six steps from end to end through the channel, spending an equal time in each location. When fuel is changed, two of the 19.5 inch-long fuel bundles are removed together from one end of the channel and two new bundles are fed in the other end. Reactor fuel is fed and discharged from both ends of the reactor, with adjacent fuel channels arranged to feed from opposite directions.

The frequency with which different channels require opening for fuel changing, ranges from about one and one-half to three times a year. The reactor refueling rate is about five bundles a day in normal operation - that is, two or three channels require changing each day. The numbers above are based on the assumption that defects in fuel will be sufficiently infrequent that removal of defective elements from the reactor will not significantly effect the fueling rates.

To refuel a channel, a fueling machine is attached to each end of the channel. The machines seal to the end of the end fittings, remove the end seals and shield plugs, and, working in unison, move the column of fuel bundles in the channel back and forth under the control of refueling machine rams. In this way, a pair of bundles can be removed from the end of the column in one machine and in another step of the procedure a pair of bundles can be added to the other end of the column in the other machine. Under abnormal conditions, the machine must be capable of changing a whole fuel channel, a pair of bundles at a time.

The refueling machines are operated by remote control from the plant control room. Interconnection of refueling machine and control and power services is effected at the cable dolly located at the refueling vault door. Each machine operates on a pair of tracks on the floor of the refueling machine vault parallel to the reactor face. The machines can also be coupled to a new/used fuel port which is fitted with the same end attachment as a fuel channel.

The new/used fuel port is connected to a fuel-transfer mechanism which is located between the two refueling machine vaults, beside the calandria, but shielded and outside of the reactor vault atmosphere. New and used fuel is fed to-and-from both machines through this transfer mechanism. When not in use the refueling machines reside in the refueling machine vaults. Doors and air locks are provided through which the machines can be withdrawn to another area for maintenance.

Used fuel is sent from the fuel-transfer mechanism to storage in a shuttle which is flushed through a pipe by a water flow. The transfer pipe is located underground for most of its length. It discharges the fuel underwater in the storage bay in the service building.

DETAILED INTERFACES AND OPERATING REQUIREMENTS

The coolant tube assemblies (see fig. 2) support the fuel in the primary coolant flow while in residence in the reactor. The tubes, of which there are 306, are arranged in rectangular coordinates having a pitch of 9 inches. Each assembly consists of a Zircaloy pressure tube attached at each end by an expanded joint to a ferritic stainless-steel end fitting. A shield plug and an end seal are located within the end fitting. Each assembly with its fuel and heavy-water coolant is supported by the end shields through sliding non-lubricated bearings and to a small degree by the calandria tube through the annular spacers. The end fittings are designed to allow relative axial movement between the coolant assemblies and the end shields. Adjustable stops are provided to limit the movement of the coolant tube assemblies relative to the

calandria tubes and end shields. The end fittings are keyed to the end shield to provide alignment and prevent transmission of torque from external loads to expanded joints and the pressure tubes. Axial restraints on the coolant assemblies are provided at the end shields to withstand the reaction thrust which may arise should the end closure blow out of the fitting. This load is transmitted through the end shields to the vault structure.

The inlet and outlet end fittings are identical and each consists of a stainless-steel tube approximately 6 inches in diameter and 7 feet long. The end fitting is designed to meet the following requirements: a) provide a transition joint between the pressure tubes and the primary circuit piping, b) provide support for the pressure tubes and their contents, c) provide a suitable high-pressure closure operable by the fueling machine to allow insertion and removal of fuel, and d) provide shielding to allow access to the fueling machine vaults and the face of the end shields at shutdown for servicing.

The heavy-water coolant enters and leaves the end fittings by means of a nozzle connection near the face of the end shield, and flows past the shield plugs through an annular passage to-and-from the pressure tube. An internal guide sleeve provides support for the shield plug, the fuel and refueling machine ram during the fueling operation. The end fitting design is such that there is no added flow resistance during the refueling operation.

The feeder pipe-to-end fitting connection consists of a V-band clamp with a metal gasket. This joint is accessible for maintenance if required.

The end fittings are fabricated of type-403 ferritic stainless-steel forgings and tubing. This material provides adequate strength, hardness and resistance to corrosion and irradiation damage and it has a relatively low thermal expansion coefficient. This condition is desirable for making an expanded joint with low-expansion Zircaloy.

The following details of the end fitting design are pertinent: a) location tolerance of the shield plug slot will not exceed 1/16 inch in either direction. This is to any point on the end fitting including the end seal seating surface, b) end fitting can withstand a 70,000 inch-pound moment at the first reaction point (outboard shield bearing), and c) maximum axial load on end fitting is $\pm$ 500 pounds.

The end seals provide end closures for the end fitting to contain D_2O at 1460 psia, 560^o F of the reactor-primary cooling circuit. The end seals consist of a sealing disc engaged with a sealing seat in the end fitting and are held in place by fingers engaged in the end fitting groove. The end seals are designed to be latched into the end fitting by a refueling machine. Maximum leakage through the end seals is limited to 10 cc per day.

The shield plugs are located inboard of the end seals in proximity with the primary-reactor shield. These plugs supplement the primary shield so that access by personnel to the refueling vault is possible when the reactor is shut down. As with the end seals, the shield plugs are latched in place in the end fitting. The plugs are essentially steel plugs approximately 36 inches in length by 3-1/4 inches in diameter with appropriate latching fingers at the outboard end. During reactor operation the shield plug in the outlet end fitting also acts as a fuel stop.

The pressure tubes are 15 percent cold-worked, seamless-drawn, nickel-free, Zircaloy-2 tubes having the following approximate dimensions:

- a) inside diameter - 3.25 inches
- b) minimum wall thickness - 0.155 inches, and
- c) length - 17 feet, 5 inches

The maximum allowable design stress for the pressure tubes is 16,000 pounds per square inch at 570^o F.

Each coolant tube assembly contains twelve 19.5 inch bundles. During reactor operation, these units in two-bundle increments will advance progressively through the tube in the direction of the coolant flow. The bundles may be of two types, one having spiral-wire-bearing spacers, the other pad-bearing spacers. In addition, the bundle length may be increased to 39 inches, which is within the capacity of the refueling machine.

During fuel-bundle handling the following conditions apply:

a. Forces.

1. Hydraulic force on fuel column due to pressure drop - 600 pounds nominal, 800 pounds maximum.
2. Friction of fuel bundles sliding through coolant tube - 200 pounds maximum.
3. Allowable axial load on center pin of element - 1200 pounds maximum.
4. Allowable axial load on any one of the peripheral pins - 400 pounds maximum.
5. Allowable radial load on any one peripheral pin - 20 pounds maximum.

b. Column Control. The bundles must be maintained in axial contact at all times when in the primary-coolant flow. This is necessary to preclude bundle impact following sticking in the tube and release by the flow.

c. Temperature and Radiation.

1. Thermal Shock. The bundle can withstand thermal shocks on the order of 1500°C (2732°F) per minute without damage to the fuel sheath.
2. Heat Output. Maximum heat output after irradiation of the bundles is not expected to exceed 15 KW. For normal refueling, individual afterheat of the bundles being handled will be approximately 1.5 KW. Rejection of this heat must be carried out to control sheath temperature below the saturation point.

3. Radiation Activity. The radiation dose of the bundles normally handled by the machine during refueling is approximately 1.7×10^5 R/day at a distance of one foot.

d. Dimensions. The size of the fuel bundle is 3.092 inches diameter by 19.500 inches long. The only dimension subject to change through irradiation is the length, where a maximum growth of 0.166 inch per bundle is expected.

The machine rails run from the refueling vault, through the maintenance door, and into the maintenance area. These rails carry the refueling machine as well as the cable dolly. The machine rails are held straight and parallel to the building and reactor centerline within 0.005-inch per foot and do not exceed 0.060 inch over 14 feet on either side of the reactor vertical centerline. The rails are held level within 0.005 inch per foot and do not exceed 0.060 inch over the same 28-foot dimensions. The machine rails are located 12 feet, 4.375 inches, ⁺-0.125 inch below the horizontal reactor centerline. The flat rail is held level with the machine rail within 0.010-inch TIR (accounting for the 1.250-inch level difference) and parallel in a horizontal plane within 0.060-inch TIR. The rails are designed to accept loads of 65K equally distributed over the four carriage wheels.

The maintenance door permits removal of the refueling machine as well as personnel access and egress to the refueling vault. When closed, the door keys in the cable dolly to effect an environmental and radiation seal.

The cable dolly provides a penetration for supplying the necessary power and control services to the refueling machine. The dolly is contained within the refueling vault door during reactor operation. When the refueling machine is removed, the dolly is pushed out by the machine into the maintenance area. In turn, the dolly is pulled back into position

by magnets on the refueling machine.

A new/used fuel port is located at the side of the reactor face, one in each refueling vault. The ports are identical in design to the reactor end fitting. They do not, however, contain end seals and shield plugs. Port shutoff is carried out by a remotely-operated valve.

ROOM ARRANGEMENTS

The two refueling vaults are mirror images except for the location of the new/used fuel ports. The floors are essentially flush except for rail and bumper protuberances. The east/west clearance limits are established by the end fittings and feeder pipes at the reactor and the monitor lines mounted on the rear vault building columns. The shield walls establish the north/south clearance limits. The ceiling limits are those defined by the insulated feeder pipes and the overhead servicing crane.

Adjacent to each refueling vault is a maintenance area. Maintenance doors separate the maintenance room and the refueling vault. Both the east and west maintenance areas have access to the outside through a common entrance as well as personnel entries. The entry tunnel is sized to accommodate large equipment being brought into the reactor building.

The maintenance area is dimensionally smaller than the refueling vault. Maximum north/south clearance is set by the face of the maintenance door and the inboard side of the concrete ventilating ducts at the reactor building periphery. East and west limits are set by the supporting columns of the mezzanine. Overhead clearance is limited by the mezzanine.

Space is available in the maintenance area for other refueling system components. On the mezzanine, an area is provided for a high-pressure CO₂ compressor.

The arrangement of the control room provides space for the refueling machine console and the starter and relay racks. Overhead

wire routing feeds the consoles and racks.

OPERATING REQUIREMENTS

Operating Modes:

- a. Normal Refueling. Normal duty will be charging/discharging an average of five 19-1/2 inch fuel bundles per day. This operation is normally carried out in the downstream direction of coolant flow. Bundles are replaced progressively, no shuffling or turning end-for-end is required. Reactor is on-power during refueling.

For normal operations, the refueling machine is capable of refueling upstream as well as downstream, and of handling end seals and shield plug at the pressures and temperatures which there prevail.

- b. Abnormal Refueling. This operation is required in the event of high-fission activity in the coolant, or pressure-tube rupture. Where fission activity is concerned, the reactor is maintained on-power, and bundles removed from the suspect channel and monitored. Where pressure-tube rupture occurs the reactor is shut down and the entire channel unloaded by transporting the fuel to the new/used port as rapidly as possible.
- c. End Seal and Shield Plug Replacement. Where gross leakage of coolant is evident at the end fitting, the machine replaces the end seal with a new one carried on the machine, or stored in the refueling vault. In the event either the end seal or shield plug do not properly latch into the end fitting, the machine shall be capable of transporting the defective components to the maintenance area for inspection.

OPERATING CONDITIONS

Room environments:

a. Refueling Vault:

1. Media - CO_2
2. Temperature - 95 to 105°F
3. Humidity - 50 percent
4. Pressure - 1/2 inch water negative
5. Radiation background
 - a. Reactor operation - 200 R per hour
 - b. Reactor shutdown - 500 MR per hour

b. Maintenance Area: Air at normal room ambient conditions.

c. Control Room: Air-conditioned and filtered (electrostatic).

D_2O Primary Coolant System:

a. Reactor Operating:

1. Temperature - 568°F maximum
2. Pressure - 1500 psia maximum
3. pH - 9.6 to 10.5
4. O_2 Content - 150 ppb (up to 0.5 ppm during test)
5. Activity of coolant:
 - a. 2.2×10^3 c/cm³ from H_3
 - b. 25 c/cm³ from N_{16}
 - c. 1 c/cm³ from O_{19}
6. Activity in core center:
 - a. Gammas - 2×10^8 R/hr
 - b. Thermal Flux - 3×10^{13} n/cm²

b. Reactor Shutdown:

1. Pressure - 14.7 psia minimum
2. Temperature - saturation

c. Operation Limits:

1. A feeder outlet temperature increase of 8°F ($\pm 2^{\circ}$ tolerance on measuring) combined with a reduced flow will cause a reactor trip (scram).
2. D_2O leakage on the order of 50 USGPM will cause a pressure drop in the primary circuit inducing a reactor trip.
3. Pressure/temperature rate of change under normal conditions should be negligible.
 - a) Outlet pressure control - 1289 to 1341 psia
 - b) Outlet temperature control - $560^{\circ}\text{F} \pm 2^{\circ}$
4. Pressure rate of change under reactor trip is either -165 psi/sec. or $+ 89$ psi/sec.
5. Temperature change during scram is $+ 4.4^{\circ}\text{F/sec}$.
6. Pressure tube rupture - Pressure will drop immediately (step function) to the saturation pressure, 1162 psi, and thereafter drop in pressure the equivalent of 20°F/min .
7. Reactivity $\pm .02$ mk/sec. maximum from refueling machine.

D_2O New/Used Fuel Port:

- a. Pressure - 15.0 psia
- b. Temperature - 150°F

SERVICES AVAILABLE

Refueling Vault Environment Control:

- a. Cooling Capacity:
 1. Steady State - 50 KW
 2. Part time - 90 KW
- b. D_2O Condensing Capacity (both vaults):
 1. End seal leakage - 0.5 pound per hour.
 2. Refueling machines - 7.5 pounds per hour maximum.

Carbon Dioxide:

Available from 12-ton capacity liquid storage tank at 300 psi and zero^o F. Can be pressure regulated to suit.

Helium:

Bottled variety can be made available.

Deuterium Oxide:

a. Supply:

1. From Primary Loop - 1480 psia at 480^o F up to 25 USGPM
2. From Pressurizer - 1340 to 1350 psia at 90^o F up to 25 USGPM
3. From Pressurizer - emergency - up to 7 USGPM

b. Return:

1. To Reactor - up to 5 USGPM
2. To Pump Inlet - 1280 to 1310 psia, 150^o F - 350^o F
3. To Pressurizer - Low pressure at 350^o F maximum

Water:

Up to 10 USGPM

Electrical:

a. Control Room:

<u>Type</u>	<u>Quantity</u>
600 volt, 3 phase, 60 cycle	50 KVA, CL. II
120 volt, 1 phase, 60 cycle	10 KVA, CL. II
48 VDC	

b. Reactor Building: 600 V and 120 V, class IV available in unlimited supplies.

CHAPTER I

REFUELING HEAD DESIGN

INTRODUCTION

Upon completion of Task I, System Conceptual Studies and Component Specifications, the reference concept was established, subsystem and component specifications were written and design approval layout drawings were completed. The next phase in the refueling system development was an engineering review of the various refueling head components with the goal of determining the extent of test data required to ensure a high level of component feasibility and reliability. Having made these analyses, the next step was to update the existing design approval layout drawings to design detail layouts. These drawings formed the basis for the subsequent preparation of end-product drawings. In the course of this design period, all key components were analyzed for proper material selection considering stress, wear, galling and corrosion characteristics. In addition, thermal-gradient analyses were made where applicable. Fabrication requirements were considered with respect to weldments, subassemblies and assemblies, and specific requirements for finishes, tolerance dimensions, inspection requirements, leak testing and cleaning were established. This design approach was used for such major components as the end-seal tube, the shield-plug-and-guide tube, the fuel-and-ram tube, shutoff valves and the cradle.

A different approach was used to develop shop drawings for the electrical control system. Here, the first step was to convert the concept schematic diagrams to approved electrical schematic diagrams. Wiring diagrams, interconnection diagrams, assembly and equipment detail drawings were then developed and used in system manufacture.

The refueling head hydraulic and pneumatic system design was accomplished by converting the concept schematic diagrams into flow

diagrams, including valving, line sizes, flow rates and finally a detailed system operational sequence was evolved.

After purchase orders for the hydraulic and pneumatic systems equipment were placed, physical arrangement and detail drawings were made defining mounting structures, plates and brackets. The systems were then fabricated and assembled from this design information.

REFUELING HEAD DESCRIPTION

Three handling tubes, mounted on a cradle structure together with the adapter valve, constitute the machine head. Two machine heads operate together during operations at a reactor pressure tube. Fuel is positioned by pushing the entire fuel column rather than by grappling individual fuel bundles. Each head is composed of: a) an adapter valve, b) an end-seal tube, c) a shield-plug-and-guide tube, d) a fuel-and-ram tube, and e) a cradle.

The adapter valve serves as a means of retaining the reactor process tube environment during refueling operations at the reactor. It is normally carried on the end-seal tube, and is capable of being clamped and sealed to a reactor end fitting as well as to any of the three handling tube shutoff valves. The valve consists of a flexible joint to accommodate machine-to-end fitting misalignment and a pneumatically actuated clamp and seal for connection to the reactor process tube end fitting. Homing sensors are located on the reactor end of the adapter valve to give final X-, and Y-control to locate the valve assembly on the applicable process tube. (AMF-388-TR-3).

The end-seal tube is one of three handling tubes mounted on the cradle. It removes and replaces an end seal at each of 306 reactor process tube locations and the spare end seal station. This tube also serves as a carrier for the adapter valve. The tube assembly contains a D_2O -operated hydraulic ram for grappling and positioning an end seal and a ball-type shutoff valve at its reactor end to contain the tube

internal environment. Ram and grappling functions are controlled by the machine D_2O subsystem which is separate from the reactor D_2O system. The normal internal environment, D_2O , is pressure and temperature controlled to match the environment of the process tube with which it is to operate. CO_2 for actuators is furnished by an off-machine compressor. Grappler position is indicated for all functions. The shutoff valve seals the tube assembly under all environmental conditions, and in the open position, permits proper functioning of all ram and grapple operations. At its outboard or reactor end, the shutoff valve carries alignment pins for engagement and a suitable sealing surface for sealing with the adapter valve. The tube assembly is clamped to the adapter valve by a remotely operated clamp carried on the shutoff valve. D_2O inlet and outlet lines are supplied in the shutoff valve for environmental control of the space between it and the adapter valve or the installed end seal.

The shield-plug-and-guide tube removes and replaces a shield plug at any of the 306 reactor process tubes, and inserts and removes a guide at the process tube end fitting for the handling of both shield plugs and reactor fuel. The tube assembly contains a D_2O -operated hydraulic ram, for grappling and positioning both shield plugs and the guide, a D_2O -operated carrier for positioning the shield plug, and a ball-type shutoff valve, at its reactor end, to contain the internal tube environment. The functional requirements of this tube are controlled by the separate D_2O system and the CO_2 supply described for the end-seal tube. Position is indicated for all grapple and carrier functions. The requirements and functions of the shutoff valve are identical to those of the end-seal tube.

The fuel-and-ram tube is the third cradle-mounted handling tube. It charges fuel to each of 306 reactor process tubes, and the new/used fuel port. Further, it is capable of receiving and cooling fuel from each of 306 reactor process tubes, and receiving new fuel from the

from the new/used fuel port. In carrying out these functions, this tube is required to ram a 234-inch column of fuel to the fuel stop in the adapter valve of the slave machine on the other side of the reactor. This action will cause a pair of 19.5-inch spent-fuel bundles to be pushed beyond the discharge machine stop and into the fuel-and-ram tube of the slave machine. The tube assembly contains a D_2O -operated fuel carrier, a D_2O -operated fuel ram for positioning fuel, and a ball-type shutoff valve identical to those described for the other handling tubes. The functional requirements of this tube are controlled by the separate D_2O system and the CO_2 supply system described previously. Additionally, the D_2O environment surrounding a spent-fuel bundle has the capacity to remove a maximum heat generation of 15KW.

The cradle structurally supports the vertically tiered handling tubes and is mounted on the column collar of the positioning carriage to limit horizontal motion for the engagement and disengagement of the handling tubes with reactor pressure tubes. This motion is defined as Z-travel. The Z-drive is capable of fully engaging and disengaging the various handling tubes with a reactor pressure tube within the axial tube tolerances. Additionally, an auxiliary Y-index drive is mounted on the cradle for the vertical indexing of the various handling tubes to any given reactor process tube. The positioning carriage Y-drive vertically positions the cradle; the cradle Y-index drive indexes tube-to-tube. The cradle also incorporates a suspension system permitting any tube to follow any axial dynamic movement of the reactor pressure tube as well as to absorb any error in machine positioning. Z- and Y-index drives operate at the maximum practical speed so as to reduce refueling time to a minimum.

DOWNSTREAM REFUELING

A typical downstream-refueling operation for charging a new 39-inch fuel bundle into a reactor process tube and for discharging a used bundle from the same tube is shown on figure 1-1, sheets 1 and 2.

Figure 1-1. Motion Diagram - Single Bundle Downstream Loading (Sheet 2 of 2)

In the following description, environment control of machine tubes and valve spaces has been intentionally omitted for the sake of clarity in defining fuel handling motions.

Upon selection of a particular pressure tube for refueling, the upstream machine is designated as the charge machine and will be positioned at the new/used fuel port to receive a new fuel bundle in its fuel-and-ram tube. It and the discharge machine are then positioned at either end of the pressure tube to be serviced. Before clamping onto the reactor, the clamping faces of each machine are thermally matched to the pressure tube end fitting.

In the first sequence (steps 1 through 3, figure 1-1), the end-seal tube of the charge machine is connected to the process tube by means of its adapter valve. The adapter valve will remain attached to the process tube end fitting throughout the following refueling operation. The charge machine then grapples and removes the upstream end seal. The charge machine then indexes its shield-plug-and-guide tube and connects to the adapter valve (step 4). In step 5, the guide is placed in position and the grapple inserted to grasp the shield plug. Simultaneously, the discharge machine is repeating step 1 on the discharge side. In step 6, the charge-side carrier and grapple withdraw the shield plug and the guide is left in position for subsequent refueling operations. At the same time, the discharge machine is grappling its end seal.

In steps 7, 8, and 9, the charge machine indexes and connects the fuel-and-ram tube to the adapter valve. The carrier, with its new fuel bundle, is inserted into the guide placed in the end fitting. The new bundle is then rammed to position at the end of the fuel column. Meanwhile, the discharge machine has removed its end seal, connected its shield-plug-and-guide tube, and inserted its guide and carrier.

In steps 10 and 11, the downstream guide is released and the

shield plug pushed to a position where the fuel stop can be inserted between shield-plug and fuel. The charging machine is simultaneously ramming the fuel column to achieve this translation. The shield-plug is then fully withdrawn in its carrier into the handling tube.

The next series of steps, (12 through 15 inclusive), discharges a spent-fuel bundle. The discharge machine fuel-and-ram tube is first indexed and connected to its adapter valve and the ram and carrier advanced to the fuel stop. The column is again under control of the rams of both machines. In step 14, the fuel column is translated by the upstream ram until one bundle passes the discharge side fuel stop. The fuel stop is engaged and the spent bundle withdrawn in its carrier into the handling tube (step 15).

The remaining steps replace shield-plugs and end seals and are essentially the reverse operations of their removal. In steps 16 and 17, the discharge machine shield-plug-and-guide tube is indexed and connected to the adapter valve. The shield-plug is inserted to contact the fuel, the fuel stop withdrawn and the insertion of the shield-plug continued until in latching position. The grapppler then withdraws the discharge side guide and the carrier (step 18). At the same time the fuel ram and carrier are retracted on the charge side.

On the charge side, the shield plug and end seal are replaced and the guide removed, (step 19 through 24). On the discharge side, the end seal is replaced (steps 19 through 21). Upon removal of the adapter valves by each end-seal tube, operations at the reactor are complete, and the machines can proceed to the new/used fuel port for subsequent loading or unloading.

UPSTREAM REFUELING

Refueling may also be carried out by charging new fuel against the direction of reactor coolant flow. This operation is shown on figure 1-2, sheets 1 and 2. Generally, equipment operation is the

same as in downstream refueling, except that three additional steps are required to maintain fuel-column control and to dispose of the spent-fuel bundle midway through the operation. As with downstream refueling, column control is maintained by contact of two rams or by one ram and a fuel stop.

The significant operational differences lie in the added time in disposing of the spent-fuel bundle while the equipment is connected to the reactor, and the added steps to hold the column against coolant flow during spent-fuel bundle transfer to the new/used fuel port. Upstream refueling is designated as an abnormal operation.

SHUTOFF VALVE

Certain design features of each of the three handling tubes are either identical or very similar in design approach. The shutoff valve described in this section is an example of the former. Similar designs occur in the tube pressure shells and in the position indication systems; these latter two are described with the Fuel-and-Ram Tube. The shutoff valve (figure 1-3) seals the end of the handling tube and provides the means for remote clamping each tube to the Adapter Valve.

The ball-type shutoff valve is similar to the adapter valve by having a flow passage machined through the ball (item 11). Ninety-degree ball rotation opens and closes the valve. With the valve open, the ball bore is aligned with the ports at each end of the valve. A wedge ring (item 22), when driven down, exerts a uniform pressure on the valve seat through the ball. The seal (item 10) has a spherically machined graphite surface which prevents flow between the body and ball surfaces when the ball is closed. Withdrawing the wedge removes the load on the seat, and facilitates ball rotation. The wedge and ball are simultaneously operated by a CO₂-actuated pneumatic motor (item 37) to drive a worm, worm wheel and a modified Geneva mechanism (item 14). This actuation is arranged to assure mechanism conformance to the basic operating principle that ball rotation does not occur during ball-seal contact, i. e., with a wedge force on the ball.

[illegible]

DESIGN

Pressure containing members of the shutoff valve conform to the requirements of the Code for Pressure Piping, ASA B 31.1 withstanding temperatures up to 600^oF. Where component failure may cause personnel injury or equipment damage, care was exercised in the adherence to code safety factors. Thermal stresses and expansion were computed at a temperature difference of 500^oF. That is, a temperature increase from 100^oF to 600^oF in gradients of 40^oF per minute. Fatigue and creep were based on the 10-year design life of the assembly.

For material selection such factors as embrittlement, reduction in ductility and radiation damage were considered. For purposes of economy, AECL technical reports were evaluated, and applicable material recommendations were selected where feasible. Aluminum was not used for any area in contact with heavy water.

Shutoff valve seal life depended on a number of factors, such as the nature of the ball-seal contact, cleanliness of the system, seal material, distortion, shrinkage, misalignment and eccentricity of mating parts which may occur over the full range of operating pressures and temperatures. Each of these criteria was assayed in the component concept and arrangement, as well as in the choice of materials.

The ball-valve-actuation mechanism was specified with consideration to speed and potential power requirements as well as the choice of a convenient power source. Available space was an important factor in the present arrangement and fail-as-is operation was a prime consideration in the choice of components and mechanism arrangement. A CO₂-actuated pneumatic motor was chosen as the

power source to drive the worm and worm wheel, and a threaded shaft to actuate the valve wedge. This wedge would exert a uniform pressure on the ball-seal combination. A modified Geneva mechanism was added to provide a synchronized motion of the ball before the wedge was seated. This assured rotation of the ball without a high unit load on the seal member.

A remote clamp was provided to couple or uncouple the shutoff valve from the adapter valve. The power source, another CO₂-actuated pneumatic motor drives through a gear reduction to actuate a compound screw and, in turn, a three segment clamp.

TEMPERATURE CONTROL

The critical nature of the thermal stresses induced in the shutoff valve, necessitated accurate control and temperature indication at discrete points. Instrumentation was provided for remote measurement and control of temperature at the following locations: a) internal fluid temperature in the forward portion, b) body temperature at the leading edge of the shutoff valve, c) body temperature at the trailing edge of the shutoff valve, d) body temperature at the ball housing, and e) sheath temperature of each segment of the heater assembly.

POSITION INDICATION

The proper sequencing of the shutoff valve into the overall refueling machine control subsystem required positive indication of motions and positions of the critical valve components. As a result, remote indication of the following positions was provided: a) ball position opened and closed, and b) forward clamp opened and closed.

CONSTRUCTION AND THERMAL STRESS

Engineering analysis indicated the need of careful control of the valve housing configuration and construction details which might have a serious effect on the thermal stress peaks. As a result, every effort was given to the reduction of stress concentration points. Sudden changes in cross-sectional areas were kept to a minimum and generous

radii were applied where cross-section changes were necessary. Every consideration was made to maintain a minimum temperature differential between the inner and outer surfaces of the housing and also to maintain the rate of temperature change to a minimum value.

In selecting a 347-stainless steel, forged valve body. (see figures 1-4 and 1-5). the prime consideration was to obtain the maximum allowable stress consistent with a corrosion-resistance material. Choice of this material reduced the possibility of crevice corrosion and provided sound performance at the maximum operating temperature.

ACTUATORS

A review of the power sources available and the allotted space for actuators indicated certain desirable goals, as well as definite system limitations, in choosing an actuator. The force output required for sealing of the ball-to-graphite or to other seal materials was another consideration in the choice of actuators.

An electrical actuator was discounted because of size and characteristics of the unit required. A hydraulic actuator was rejected because of the introduction of additional, potential heavy-water leakage and the need for a reliable hose hook-up trailing between the limits of travel of the refueling machine.

A pneumatic actuator seemed to be the likely choice. A CO₂ supply was available and there was no problem of leakage into the refueling room, therefore pneumatic motors were used as actuators where required.

One requisite considered to be of prime importance was that all actuators were fail-as-is upon loss of power. In each case where a pneumatic actuator was used, the related mechanism was self-locking to assure conformance to this requirement.

STEM SEALS

The metallic stem seals (46, figure 1-3) were designed to seal the ball (16) and wedge shafts (15) at the point of shaft penetration

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Figure 1-4. Shutoff Valve Body - Rough Forging

Figure 1-5. Shutoff Valve Clamping Hub - Rough Forging

through the shutoff-valve body. These seals contain both static and dynamic sealing members. The dynamic seal contacts the shaft while the static seal contacts the valve housing. The stem seals were commercial proprietary items, and initial investigations and development were accomplished by the vendor.

HERMETIC-TYPE END-SEAL HANDLING TUBE

The machine-mounted hermetic-type end-seal handling tube, (figure 1-6) is a hydraulic mechanism designed to perform certain portions of the refueling cycle.

The tube was designed to remove an end-seal from the reactor process-tube, house it during the refueling operation, and replace the seal at the end of the operation. The end-seal tube would also carry the adapter valve between refueling cycles. At the start of a cycle, the end-seal tube would place the adapter valve on a reactor process-tube and retrieve it at the end of the cycle.

The tube was designed to consist of two basic subassemblies: the end-seal tube subassembly (figure 1-6), housing the hydraulic mechanism necessary for the operation of the end-seal tube, and the shutoff valve (figure 1-3) for containing the refueling-machine environment.

The hydraulic, end-seal tube subassembly has a grappler mechanism (figure 1-7) at the forward or reactor end of the tube, double-acting pistons at the rear (figure 1-8) connected to the grappler by concentric shafts, and a pressure shell, housing the assembly, (items 1 and 3, Figure 1-6). The grappler mechanism is made up of three separate tubes. The outer tube contacts and loads the end-seal body and carries locking balls which engage in the body groove. The second tube pushes on the end-seal sleeve, and withdraws the end-seal fingers. The third, and innermost tube, pushes on the end-seal-lock rod, which, in turn, depresses the end-seal plate. Each of the grappler-mechanism tubes is

Figure 1-7. End-Seal Tube Grapple - Forward End

Figure 1-8. End-Seal Tube Internals - Rear (Piston) End

connected to a piston or spring actuator. These pistons are actuated by the pressure differential across the pistons. The driving piston assemblies consist primarily of pistons, springs, and seals, and provide the necessary grapple mechanism operational sequences with minimum external valve sequencing. Attached to the rear-most piston is a magnet whose position is sensed by external reed switches providing position indication readout. Hydraulic porting at discrete points in the pressure shell provides piston sequential actuation and D_2O circulation in the end-seal storage section. Reed-type switches are attached to the pressure shell which are actuated by magnets located within the shell. These switches indicate position of the grapple within the shell.

END-SEAL-TUBE OPERATION

The end-seal tube (figure 1-6) was designed to remove an end-seal from a reactor process tube as follows:

- a) The end-seal tube and adapter valve clamp to the process tube at operating conditions. The adapter valve is opened.
- b) The pneumatic motor on the shutoff valve is actuated by CO_2 , and causes the wedge to withdraw and the ball to rotate 90 degrees to the open position.
- c) The end-seal-tube grapple is actuated by pressure applied to the rear of the piston assembly and acting on piston ring (47). The assembly will drive forward until ring (19) and sleeve (16) make full contact with the end-seal. Springs (27) push the locking sleeve (23) forward, engaging balls (67) in the groove.

- d) Further forward movement compresses the 1500-pound rated Belleville spring (9). The spring depresses the end-seal-lock rod and loads the seal plate to 1500 pounds. Concurrently, balls (68) engage in their grooves forming an interlock. During end-seal insertion, at the conclusion of the refueling cycle, this interlock precludes grapple withdrawal if the end-seal-lock rod is not extended.
- e) Pressure at 600 psi is applied to the rear of the piston assembly which loads the end seal body with 6000 to 8000 pounds.
- f) To retract the end-seal fingers and lock the end seal to the grapple, 200 psi pressure is applied to the rear of the end cap (11) causing sleeve (25) to move forward. Locking balls (67) are then depressed into the lock groove by spring-loaded ball retainer (13).
- g) Pressure applied forward of the ball retainer (13) causes the assembly to retract.
- h) When the position indicators show the full retraction of the assembly, the shutoff valve closes, the inter-valve space drains and the adapter valve disengages.

When inserting an end-seal into a reactor process tube, the tube must be heated to approximate the temperature of the adapter valve. The shutoff valve-forward clamp temperature will adjust to match the temperature of the adapter valve clamp. Thermal adjustments are accomplished through electric

heaters. Guide pins on the shutoff valve ensure adapter valve alignment during homing. The shutoff valve clamps to the adapter valve and the void between the valves is filled with D_2O . End-seal replacement on the process tube is basically the reverse of procedure outlined for the end-seal removal.

If the end-seal-lock rod does not extend when withdrawing the grapppler at the conclusion of the operation, the interlock created by ball (68) in its groove prevents release of the end-seal. Piston pressures and velocities are controlled by valves and orifices during the above operations. To prevent damage caused by rapidly moving parts, the velocities are throttled to limit impact.

Certain force limits are required by the end-seal tube to perform its assigned function. Since the maximum permissible axial load on the reactor process tube is 500 pounds, the end-seal tube was mounted on the cradle to prevent axial loads in excess of 500 pounds from being imposed during operation on the reactor process tube. Suitable mounting pads were provided to facilitate mounting the end-seal tube without an excessive build-up of thermal or mechanical stresses.

The position-indication equipment makes the tube-piston position known to the operator and whether the unit is functioning properly. A signal from the shutoff valve indicates the fully-opened or -closed position. End-seal grapple position indications are obtained at discrete uniform intervals over the entire tube length.

A signal from the clamp, located between the adapter and shutoff valves, indicates engagement or disengagement. Indication of a fully retracted or extended grapple is provided within one-eighth inch. If control pressure is lost, and equipment malfunctions, the end-seal will stay at the position indicated. This situation is assured by an interlock which prevents accidental unlatching of the end-seal. In the same manner, the shutoff valve

setting would remain as indicated. The pneumatic-drive motors will lock in position if power or pressure is lost.

SHIELD-PLUG-AND-GUIDE TUBE DESIGN

The shield-plug-and-guide (SPG) tube (figure 1-9), a machine-mounted, hydraulic mechanism, was designed to perform portions of the refueling cycle. In the refueling process, the SPG tube removes the shield-plug from the reactor tube, contains the shield-plug during refueling operations and replaces it in the process tube after refueling is complete. The SPG tube also inserts a guide into the end fitting creating a smooth, uninterrupted internal bore between the adapter valve and the end-fitting. At completion of refueling operations the SPG tube removes the guide tube from the end-fitting and stores it in the SPG tube.

The SPG tube assembly consists of two basic subassemblies: a shutoff valve which isolates the machine, and the SPG tube subassembly, which houses the hydraulic mechanism. The SPG tube subassembly consists of a grapppler mechanism, a guide tube and a carrier tube. Pistons at the rear are connected to the grapppler, guide, and carrier by concentric tubes. A pressure shell houses this assembly. The grapppler mechanism utilizes locking balls to lock the grapppler to the shield-plug-lock rod. A sleeve, part of and surrounding the grapppler, provides an interlock securing the grapppler to the guide or the shield-plug.

The tube-like guide provides a smooth bore in the reactor process tube for the shield-plug and the fuel. The ID of the guide corresponds to the ID of the fuel bearing portion of the process tube.

The tube-like carrier carries the shield -plug as it is withdrawn into the SPG tube by the grapppler. The grapppler, its sleeve, and the carrier tube are connected to pistons and actuated by the D₂O hydraulic system. Each piston is provided with a magnet to indicate the position of the grapppler and the carrier tube.

Figure 1-9. Shield-Plug-and-Guide Tube Subassembly

The pressure shell, housing the SPG tube, is provided with suitable hydraulic porting for piston actuation, and for containing and conditioning the environment of the shield-plug storage section. Sealed ports are also provided in the design for filling and draining during assembly and maintenance.

The SPG tube is similar to end-seal tube design in that it is also divided into zones II, III and IV with respect to temperatures, pressures and fluids. (See figure 1-15, page 1-50 for definition of zones).

At the conclusion of the conceptual phase, the SPG tube design evolved based on the then current AECL shield-plug and end-fitting design for the Douglas Point Plant. The SPG tube design as it then existed was based on having the finger locking slot in the end-fitting located within ± 0.005 inch. Upon receipt of subsequent end-fitting information it was noted that the finger-locking groove was actually located within $\pm 1/16$ inch. This modification led to an analysis to ascertain whether the existing design could properly replace the shield-plug by extending and locking the fingers into the end-fitting groove. The analysis indicated that some redesign was necessary to accommodate the new requirement. During the analysis period, the design was also reviewed for its capability of clearing all internal diameters when the gimbal assembly of the adapter valve was deflected one-half degree. This review also indicated that some changes in design were necessary. In addition, this final review considered the possibility of internal components of the SPG tube drifting due to leakage by seal rings or variations in D₂O hydraulic system pressures.

The result of these analyses was a redesign of the SPG tube, similar in concept but with changes to accommodate the above-described features. Figure 1-9 is a subassembly drawing of the final design of the SPG tube.

Before a remove-shield-plug sequence can be started, the following machine conditions must exist:

- a) The SPG tube clamped to the adapter valve which, in turn, is clamped to the reactor end-fitting.
- b) The end-seal removed from the end-fitting and stored in the end-seal tube.
- c) The shutoff valve and adapter valve in the open position.
- d) Zones II and III filled and brought to reactor pressure and temperature.

The first step in the remove shield-plug sequence is to insert the carrier. By sequential application of D_2O hydraulic pressure at the proper ports, the entire internal assembly of the SPG tube will move forward until the guide tube bottoms on the sealing shoulder in the end-fitting. The carrier is held forward throughout the shield-plug removal cycle by 200 psi pressure applied to the rear of the carrier piston. The next step is to advance the grapppler. This is accomplished by pressurizing port 9 to 200 psi. During this step, the locking balls (51) remain stationary but roll in their guide-tube groove until the grapppler is fully advanced. The guide-tube (3) remains behind. The fully-advanced condition is indicated by a light on the manual control panel which receives its signal from the position indication control switch and magnet (20). It should be noted that during this grapppler advance step, the pressure in port 10 is maintained at 300 psi. The purpose of this is to cock springs (16 and 18) into a position which prepares the grapppler for shield-plug finger retraction. Four locking balls (63) now rest in the shield-plug groove. To grapple the shield-plug (retracting the shield-plug fingers), the pressure in port 10 is dropped to reference pressure. This allows springs (16 and 18) to push forward on the locking-mechanism piston (14) which in turn pushes on the shield-plug push rod and retracts the fingers.

To retract the grapppler, 50 psi pressure is directed into port 11. Since locking balls (51) are in the groove to the rear of the locking-mechanism-forward weldment (5), the entire grapppler with the shield-plug retracts in the SPG tube, leaving the guide tube (3) behind in the end-fitting. To retract carrier, the pressure in rear port 8 is dropped to reference pressure and the entire assembly is retracted into the SPG tube. To minimize any heat transfer from Zone III (hot area) into Zone IV (cold D₂O hydraulic system), while the SPG tube is retaining the shield plug, D₂O coolant is introduced to the Zone III and IV interface by opening a solenoid valve.

To perform an insert shield-plug sequence, the following machine conditions must exist:

- a) The SPG tube clamped to the adapter valve which, in turn, is clamped to the reactor end-fitting.
- b) The end seal removed from the end-fitting and stored in the end-seal tube.
- c) The shield-plug removed from the end-fitting and stored in the SPG tube. The guide tube in the end-fitting.
- d) The shutoff valve and adapter valve in the open position.
- e) Zones II and III brought up to reactor pressure and temperature.

The first step in the insert shield-plug sequence is insert carrier which is accomplished by applying 200 psi at port 8 while port 9 is at reference pressure, port 10 is blocked, and port 11 is set to relieve at 50 psi. The assembly (carrier, grapppler and shield-plug) will move forward until it bottoms on the short-stop plunger (30) which was energized at the start of this step. The short-stop ensures that the shield-plug fingers locate axially at the mid-point of the end-fitting slot. As mentioned earlier, the location tolerance of this slot is within $\pm 1/16$ inch, therefore, the short-stop was introduced to ensure that the shield-plug fingers are located as close to the mid-

point of the slot as the tolerances will permit.

The next step, advance grapppler, is accomplished by applying 200 psi to port 9. With the carrier having been located in the previous step, the bottoming of the grapppler mechanism locates the shield-plug so that the fingers are ready to be engaged. The engage-fingers step is performed by pressurizing port 10 to 200 psi. This pressure is sufficient to compress spring (16) which in turn retracts the grapppler enough to allow the springs in the shield-plug to engage fingers. It was necessary at this point to provide a means for testing whether the shield-plug fingers have been engaged to the end-fitting groove since having a loose shield-plug in the process tube could conceivably damage the fuel bundles. Therefore, the next step in SPG tube operation is test which determines whether the shield-plug is locked to the end-fitting. This is accomplished by dropping the pressure in the rear of the grapppler piston (port 9) to reference pressure. If the shield-plug is locked to the end-fitting, the grapppler will remain stationary. If the shield-plug is not locked to the end-fitting groove, the grapppler will move back into the carrier tube and be so shown on the display panel. If a loose shield-plug is indicated, the sequence would then revert to step 2, advance grapppler, and engage-fingers step repeated. If the system passes the fingers-engaged test, the next step in the sequence is unlock grapppler. To accomplish this step, the supply pressure in port 10 is increased to 300 psi while the pressure in port 9 is returned to 200 psi. The 300 psi pressure in port 10 is sufficient to fully compress springs (16 and 18), remove the grapppler from the shield-plug, and permit the lock balls (63) to drop inward from the groove in the shield-plug. The retract grapppler step may now be performed by returning port 9 to reference pressure while a 50 psi supply is directed into port 11 until lock balls (51) are aligned with the groove in the guide tube. The assembly can be retracted by the retract carrier step, by dropping pressure in

port 8 to reference pressure. As the assembly retracts, the guide tube, which was locked to the grappler in the previous step, is also removed from the end-fitting so that the end-seal may be replaced in the next sequence. The last step in the insert shield-plug sequence is return-to-park which again introduces a 50 psi supply of D_2O coolant into port 11 which also serves to keep the assembly fully retracted into the pressure shell.

Certain force limits are required by the SPG tube to perform its assigned functions. The maximum permissible axial load upon the reactor process tube is 500 pounds. As a consequence, the SPG tube is mounted on the cradle in a manner such to prevent axial loads, in excess of 500 pounds, from being exerted on the process tube during SPG tube connection. To limit the force on the fuel, the maximum-applied force by the SPG tube on the fuel bundle is controlled to less than the permissible 1200 pounds. This requirement occurs when the SPG tube, working with the F & R tube, moves a fuel column. The force is limited by controlling the back-pressure applied to the piston. Also considered is limiting the impact of moving parts against reactor components to prevent equipment damage. Piston speed is controlled to keep impact within reasonable limits.

A means of position indication is provided to make the position of the equipment known to the operator and assure proper equipment function. A signal from the shutoff valve indicates the fully-open or -closed condition. Similarly, limit switches, on the remote clamp of the shutoff valve, signal full-clamp engagement or disengagement. Position indication of SPG tube subassembly components is provided at discrete uniform intervals over the entire length of travel. Indication within one-eighth inch is provided for the fully-extended or -retracted grappler. Position indication always provides the true location of the shield plug. The mechanism is further fool-proofed by the positive lock of the grappler to avoid equipment damage in the event of pressure loss or machine malfunction.

FUEL-AND-RAM (F & R) TUBE DESIGN

The F & R tube, mounted on the cradle assembly, with the end seal and SPG tube, comprise the refueling head design. The F & R tube consists of two subassemblies; a shutoff valve subassembly and a ram-carrier subassembly within a pressure shell. The primary function of the F & R tube is to pick up a new 39-inch fuel-bundle at the new/used port and charge it into the reactor while a similar functioning tube simultaneously receives a spent-fuel bundle from the reactor and discharges it at its new/used fuel port.

The shutoff valve has the capability of clamping onto the new/used fuel port at which point a ram drives a fuel bundle into the F & R tube. This is done at essentially atmospheric pressure and temperature in a D_2O environment. The shutoff valve closes and seals the assembly. The assembly is unclamped from the new/used fuel port, the temperature and pressure are raised to approximate that of the reactor environment, and the refueling heads move to the process tube being serviced. At this point, the shutoff valve is clamped to the adapter valve; the area between the shutoff valve is filled with D_2O ; both valves are opened, and the fuel-bundle is inserted into the reactor.

Loading a new bundle into the reactor drives the spent-fuel bundle into the F & R tube of the refueling head operating at the opposite face of the process tube. It is therefore a function of the F & R tube to pick up a spent-fuel bundle and discharge it at the new/used port. Since a spent-fuel bundle will dissipate approximately 15 KW of heat energy after removal, a space must be provided for circulating cooling water around the spent-fuel bundle while in transit to the new/used fuel port.

Cooling water for the fuel bundle will not be mixed with the hydraulic fluid of the machine. Basically, the operation of the ram and carrier is accomplished by sequential porting of the hydraulic system directing the hydraulic pressure necessary to drive the ram

and carrier assembly into the process tube. When the carrier reaches its travel limit, the ram piston is pressurized and the bundle pushed out of the carrier into the process tube. Since a solid column of bundles exists in the process tube, the insertion of a new bundle would eject a used bundle from the opposite end. Column control, i. e., the fuel bundle always under compression and both rams contacting the bundle, would be maintained at all times.

Continuous readout data, relating to the ram and carrier positions, is visually displayed on the control panel for operator surveillance. The readout data is initiated by piston-mounted magnets. The magnets close the contacts of the axially-placed reed switches located at short intervals on the shell. Closing of the switch contacts in turn, provides electrical signals to corresponding indicator lights on the control panel. The lights then indicate the ram and carrier position.

A cross section of the F & R tube is shown in figure 1-10. The major components comprising the F & R tube are: a) pressure shell, b) carrier, c) ram, d) service ports, e) ring magnets, and f) position indicators.

PRESSURE SHELL

The pressure shell is a cast tube approximately 19 feet in length and 5 inches in diameter. It houses the internal fuel-and-ram mechanism and maintains the appropriate operational environment in terms of fluid temperature and pressure.

Hydraulic pressure and flow enters the internal environment of the pressure shell through a number of ports welded to the outside of the shell.

The pressure shell consists of three weldments:

- a) the forward-shell weldment (2)
- b) the center-shell weldment (13), and
- c) rear-shell weldment (15).

REV	DATE	DESCRIPTION	BY	CHK
1	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
2	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
3	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
4	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
5	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
6	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
7	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
8	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
9	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
10	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W

REV	DATE	DESCRIPTION	BY	CHK
1	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
2	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
3	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
4	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
5	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
6	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
7	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
8	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
9	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
10	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W

REV	DATE	DESCRIPTION	BY	CHK
1	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
2	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
3	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
4	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
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8	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
9	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W
10	10/10/55	REVISED HOLD ON MUST QUALIFIED PERSON	W	W

The three weldments, joined by two Grayloc clamp assemblies (44 and 45) and the structure, contain the entire fuel-and-ram assembly, and are supported and mounted on the cradle by mounting brackets. The mounting method used provides a fixed mount in the forward position and several hinged mounts, affording one degree of freedom in the axial direction, in the rear. The fixed mount establishes a connection between handling tube, cradle, and the particular process tube being serviced. Thermal contraction, due to a scram condition, will force the cradle toward the process tube within the 500-pound axial-force limit. The hinged mounts eliminate thermal stresses arising from axial expansion and contraction of the entire shell.

CARRIER

The basic function of the carrier is to provide fuel-bundle transfer facilities. This is afforded by a cavity in which a 39 inch fuel-bundle can be stored during transfer operations. This fuel-bundle cavity, part of the carrier, is located at the forward or reactor end of the F & R tube. When the refueling head performs a loading operation, the fuel-bundle cavity will contain a new fuel-bundle which will be transferred into the reactor process tube. At the same time, the fuel-bundle cavity of the receiving refueling head will be empty so a spent-fuel bundle can be transferred into it.

The carrier, like the pressure shell, is a welded assembly consisting of the following four major welded subassemblies: a) forward-carrier weldment (1), b) right- and left-hand carrier seal-ring housing (6 and 8), c) rear-carrier weldment (10), and d) carrier piston (22).

The forward carrier weldment, the structure containing the fuel-bundle cavity, is approximately 3.5 feet long and 4 inches in diameter. A pin projecting through the pressure shell rides in a longitudinal groove welded into the forward carrier. The purpose

of this design is to maintain orientation of the fuel-stop slot at the forward end of the carrier, perpendicular to its axis. The forward-carrier weldment, threaded into the carrier-seal ring housing, contains the carrier-seal ring (7).

The rear-carrier weldment, a welded-tube structural member, connects the carrier seal-ring housing and the carrier piston (22). The carrier piston provides the motive force for the carrier. Among its features are provisions for mounting the position-indicator-carrier magnet (24) and a conical-buffing spar. Stationary seals between carrier assembly and the pressure shell are provided at the two Grayloc clamp assemblies (33 and 36).

RAM

The ram provides the force necessary to move the fuel bundle from the carrier cavity into the process tube or provide required resistance during fuel bundle receiving operations. The major components of the ram are: a) ram nose (3), b) ram tube (11), and c) ram piston (19).

The ram tube structurally connects the ram nose and ram piston. A special feature of the ram design is the spherical-segment joints for the ram nose and piston. These joints perform universal-joint-type action and compensate for ram sag, misalignment of the process tube, and assure perpendicular engagement of the fuel-bundle by the ram nose. A spring (9) in the ram nose serves as a shock absorber during the fuel-bundle-engagement operation. The ram magnet (21) acts in a similar manner as the carrier magnet, as a position indicator. Also similar is the ram buffering chamber which consists of a conical spar entering a cylindrical blind hole. The ram assembly slides within the carrier tube and is sealed hydraulically by seal rings located in the carrier-seal ring (7) of the ram nose and in the ram piston.

SERVICE PORTS

The service ports provide the proper pressure and flow sequencing of hydraulic fluid made available at the ports by the appropriate valve positions of the hydraulic manifold. The following description traces the functional operations of transferring a fuel bundle by the F & R tube.

For the insert carrier command, 200-psig pressure, established in the rear of a piston located approximately 3 feet forward of the carrier piston, provides the necessary force to actuate the carrier and drive it forward. Seals (38) between the pressure shell and the carrier structure contain the pressure in this region. Motion stops when the forward shoulder of the carrier engages the guide tube which is installed in the end fitting by the SPG tube. The stroke of this operation is approximately 3.5 feet.

The advance ram command is accomplished by maintaining 200 psig pressure at port 9 in order to keep the carrier in the forward position of the previous command. Since the motive forces required in this command are functionally dependent on the mode of operation, i. e., advance ram upstream or downstream, 15 psig for downstream and 140 psig for upstream are provided at port 8 for the respective commands. Accordingly, the ram will advance by applying applicable pressure at port 8, with the pressure acting in the cavity between ram and carrier and acting on the ram piston area to generate the necessary motive force. The pressure path from port 8 to the carrier/ram piston cavity is through the circumferential holes and carrier-piston ram forward of the carrier magnet. These holes line up with the port position when the carrier is forward. The force developed by the presence of pressure in the carrier/ram piston cavity tending to retract the ram is counterbalanced by the force acting on the forward carrier piston. In this manner, the net force acting on the carrier is forward, maintaining it in the forward position.

The operation of receive ram was previously discussed. Again, the mode of the operation (upstream and downstream) dictates the pressure magnitude at port 8. The same pressure path, discussed above, admits the applicable pressure into the carrier/ram piston cavity. In this operation, however, an opposite force is developed. The resisting force in addition to friction forces will balance the force applied to the ram and its magnitude will be a function of the mode of operation.

When the ram retraction command is initiated 140 psig pressure is supplied to port 10. In this case, a pressure path is established between ram and carrier shells with pressure acting between the two shells at the forward end of the ram piston and on the piston surface in the interior of the ram tube. The pressure path is through the forward, longitudinal, annular space of the rear-carrier weldment, the circumferential holes at the forward end, the annular space between ram tube and rear-carrier weldment, and through the circumferential holes. Pressure at 200 psig at port 9 will maintain the carrier in the forward position as in the preceding commands.

Carrier retraction is accomplished by applying 140 psig to the opposite face of the forward carrier piston used for carrier advance operation. The pressure is applied through port 10 and its path is between the pressure shell and carrier tube in the forward section of the handling tube.

Figure 1-20 reveals that, in addition to the pressure magnitude discussed above, some ports are at reference pressure in practically all operations. This reference pressure is basically a venting pressure, allowing flow to occur from the cavities which are reduced in volume due to the motion of the various assemblies.

RING MAGNETS AND POSITION INDICATION

The ring magnets in conjunction with the position indicator serve as a continuous position-readout device. The carrier ring

magnet (24) is installed on the carrier piston and the ram-ring magnet (21) on the ram piston. The spatial relationship between the handling tube and the reed switches is shown on figure 1-11. In this method of operation, the magnetic flux closes the contacts of a reed switch which in turn completes the individual circuit causing a position-indicator lamp to light on the position-indicator panel. In this manner, a continuous readout of ram and carrier position are possible depending on the number of individual position indicator circuits available.

CRADLE ASSEMBLY

The cradle assembly (figure 1-12) provides a common support for the three handling tubes, their respective shutoff valves and the machine-mounted D₂O hydraulic system. In addition, the cradle assembly serves to orient any of the three handling tubes with a reactor process tube through the adapter valve. The cradle was designed with two drive systems.

The Y-index drive locates any of the three handling tubes at a process tube. After the end-seal tube is oriented and completed its end-seal-removing function, the Y-index drive positions the cradle so the next tube, the SPG tube, is aligned with the process tube for shield-plug removal.

The Z-drive provides the axial motion required to drive the cradle forward until the handling-tube shutoff valve contacts the adapter valve, or until the adapter valve contacts the end-fitting, permitting remote clamping. The Z-drive also retracts the cradle after unclamping.

The cradle consists of the following components: the cradle-truss assembly, a rigid frame, which provides part of the mounting surface for the three handling tubes and the D₂O hydraulic system manifolds; the Y-drive subassembly which consists of a gearmotor and ball-screw drive, four sets of rollerway bearings, riding on two ground and hardened rollerways, and a structural member which mounts

Figure 1-11. Typical Reed Switch Position Indicator Installation

Figure 1-12. Handling Tube Cradle Assembly

this assembly onto the carriage; the Z-drive subassembly which consists of a gearmotor that drives a spring-loaded rack through a pinion gear; the cradle subassembly, the forward end of the cradle assembly which carries four sets of roller bearings that ride on the Z-drive ground and hardened rollerways.

The cradle was designed with the ability to home the adapter valve/end-seal tube assembly to a process tube. It is also capable of homing the SPG and F & R tubes to the adapter valve when the valve is located on a process tube. The cradle is capable of rigidly supporting the handling tubes in the Y- and Z- axes and of indexing from tube-to-tube. The long overhang of the cradle was considered to preclude excessive bending deflection of the handling tubes. In addition, the cradle is also capable of supporting the D₂O hydraulic system associated with each handling tube. Also considered was that the cradle and its components could not transmit axial loads greater than 500 pounds into the process tube. The maximum permissible moment considering the center of rotation to be the reactor face-shield, could not exceed 70,000 inch/pounds.

The Z-drive (figure 1-13) consists of a two-speed gearmotor drive, having a pinion gear on its output shaft, and capable of driving a spring-loaded rack on the moving element of the cradle. Since the handling tubes are rigidly mounted on the cradle (except for the rear mounts where handling tube thermal expansion was considered), the Z-drive is capable of limiting the axial force on the reactor process-tube to a maximum of 450 pounds. A compression spring at the rear of the drive rack is preloaded to 350 pounds and has a spring rate of 85 pounds per inch and limits this force. As the cradle is driven forward, it contacts either the end-fitting or the adapter valve against which the 350-pound preload force is imposed. To ensure that complete contact is made, the rack is driven forward an additional one inch which actuates a limit switch and de-energizes the Z-drive motor. This

Figure 1-13. Z-Drive and Roller Ways

design approach was postulated on calculations indicating that the force necessary to overcome bearing-way friction was 332 pounds. The target requirement was to keep the force below 450 pounds so that any expansion or contraction of the process tube, when the machine is clamped to the process tube, would move the cradle but not overload the process tube with axial forces in excess of 500 pounds.

The Y-drive was designed to accurately locate the handling tubes vertically with the reactor end-fitting. Cradle positioning along the Y-axis is provided by upper and lower mechanical stops and a retractable rocker-arm-type stop at the mid-position, (SPG tube index position). The fixed stops are adjustable for positioning accuracy, and a stall-overload device stops the drive. Three limit switches indicate on the control system when positioning is complete.

It should be noted that the preceding paragraphs describe the Y-drive system as it was originally designed and built. During cradle testing changes were made to the drive system, as stopping and positioning by means of mechanical stops proved unfeasible. In lieu of the mechanical stops, limit switches were installed with a gearmotor having an integral brakemotor. This feature allowed the drive-motor to stop by dynamic braking. This combination yielded positioning repeatability within ± 0.002 inch.

The cradle assembly is raised and lowered by transmitting a gearmotor-drive output to a ball-nut-and-screw assembly. The screw is supported in the Y-drive structure by the upper- and -lower-radial bearings and an upper thrust bearing. The ball-nut is secured to the cradle structure. Raising and lowering are facilitated by roller bearings on two vertical rollerways. (See figure 1-14).

CRADLE ASSEMBLY TOLERANCES, ALIGNMENT AND ADJUSTMENT

To support the handling tubes and position the cradle vertically and axially to accomplish remote clamping to the reactor end-fitting, the following alignment tolerances were established:

Figure 1-14. Y-Index Drive Gear Motor and Ball-Screw Assembly

- a) The dimensional tolerance between any handling-tube shutoff valve and the plane of the Y-index rollerways should not exceed ± 0.005 inch.
- b) As a target, the dimensional tolerance between the centerline of any handling-tube pressure-shell and the Y-index rollerways could not exceed ± 0.020 inch.
- c) The Y-index should position the centerline of any handling-tube shutoff valve to a repeatable point accurate within ± 0.005 inch.
- d) As a target, the three handling tubes should be positioned on the cradle on 18-inch centers within ± 0.010 inch at the shutoff valve end and within ± 0.020 inch at the other end. The front face of the three shutoff valves should be positioned in the same vertical plane within ± 0.010 inch.
- e) The front-face plane of the shutoff valve should be mutually parallel within $\pm$ zero degrees, 5 minutes.

These dimensional modifications were accomplished by shimming, adjustment screws or other means.

The cradle was so designed that when fully loaded with handling tubes, shutoff valves, hydraulic-system components, and other auxiliary equipment, the center of gravity fell between the proposed location of the carriage rails. This precluded overturning the cradle in any of its operating positions.

The cradle was fabricated of standard structural materials, such as piping tubes, AISC structural shapes, castings and forgings. The Y- and Z-rollerways were fabricated of SAE 52100 steel on the hardened surfaces and SAE 1015 steel for the base material. The bearing surfaces of the rails were hardened to Rockwell C 57 to 60.

D₂O HYDRAULIC SYSTEM

The operation of the refueling head handling tubes is performed by hydraulic components and controls interconnected to form a D₂O hydraulic system. The basic function of this system is to provide a constant source of D₂O at pressures sufficiently above reservoir reference pressure so that all required hydraulic input forces and ram speeds may be applied at controlled rates. In addition, a means of conditioning the forward end of the handling tubes and shutoff valves to match reactor condition is provided. The hydraulic system supplies D₂O at pressures ranging from zero to 2100 psig, and at flow rates up to 10 gpm and temperatures ranging from 75° F to 560° F. These fluid conditions represent the minimum and maximum D₂O conditions matching reactor environment and furnish the necessary power for refueling-head handling-tube actuation.

In designing the handling tube hydraulic circuitry, consideration was given to the specific requirements and sequential operation of each handling tube. Accordingly, the separate hydraulic subsystems were designated as: a) ES tube subsystem, b) SPG tube subsystem, and c) F & R tube subsystem. Each subsystem, consisting of appropriate hydraulic components and interconnecting lines, was mounted on separate manifold trays. Each tray was mounted on a common frame which, in turn, was mounted on the cradle. Each subsystem was connected to common headers and was supplied with hydraulic power through the test facility.

As an aid in presenting the design of the D₂O system, the handling tubes were divided into zones. This arrangement divides a typical handling tube into areas of similar function and environmental operation. The following figure 1-15 describes these zones relative to function.

Zone	Description
I	Cavity between the end seal and adapter valve (when connected to reactor)
II	Cavity between the adapter valve and shutoff valve.
III	Cavity between the shutoff valve and the forward internal tube seal.

This zone contains the following.

- a) ES tube - the end seal grapppler which retracts and holds the end seal in this zone during refueling operations.
 - b) SPG tube - the shield-plug grapppler which retracts and holds the shield plug in this zone during refueling operations. In addition, the guide tube, which was inserted into the end fitting to provide a smooth, uninterrupted internal bore for the movement of the shield plug and fuel bundles, is located in this zone.
 - c) F & R tube - new or used fuel bundles are housed in this zone. In addition, the forward end of the carrier tube and the ram for pushing fuel bundles are located in this zone.
- IV The zone in which all pistons and hydraulic input mechanisms necessary for performing the operations of each handling tube are located.

Figure 1-15
Zone Definition

ES TUBE HYDRAULIC SUBSYSTEM (See figure 1-16 for Design Data)

The ES tube hydraulic system is shown in figure 1-17. In the end-seal removal operation, the grapppler advances by venting ports 12, 13 and 14 to reactor pressure, applying a 300 psi differential to port 9 and shutting off the coolant flow through port 5. This is accomplished by energizing the solenoids of valves 70005, 70006, 70007 for the venting operation, energizing the solenoid valve 70017 (300 psig at port 9) and energizing

END SEAL TUBE DESIGN DATA

OPERATION	STROKE max.in.	REQ'D FORCE lbs.	REQ'D SPEED fpm	PORT PRESSURE psig (Note 1)				FLOW RATE gpm				DE- SIGN LEAK gpm	FRICTION DE- SIGN lbs.
				14	13	12	9	14	13	12	9		
<u>Remove End Seal</u>													
Advance Grappler & Engage E.S.	56 3/4	0 1500 ±15%	4-6	R	R	R	300	2.04- 2.95			2.82- 4.13	.21	0-50
Load Body & Retract Fingers	.02 9/16	5000 400	0 1-2	R	R	R	600	0	0	.21	.21	.21	0-50
				R	R	200	600	1.83- 2.74	.25- 3.11	.76 1.07	.21		0-50
Retract Assembly	56 3/4	0	4-6	200	200	200	R	2.41 3.32			2.82- 4.13	.33	0-50

NOTE: R = Reference Pressure;
all other pressures
are reference plus
stated value.

FIGURE 1-16

End Seal Tube Design Data (Sheet 1 of 2)

END SEAL TUBE DESIGN DATA

(continuation)

OPERATION	STROKE max.in.	REQ'D FORCE lbs.	REQ'D SPEED fpm	PORT PRESSURE psig (Note 1)				FLOW RATE gpm				DE- SIGN LEAK gpm	FRICTION DE- SIGN lbs.
				14	13	12	9	14	13	12	9		
<u>Insert End Seal</u>													
Advance Assy. & Load Body	56 3/4 0	0 1500- 3000	4-6 0	R R	R R	R R	300 300	2.04- 2.95 0	0	.21	2.82- 4.13 .21	.21 .21	0-50 -
Extend Fingers	9/16	112	1-2	R	200	R	300	2.16- 3.01	1.03- 3.52	.89- 1.20	.21	.13	0-50
Unload Body	1/2	0	-	R	R	R	R	0	0	3	3		0
Disengage 2nd Interlock	1/2	112	1-2	R	200	R	R	.33	1.03- 1.28	.68 .99	0	.13	0-50
Retract Assy.	56 1/4	0	4-6	200	200	R to 200	R	2.41- 3.32			1.39- 2.70	.33	0-50
Park	0	0	0	200	200	200	R	.21			.21	.33	0

NOTE: R = Reference Pressure;
all other pressures are
reference plus stated value.

FIGURE 1-16
End Seal Tube Design Data (Sheet 2 of 2)

the solenoid of valve 70012 to stop the coolant flow. The velocity of the grapppler advance is controlled by a one-way flow-control valve (70016) with a check valve bypass for unrestricted flow in the opposite direction. When the grapppler advances to engage the end-seal, the body is loaded and fingers of end-seal are retracted by applying a 600 psi differential pressure to port 9. This develops the force necessary to actuate the plunger mechanism which withdraws the fingers of the end-seal. With the action of the grapppler ball-lock keeping the end-seal fingers depressed and locking the end-seal to the grapppler, the end-seal is free to withdraw. This is accomplished by providing a 200 psi differential pressure at ports 12, 13 and 14 and venting port 9 to reference pressure by de-energizing all solenoid valves previously energized, with the exception of solenoid valve 70012. The latter is de-energized at the completion of grapppler and end-seal assembly retract stroke, port 5 is opened and coolant flows through the ES tube.

In the end-seal insertion operation, ports 12, 13 and 14 are pressurized to 200 psi differential pressure. Closing valve 70012 stops coolant flow, and port 9 receives 300 psi differential by energizing solenoid valve 70017. This procedure advances the grapppler and end-seal assembly to the load-body position at which time pressure switch 70018 is actuated indicating that 300 psi differential pressure is available at port 9. With the verification of pressure, solenoid valve 70007 opens applying 200 psi differential pressure at port 13. This causes the returning sleeve to release end-seal grapppler ball locking mechanism causing the fingers of the end-seal to extend. The body is unloaded by re-energizing the solenoid valve 70007 (venting port 13 to reference pressure) and de-energizing solenoid valve 70017 which vents port 9 to reference pressure. After the second interlock is disengaged, solenoid valve 70006 is de-energized, pressurizing port 14 with 200 psi differential pressure. This action causes the grapppler assembly to be retracted at a velocity controlled by the flow

of D₂O through single-direction flow-control valve 70013. After the grapppler assembly is fully retracted, solenoid valves 70005 and 70012 are de-energized. By action of the former, port 12 is pressurized to 200 psi differential pressure, the latter allows coolant flow to circulate through the handling tube.

SPG TUBE HYDRAULIC SUBSYSTEM (see figure 1-18 for Design Data)

The hydraulic schematic diagram for the actuation of the SPG tube is shown in figure 1-19. In the shield plug insertion procedure, insert carrier would be the first command which energizes the solenoids of valves 80005, 80014 and 80007. This stops coolant flow and applies the following differential pressures at the ports indicated. The differential pressure at port 8 would be 200 psi minus the pressure drop across flow control valve 80021 (variable flow control with internal check valve). The pressure drop across the above flow control valve is a function of its setting. This flow rate in turn governs the velocity at which the carrier is inserted. Port 9 is vented to reference pressure, port 10 is blocked and the pressure at port 11 is somewhat greater than 50 psi as a function of the pressure drop across variable-flow-control valve 80018. The advance-grapppler command energizes, in addition to the above, the solenoid valve 80013, which applies 200 psi differential pressure minus the pressure drop across flow control valve 80020 (variable-flow-control valve with internal check) during flow conditions. When static conditions are established, the pressure applied at port 10 is 200 psi differential. The pressures at the other ports remain as indicated above for the insert-carrier command.

The engage-fingers command energizes solenoid L1 of valve 80011 which applies 200 psi differential pressure to port 10 for actuation of the fingers. All other pressures at the remaining ports remain as discussed in the advance-grapppler command. The Test command, to verify execution of engage-fingers command de-energizes the solenoids of valves 80007 and 80013 which vent port 9 to reference pressure and apply 50 psi differential pressure to port 11, maintaining the pressure

SPG TUBE DESIGN DATA

	STROKE In.	REQ'D FORCE lbs.	PORT FLOW gpm				PORT PRESSURE psig (Note 1)			
			11	10	9	8	11	10	9	8
<u>SHIELD PLUG REMOVAL</u>										
1. Insert Carrier	52 1/16	502	.32- .48	-	-	2.61- 3.91	300	-	R	200
2. Advance Grappler	17 1/4	923	.63- .94	-	1.86- 2.97	-	300	300	200	200
a. Retract Locking mechanism	7/8	133	-	.61- .92	-	-	300	300	200	200
3. Grapple Shield Plug	7/8	133	LF	.61- .92	LF	-	300	R	200	200
4. Retract Grappler										
a. Upstream	69 5/16	37	.63- .94	-	1.86- 2.97	LF	50	-	R	200
b. Downstream	69 5/16	37	.63- .94	-	1.86- 2.97	LF	50	-	RB	200
5. Retract Carrier	52 1/16	63	.32- .48	-	LF	2.61- 3.91	50	-	R	R

NOTE 1: All pressure values are in
excess of reference pressure

LEGEND: - = Blocked Port
 R = Reference Pressure
 RB = Back Pressure
 LF = Leakage Flow

FIGURE 1-18
SPG Tube Design Data (Sheet 1 of 2)

SPG TUBE DESIGN DATA

SHIELD PLUG INSERTION	STROKE In.	REQ'D FORCE lbs.	PORT FLOW gpm				PORT PRESSURE psig (Note 1)			
			11	10	9	8	11	10	9	8
1. Insert Carrier	53 13/16	139	.32- .48	-	-	2.61- 3.91	50 RV	-	R	200
2. Advance Grapppler	69 5/16	1181	.63- .94	-	1.86- 2.79	-	50 RV	-	200	200
3. Engage Fingers	1/2	83	LF .92	.61-	LF	-	50 RV	200	200	200
4. Test										
a. Upstream SP	-	300	LF	-	-	LF	50	200	R	200
b. Downstream SP	-	300	LF	-	-	LF	50	200	RB	200
5. Unlock Grapppler	3/8	133	LF	.61- .92	LF	-	50 RV	300	200	200
6. Retract Grapppler	17 1/4	20	.63- .94	-	1.86- 2.79	LF	300	300	R	200
7. Retract Carrier	52 1/16	46	.32- .48	-	LF	2.61- 3.91	50	-	R	R

NOTE 1: All pressure values are in excess of reference pressure.

LEGEND: - = Blocked Port
 R = Reference Pressure
 RB = Back Pressure
 LF = Leakage Flow
 RV = Relief Valve Setting

FIGURE 1-18
SPG Tube Design Data (Sheet 2 of 2)

at the remaining ports as established by the previous command.

The unlock-grappler command would re-energize the solenoids of valves 80007 and 80013 in addition to energizing the solenoid of valve 80008. Since this operation involves negligible fluid flow, pressures at the ports are basically static; pressure at port 8 would be 200 psi, at port 9 (200 psi) at port 10 (300 psi) and port 11 would relieve to 50 psi pressure differential.

The retract-grappler command would de-energize the solenoids of valves 80007 and 80013 and energize the solenoid of valve 80010, applying 200 psi pressure differential at ports 8, reference pressure at port 9 and 300 psi differential pressure at port 10 and 11.

The retract-carrier command de-energizes all solenoids previously energized with the exception of solenoid valve 80005 (no coolant flow). This action applies a 50 psi differential pressure, blocks port 10 and vents ports 8 and 9 to reference pressure.

The park command de-energizes the solenoid of valve 80005 allowing coolant flow to circulate through the handling tube.

In the shield-plug-removal procedure, the first command would be insert carrier. This energizes valve 80005 shutting off coolant flow for the entire shield-plug removal cycle. With the energization of solenoid valve 80014, the pressures at the ports are the following: pressure at port 8 is 200 psi differential, port 9 vents to reference pressure, port 10 blocks and port 11 is at 50 psi pressure differential.

Since the distance the grappler advances is relatively short, (approximately 3 feet), pressure conditions existing at the ports are relatively static. Nevertheless, fluid displacement due to grappler advance and leakage past the internal seals, causes the pressure to build up in port 11 to 300 psi differential pressure, the setting of relief valve 80017.

The grapple-shield-plug command de-energizes solenoid valve 80008 and 80011-L1, maintains solenoid valve 80005 and 80014 and energizes solenoid valve 80011-L2. Under these relatively static conditions, the pressures are as follows:

- a. Port 8 has a pressure of 200 psi differential applied, ports 9 and 10 are vented to reference pressure and port 11 is at 50 psi differential pressure.

Grappler retraction is accomplished by de-energizing solenoid valves 80013 and 80012-L2 and maintaining the solenoids energized in the previous command. This maintains 200 psi differential at port 8, reference pressure at port 9, blocks port 10 and establishes 50 psi differential pressure at port 11.

For carrier retraction, solenoid valve 80014 is de-energized keeping only solenoid valve 80005 energized. This action vents ports 8 and 9 to reference pressure, blocks port number 10 and applies 50 psi differential to port 11.

When in the park position, solenoid valve 80005 is de-energized and coolant flow is recirculated through the tube.

F & R TUBE HYDRAULIC SUBSYSTEM (See figure 1-20 for Design Data)

When charging the reactor with new fuel, the F & R tube receives a new fuel-bundle at the new/used fuel port, carries it to the reactor, and rams it into the reactor process tube. When discharging used fuel from the reactor, the tube receives a fuel-bundle at the reactor process tube, carries and cools the used fuel in transit to the new/used fuel port and rams it into the new/used fuel port. The D₂O hydraulic system for fuel-and-ram tube actuation is shown on figure 1-21.

Basically, ports 8, 9 and 10 are subjected to various pressure levels and flow rates as determined by the processes of the handling tube. Port 5 allows coolant flow through the tube which is controlled by solenoid valve 90006. The solenoid of this valve is energized during functional performance of the tube stopping coolant flow through

FUEL & RAM TUBE DESIGN DATA

OPERATION	F R I C T I O N FORCE				F O R C E		FUEL BUNDLE PRESSURE DROP lbs.	P O R T PRESSURE psig (Note 1)			LEAKAGE gpm	FLOW gpm	
	STROKE in.	VELO- CITY fpm	FUEL COLUMN lbs.	F&R TUBE lbs.	F&R OUT- PUT lbs.	PISTON lbs.							
						Max.		Min.					
									8	9			10
1.Advance Assy (insert carrier)	35 3/16	4-6	-	-	0	382	100	-	R	200	40	.01	.33-.48
2.Advance Ram a.with flow	139	4-6	0-200	0-100	25-400	400	75	600-800	15	200	R	.01	1.74-2.59
b.against flow	178	4-6	0-200	0-100	1075-1200	1200	1125	600-800	140	200	R	.01	1.74-2.59
c.Ram Only	113 3/16	4-6	-	0- 50	0	1200	50	-	140	200	R	.01	1.74-2.59
d.Ram & Fuel Bundle- no flow	74 3/16	4-6	0-200	0- 50	0	1200	100	-	140	200	R	.01	1.74-2.59
3.Receive Ram a.against flow	178	4-6	0-200	0- 50	75-150	100	25	600-800	7	200	R	.01	1.74-2.59
b.with flow	139	4-6	0-200	0- 50	425-750	700	375	600-800	45	200	R	.01	1.74-2.59
4.Retract Ram	113 3/16	4-6	-	0- 50	-	590	50	-	R	200	140	.03	.52- .76
5.Retract Carrier	35 3/16	4-6	-	-	0	382	100	-	R	R	140	.03	.35- .50

NOTE 1: R = Reference Pressure. All other pressures are reference pressure plus stated value.

Figure 1-20
Fuel & Ram Tube Design Data

it. In the sequential operation of loading a fuel bundle, the carrier is inserted by energizing the solenoids of valves 90006, 90011-L2 and 90018-L2. This stops coolant flow through the tube and applies 200 psi differential pressure to port 9, a 140 psi differential pressure to port 10 and vents port 8 to a reference pressure. To advance the ram downstream, solenoids of valves 90006, 90018-L1, 90012 and 90007 are energized. This action applies reference pressure to port 10, 200 psi differential pressure at port 9 and 15 psi differential pressure at port 8. Ram velocity is governed by fluid flow through control valve 90008, a pressure-compensated, internal-check, flow-control valve. Ram retraction is accomplished by energizing solenoid valves 90006, 90011-L2 and 90018-L2, which causes the application of 140 psi pressure differential at port 10, a 200 psi pressure differential at port 9 and a pressure differential as a function of the setting of flow control valve 90015. The latter, a variable orifice flow control valve, governs the ram-retraction velocity. Carrier retraction is accomplished by continuing energization of the solenoid of valve 90006 (stop coolant flow), energization of solenoids of valves 90018-L2 and 90011-L1 which establishes 140 psi pressure differential at port 10 and a pressure differential as a function of the setting of flow control valve 90015, the flow through which governs the retracting velocity of the carrier. In the park position, all solenoids are de-energized allowing only coolant flow through the tube.

When the F & R tube functions as fuel-column control for receiving a fuel-bundle, the receive-ram-against-flow command energizes the solenoids of valves 90006, 90011-L2, 90018-L1, 90012 and 90013.

The actuation of these valves: a) stops circulation of coolant flow, b) vents port 10 to reference pressure, c) applies 200 psi differential pressure to port 9, and d) applies 7 psi differential pressure to port 8.

The latter back-up pressure, which when acting against the net

operating area of the ram (8.30 square inches), develops a force to counterbalance the net forces acting against the ram as caused by the loading ram, pressure drop across the fuel-bundle and fluid friction. The theoretical force is approximately 60 pounds.

The receive-ram-with-flow command energizes the solenoids of valves 90006, 90011-L2, 90012, 90016, and 90018-L1.

This action: a) stops circulation of coolant flow, b) vents port 10 to reference pressure, c) applies a 200 psi differential pressure to port 9, and d) applies a 45 psi differential pressure to port 8.

Again, the latter back-up pressure, when acting against the net operating area of the ram develops a counterbalancing force of approximately 375 pounds.

FILL AND DRAIN SYSTEM

Schematic diagrams of that portion of the fill-and-drain system built with the refueling head are shown on the left side of figures 1-17, 1-19 and 1-21. It will be noted that the hydraulic and pneumatic circuitry for each handling tube is identical except for the CO₂ collector tank which is common to all three tubes. To describe the operation of this system, the ES tube filling and draining will be described:

After the adapter valve and ES tube have been clamped to an end fitting, before opening the shutoff valve, it is necessary to fill the zone from the shutoff valve to the end seal with D₂O (see figure 1-17). Vent valve (70035) on the collector tank is closed while valves 70024 and 70010 are opened. As valve 70008 is opened, D₂O fills the cavity between shutoff valve and end seal and rises into the CO₂ collector tank as the gas is compressed at the high point of the system. Valve 70008 is then closed and the tube is ready for operation.

After a refueling cycle is complete it is necessary to drain the cavity between the shutoff valve and end seal. This draining operation

is performed by opening valves 70008 and then 70010 and 70024 causing the high-pressure -temperature D_2O to flash into a drain tank. After the D_2O has drained and the pressure in this zone has reached atmosphere, vent valve 70025 is opened to break any vacuum which has been created as a result of draining and to allow vault atmosphere to enter this zone. After completion of draining the four valves mentioned above are then closed and the handling tube can now be unclamped from the end fitting.

CONTROL SYSTEM

At the end of the conceptual phase of this program the design consisted of three special-function tubes, mounted on a cradle; each tube terminating in a shutoff valve, and an adapter valve that might be attached to either of the three tubes, and, in turn, to the reactor vessel end-fitting. The adapter valve would serve the function of the end-seal once it was removed from the end-fitting. As all major machine components were fixed in concept, a machine control system, that would program the operations required to carry out the selected sequences, was devised to handle refueling head requirements. Four machine programs were required to satisfy the concept; a) single fuel-bundle downstream transfer, b) single fuel-bundle upstream transfer, c) full channel upstream unloading, and d) full channel downstream unloading.

The initial control system specification tabulated all operations and the times postulated for carrying out each program. Each program consisted of every discrete operation required to further a particular function.

As a start to the control system design, all concept-evolved data was organized. All tabulations were reviewed and edited in order to systematize the nomenclature and check for any inherent discrepancies. As this research was completed, the operations were carefully examined for pattern development. Once the pattern was

found, basic combinations of operations were sought which might form larger components of the whole program. Since the refueling system required the operation of two machines, a method had to be devised in which the two machines would work in concert while servicing a process tube. The simplest approach, it was found, would be one machine acting as a master and the opposite as a slave. Either machine could be master or slave depending upon the mode selected by the operator. The master machine would actually load the new fuel-bundles into the reactor while the slave would receive the spent fuel-bundles from the other side. Control logic is shown in Figure 1-22. With this in mind the programs were expanded into larger combinations of sequenced operations which were further combined to yield the required program.

Since the machine has three separate tubes each performing a single function, and since each tube must remain connected to the end-fitting until it completes this function, the sequences were arranged to permit a tube to complete its function. Therefore, each time a tube was brought up to an end-fitting, a sequence began and was not complete until the tube was withdrawn from the end-fitting. Consequently there were at least four natural sequences occurring: a) the removal of the end-seal from the end-fitting, b) the replacement of the end-seal into the end-fitting, c) the removal of the shield-plug and d) the replacement of the shield-plug. These four basic sequences formed a component of all programs required during fuel loading, whether full-channel or single-bundle transfer.

The other break in the program pattern was developed when requiring the slave machine to come into operation. Note that the master machine handles the new fuel-bundle while the slave machine receives the spent fuel-bundle. In order to exercise column control, that is, not permit the fuel-bundles to float freely within the process tube, it was decided to insert the master-machine ram past the

end-fitting and then initiate slave machine assistance, rather than use the rams of both machines to control the fuel column. This would occur when the master machine had removed the end-seal and shield-plug and rammed a fuel-bundle into the reactor while waiting for the slave machine to remove its shield-plug. As the slave grapples the shield-plug, the master-machine ram, driving against the entire fuel column, would push the shield-plug into the slave machine SPG tube. As the shield-plug enters the slave machine, the fuel stop closes holding the following bundles in place against the force of the master machine ram. The slave would then withdraw the shield-plug, disconnect from the end-fitting, index to its F&R tube position, and adjust the column length as required. Using this approach, the total number of sequences required was seventeen.

These sequences in combination made up any one of the four programs. The sequences, their sequence designations, and the descriptions of the operations performed, are tabulated in figure 1-23.

Having established the ingredients of each program, stepping switches were incorporated to select the sequences to be followed by either the master or the slave at each program step. Having established the programming order, the logic of each given sequence was developed.

One function of a typical sequence, that of preparing the F&R tube for ramming, is shown in figure 1-24.

In order to adhere to the requirement for semi-automatic operation, the programmer selected the particular operational sequence, but the actual sequence would be issued manually by a specific pushbutton. The sequences were developed such that the pushbutton would automatically call for the first step of the sequence, and upon completion and verification of that step, the second step command would be

TABLE OF CONTROL SEQUENCES

SEQ. NO.

1	Pickup or Discharge Bundle at N/U Port
2	Align with Selected End-Fitting
3	Remove End-Seal
4	Remove Shield-Plug & Insert Guide
4A	Prepare to Remove Shield-Plug
4B	Withdraw SPG Tube
5A	Prepare to Insert F&R Tube Ram
5B	Withdraw F&R Tube
4P5	Receive Downstream Machine's Shield Plug
5A5	Ram Fuel Column Away from Machine
6A5	Insert Downstream Machine's Shield-Plug
6A	Prepare to Insert Shield-Plug
6B	Withdraw SPG Tube
6	Insert Shield Plug
7	Insert End-Seal
3S7	Replace End-Seal
8	Return to Standby

Figure 1-23
Table of Control Sequences

Figure 1-24. Partial Sequence Logic - F&R Tube

DO NOT SCALE DWG.		DATE		DIMENSION LIMITS UNLESS OTHERWISE SPECIFIED ARE: X.X EQUALS PLUS OR MINUS .06 X.XX EQUALS PLUS OR MINUS .015 X.XXX EQUALS PLUS OR MINUS .005 ANGULAR S		ITEM SIZE PART NO. RECD DESCRIPTION		AMERICAN MACHINE & FOUNDRY COMPANY		TRADE MARK	
SCALE		DRAWN		CHECKED		MATERIAL SPEC.		MAT. SIZE OR PATTERN NO.		MODEL	
NEXT ASSEMBLY		APPROVED		PART NAME		CLASS		DIV.		DWG. C SIZE	

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given. In turn, the second step command would be issued, and if successfully carried out by the machine, the third step would be commanded, until all steps in the sequence were properly executed. Upon completion of all steps in the sequence, the programmer would be so informed, and in turn, would wait for corroboration that the slave machine sequence had been completed. Having received the information that the sequences selected by the slave and master had been completed, the programmer would proceed to the next step and call for the next two sequences required by both machines. Should a machine not be capable of carrying out a command for some control or mechanical fault, the sequence would be held up, and the next command would not be issued until the initial command had been completed. The sequences, therefore, would remain at this particular step, and the operator would be so informed on the sequence board. A board light would show that the command had been given, but as correlation had not been received, the command had not been executed. The programmer could not progress to the next step even if, for example, the slave machine had completed all its steps and was held up pending completion of master machine operation. The operator could, using the manual panel, carry out the required step manually. The manual circuit would go directly to all machine actuators and by-pass all control components in the automatic control system. If the automatic control system faulted, the operator could actuate the machine components and cycle the machine until it could proceed automatically. The operator could perform all sequences required to complete the operation by simply using the manual controls provided.

By allowing the manual system to perform every step required to complete the program, the operator could, therefore, using an operational procedure, complete the entire program. Having the manual system by-pass the controls and go directly to the machine

actuators afforded a means of eliminating or by-passing possible control system failures. If, however, the machine still failed to perform, the fault lay with the machine proper. Other means would then be taken to complete the operation or put the machine in a safe condition for removal from the vault. A means now existed for carrying out all steps required to perform a certain sequence and these sequences combined to form programs.

The means to select any one of the four programs was also made available. Figure 1-25 shows in logic diagram form those machine conditions required for program selection, and the selection of a typical program. As only the refueling head was to be built, a means was devised to supply the control system with all inputs required from the opposite machine and hydraulic power system. The power system was simulated by AMF facilities. The point in the program at which these facilities were called upon was annunciated to a simulator board. This simulator would take the place of the missing system parts. Lamps would light whenever action was required by the operator or whenever an action was requested by an operator to be performed by simulation.

The overall control system may be considered to consist of the following physical parts:

- a) Instrumentation Display
- b) Manual Controls
- c) Sequence Display
- d) Relay Racks & Programmer
- e) Timer Racks
- f) Position Display

The instrument display provides the operator with information from machine-mounted pressure or temperature transducers or from the adapter valve mounted-homing sensors. These instruments indicate whether the temperatures are within limits, and in turn, regulate the power to the heaters on the adapter and the shutoff valves making sure skin or heater temperatures are not exceeded.

The manual controls permit the operator to open and shut all clamps and ball valves, index the machine to any position or to carry out the special operations of each handling tube. The operator, therefore, is able to manually remove an end-seal or shield-plug, or manually insert the ram in an end-fitting. Correlation lights are placed around the manual controls to indicate the current status of the machine. The lights indicate which valves are open or closed, which clamps are open or closed, and in what position the machine was indexed. The sequence display contains a light and a description for every step required to perform a given sequence. At the head of each sequence, a series button served to start or stop a sequence, and lights indicate whether or not a sequence had been called for. All sequences required for the refueling head test were included in this panel. The sequences pertaining to stand-by conditions and faulty end-seal replacement were omitted. The omitted sequences, although not fully established or determined, did not contain any new steps which could not be simulated or developed in the other sequences. Every step actually required of the overall refueling machine, except seeking and positioning itself opposite any selected end-fitting can be carried out on the refueling head.

The relay racks carry out all control system logic. Included are the power relays required to operate all the hydraulic system solenoids called for in each sequence. Two programmers are installed, one for single-bundle upstream refueling and another for single-bundle downstream refueling. (These were the only two operations contemplated for refueling head test). Full-channel transfer would not present any different problems to the machine since the single-bundle transfer cycle need only be repeated five more times.

The timer rack contains all the timers necessary to carry out those portions of the timed operations. The machine is directly interrogated, whenever possible, to determine its condition to ascertain whether all commands have been successfully executed. There are

operations, however, wherein the machine internals cannot be directly probed to verify the successful completion of an operation. In such cases, a predetermined period of time is allotted for the operation and once that time has elapsed, the step is considered complete and the machine proceeds. As the machine cannot complete the next step if the previous step is not complete, if the machine were to stop, it could be assumed that the previous timed step had not been completed. At no time can the machine long escape the scrutiny of the operator without having its responses directly probed.

The last component of the control system item is the position indicator panel. This panel consists of a graphic display which simulates the actual machine tubes complete with adapter valve and end-fitting. Associated with each tube are position indicating devices which transmit information to this panel. The panel consists of a row of lights over which the graphic display is superimposed. By viewing these lights the position and direction of movement of each tube's ram, grapppler or carrier can be determined. In this way, stroke speed can be defined, or the point at which the ram stopped, for one reason or another, can be ascertained. In addition, the progress of the tube or ram, during an operation, can be continuously monitored by the operator. By watching these lights traverse across the position indicating panels, the operator can visualize rams and grapplers moving, end-seal tube grapplers locking on the end-seal or returning with an end-seal. Whether or not the grapppler has the end-seal can also be determined by looking at this panel. Associated with the tube-mounted position indicating switches were control switches. These switches feed specific information to the control system. The control switches are located precisely at known points. For example, the switches determine one-half inch motion at the end-seal tube grapppler locking device. The switches indicate whether the end-seal tube has successfully picked up and locked on the end-seal by being triggered by the flux field of its applicable magnet. The magnet and

switch combination also differentiate between being forward and locked, forward and unlocked, having the grappler retracted and locked with an end-seal, or retracted and unlocked without the end-seal.

CHAPTER II

REFUELING HEAD MANUFACTURE

INTRODUCTION

Manufacture of the refueling head fell into four categories:

- a) parts wholly or partially fabricated in AMF shops,
- b) parts wholly or partially fabricated in vendors' shops,
- c) components purchased as standard products from vendors, and
- d) standard components modified to AMF specifications in accordance with the specific requirements of reactor on-power refueling environments.

Manufacture and inspection procedures were generally handled in accordance with figure 2-1, Flow of Material and figure 2-2, Inspection of Product. Source inspection of raw materials and standard commercial components was omitted. Quality assurance of these items was controlled by material certification and receiving inspection.

Each part manufactured in the AMF shops had a shop traveler prepared which listed all the machining operations, from raw material to finished product, for a particular component. The shop traveler also indicated inspection points for in-process components. At each of the inspection points a report was made reporting any discrepancies and disposition as to whether the part met design dimensions and tolerances. A discrepant part was then either reworked or scrapped. It was found that intermediate inspections were useful in finding discrepancies as early as possible and avoided further work on a part which might be judged as unacceptable.

A final dimensional inspection was performed on each fabricated part. Due to the developmental nature of this project, certain dimensions were designated by engineering as critical. The actual as-built dimensions were recorded so the information was available for reference during the assembly and test phases.

FLOW OF MATERIAL

TYPES OF QUALITY CONTROL ACTIVITY

VISUAL AND/OR DIMENSIONAL
 ENGINEERING CHANGE CONTROL
 FUNCTIONAL TEST
 LAB CONTROL
 PROCESS CONTROL
 COORDINATION OF QUALITY ITEMS

Figure 2-1. Flow of Material

QUALITY ASSURANCE SECTION

INSPECTION OF PRODUCT

Figure 2-2. Inspection of Product

Subcontracted fabrication work was generally subject to source inspection. In addition to dimensional and material requirements for fabricated parts, code requirements such as Pressure Piping Code and Pressure Vessel Code (including Nuclear Cases) were specified on the design drawings and certifications of compliance were required of the vendor.

Standard design items, such as those which made up a large part of the electrical control system, received only receiving inspection for compliance with catalog and purchase order requirements.

Non-standard commercial components, such as valves and regulators in the D₂ O hydraulic system, were handled differently. In most instances the reactor environment requirements imposed extensive modifications to the vendor's standard design. Reactor-environment equipment was ordered from AMF purchase specifications and acceptance tests were witnessed at the vendors' plant when possible. In addition, vendors' certification of compliance to design specifications was a requirement. The cognizant AMF development engineer closely followed the manufacturing progress to insure a functional and reliable end product.

Upon completion of fabricated parts and receipt of commercial items, components were retained in storage until all parts for a major assembly were received. Assembly was then initiated in accordance with AMF assembly drawings.

Due to the complexity of some major assemblies, detailed assembly procedures were written prior to assembly. These procedures specified the order of assembly, special tools or fixtures and special instructions. Where special assembly fixtures were required, detail drawings were made and fabrication was completed in time for assembly.

Prior to assembly, all critical operating parts were cleaned in a hot detergent bath, thoroughly rinsed in demineralized water and air dried. Components were then placed in polyethylene bags until final assembly. Overall equipment assembly was accomplished in accordance with AMF drawings.

GENERAL

The similarity of many component parts of the ES tube, F § R tube and the SPG tube permitted single vendor fabrication. Typical of these component parts were handling tube pressure shells, internal tubing mechanism, clamps, wear rings, piston- and seal-rings. The majority of the smaller handling tube mechanisms were manufactured by AMF and final assembly of all three handling tubes was accomplished in the Steamboat Road Laboratory of AMF Atomics.

HANDLING TUBE PRESSURE SHELLS

The pressure shells were centrifugally cast and rough machined in accordance with AMF Specification 89-58-1034. Specific requirements for material composition, geometry, inspection, testing, and cleanliness were contained in the specification and formed the criteria for acceptance or rejection of the pressure shells.

The selection of a centrifugally cast stainless steel in lieu of an extruded stainless steel resulted from the decision to machine the pressure-shell body and flanges from a single piece of stock. One-piece construction eliminated alignment problems associated with welding flanges to the pressure shell; a precision fit was required to insure proper pressure sealing between different segments of pressure shells with metallic sealing rings. The centrifugally cast process also proved to be the most economical method of fabricating the handling tubes which have a casting wall thickness of approximately 2 inches and maximum outside diameter of 8 inches. The final material selection was ASTM CF8 C Stainless Steel. Centrifugal casting was done in accordance with ASTM A-351.

During the initial phase of centrifugally casting CF8C, the material specimens did not meet the yield- and ultimate-strength requirements. A modification of the chemical composition increased the material strength properties. However, a slight decrease in

ductility, resulted in the material failing to pass a flattening test. A compromise was made in the chemical composition of the stainless steel that enabled successful flattening tests with physical strength values just below the ASTM allowable limit. However, the overall safety factor used for the pressure shells, based upon design operating conditions, was greater than 4, thereby meeting code safety-factor requirements.

A summary of the properties required for the pressure shells are:

a. Material - CF8C (Stainless Steel Type 347)

b. Chemical Composition (Percentage)

Carbon	-	0.08
Manganese	-	1.50
Silicon	-	2.00 (max.)
Sulfur	-	0.040
Phosphorus	-	0.040 (max.)
Chromium	-	18.0-21.0
Nickel	-	9.0-12.0
Molybdenum	-	0
Columbium	-	8 x carbon content but not to exceed 1.0

The centrifugally cast stainless steel CF8C stock was accepted after careful metallurgical study at the vendor and AMF Laboratories. The test specimens were found to be homogeneous and free from any dendritic structure, and the material showed very good ductile properties during destructive testing. Based on this, permission was given to proceed with rough machining of the pressure shells. The next check of the pressure shells, after machining, consisted of radiographic examination and hydrostatic testing.

At the AMF Laboratories, the hydraulic pressure ports were welded to the pressure shell. Prior to the welding operation, the pressure shell ports were machined to a J-groove configuration for the welding operation. The root pass of all port welds were dye-penetrant inspected, and the welding operations completed and inspected in accordance with established procedures. Hydrostatic pressure tests were

again performed on all pressure shells as a final check of the material added during welding.

The pressure shells were now ready for final precision machining operations of the inside diameter surfaces. Close-tolerance boring, grinding and honing operation were required to obtain a 16 RMS finish and dimensional tolerances, within ± 0.002 inch required to mate piston rings which ride these surfaces. Final machining of the pressure shell hubs was then referenced to these bores. All pressure shells were checked and conditionally accepted pending hydrostatic pressure testing at the AMF test facility.

Overall fabrication and final machining of handling tubes internals and the pressure shells were monitored to insure exact dimensions, materials and surface finishes. The pressure shells had sufficient wall thickness so that minimum deflection occurred during turning operation. The pressure shells ranged in lengths up to 16 feet, and were readily handled in long-bed engine lathes equipped with steady-rests.

The three pressure shells are shown mounted on the cradle during Refueling Head assembly in Figure 2-3. Figure 2-4 shows a rear end view prior to installation of hydraulic lines.

SEAL AND WEAR RINGS

The selection of the wear rings used in the internal mechanisms and pressure shells of the handling tubes was based upon the following factors: load capability, service life, material, thermal conditions, assembly, and cost.

The wear rings selected were manufactured of a silver-graphite composition. Silver-graphite material was chosen because of its good load-bearing capabilities under long-stroke operations, its low coefficient of friction which minimized input power requirements and its compatibility with other handling tube component materials. The wear rings were also desirable because of their range of use for all

Figure 2-3. Handling Tube Pressure Shells during Assembly to Cradle

Figure 2-4. Rear View of Pressure Shells Mounted to Cradle

handling tubes. The wear rings were fabricated in two pieces to allow for thermal expansion and contraction, and to facilitate assembly. The use of two-piece wear rings was also based on past experience, for a similar application, and the vendor's recommendations. Graphite wear rings are shown in the lower portion of Figure 2-5. The smaller rings just above are piston rings selected to control leakage of driving pressures. Figures 2-6 and 2-7 are additional views of the SPG Tube internals showing typical quantities of wear rings and piston rings.

The procurement of piston- and seal-rings for the handling tubes was based on the following considerations:

a. PRESSURE.	The rings would operate at differential pressures of 200, 300, and 600 PSI, at maximum pressures of 1500 PSI and 2100 PSI, and be capable of sealing in both directions.
b. TEMPERATURE.	Operating range of 70 ^o to 560 ^o F.
c. ENVIRONMENT.	D ₂ O or demineralized H ₂ O.
d. VELOCITY.	5 feet per minute.
e. CYCLING.	20,000 cycles through a 6 foot stroke.
f. LEAKAGE.	100 CC per minute, per 1 inch of diameter.
g. LUBRICANT.	D ₂ O or H ₂ O (system fluid)
h. MATERIAL.	Silver-graphite for the ES tube and a bronze metallic composition for the other handling tubes. Materials are non-corrosive in D ₂ O and H ₂ O and non-magnetic. No aluminum or organics were permitted.
i. SURFACE FINISH	16 RMS capable of sliding against a 300 series stainless steel.
j. GEOMETRY.	Compatible with ring-seat configurations.

Figure 2-5. Shield-Plug-and-Guide Tube Internals

Figure 2-6. Shield-Plug-and-Guide Tube Internals

Figure 2-7. Shield-Plug-and-Guide Tube Internals

The silver-graphite ES tube rings were fabricated in two pieces to facilitate installation. See Figure 2-8 and Chapter 1, Figure 1-7. The rings used for hydraulic pistons were equipped with expanders, while piston-rod rings were equipped with contractors to insure maximum leak-proof operation. All rings have lap joints to minimize possible leakage due to high differential pressures in the ES tube. The silver-graphite material, designated Grade BI-O2, was found to be ideal because of its inherent lubricating qualities. Impregnated particles of graphite in the bearing surface provided the lubricity. When ring wear-in was complete, the silver-graphite ring and mating part, provided a smooth operating surface. The anticipated leakage rate under these conditions is less than 100 CC per minute, per 1 inch of diameter.

The piston- and seal-rings for the F & R tube and the SPG tube were of one and two-piece construction. The two-piece rings were used with stainless steel contractor springs to obtain proper sealing action. The ring material was a bronze alloy, designated Cookmet No. 14. This particular material was chosen because its relatively low coefficient of friction over long-stroke applications and its good load-carrying and sealing capabilities.

The bronze-alloy rings had a greater leakage rate than the silver-graphite rings due to material composition. However, the bronze-alloy rings provided greater load carrying capabilities. The increased leakage rate was recoverable and handling tube operating pressures could be maintained.

CHROME PLATING

Refueling head system components were chrome plated in accordance with Federal Specification QQ-C-320, Class 2 conditions. The chrome plating used was of the hard-chrome series and applied to the dimensions specified on the detail drawings. Flash-chrome plating was used on a limited basis for threaded assemblies to prevent galling of mating stainless steel parts.

Figure 2-8. End-Seal Tube Internals

Hard-chrome plate was applied 0.002 to 0.004-inch thick in the area subjected to wear conditions, with a 0.125-inch chrome fade into adjacent areas. After the plating process, all parts were inspected for dimensional requirements and to insure overall quality.

Prior to chrome plating, all stainless-steel parts were cleaned by vapor degreasing or organic solvents. The surfaces were then grit or vapor blasted to a good adhering surface.

BELLEVILLE SPRINGS

A force of 1275 to 1575 pounds is required to either seat or unseat the end-seal sealing disc at its sealing face. In the development of the ES tube design, space requirements indicated that this force input could be best supplied by a Belleville spring having desirable load-deflection characteristics. The Belleville spring was to be installed with a preload of 1050 pounds (1500 pounds minus 30 percent) and the spring force was not to exceed 1500 pounds through its operating range of 0.072 inch. The requirements for the Belleville spring to perform as outlined were thoroughly investigated analytically and empirically to determine the dimensional and material data for furnishing the springs.

The dimensional and performance data was submitted to spring manufacturers and, though the requirements were difficult to meet, a vendor was chosen. After a number of attempts at fabricating the spring, the selected vendor decided he could not meet the performance requirements on fixed-price basis.

The initial spring requirements were then reviewed and, where possible, the requirements were simplified. Quotes were solicited and a second vendor chosen to furnish the springs on a fixed-price basis. The springs initially furnished by this vendor did not meet performance requirements as tested in AMF facilities. It then became apparent that the new vendor would have to produce a number of sets of springs and obtain an operating set by trial-and-error testing. Because of the

importance of these springs, much of the trial-and-error testing was performed by AMF. This approach finally yielded a set of Belleville springs which operated according to the performance requirements. However, they varied slightly dimensionally. Minor changes were then made to some ES tube internals to accommodate the springs.

HYDRAULIC SYSTEM

The procedures established for the manufacturing of the hydraulic system followed closely those normally encountered in the procurement, manufacture, assembly of control equipment.

Most of the hydraulic system components, i. e., pumps, control valves, regulators, fittings, and attaching hardware were vendor-purchased items. To purchase these components, it was necessary to initiate a specification control system, which consisted of:

- a. Establishing general and equipment specification
- b. Soliciting vendor bids
- c. Engineering evaluation
 1. Vendor qualification
 2. Engineering evaluation of bids
 3. Negotiate specification changes for commercially unavailable components
- d. Release purchase orders and
- e. Institute a quality-control system which witnessed performance tests of functionally critical components at vendor facilities.

The greatest single difficulty in obtaining commercial, hydraulic components concerned the material requirements. Valve bodies of 300 series stainless steel, high tensile and hardened-steel alloys for seal stems and spool surfaces and stringent leakage requirements presented problems in terms of vendor selection. One vendor supplied the directional-relief valves, flow-control valves and pressure regulators used extensively throughout the refueling head design. During

functional, subassembly and integrated testing, it was found that, with the exception of some adjustments, the components functioned as specified. There were, however, cases where components were not commercially available. One example was the three-way, two-position, detented, solenoid directional valve with 0.5-inch ports. In this case, flow, pressure and size requirements dictated the use of a pilot-operated valve. Accordingly, after extensive vendor negotiations, a suitable vendor configuration was found acceptable.

Manufacturing decision, in the design stage, had to be made regarding welded joints versus threaded fittings in the construction of the hydraulic circuitry. The main advantage of welded construction was the elimination of leakages. Yet, in terms of hydraulic circuit modification and repair, welded joints proved to be disadvantageous. The use of threaded fittings would provide easy hydraulic alteration, with possible leakage due to improper sealing caused by insufficient torquing or loosening due to vibration. A compromise solution was arrived at which called for welding the greater portion of the hydraulic circuit, yet leaving a sufficient number of fittings in the circuit to provide circuit alteration capability. In evaluating the success of this system, it can be stated that the desired flexibility was achieved with a minimum amount of external leakage. Fittings used off machine and throughout the test facility system were almost exclusively Autoclave fittings.

As noted earlier in this report, the availability of standard designs for water hydraulics control valves was thoroughly investigated. In general the directional, pressure and flow control valves purchased for the D₂O hydraulic system were standard in concept but modified with respect to materials, clearances and internal and external leakage requirements. Several of these valves operated extremely well during the test program and therefore a detailed description and vendors' cross-sectional drawing are here presented.

a) Three-way, two-position, pilot operated, solenoid valve

Two valves covered by AMF Specification 89-58-9022 were purchased from Kemp Aero Products, West Milford, N. J. and were incorporated in the F § R tube hydraulic subsystem (90011 and 90018, Chapter I, Figure 1-21). A cross-sectional view of the assembly of this valve is shown in Figure 2-9. The pilot section (1) actuates the main part of the valve. Both hydraulic sections, pilot and main valve, operate basically on the poppet principle. The pilot poppet is actuated by the solenoid which provides the motive force for shifting the pilot poppet spool. The main valve pressure cavities, reading from right to left are: pressure port, cylinder port and return port. Maintaining the pilot poppet to the left provides a pressure path which increases pressure behind the left side of the main valve spool, shifting it to the right. This blocks the pressure path between pressure and cylinder ports and vents the cylinder to the return line, which is the reference pressure line. Shifting the pilot spool to the right hand side admits pressure behind the right hand and left hand pistons of the main spool. Area differential provides the necessary force to shift the main spool to the left hand side connecting pressure and cylinder ports.

All internal metallic parts are 300 series stainless steel. Excellent performance was obtained by the use of the common reference pressure line for pilot and main valve operation. However, for a valve inlet pressure of 200 PSI differential pressure, a minimum pilot pressure of 515 PSI differential is required.

Specific requirements are as follows:

Description	Three-way valve, 2 solenoids, momentary contact (pulse), two positions, detented.
Ports	1/2-inch diameter.

Pressure Drop	Maximum 10 PSI at 5 GPM (either position)
Internal Leakage	Maximum 50 cc/minute (either position)
Life	Service free, 10,000 cycles minimum
Shifting Time	Maximum 0.5 second (to either position)

(b) Pressure Regulator

Figure 2-10 is a cross-section of the pressure regulator purchased from Kemp Aero Products, West Milford, N. J. and covered by AMF Specification 89-58-9025. Two regulators are incorporated in the hydraulic subsystem circuit of the F § R tube (90009 and 90010, Figure 1-21, Chapter 1 and one 80006, Figure 1-19, Chapter 1 in the SPG tube hydraulic subsystem. The regulator utilizes a variable-orifice principle increasing or decreasing the pressure differential across the regulator by adjusting the flow through it. Inlet and outlet pressures are sensed and utilized to move the poppet (12, Figure 2-10.) against spring (28) changing the orifice size which determines the pressure drop across it. Adjusting screw, (39) acts on spring, (27) for range adjustment purposes. A special feature incorporated in the design of this regulator is its application to dead-end service, i. e., there will be no pressure build up due to no-flow conditions. To accomplish this, a vent poppet (15) unseats and opens a pressure path between inlet and vent ports. The net force generated by the differential pressure acting on the poppet and the spring (26) causes the vent poppet to unseat.

All metallic components, in contact with the fluid, are either 300 series stainless steel or high-tensile steel alloys.

Figure 2-10. Pressure Regulator

Highlights of the specification are presented below:

Description	Pressure regulating valve, dead-end service
Ports	1/2-inch diameter
Range	15 to 185 PSI differential with flows from zero to 5 GPM
Internal Leakage	Maximum 25 cc/minute at 185 PSI differential
Life	Service free, 5,000 cycles minimum

NOTE: 1. input pressures available are either 1700 PSIA or 1800 PSIA; output must be adjustable from 1685 PSIA to 1515 PSIA.

2. discharging into a vented reservoir (output pressure zero PSIG) the regulator shall be capable of zero to 5 GPM with an input pressure within the range of 15 PSIG to 185 PSIG.

c) Three-way, two-position, closed-center, spring-centered solenoid valve.

A cross-sectional view of the valve is shown in Figure 2-11. The valve was purchased from Marotta Valve Corp. of Boonton, N. J. and incorporated in the hydraulic subsystem of the SPG tube, Figure 1-19, Chapter I. It is a double-poppet valve (31), providing either a high-pressure path or a reference-pressure path to the exit port as a function of solenoid energization to unseat the respective poppet. When the solenoids remain energized, the two poppet springs (22) maintain the seated position of the poppets. In this manner, the high-pressure and reference-pressure ports are effectively blocked providing the closed-center position.

The specification of the valve utilized in the hydraulic system did not contain the override assembly (3). The salient features of the specification for this valve are as follows:

Description	Three-way valve, three positions, closed center, two solenoids, spring centered
Ports	1/2-inch diameter
Pressure Drop	Maximum 10 PSI at 5 GPM
Internal Leakage	Maximum 15 cc/minute (either position)
Shifting Time	Maximum 0.5 second (to either position)
Life	Service free, 10,000 cycles minimum
Shifting Conditions:	

	<u>Center</u>	<u>Energized Sol. I (PSI)</u>	<u>Energized So. II (PSI)</u>
P	1700/1800	1700/1800	1700/1800
R	1500	1500	1500
C	1500	1700/1800	1500

d) Safety Relief Valve

Figure 2-12 is a safety relief valve with a bellows seal as manufactured by the Valcor Engineering Corp. This valve is used in the hydraulic circuitry of the SPG with the purpose of relieving any build up of pressure forward of the grapppler mechanism.

The salient features of this relief valve are its stainless steel body with stellited seating surfaces in the body and valve plug. In addition the bellows type housing for the calibrated stainless steel spring creates a leak tight closure. All parts in contact with the D₂ O are stainless steel.

This valve was furnished in accordance with AMF specifications calling for a 1/2 inch valve with a range of 250 to 350 PSI differential at a flow of 1 to 3 GPM. The valve must maintain the differential pressure setting within 5 percent with flow fluctuations of

NOTES:

1. -- FLOW - S.O.
2. -- MAX. PRESS. 300 P.S.I.
3. -- PRESS. DIFFERENTIAL: 250-350 P.S.I.
CRACKING PRESS.: 90% OF DIFF. PRESS. SETTING
RESET: 85% OF DIFF. PRESS. SETTING
4. -- INTERNAL LEAKAGE: 15 cc/min. (MAX.) AT 75% OF SETTING

11	1	CONNECTIONAL	NUT, 1/2-13 UNF	ST. STL.	
10			GASKET	BUNNY	
9	1	V-42623-05	CRP	ST. STL.	304
8	1		GASKET	BUNNY	
7	1	V-42619	BUSHING	ST. STL.	303
6	1	V-42618	GUIDE, SPRING	ST. STL.	303
5	1	V-42617-05	SCREW, SPRING ADJ.	ST. STL.	
4	1	V-42615-05	NAMEPLATE	ST. STL.	ELEC. ETCH
3	1	V-42604-05	SPRING	STAINLESS STEEL	
2	1	V-42654-05	BODY ASSEMBLY		
1	1	V-42652	BEULABO'S-PLUG ASSY		
ITEM	QTY	PART NO.	DESCRIPTION	MAT'L	MAT'L SPEC.

Figure 2-12. Safety Relief Valve

10 percent. The cracking pressure is to be 90 percent of the differential pressure setting and reseal at approximately 85 percent of the differential setting. The allowable internal leakage is not to exceed 15 cc per minute at 75 percent of the setting, over a service life of 5000 cycles.

This valve, during the test program, operated extremely well and in accordance with the design requirements.

ELECTRICAL CONTROLS

The operator's control station (figure 2-13) consists of the following subsystems, reading from right to left: a) a control panel for refueling-head pressure and temperature indications and homing controls (figure 2-14). b) two control panel sections for manual control of the refueling-head hydraulics, remote clamping, shutoff and adapter valves and fuel-stop actuation, and the Y- and Z-drives and the associated interconnecting wiring (figure 2-15). c) a control panel for automatic sequence control (figure 2-16). d) a control panel section for slave machine simulation, and e) position-indication display (figure 2-17).

Handling tube pressure transmitter mounting is indicated in figure 2-18 while position-sensing reed switches are shown in figure 2-19.

Equipment racks for supporting components to the control system consist of: a) logic relay racks (figure 2-20). b) a drive relay rack (figure 2-21) and c) a timer and automatic programmer rack (figure 2-22)

The design phase of the electrical control system resulted in drawings and specifications in the following categories: a) schematic diagrams, b) wiring diagrams, c) equipment-purchase specifications, d) control-panel arrangements and detail drawings, and e) installation drawings showing physical wire routing, junction box locations and mounting details, and position-indication chassis arrangements and details.

Figure 2-13. Operator Control Station

Figure 2-14. Pressure/Temperature Indicator Panel

Figure 2-16. Simulator Panel and Sequence Control Panel

Figure 2-17. Position Indicator Display

Figure 2-18. Handling Tube Pressure Transmitters

Figure 2-19. Position Sensing Reed Switches

Figure 2-20. Logic Relay Racks

Figure 2-21. Drive Relay Rack

Figure 2-22. Timer and Automatic Programmer Rack

The manufacture of the electrical control system, utilizing these documents, was the next phase in refueling-head development. To ensure continuity of approach, several key design personnel served in a supervisory role, while the entire control system was assembled at the Steamboat Road Facility.

The magnitude and complexity of the control system made it mandatory that the fabrication proceed in a closely planned and orderly manner. Wiring was installed according to the design drawings. Changes, if found necessary during fabrication, were immediately documented to facilitate system checkout upon completion.

The control system was fabricated, for the most part, from commercially-available components. In considering the prototype nature of the equipment, flexibility of correction and change was an important consideration. Consequently, standard equipment and open console racks were chosen. The logic and drive relay racks were arranged in groups so that bench-wiring production techniques could be used to a great degree. A large quantity of interconnecting wires was automatically precut, skinned, and tinned to reduce technician wiring time. Interconnecting wires were run in cable trays rather than closed conduit. Refueling-head wiring was collected in harnesses and terminated in plug-in connectors at the transition boxes. Connections from the control and relay racks originating in a connector were routed along the cable trays to the panel connection points. Accessibility and ease of maintenance was a prime consideration for the prototype system.

CHAPTER III

REFUELING HEAD TESTING

REFUELING HEAD TESTING

INTRODUCTION

Recognizing the developmental character of the refueling head, its handling tubes, shutoff valves, electrical-control and hydraulic sub-systems, the intent of the test program was to install the refueling head in the test facility, statically and dynamically test the individual handling tubes, and then dynamically test the entire refueling head as a unit. The testing was to be performed under simulated non-radioactive reactor conditions.

To initiate the program, engineering analyses were made to determine the requirements of a centralized water supply system for the test facility and to create those specifications and drawings required to build this system. In addition, power supplies, instrumentation and controls were determined to perform the test program.

Secondly the equipment, instrumentation and controls necessary for a complete test facility capable of testing the refueling head were procured, installed and checked out.

The test stands required to support the refueling head in the test facility and to install the AECL-furnished reactor end-fittings were then designed. The result was shop drawings, and specifications leading directly to the manufacture and erection of a test stand.

The test stand structural supports were then fabricated and installed in the test facility in accordance with refueling head testing requirements. The following section gives a complete description of the test facility as designed and fabricated under this approach.

TEST FACILITY

The test facility was designed to provide the following conditions:

- a. simulate and maintain demineralized water under reactor environmental conditions of temperature and pressure in the end-fitting and handling tubes.
- b. provide a pressure head of demineralized water for the

actuation and sequential operations of the handling tubes, and
c. simulate the F & R tube of slave refueling head.

The design of the test facility as shown schematically on figure 3-1 consists of two major subsystems, the hot loop and hydraulic loop.

The function of the hot loop was to simulate reactor environmental conditions. The hot loop was capable of supplying and maintaining demineralized water at pressures ranging from 50 psi to 1500 psi and temperatures from 180^o F to 560^o F. The flow rate in this system does not simulate reactor-pressure-tube flow conditions, but is sufficient to maintain constant temperatures in the end-fitting. Another function of this system was to fill and drain the forward end of the handling tubes when connected to the end-fitting.

The hot loop subsystem consisted primarily of two branch systems, the water hydraulic system and the reactor environmental system. Both subsystems were supplied from a single autoclave reservoir, having a 49-gallon capacity of demineralized water which was pressurized by a nitrogen blanket under 1500 psig. Figures 3-2 and 3-3 show this reservoir. The latter shows the relief valve and frangible disc safety valve. The autoclave reservoir was filled under blanket pressure conditions, by a duplex pump (figure 3-4) or by a centrifugal pump under vented conditions. Both pumps were capable of drawing fluid from the demineralized water reservoir shown with the autoclave reservoir, figure 3-5. Suitable piping, valving, and controls permitted operation of either autoclave reservoir filling system. Figure 3-6 shows the demineralizer system with interconnected piping leading to the reservoir pumps.

The autoclave control panel is shown on figure 3-7. Gages indicating blanket pressure, pneumatic system pressures, and autoclave water level in addition to air pressure regulators, pump-motor starter, switches, and shutoff valves for manipulating filling operation and N₂

89 58 E SK3546

REVISED	PART NO.	REV.	DESCRIPTION
1	89 58 E SK3546	1	AMERICAN MACHINE & FOUNDRY COMPANY
2	89 58 E SK3546	2	AMERICAN MACHINE & FOUNDRY COMPANY
3	89 58 E SK3546	3	AMERICAN MACHINE & FOUNDRY COMPANY
4	89 58 E SK3546	4	AMERICAN MACHINE & FOUNDRY COMPANY
5	89 58 E SK3546	5	AMERICAN MACHINE & FOUNDRY COMPANY
6	89 58 E SK3546	6	AMERICAN MACHINE & FOUNDRY COMPANY
7	89 58 E SK3546	7	AMERICAN MACHINE & FOUNDRY COMPANY
8	89 58 E SK3546	8	AMERICAN MACHINE & FOUNDRY COMPANY
9	89 58 E SK3546	9	AMERICAN MACHINE & FOUNDRY COMPANY
10	89 58 E SK3546	10	AMERICAN MACHINE & FOUNDRY COMPANY

Figure 3-2. Autoclave

Figure 3-3. Autoclave Pressure Head

Figure 3-4. Autoclave Water Make-up Pumps

Figure 3-5. Bottom View of Autoclave and Demineralized Water Reservoir

Figure 3-6. Test Facility Demineralizer System

Figure 3-7. Autoclave Pressure and Level Control Panel

blanket application were incorporated.

A triplex 10-GPM pump (figure 3-8) draws autoclave water at blanket or reference pressure and boosts the pressure by 600 psi as determined by a relief valve setting. Pneumatically operated shutoff valves (figure 3-9) control the flow to the pump. The pneumatic valves close and the pump is deactivated when the emergency circuit is activated.

Two pressure regulating valves allow two pressure reduction stages. Hydraulic power delivered to the refueling head consists of four pressure stages: reference pressure (directly from autoclave), reference pressure plus 200 psi, reference pressure plus 300 psi and, reference pressure plus 600 psi. Flow at these various pressure levels is determined by the demand of the refueling head which is governed by various flow control valve settings and orifice sizes. Figure 3-10 shows the hose connections of the four pressure levels from the test facilities to the refueling head manifolds.

Figure 3-11 shows the control panel of the water hydraulic system. The gages shown provide the means for monitoring the four pressure levels. The relief valve for controlling reference pressure plus 600 psi appears in the bottom center of the panel and the two pressure regulating valves are seen at the right and left hand side below the center of the panel. The shutoff valve at lower left is used for regulating by-pass flow through the heat exchanger (figure 3-9). The flowmeter element for measuring by-pass flow appears in the foreground with its read-out mounted adjacent to the right hand pressure regulating valve.

The environmental system of the hot loop is designed to duplicate reactor environmental conditions in terms of pressure and temperatures. This system consists basically of the common autoclave reservoir, a canned rotor turbine pump, (figure 3-12), two 10-kilowatt, thermostatically-controlled immersion heaters, and a distribution manifold with interconnecting piping. The distribution manifold consists of a supply and return manifold with interconnected piping and distributes

Figure 3-8. D_2O Hydraulic System Pump

Figure 3-9. D₂O System Cooler and Pneumatically Operated Shutoff Valves

Figure 3-10. Hydraulic Manifolds with Four Pressure Level Supply Lines

Figure 3-11. Test Facility Hydraulic Control and Monitoring Panel

Figure 3-12. Environmental Hot Loop System

environmental water to the refueling head and end-fitting. Fluid friction and other restrictions in the end-fitting gave rise to a 150 to 200 psi pressure differential across the pump. The environmental loop is self-contained, in that it circulates its fluid in a closed loop preventing mixture of hot and cold fluid in the autoclave and is capable of drawing make-up fluid to maintain system level.

Temperature conditions at various points in the environmental system of the hot loop were sensed by 10 thermocouples. Temperature traces indicating temperature location and time were recorded on the multipoint recorder (figure 3-13).

Temperatures were recorded at the following locations:

<u>Location</u>	<u>Numerical Designation</u>
End-Fitting - Inlet	1
End-Fitting - Outlet	2
Triplex Pump Suction	3
Autoclave - Return	4
Heat Exchanger - Inlet	5
Autoclave Suction	6
Environmental System - Return	9
Triplex Pump Discharge	10
Heat Exchanger - Outlet	11
Heaters - Downstream	12

The oil hydraulic loop of the test facility was a self-contained system for simulating the slave refueling head. The actuator was a double-acting hydraulic cylinder (figure 3-14). The hydraulic cylinder was connected to a system of shutoff valves, relief valves, directional valves, and piping which provide controlled forward and retarding forces at predetermined ram velocities. A power pack, consisting of an integral reservoir, pump, and motor, supplied hydraulic power.

Figure 3-13. Environmental Multi-point Recorder

Figure 3-14. Test Facility Fuel Ram

Figure 3-15 shows the hydraulic pump and electric motor mounted on the oil reservoir. Figure 3-16 depicts the control panel for the oil hydraulic system. The pressure gages near the top of the panel are used for monitoring system pressure, piston-end pressure, and rod-end pressure.

Figure 3-17 shows hydraulic cylinder end-fitting interface. The vertical piping and shutoff valve entering the end-fitting supplied the environmental conditions to the hydraulic ram head. On top of hydraulic cylinder was mounted a rod-extension sensor which was connected to rod-extension indicator of the control panel in the control room. The hydraulic line connected to the hydraulic cylinder supplied pressure for ram movement.

Figure 3-18 shows part of the environmental loop components and controls, the main valve control station and emergency shutdown. Next console was the multipoint temperature recorder. Electrical controls for pump and heater were located above hot-loop centrifugal pump followed by the two immersion heaters. The forward end of the Refueling Head with adapter valve in place, ready for testing, is shown in figure 3-19.

SHUTOFF VALVE AND SUBSYSTEM FUNCTIONAL CHECKOUT

Prior to the actual testing of the refueling head, major sub-assemblies and subsystems were functionally checked out for proper assembly, operability of moving parts, and correctness of hook up for electrical and hydraulic lines. This checkout then formed a base line from which troubleshooting or analysis of system malfunction could be made during performance tests of the refueling head. As an example, the internal mechanism of each of the handling tubes was inspected for the desired fits during the assembly stage, and minor corrections to clearances accomplished in order to assure the desired freedom of operation. Likewise, cradle bearing alignment was adjusted, limit switches set, and gear backlash adjusted. The following paragraphs describe checkout of a) shutoff valves, b) hydraulic system, and c) electrical control system carried out in

Figure 3-15. Test Facility Pump (Ram)

Figure 3-16. Test Facility Ram Control Panel

Figure 3-17. Penetration of Test Facility Ram into End Fitting

Figure 3-18. Environmental Hot Loop and Controls

Figure 3-19. Refueling Head Ready for Testing

preparation for the actual performance testing.

SHUTOFF VALVES

Operability of the three handling tube shutoff valves depended mainly on: a) proper sealing of the ball-rotating and wedge-driven stem seal. b) minimum leakage across the ball-seal during full pressure and temperature operating range, and c) functional operation of the remotely operated forward clamp, with minimum leakage.

The metallic stem seals (figure 3-21) required careful installation and controlled torque adjustment to operate at zero leakage. Adjustment of the first set of stem seals was performed by a vendor's representative at the AMF facility. The shutoff valve was bench-tested as shown in figure 3-20.

Figure 3-20
Shutoff Valve Bench Test

Figure 3-21. Metallic Stem Seal Assembly

Valves 2 and 3 were closed while valve 1 was opened and pressure was applied to the valve. The adjusting nut of the seal was tightened to the recommended torque value of 120 inch-pounds. Leakage was observed. The pressure was increased in increments of 250 psi from zero to 1250 and in 50 psi increments from 1250 psi to 1500 psi. The stem seals of the ES tube and the F&R tube shutoff valves showed no visible leakage throughout the entire pressure range. The stem seals of the SPG tube shutoff valve had to be torqued to 156 inch-pounds before a no-leakage condition occurred throughout the pressure range. This was due to slight dimensional differences in the valve body.

During subsequent functional and hot testing stem seal performance was excellent. Throughout the testing ranges at pressures from zero to 1445 psi and temperatures from 80 to 480 degrees, the ES tube shutoff valve leaked slightly under cold, high-pressure conditions. Adjustment of the seal torque corrected this condition.

Adjustment of the ball-seal assembly was also made while the shutoff valves were installed in the test fixture. The procedure for determining the amount of leakage across the ball-seal was as follows:

1. Open valves 1 and 2 and close valve 3. Circulate water through the shutoff valve, close the ball and lower wedge.
2. Close valve 2 and vent test chamber by opening valve 3.
3. With valve 3 slightly open, open valve 2 until a steady stream of water pours from the vent. Close valve 2.
4. With valve 2 closed and valve 3 slightly opened, increase pressure on upstream side of ball to 1500 psi in increments of 250 psi.

5. Any additional water discharged through valve 3 was considered ball-seal leakage.

According to specification, the maximum permissible leakage across the ball valve was not to exceed 300 cc per hour. Experience gained from testing the adapter valve showed the best sealing characteristics occurred when the torque on the wedge drive shaft was from 15 to 20 foot-pounds. For adjustment purposes the first torque setting used was 15 foot-pounds. Leakage measured across the ball seal at this torque was a maximum of 330 cc per hour for the SPG tube shutoff valve to a minimum of 42 cc per hour for the ES tube shutoff valve. By increasing the torque on the wedge drive shaft to 20 foot-pounds, sealing characteristics were improved considerably. At this torque setting the maximum leakage was 144 cc per hour maximum for the SPG tube shutoff valve to a minimum of 10 cc per hour for the ES tube shutoff valve. No further ball-seal adjustments were made; all shutoff valves were now sealing well within specified limits.

Operating results of the shutoff-valve forward remotely-operated clamps were excellent. These clamps were set to stall with a nitrogen gas supply of 50 to 75 psig. Nitrogen pressure of 50 to 75 psig is approximately equivalent to a stall torque of 75 to 100 foot-pounds. Operating at this pressure range during functional and hot testing yielded an absolutely leak-tight connection between the shutoff valve forward clamp and the adapter valve. Two important comments on the forward clamp design should be noted.

- a) The gear train speed reduction from the pneumatic-motor output shaft to the clamping screw was too high. Because of the soft stall torque of the pneumatic motor it was possible to operate the clamp at considerably higher speeds than the present design.

- b) The pneumatic motor casings were modified to operate with CO_2 . To prevent exhaust-ports freezing, the muffler was removed and the exhaust port enlarged. This modification made the pneumatic motors exceptionally noisy.

HYDRAULIC SYSTEM

Checkout of the hydraulic system was divided into the following subsystem checkouts:

- 1) ES tube hydraulic circuit. (See figures 1-17 and 3-22)
- 2) SPG tube hydraulic circuit. (See figures 1-19 and 3-23)
- 3) F & R tube hydraulic circuit. (See figures 1-21 and 3-24)

The hydraulic components for each sub-classification were mounted on individual trays (figure 3-25) and the trays mounted in a frame attached to the cradle (see figure 3-26). Common pressure headers connected each handling tube hydraulic manifold to the test facility hydraulic supply (see figure 3-27). The output lines of each hydraulic manifold were connected to the appropriate ports of the handling tube. (see figure 3-28). Each hydraulic manifold was functionally checked by disconnecting it at the handling-tube interface. The hydraulic manifolds were then connected to a test fixture consisting of pressure gages, a flowmeter, shutoff valves, and interconnecting piping.

Criteria for successful operation of each hydraulic manifold was the comparison of measured pressure and fluid-flow rates to pressure and flow rates established through analytical computations, based on force, velocity and leakage analysis. These values were tabulated for handling tube operation (see figures 1-16, 1-18, 1-20). In order to meet the criteria of successful manifold operation, manifold flow-control valves and pressure switches had to be adjusted to obtain the calculated pressure and flow rates.

Figure 3-22. End-Seal Tube Manifold

Figure 3-23. Shield-Plug-and-Guide Tube Manifold

Figure 3-24. Fuel-and-Ram Tube Manifold

Figure 3-25. Assembly of Hydraulic Manifolds

Figure 3-26. Hydraulic Manifold Mounting

Figure 3-27. Hydraulic Manifold Supply Lines

Figure 3-28. Handling Tubes Hydraulic Connections

Problems were encountered with two identical pilot-operated solenoid valves, 90011 and 90018. These valves are located in the F & R tube D₂O hydraulic system (see figure 1-21) and regulate directional flow. During initial installation, valve 90011 was connected to the reference (1500 psi) pressure differential line to allow either return flow from port number 9 of the F & R handling tube or flow to the 200 psi differential line depending on the position of the valve spool. It was calculated that 200 psi differential pressure at port 9 would shift the spool. During the checkout phase, it was discovered that the 200 psi pilot-pressure differential was insufficient to completely shift the valve spool. This condition precluded the maintenance of 200 psi differential pressure. After mutual discussion with the component vendor, it was agreed to use a 600 psi differential pilot pressure in lieu of 200 psi. Because of the availability of the 600 psi pressure, the appropriate modification to the hydraulic circuitry was implemented, and proper operational sequence was obtained.

It can be stated that, with the exception of valves 90011 and 90018, checkout procedures were accomplished with minimum difficulties, and after appropriate adjustments were made.

ELECTRICAL CONTROL SYSTEM

Refueling-head electrical control system checkout was carried out in two phases. The first phase was concerned solely with testing the off-machine controls, while the second phase concerned itself with testing the machine mounted control elements.

Off-machine control testing was accomplished by simulating operating signals at the transition box (see figure 3-28). This was accomplished by bridging the electrical connector pins in refueling-head command-and-response operational sequence, and checking the appropriate command-completed signal on the operator control panel. Careful consideration was given prior to each circuit checkout to

Figure 3-29. Refueling Head Electrical Transition Box

preclude inadvertent circuit actuation which might result in equipment damage. The most subtle difficulty encountered during electrical control system testing was the inability to differentiate between the master machine and the slave. Only the master was built, and its mate, the slave, which would normally operate at the other end of the process tube, was simulated. The slave would normally submit response signals to the master machine enabling it to carry out step-to-step functions. The difficulty came when circuits were inadvertently closed upon themselves and the master was acting as its own slave. When the circuit was remedied the master machine received proper sequence signals.

It was decided to test only the semi-automatic mode of operation for single-bundle downstream refueling. Consequently only those applicable programmers were checked. Programmer sequences were verified and circuits to the refueling head and return correlation were also checked.

Instrumentation was checked and calibrated and performed well throughout all the tests. The pressures and zones of each tube were monitored as were the temperature of the shutoff valve bodies and the temperatures of the heater elements. The temperature sensing elements seemed to be rather sluggish in that heater elements almost reached incandescence before the temperature indicators recorded the excessive temperatures.

One most satisfactory segment of the control system was the position indicators and the control switches. The magnets worked well and the reed switches transmitted the position information. However, flux associated with each of the large magnets at the rear end of the handling tubes was too large and about four or more lamps were always lighted as the magnets moved forward. (Recommendation - to correct this condition the magnets could be shaped differently to reduce the flux and the picture associated with each of the magnets. Two or three lights are all that is needed for position indication.) Because of this particular light pattern any motion of the grapples or the rams and carriers, however slight, could be immediately appraised. The light pattern changed every two inches and a

change within the pattern occurred as motion was about to start. An operator, when accustomed to the large pattern associated with each magnet could be afforded the extra benefit of being able to observe any motion, however small, in addition to being able to plot the path of the magnets in two-inch intervals.

The telephone relays chosen for the logic portion of the control system functioned well. During equipment design, precautions were taken to insure optimum relay operation by shunting all relay coils with transient clipping diodes to prevent any arcing across the contacts. To further minimize arcing, the programmer switched from one set of contacts to another under no-load conditions. Dual sets of contacts were employed so that any load across the contacts would be split instead of simply having a single contact carry the breaking arc. All of these precautions were well worth the effort employed. The electrical control system functioned well during entire refueling-head testing. The logic circuits for hydraulic circuit manual controls were very heavily worked during all the handling-tube trials and provided a great degree of operating flexibility especially during end-seal handling checkout.

All relays had a non-retaining memory, that is, with a loss of electrical power, knowledge of what had been energized is not retained. Non-retaining memory relays had the advantage of allowing steps to be reversed during sequenced refueling-head checkout. This was particularly helpful should malfunction occur. By turning off electrical power, manual control switches could be reset and hydraulic control valves repositioned allowing reverse operation. Overall electrical control system performance indicated a high degree of reliability. Aside from the minor annoyances of having to use jumpers and other expedients in order to overcome portions of the machine either not present or portions of the machine not utilized, the system worked well.

FUNCTIONAL AND PERFORMANCE TESTING

GENERAL

At the start of the test phase, the development of the refueling head had progressed to the point where the cradle was installed in the test facility, handling tube internals were being assembled into their respective pressure shells, the three shutoff valves were assembled and checked for ball-seal and stem-seal performance, the individual hydraulic manifolds assembled and checked out for continuity, flow and pressure control and the electrical control consoles and equipment racks installation assembled and checked for continuity of wiring and function of circuits by simulating signal inputs. At this point cradle functional testing was started without having handling tubes mounted to the cradle. This procedure was followed to ensure that the handling tubes, upon assembly completion, could be mounted to a functionally tested cradle.

When cradle testing was completed and the cradle considered functional, the assembled handling tubes and shutoff valves were mounted on the cradle. In mounting the tubes on the cradle, extreme care was taken in their alignment to both the Y-index and Z-planes of cradle traverse and to the test facility end-fitting. The alignment tolerances, listed in the cradle design section of this report, were met.

At this point, before handling-tube functional testing could be started, the hydraulic and electrical interconnecting piping and wiring had to be installed. The hydraulic manifolds were mounted on the cradle and the stainless-steel tubing between the hydraulic manifolds and their respective pressure ports on the handling tubes was installed. In addition, the carbon-steel tubing which connected the pneumatic system directional valves to their respective pneumatic motors was also installed.

Concurrently, the refueling head electrical wiring was installed on the cradle. This included the installation of all position indication and control switches on the handling tubes and shutoff valves and connecting and routing the wiring to the transition box. In addition, all the wires necessary to operate the electrically operated solenoid valves of the hydraulic and pneumatic systems were installed. The system had reached a point where the first component functional test of the ES tube could be initiated. The following sections describe these functional tests together with the subsequent high-pressure-temperature tests performed.

From the start of functional testing, close planning was necessary to obtain the most significant test results, in spite of the problems encountered in getting certain components to function properly. It should be noted that in testing a developmental machine of this magnitude and complexity, the procedure is one of test, troubleshoot and analyze, modify and fabricate changes and retest until the component is considered functional. This, of course, was the procedure followed, always limiting modifications or changes to only those necessary to yield a functional component. It should, therefore, be considered, in the subsequent section describing the functional testing that the tests performed were by no means consecutive. The entire functional testing program was conducted with the goal of yielding as completely a functional refueling head as could be accomplished in the time allotted for testing.

At the point where the time allotted for functional testing was exhausted, final preparations were made for high-pressure -temperature testing (hot testing). The electrical heaters and thermal insulating jackets on the shutoff valves were installed. Also, the thermocouples for sensing internal, external and heater temperatures were installed together with their interconnecting wiring. It was at this point that hot testing was initiated. It should be noted that

hot testing was performed only with the two handling tubes considered fully functional, i. e., the ES tube and the F & R tube.

CRADLE TEST

The cradle was tested in accordance with requirement of paragraph 4.2 of the AMF On-Power Refueling Head Task 5 Test Specification, 89-58-1058 for component functional testing. This required operational checkout of the Y-index and the Z-drives and the determination that the Z-drives did not exert more than 450 pounds against the end-fitting. This was to be accomplished in 20 cycles of both the Z-drives and Y-index drives. Tests were to be conducted initially without the handling tubes mounted to the cradle and were to be again checked after the cradle had been completely assembled. In order to satisfy the requirements of this performance test specification, however, it was only necessary to check the operation of the cradle without the handling tubes. Recall that the Y-index drive was designed to index the cradle assembly 18 inches to align each handling tube in turn with the end-fitting. In order to achieve the specified accuracy of alignment, the cradle was to be moved up against fixed stops at both top and bottom of its travel. These would have aligned, therefore, the upper ES Tube and the lowermost F & R Tube. Aligning the middle shield-plug-and-guide tube was to be accomplished by use of a rocker arm. This rocker arm would be inserted in the path of the cradle as it moved up or down. Upon coming to rest against the rocker arm, the shield-plug-and-guide tube would align with the end-fitting. The cradle, then traveling down from its uppermost position to align the shield-plug-and-guide tube, would position on the lowermost stop on the rocker arm, and the cradle would come to rest at this point.

In order to continue further, once SPG tube had been aligned, the rocker arm would be retracted removing the stop and the cradle would then continue down until it hit the bottom stop. The operation would be reversed when traveling upward. When traveling upward, to align the

SPG tube after the tube had been aligned, the cradle would come to rest against the upper stop on the rocker arm, aligning the SPG tube with the end-fitting. To raise the cradle to its upper limit, the rocker arm would again be retracted from the path of the cradle and then the cradle could proceed to the upper limit. When the rocker arm pivoted the top stop was inserted and the bottom stop was removed. The object of this rocker-arm device was to preclude having a separate system of solenoids and stops which would have been required had two discrete stops been employed instead of this rocker-arm-type stop. When the Y-drive was actually tested it was found that since the cradle assembly hung on the upper thrust bearing, once the cradle came to rest upon a stop, it actually lifted the screw off the thrust bearing and the entire weight of the cradle was supported by whatever stop it came to rest on. This condition was not objectionable as long as the entire cradle was resting on the bottom stop. However, when the cradle was resting upon the rocker arm, there were problems upon resuming operations. This operation required that the rocker arm be pulled out from under the cradle. When the rocker arm was removed and the cradle dropped, the screw lifted out of its supports. The shock transmitted to the ball-nut-screw assembly was not acceptable.

Another problem associated with driving to a cradle-positioning stop occurred in trying to limit the force exerted by the cradle against the mechanical stops. There was sufficient force when driving to the bottom stop to shear a pin in the ball-nut-screw assembly. In addition, two bolts holding the top stop in place on the mounting platform were sheared when driving the cradle against it. To limit the torque that the drive motor exerted resistors were inserted in series with the power supply to the motor. These resistors would be effective when driving the cradle. The function of the resistors was to impede the current to the motor when the motor was about to stall. The resistors would not cause the line voltage impressed on the motor to drop very

seriously when the motor was drawing only rated current. However, as soon as the motor began to stall, indicating that the stop had been reached, the additional impedance inserted in the line by the resistors would continuously reduce the voltage to the motors and consequently less torque would be exerted by the motor in coming to a stop. Unfortunately, these resistors also limited the amount of torque the motor was exerting when trying to pull away from the stop against which it had stalled. A very careful balance was required in trying to provide sufficient torque to pull away from a stop and also limit the torque that was exerted when driving into a stop. When one of the bronze ring seats, used on the top and bottom of the rocker arm, was crushed, it was decided that the best approach would be to abandon the mechanical stops and position by limit switch and a motor and a brake assembly. Under these conditions, the cradle could be driven up to a point, determined by the limit switch, and upon reaching this point, power would be removed and the cradle would be stopped by the brake. Another problem, not mentioned before, associated with the un-braked motor driving the cradle up against a stop occurred when the cradle was driven downward. When driving the cradle up the cradle came to an almost immediate halt upon stopping the motor, however, when driving the cradle down the cradle did not stop immediately, but coasted several inches beyond the prescribed stop point. This condition would impose a serious problem in attempting to align the cradle with the end-fitting in the downward direction.

It had been assumed that the reduction, achieved through the worm gear in the motor drive, would have been sufficient to stop the entire assembly. However, this only occurred when driving up and not when driving down. This, therefore, was another reason for deciding in favor of a limit switch and a braked-motor drive. When this special braked-motor drive was substituted for the Y-indexing drive on the machine, the cradle worked perfectly. It was able to come to a position and, once the switch had been set, it could reestablish this

position repeatedly within ± 0.002 inch. The original specification, it should be noted, required the cradle to be positioned repeatedly within 0.005 inch. An additional refinement was incorporated when the limit-switch brake-motor system was installed in the Y-indexing drive. It was determined that the best technique would be to approach all limit switches from the same direction. This presented no problem for the top and bottom limit switches since the cradle would drive either to a top limit switch and stop there, or drive to a bottom limit switch and stop there. However, since only one switch was utilized to indicate the SPG tube position on the cradle, this switch could be approached driving either down or up. Therefore, it was decided that the only time the control system would stop the drive would be when the limit switch was approaching the down direction. Therefore, the machine would index from the F & R tube position to the SPG tube position, a circuit would have to be installed which would enable the drive to continue past the SPG tube limit switch position for six or seven seconds and then drive down and be stopped by the limit switch. This required the use of a few relays and a timer. It worked quite successfully. In fact, all during operational testing, this entire drive was used and it always operated to achieve the specified alignment.

Attention was then devoted to the Z-drive test. The entire cradle was driven through a rack-and-pinion drive, the rack being connected to the cradle through a spring, such that the entire force transmitted by the cradle to the end fitting, could be limited by the spring. The force exerted by the cradle, when driving up against the end fitting, was measured and found to be about 200 pounds which was less than half that specified in the original specification. The 200 pounds compared to the originally specified 450 pounds were felt to be safe and were sufficient to adequately perform the clamping operations required during testing. The reason for the force being lower than design is attributed to greater than estimated friction in the "X" rollerways and slight undersizing of the "Z" drive motor.

The Z drive was a two-speed drive which enabled the cradle to be advanced toward the end fitting rapidly at first and then stopped while fine homing was taking place. Fine homing being the operation whereby the entire carriage would have been adjusted to properly align the machine with the selected end fitting. Once this had been done and the end fitting was aligned with the ES tube within the specified tolerances, the cradle was advanced toward the end fitting at a lower speed. The Z drive speed of about 4 inches per minute seemed adequate. However, the final slow-speed approach into the end fitting was too slow. The entire Z-drive could have been advanced at the same speed all the way through. In fact, during most of the tests, the Z-drive had sufficient force when driving at high speed, but seemed to stall too readily when driving at the lower speed. It could have been safely driven at the high speed for the entire operation.

When the cradle was fully loaded with all manifolds and handling tubes plus the harnesses and hydraulic piping, the horizontal and vertical ways were adjusted slightly in order to maintain the tube alignment. Aside from a minor problem in locating a shim on the horizontal bearing blocks, they worked perfectly. The entire suspension was somewhat flexible and allowed for some degree of misalignment. This flexibility was inherent in the suspension employed for the tubes on the cradle, in addition to the ability of the cradle to swing about the main suspension system. It was supported about a collar which fit over the main support tube on the carriage and this enabled the entire cradle structure with the handling tubes to pivot slightly about this support when excessive forces were being exerted against the end fitting. These forces, however, did not exceed the 475-pound limit which had originally been allocated as the maximum permissible force to which the end fitting was to be subjected.

In summary, then, the cradle structure as it finally evolved for the handling tube tests, contained a Y-indexing drive that was motor driven with an integral brake and the three points in its travel, utilized in operating the tubes, were determined by limit switches. The combination

of limit switch and brake motor drive proved extremely satisfactory since the tubes could be located to the points established by the limit switches with a total error of ± 0.002 inch. The switches had to be reset as the cradle structure was loaded with tubes, manifolds, harnesses and piping. However, once set, it did not vary for the duration of the test, and the switches no longer required readjustment.

END SEAL (ES) TUBE FUNCTIONAL TESTS

Functional testing of the ES tube was conducted in accordance with the test specification. Six successful end seal "insert" and "remove" cycles were performed during this test resulting in a functional ES tube. Testing was initiated after the following prerequisites were established:

- 1) A shield plug and an end seal were installed in the test facility end-fitting.
- 2) The adapter valve test spacer was clamped to the test facility end-fitting.
- 3) The ES tube was clamped to the adapter valve test spacer.
- 4) The ES tube position indication switches and control switches had been checked for proper operation.
- 5) The pneumatic motors on the ES tube shutoff valve were operated and checked for proper operation, and
- 6) The test facility hydraulic system was pressurized to 25 psig with a nitrogen gas blanket.

The initial functional ES tube test sequence was set for end-seal removal from the test facility end-fitting. The test was started by filling of Zones I and II of the ES tube. Filling of Zones I and II was accomplished before the supply valve in line 2 (see figure 1-17) was opened. It was evident that water leakage through the ES tube hydraulic manifold into port 9 and past the ES tube internal seal rings was sufficient to fill Zones I and II.

The ES tube was then operated by manipulation of the REMOVE END SEAL control stepper switch. The tube was cycled through its advance, grapple, load body, load sealing disc, retract fingers, and retract grapples sequences and appeared to operate satisfactorily. Upon retraction of the ES tube, the forward clamp on the shutoff valve was opened, the cradle was retracted, and a visual inspection revealed that the ES tube had failed to remove the end-seal from the end-fitting.

An inspection was conducted to determine the cause of the test failure. It was discovered that the ES tube grapples did not properly engage the end-seal and thus could not carry the end-seal out of the end-fitting when the ES tube was retracted. The four spring-loaded lock balls (see Chapter I, figure 1-6, item 67) which are located within the grapples subassembly, and serve to lock the grapples to the end-seal were prematurely triggered as they passed over the 15-degree, 0.250-inch chamfer at the mouth of the end seal. The four lock balls left slight indentations on the end-seal chamfer as they were drawn across this surface.

To eliminate this problem, an adapter ring was designed which attached to the grapples end of the ES tube and mated with the lead-in chamfer of the end seal. This ring provided a smooth transition surface for the lock balls as they enter the end-seal.

To install the adapter ring, it was necessary to partially disassemble the ES tube. At this time, it was discovered that two snap rings and a spacer had also been damaged during the initial ES tube functional test.

The damaged section of the ES tube was modified and repaired. The damaged spacer and snap ring were replaced with a specially designed nut which served as a combination spacer-snap ring assembly. The end of the shaft on which the spacer and snap ring were originally installed, was threaded to accommodate the new nut (33). The ES tube internals were then reassembled and reinstalled into the ES tube pressure shell.

A second "remove end seal" test was then conducted. The tube appeared to successfully cycle through steps 1 through 6 (open valves, open bleed valve, advance grapppler and engage end seal and load body, retract fingers and close bleed valve) on the control stepper. Step 7 (retract grapppler) was obviously unsuccessful as the ES tube could not be retracted indicating that the end-seal fingers had not been retracted from the test-facility end-fitting. The tube was then cycled through an insert-end-seal cycle in order to disengage the ES tube grapppler from the end-seal and then retract the grapppler mechanism without the end seal. This also was unsuccessful. The end-seal-grapppler mechanism was therefore locked to the end seal and the end-seal fingers were still extended.

In order to disengage the ES tube grapppler mechanism from the end-seal in the end-fitting, it was necessary to remove the rear section of the ES tube pressure shell and disassemble the ES tube internals from the rear.

Two areas were found which caused the malfunction. The front secondary lock balls (68) were locked in their groove by the locking sleeve (29). The locking sleeve could not be retracted to release the secondary lock which would allow the front primary lock to be released. The center loading rod (28) had not been actuated, as required during the disengage end seal operation, by the center plunger of the end seal. The center plunger of the end-seal should have been spring loaded; however, this spring was not included in the end-seals supplied by AECL. The rear lock balls (67) were also jammed in their locking groove. The snap ring was again damaged as was the special nut serving to replace the previously damaged snap ring and spacer.

A spring having the following dimensions and characteristics was installed behind the center rod of the end seal:

- a) 0.062 diameter spring wire, b) 1-1/8 inches long, c) 1/2 inch OD, and d) 28 pounds per inch spring rate.

The special nut was repaired, and a new snap ring was installed in the ES tube.

The ES tube internals were installed in the ES tube pressure shell. All hydraulic and electrical interfaces were connected in preparation for continuing the ES tube test.

The ES tube was then cycled through another remove-end-seal cycle and then the shutoff-valve forward clamp was opened and the cradle retracted. An inspection revealed the end seal had not been removed from the test-facility end-fitting.

The ES tube was then reclamped to the end-fitting and the test repeated. This time the tube advanced, locked on to the end-seal, the end seal loaded, and the end seal fingers retraction was command given. The command to retract the grapppler mechanism was given, but the machine did not respond. The ES tube was now locked to the end-seal which was engaged in the end-fitting. The ES tube did not properly retract the end-seal fingers which were engaged in mating slots in the end-fitting. The ES tube also would not disengage itself from the end-seal once it was locked on.

The ES tube was disengaged from the end-seal in the end-fitting by removing the rear section of the ES tube pressure shell, and disassembling the ES tube internals from the rear.

It was felt that the end-seal fingers were not being properly retracted due to pressure fluctuations during the grapple operation. Additional shutoff valves were installed in the line leading to the tube hydraulic supply port. These valves permitted more precise pressure and sequence control of grapple actuation.

The ES tube was then cycled through a remove-end-seal operation. The carrier and grapppler were advanced successfully, the end seal was grappled, the body loaded, and the finger retracted. The manual shutoff valves, in the lines leading to the tube hydraulic supply ports, were adjusted as required during this operation to attain the proper

pressure required for finger retraction. The carrier and grappler were then signaled to retract, but did not respond. It appeared that the mechanical lock (13) that locked the fingers in the retracted position, was not holding when the hydraulic force was removed during the retract cycle. The carrier and grappler were then retracted by first conducting an insert-end-seal cycle, thus unlocking the grappler and retracting the grappler and carrier without the end-seal. This test was conducted two more times with identical results.

ES tube testing was suspended while an investigation of this problem was conducted. A dimensional check indicated that sufficient stroke, of the grappler mechanism, to retract the end-seal fingers was available. Since a possibility existed that the Belleville springs (9) used to load the end-seal-sealing disc may have relaxed slightly, it was decided to add a 0.125 inch spacer (52) within the grappler mechanism, thus increasing the stroke available for finger retraction. The doughnut-shaped spacer was pressed into the ID of the grappler mechanism. The ID of the spacer was dimensioned to give a slip fit over the seal disc loading rod.

The ES tube was reassembled and functional testing resumed. However, during testing, the ES tube's unlocking mechanism failed to remain engaged and did not retract the end-seal fingers. The ES tube was disassembled in order to conduct a dimensional analysis of all parts and tolerances that might affect the operation of the rear lock which retained the end seal fingers in the retracted position when the end seal is removed from the end-fitting. This lock allowed the end-seal fingers to release and thus relock the end-seal to the end-fitting, when the tube retraction cycle was initiated. This analysis indicated that the mechanical lock was not engaging the lock balls in the finger actuating sleeve. The spring loaded mechanical lock did not fully advance past the balls because of interference with item 12. This allowed part 13 to advance further and thus retain the lock balls in their locking groove. As an added protection stronger springs were

incorporated in part 13 to give a more positive sliding action to the part.

Upon completion of the ES tube ball-locking-mechanism modifications and re-assembly of the handling tube, functional testing of the ES tube continued. A successful remove-and-insert-end-seal cycle was accomplished, but a repetition of the cycle could not be achieved. ES tube motion studies were made, and it was believed that improper cocking of the grapple mechanism, after the insert-end-seal cycle, had caused the subsequent end-seal removal malfunctions.

ES tube motion studies were concluded and resulted in removal of four of the eight finger-locking-mechanism springs. Spring removal was accomplished in an attempt to eliminate improper cocking of the ES tube's grapple mechanism. Subsequent reassembly and functional testing of the ES tube proved the feasibility of eliminating these springs. Six successive insert-and-remove-end-seal cycles were successfully achieved and functional testing of the ES tube was completed.

HOT TESTING OF ES TUBE

Prior to hot testing of the ES tube, leak testing of the machine-installed end-seal was accomplished. End-seal testing was conducted utilizing the hot loop to supply fluid at temperatures up to 500^oF and pressures of 1300 psig. Fluid pressure and temperatures were maintained for one hour with no end-seal leakage evident. It should be noted that initial installation of the end seal in the end fitting was accomplished using a manual tool built by AMF. Figure 3-30 shows this tool mounted on the end fitting ready for end seal installation. Installation of the ES tube shutoff valve heaters, thermocouples, and insulation was also completed at this time.

Hot testing of the ES tube was then initiated. A preliminary successful series of end-seal removals was accomplished at autoclave pressures of 500, 1000, and 1445 psig and a temperature of 75^oF. Further end-seal-tube testing continued at 1445 psig, during which time temperatures of 200, 340, and 460^oF were maintained. Successful end-seal

Figure 3-30 Manual End-Scal Insertion Tool and
Auxiliary Equipment

removal and insertion were accomplished during the 200 and 340^o F tests; however, at 460^o F end-seal removal could not be accomplished. When all heated components had cooled, the end-seal was manually removed. Examination of the end-seal and end-fitting indicated a build up of corrosion products on the end-seal internals prevented the fingers from unlocking. Figure 3-31 contains a summary of hot testing.

The end-seal was disassembled, thoroughly cleaned, reassembled, and testing was continued. Operation of the ES tube was now erratic. It was possible to perform successful insertion and removal cycles, although not consistently. Testing of the ES tube was concluded with the knowledge that further development testing was required to develop a fully operational and reliable handling tube.

SPG TUBE TEST

Functional testing of SPG tube was conducted in accordance with the test specification (89-58-1058). Testing was initiated after the following prerequisites were established.

1. A shield plug had been installed in the end fitting with the end seal removed.
2. The adapter valve test spacer was clamped to the end fitting.
3. The SPG tube clamped to the adapter valve test spacer.
4. SPG tube position indicators and control switches checked for proper operation.
5. Pneumatic motors on the SPG tube shutoff valve were operated and checked for proper operation.
6. Test facility hydraulic system was pressurized to 25 psig with a nitrogen gas blanket.

The shield-plug-and-guide tube (SPG) was functionally tested with limited success. The first test attempted was a Remove Shield Plug cycle. To start, the tube with its shutoff valve was clamped to the

END SEAL TUBE - HOT TESTS

DATE	TIME	TEST	BLANKET	END FITTING TEMP.		REMARKS
			PRESSURE	Inlet	Outlet	
4/1/64			psi			
			500	75	75	Successful insertion verified
			975	75	75	Successful removal -
						(manual valve manipulation)
			1440	75	75	Successful insertion verified
		ES				
4/2/64	10:00	Warm-up	1100	190-220	190-215	
	10:45-11:30	ES	1400	200-235	200-230	Remove ES and replace
	1:40- 3:30	ES	1450-1550	250-340	250-330	ES removal and replacement
4/3/64	11:00-11:30	Warm-up	1400-1500			
	11:30	ES	1500	400-410	370-380	Successful replacement End seal leaked, apparently ES was not put back properly.
	2:40-4:15	ES	1500	425-480	400-470	Unable to remove ES

Figure 3-31. End Seal Tube - Hot Tests

adapter valve test spacer and zones II and III were filled with demineralized water. The Advance Carrier command was actuated at the manual control panel and by observation of the position indicators it was determined that the carrier advanced at design speed of 5 feet per minute. The Advance Grapple command was next initiated and again the position indicators showed that the grapple had contacted and entered the shield plug.

The next input signal was Grapple Shield Plug which appeared to operate satisfactorily. When the next signal, Retract Grappler, was actuated nothing happened. To check grappler function and see if another attempt could be made retract the shield plug, operations were switched to the Insert Shield Plug sequence to remove the grapple from the shield plug. Specifically, the Advance Grappler command was actuated and then the Engage Fingers command was given. The test step was then accomplished so that the Unlock Grappler step could be completed. When the next step Retract Grappler was initiated position indicators showed that the grapple had in fact been unlocked from the shield plug.

A second attempt was then made to remove the shield plug by switching to this sequence. The necessary steps up through Retract Grappler were again accomplished but the grappler would still not retract the shield plug. At this point it was postulated that the retracting force provided by 50 psi at port 11 was insufficient to retract the shield plug and it was decided to close off the supply and return line at the end fitting. This would allow the pressure in the end fitting to build up to 50 psi and thereby increase the shield plug retracting force.

This was done and as the pressure built up in the end fitting, the position indicators showed that the shield plug was being retracted, however, the speed of retraction was much lower than design speed. In addition, the position indicators showed that the shield plug was not completely retracted in to the SPG tube. After draining zones II and III

and unclamping the shutoff valve from the adapter valve test spacer, visible inspection was made of the SPG tube internally. The shield plug had in fact been removed and the guide tube had been left behind in the end fitting as it was supposed to be. The guide was then examined and revealed the source of difficulty in retracting the shield plug. A very pronounced score mark had been made on the inside of the guide tube. (See figure 3-32). The score mark was made by a locking ball being dragged across this surface. Apparently one of the locking balls (item 51, figure 1-9, Chapter I) had not been retained in its groove of item 5 (locking mechanism, forward weldment). In addition, a long groove was made on the inside of the carrier tube. The next functional test performed with the SPG tube was an Insert Shield Plug sequence. The shutoff valve was again clamped to the adapter valve test spacer and zones II and III were filled. All eight steps of this sequence were performed without difficulty and in accordance with expected performance. Upon completion, zones II and III were again drained, the shutoff valve unclamped and the cradle retracted. Examination of the end fitting and the SPG internal showed that the shield plug had been replaced perfectly. This aspect of SPG tube operation was therefore considered completely functional.

Having successfully accomplished shield plug insertion, attention was then directed to correcting the deficiencies in shield plug removal. Thorough motion studies and analyses were made of the SPG tube operation in removing a shield plug. The conclusions were that a positive means of "pulling in" the locking balls (51) must be provided to counteract the tendency of the lowest ball to drop away from its groove by gravity. It was decided that a magnet installed into the locking mechanism forward weldment (5) just forward of dowel pin (50) would solve this difficulty. An Alnico magnet was then purchased and installed into the locking mechanism. After reassembling the SPG tube internals checks were made as to the strength of the magnet in

Figure 3-32. Ball-Scoring on Guide Tube

retaining the locking balls. It performed very well and it was hoped would solve the problems encountered in shield plug removal.

Again functional testing was resumed for shield plug removal. The SPG tube was again clamped to the end fitting, zones II and III filled and the Insert Carrier command was actuated. The entire sequence was performed with apparent success, however, upon unclamping and draining a visual inspection was made and the shield plug had not been removed. It was still locked into the end fitting but the guide tube had unlocked from the mechanism and remained behind in the end fitting as it was supposed to.

Further studies were made to ascertain the reason for the shield plug not having been removed. With the cradle retracted and the forward end of the SPG tube open, the grapple was advanced cautiously to see if the grapple mechanism was cocking properly as it approached its end of travel. Reference to the description of SPG tube operation as depicted earlier in this report, shows that hydraulic pressure is supposed to compress the inner and outer springs (items 16 and 18, figure 1-9), so that the grapple is cocked in such a position that locking balls (63) are pulled in and ready to enter their respective groove in the shield plug. While observing the grapple advance it was noted that this required cocking action was not taking place. For this reason the grapple never entered the shield plug so that it could be locked to the grapple and removed. It could only be guessed at this point that a set of piston rings were not properly installed during reassembly. Another possibility was that excessive leakage was occurring at one of the numerous pinned connections such as at items 55 and 56, figure 1-9. It was at this point that functional testing of the SPG tube had to be suspended so that hot testing of the ES tube and the F & R tube could be started. Although the completing of the tasks in the overall test program precluded further efforts to achieve a successful shield plug removal, the results from testing accomplished indicated that only minor modifications would be required to produce a fully functional mechanism.

Let us here review some of the results of SPG tube functional testing. The shield plug was removed twice and reinstalled into the end fitting in spite of some malfunction of the tube internals during the remove cycle. There are, it should be noted, numerous aspects of SPG tube operation which functioned flawlessly. The concept of the solenoid operated "short stop" proved to be completely feasible with regard to properly locating the fingers of the shield plug axially in the end fitting. This was best illustrated by the faultless operation of inserting the shield plug twice. The metallic static seal at the rear of the pressure shell (item 64 figure 1-9) operated without any visible leakage. The Grayloc joints and the bronze alloy seal rings and silver graphite wear rings at the forward cartridge operated without difficulty. The magnetically actuated position indication reed switches worked perfectly and were invaluable in following the operation of the SPG tube during the test program. The hydraulic control system for the SPG tube also functioned without any problem providing the required pressures and flows at the proper ports and in correct sequence. Incidental to SPG tube testing was the proof of functional feasibility of the remote clamping of the shutoff valve to the end fitting and the faultless operation of the cradle with its "Y" index and "Z" drive operation. The electrical controls for sequencing of the SPG operations also worked extremely well.

FUEL-AND-RAM TUBE TESTS

The primary objective of testing the fuel-and-ram (F & R) tube as a major subassembly integrating mechanical operation with hydro-pneumatic and electrical controls was the verification of handling-tube performance in terms of charging and receiving a fuel-bundle within the confines of controlled pressures and flows to meet force and velocity criteria.

The second major objective, in addition to the functional nature of this test, was the determination of forces acting on the fuel bundle and exerted by the F & R tube during charging and receiving operations.

Basically, the forces acting on the fuel-bundles were caused by the following factors:

- a) pressure drop across the fuel bundle,
- b) fuel bundle dynamic and static friction,
- c) applied ram forces of the F & R tube,
- d) pressure forces when receiving the ram of the F & R tube, and
- e) ram friction losses.

The functional test procedure for testing the F & R tube conformed basically to the procedures of AMF Specification 89-58-1058, AMF On-Power Refueling Head, Task V Test Specification for Component Functional Testing.

Prior to the initiation of a procedure simulating the charging or receiving of a fuel bundle, the following conditions were verified:

1) Refueling Head

- a) To simulate the loading of a fuel bundle, the test facility hydraulic ram was brought into contact with the ram of the F & R tube after a CARRIER INSERTION command. It was decided as a safeguard not to use an active fuel-bundle for these procedures, for the following reasons:

Prior to the use of an active fuel-bundle the F & R tube must be declared functional in that the velocities of the ram of the F & R tube and the ram of the oil hydraulic test facilities cylinder meet the design criteria under both cold and environmental conditions, forces acting on fuel-bundle were established and known so as to prevent possible crushing and hence contamination of the system, and it was anticipated that after this data was verified a fuel-bundle would be used for additional demonstration purposes.

- b) F & R tube clamped to adapter valve test spacer
- c) Shutoff valve open
- d) Zones I, II and III filled.

2) Test Facilities:

- a. test facilities fuel ram active,
- b. load cylinder fully retracted,
- c. end-seal and shield-plug removed from process tube, and
- d. hydraulic system pump actuated,
- e. heaters:
 - 1) OFF for non-environmental tests
 - 2) ON for environmental tests
- f. blanket pressure:
 - 1) 25 psig for non-environmental tests
 - 2) function of temperature for environmental tests,
- g. guide tube properly located in the end fitting

In order to achieve fuel-column control, the carrier was inserted. This was accomplished by giving the INSERT CARRIER command advancing the carrier. Speed and stroke limits were obtained from the position indicator panel.

When the carrier had reached the limit of its stroke, the test facilities fuel ram was advanced until it made contact with the ram of the F & R tube. The test facilities hydraulic system was set to provide predetermined hydraulic ram head end pressure, developing the appropriate resistance forces for fuel-column control for the subsequent command ADVANCE RAM WITH FLOW. The initiation of this command actuated the appropriate manifold valves which, in turn, pressurized the corresponding ports to develop the force required to advance the ram with flow. The hydraulic ram net output force is composed of the net force acting against the head of the cylinder and the frictional force opposing motion.

After completion of ADVANCE RAM WITH FLOW operation, the RECEIVE RAM AGAINST FLOW command was initiated. In this opera-

tion the test facilities ram was pressurized to drive the F & R tube ram back. The test facility hydraulic ram pressure was predetermined to develop sufficient forces to provide a 25-pound force of full-column control taking into account all friction forces.

In the next operation, the RETRACT RAM command was initiated. The command of the previous step RECEIVE RAM AGAINST FLOW, if properly executed, would return the ram to its initial position. Thus, the command of this step is merely a verification command to establish ram position and ensure that the ram was fully retracted into the carrier.

At the completion of this step, the test facilities hydraulic ram was depressurized so as not to exert a force on the receiving ram of the F & R tube.

Then the RETRACT CARRIER command was issued by actuating the corresponding pushbutton on the control panel. This actuates the appropriate water hydraulic valves in the F & R manifold, pressurizing the corresponding ports necessary for carrier retraction. When the stroke limit was reached the next command PARK was initiated. After the verification of the execution of this command the end fitting supply was closed, leaving shutoff valve open and draining zones II and III.

The basic functional test described was performed twice at the low pressure temperature conditions. There were no problems encountered in these two tests and the operation of the F & R tube was considered to be most satisfactory. At this point, hot testing of the F & R tube was undertaken.

Since testing of the F & R tube at low pressure-temperature was successful and without any significant problems, hot testing was initiated by attempting to go directly to pressure tube inlet design operating pressure and temperature (1445 psia, 480°F.) The first high pressure temperature test was successful, however, the maximum temperature attained at the end fitting inlet was 360°F. This was due to considerable steam leakage from the oil cylinder rod seal at the rear of the end

fitting. The operations performed in this test were as follows:

- a) the carrier was inserted until it contacted and bottomed on the guide tube in the end fitting
- b) the test facility fuel ram was then advanced until it contacted the nose of the F & R tube ram.
- c) the F & R tube ram was then advanced into the end fitting pushing the test facility fuel ram under controlled speed and force settings. After having pushed the test facility fuel ram for approximately twelve feet, the ram advance sequence was completed.
- d) the F & R tube ram was then set for RECEIVE RAM which resulted in the test facility fuel ram pushing the F & R tube ram back into the carrier tube at a controlled rate and force. It is to be noted that throughout this testing the position indicators were invaluable in following the progress of each sequence and in verifying the successful operation of the handling tube.
- e) the carrier with the ram of the F & R tube was then retracted into the handling tube and the test facility fuel ram was then retracted into the oil cylinder. The F & R tube was then sequenced to the PARK position and the test was complete.

The hot test described above was repeated approximately a week later and this time temperatures of 440^o F were attained at the end fitting inlet. This was possible due to improved performance of the oil cylinder rod seal with very little steam leakage. This test, however, was not fully completed due to the structural failure of one of the test facility fuel ram supports. It was at this point that hot testing of the F & R tube was concluded.

CHAPTER IV

CONCLUSIONS and RECOMMENDATIONS

GENERAL

At the completion of refueling head testing, an assessment was made of the various components, systems and the overall refueling head. The overall conclusion drawn was that testing had proven the concept feasibility and that development to date had indicated the suitability of the prototype design.

A review of some salient features of the refueling head concept to discern whether the advantages claimed for these features were in fact proven in the testing of the refueling head follows:

First, the handling tubes are to be single function, of tubular geometry working in line with the reactor process tubes. This feature was to provide greater reliability under the imposed pressure and temperature operating conditions and to minimize any decontamination problems by a geometry devoid of pockets. In addition, the pressure tube size was to be held to the smallest possible cross-section, reducing the D_2O inventory of the system and maintaining minimum wall thicknesses to reduce stresses due to thermal gradients.

The concept of single function tubes not only proved to be a definite asset to the handling tube design but actually a necessity. The operating requirements for the ES tube are quite numerous and it would be most difficult to expect additional functions to be performed. The same may be said for the SPG tube and the F & R tube. Of the three handling tubes, the SPG tube comes closest to serving a dual function in that it must remove and replace shield plugs and remove and insert a guide tube. This dual function added considerably to the design complexity of this tube and in fact is one of the reasons why only limited success was achieved in making the tube functional. The tubular geometry of smallest possible cross-section requires minimum wall thicknesses for containing internal pressures. This was a definite advantage with regard to thermal stresses. In the limited hot testing performed with the ES and

F § R tubes, there were very few problems due to thermal expansion and/or clearances. In the hot testing of the F § R tube, however, some clearance problems occurred with the carrier tube associated with the pressure tube. When Zones II and III of the F § R tube had been heated to approximately 450^oF, the hydraulic valves actuated, and hydraulic flow directed to the proper ports the carrier did not advance. Though there are many variables which may be attributed to the malfunction at this point, it appears that temperature, with its attendant thermal expansion was the cause of the carrier's being frozen in place. Carrier movement, however, was attained by initiating the advance-ram operation. When the ram was fully advanced it also moved the carrier with it. This was the only instance of thermally-induced expansion or clearance problems.

Second, cradle drives for control and positioning alignment are to be electromechanical to provide the required flexibility and accuracy of positioning. The handling tubes were to be D₂ O hydraulically powered to drive the grapples and ram mechanisms. This eliminated problems associated with mechanical drives, minimized leakage problems and at the same time provided internal environmental control and fuel bundle cooling. This also avoided the problems of mechanical drives operating in a D₂ O environment. D₂ O hydraulic drives also avoided the use of another fluid in the refueling vault with its possible contamination problems.

The choice of electromechanical drives for the Y-index drive and the Z-drive was well founded, with the one exception of trying to position the cradle in Y-index by stalling the drive into mechanical stops. Once the change was made to limit switch and brake motor positioning, the Y-index operated excellently. Z-drive, with its spring-type, force-limiting, rack-and-pinion drive, operated with good controllability.

Complete water hydraulic powering of the handling tube grapple and ram mechanisms, is one of the most unique features of the refueling head design. Operation of the handling tubes hydraulically proved

to be an extremely good concept with excellent controllability. Although there were some difficult hardware problems to solve in using water hydraulics, the directional, flow control, pressure regulating and relief and other valves selected operated exceptionally well. Leakage from the system was so low that this advantage should definitely be considered. In addition, the use of water hydraulics can claim the advantages of avoiding the problems of another fluid in the refueling vault with its possible leakage and contamination problems.

The third feature is that of grouping major components on the machine within the confines of the refueling vault. Thus, the hydraulics and electrical through-wall input would be essentially static and yield a self-contained machine easily removable from the refueling vault. This arrangement would also reduce the number of high-pressure - temperature hoses supplying the machine.

The cradle structure of the refueling head allowed the hydraulic manifolds to be readily mounted. In fact, the location for the mounting of the hydraulic manifolds moved the center of gravity of the cradle closer to its point of support and between the proposed carriage rails. This arrangement also allowed the hydraulic valves to be close to the respective pressure ports thereby providing better controllability.

The assessment was then directed towards an evaluation of major components and subsystems. The salient points of conclusion and recommendation with regard to these major components and subsystems follow:

CRADLE

The design and subsequent operation of the cradle during testing was very satisfactory. The cradle has the primary function of supporting the handling tubes, indexing in Y-direction and Z-drive into the end fitting to allow clamping of the handling tube to the end

fitting. The cradle satisfied its function of supporting the handling tubes extremely well. Once the handling tubes with all the required hydraulic and electrical equipment were mounted on the cradle some adjustment to the Y- and Z-roller bearings and ways was made for realignment purposes. However, once realignment was accomplished the cradle maintained alignment throughout the test period. It should be noted that the cradle was quite flexible in horizontal Y-plane which proved to be an asset to the design. In fact, it made the cradle self-aligning in this plane about the cradle support structural axis.

END SEAL TUBE

The ES tube, in spite of a number of early difficulties in functional testing, was successfully operated for a number of insert and remove cycles under low-pressure -temperature conditions. It was also successfully operated up to 1445 psia, 360^o F hot conditions. The failure to operate at 1445 psia, 460^o F, when a remove-end-seal operation was unsuccessful, was attributed to end seal malfunction.

The internal grappler mechanism of the ES tube is operated by the sequential application of water hydraulic pressure to the pistons at the rear of the tube. One force input in the ES tube sequence, however, is provided by the preload force of the Belleville springs. Though difficulties were encountered in procuring the Belleville springs, their operation in loading the sealing disc of the end seal with 1500 pounds, $\pm$ 15 percent was very satisfactory. The controlled application of hydraulic forces was also quite satisfactory with one exception. The somewhat pulsating output pressure of the positive displacement triplex pump when applied to extremely pressure sensitive areas, such as the ball lock mechanisms, causes erratic operation. The pulsating pressure becomes particularly evident when a hydraulic force is being applied in a dead-ended, no-flow-type force application.

A feature of the ES tube internals that gave testing problems was ball lock mechanisms. They did not lock as positively as expected and were susceptible to hydraulic-pressure pulsation. When ball lock mechanisms are used, it is recommended that a very conservative approach be taken in their design, especially the retaining or locking member of the mechanism which should be amply proportioned.

The concept of hot-to-cold interface between Zone III and Zone IV which occurs at the Grayloc joint and seal cartridge operated very well. A surface pyrometer was used to monitor temperatures along the handling tube, at the shutoff valve, at the test spacer and at the test facility end fitting. A temperature difference as high as 170°F was maintained across the Zone III, Zone IV interface. These results indicated that a cold water hydraulic system could be maintained even while operating with a hot forward end.

SPG TUBE

The SPG tube, because of its limited success in test, was rather disappointing. It should be noted, however, that the test period was drastically cut so that hot testing of the other two handling tubes could be accomplished. It is felt that with very little additional development this tube could have functioned well. It should also be noted that successful remove and insert cycles were performed with this tube and in fact, the insert sequence operated flawlessly. It was during the remove cycle when the guide-tube ball-lock mechanism malfunctioned. Corrective measures consisting of adding a magnet to the internals to maintain the locking balls in a retracted condition and thereby prevent jamming, were successful. However, reassembly of the SPG tube and subsequent testing indicated that an internal leakage path was preventing the grapples from cocking properly to pick up the shield plug.

The concept of utilizing a guide tube inserted into the end fitting to produce a smooth uninterrupted internal bore was proven quite

feasible. This requirement did, however, add considerable complexity to the SPG tube mechanism. Another SPG tube feature which operated well was the solenoid operated short stop. As described earlier, the function of the short stop was to locate the fingers of the shield plug latching mechanism at the center of the groove in the end fitting, when the shield plug is being replaced. The electrical sequencing and repositioning capability of this short stop operated very well.

F§R TUBE

Test experience with the F§R tube was the most satisfactory and encouraging of the three handling tubes. The tests showed conclusively that it is feasible to consider the movement of a horizontal column of fuel bundles under closely controlled force and speed requirements. The design approach of making the master machine the controlled driving ram while the slave machine was to have its ram driven while maintaining a fixed backing force was excellent. In functional testing it was possible to accurately position the fuel ram, maintain a fixed position without drift and reverse directions of movement with good controllability. While the fuel bundle force analysis indicates that the forces imposed on a fuel bundle were somewhat greater than design targets, rather minor changes to the hydraulic circuitry could easily remedy this condition.

In hot testing the F§R tube it showed the same controllability that was possible under low-pressure -temperature conditions. In addition, monitoring the temperatures along the handling tube showed a gradually decreasing temperature gradient from the shutoff valve back to the Zone III-Zone IV interface. This condition helped minimize inherent problems due to thermal stresses. As mentioned earlier, a clearance problem of the carrier of the F§R tube binding within the pressure tube when operating hot did occur. The location and reasons for this malfunction could not be determined during the limited hot

testing period.

The speed of 5 feet per minute selected for F§R tube operation proved to be a good choice. There appeared to be an absence of impact problems at this speed both in carrier and ram operations. In fact, the need for the hydraulic snubbers incorporated into the rear of the carrier and ram design is questionable. Another reason for the absence of impact problems at this speed is the relatively small mass of the F§R internals, together with the soft action of water hydraulic powering of the tube.

The nose of the fuel ram has been designed to negotiate a 1/2 degree misalignment between the F§R tube and the end fitting. Though it could not be determined if any misalignment existed between the F§R tube and the test facility end fitting, the fact that there was no fuel ram binding or rubbing problems in the end fitting can be attributed to the ball-joint construction of the fuel ram.

SHUTOFF VALVES

The three shutoff valves (one on each handling tube) performed their function and operated extremely well. Most important was their excellent shutoff characteristics. It is to be noted that quantitative data on leakage across the shutoff valves was not determined during functional testing. However, on numerous occasions during functional testing and hot testing there was occasion to close the valves and qualitatively note the sealing capacity. In all cases, visible leakage was negligible.

The other unique aspect of shutoff valve design was the use of metallic-lip seals for sealing the ball rotating shaft and the wedge operating shaft. Again, leakage characteristics during functional and hot testing were only observed qualitatively with very good sealing characteristics. It should be noted that some of the experience gained in adapter valve design and testing led to changes which were incorporated into

the design of the shutoff valves. These modifications proved to be excellent improvements in the shutoff valve operation. As mentioned earlier, the pneumatic motor for ball rotation and wedge actuation also worked well, the only criticism being that the gas consumption of the motors was rather high and they were very noisy because their mufflers were removed. The mufflers were removed to increase the motor efficiency and to prevent freezing at the outlet ports when using CO₂ as the operating gas.

TUBE JOINTS - Grayloc joints, fixed and remote clamping.

Throughout the refueling head there are numerous joints which utilize the Grayloc joint to statically seal pressures up to 2100 psig and temperatures up to 560^o F. The hub ends for these joints were machined in accordance with information furnished and licensed by the Gray Tool Company. Metallic seal rings for these joints were either type 316 or 410 stainless steel, silver plated in accordance with Gray Tool Company's latest standard.

Operating experience with the fixed type of Grayloc joint was excellent with no perceptible leakage from any of these joints. Remote clamping Grayloc joints also operated extremely well. In the course of functional and hot testing it is estimated that the remote clamping and unclamping of a handling tube shutoff valve to the test spacer on the end fitting was performed approximately 40 times. Each of these clampings was successful in its mechanical operating aspects and in water pressure sealing aspects. It is to be noted that several of these clampings were performed at high temperature and, with the subsequent filling at high-pressure and temperature, leak tightness was maintained. As described earlier, the remotely operated clamps are actuated by pneumatic motors. Because of the soft stalling characteristic of this motor type, it would be possible to operate the remote clamps at considerably higher speed than the present extremely slow design.

SEAL RINGS AND WEAR RINGS

In the design and manufacturing phase of the program a thorough investigation was conducted to find the most suitable seal rings and wear rings for handling tube internals. Two types of seal rings were found to be quite promising and it was decided to use silver-graphite rings for the ES tube and bronze-alloy rings for the SPG and F&R tubes. The two types of seal rings were chosen so that broader seal-ring experience could be derived from the test program.

Test experience with the silver-graphite seal rings in the ES tube was very good. During functional and hot testing, when operating the ES tube, the desired system hydraulic pressures were maintained within the tube without any excessive leakage. The fact that grapple mechanisms could be operated at controlled speeds and the required force inputs were also controllable is an indication that the seal rings were functioning properly. On several occasions, with the ES tube forward end open, the grapple was advanced for visual examination. In these instances, the amount of leakage forward past the seal rings was very small. An important feature of the silver-graphite rings is their good lubricity in a water medium. They appeared to wear-in easily.

The bronze seal rings used in the SPG and F&R tube operated equally well. Here again, the operability of the handling tubes at controlled speeds and forces is the best indication of the proper function of these rings in the SPG tube. It will be noted that in the SPG tube testing, it was not possible to properly cock the grapple mechanism in the last tests. This is to be attributed to leakage, but it is not certain whether the leakage occurred past seal rings or whether the leakage was past a tube-pinned connection. Although the latter reason is suspected.

The use of wear rings in conjunction with seal rings in a horizontal tube application is mandatory. The wear rings, of silver-graphite construction, used in all three handlings operated very well. They performed their function of taking the supporting load of the tube internals allowing the seal to perform its function of sealing only. The wear rings also maintained the tube internals concentric with the pressure tube. The trouble-free operation of the seal rings can be, to a large degree, attributed to the use of wear rings.

POSITION INDICATION AND CONTROL

The only means that a refueling head console operator has to determine if movement is occurring within the handling tubes is by noting the position indication panel. For this reason, in a developmental machine such as the refueling head, the indicators were invaluable. The indicators operated flawlessly throughout the test program. In addition, because of the pictorial representation of the position indication panel it is felt to be not only most useful in test but is recommended for any such machine operating in a reactor facility. The reason for this is its projected use in aiding a machine operator to extricate the machine from trouble manually should a machine malfunction occur.

The use of reed-type switches actuated by internally installed magnets also operated extremely well for control purposes. The use of position control switches was most adaptable to the function of the F&R tube. It is this tube that requires in the normal sequence of one bundle loading, that the ram be stopped and held at specific points in its range of travel. While the testing never applied these switches for semi-automatic operation, they were accurate, reliable and of great use in manual operation. The feasibility of this system was most certainly proven in the test program.