EXPERIMENTAL TESTING
OF CORE COMPONENT HANDLING EQUIPMENT
AND HANDLING TECHNIQUES FOR
HALLAM NUCLEAR POWER FACILITY

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ABSTRACT

Satisfactory operation of the core component handling equipment and handling techniques for the Hallam Nuclear Power Facility was accomplished and confirmed by a program of testing. The test results indicated that the operational techniques were safe, and that the equipment is dependable throughout its expected range of operations.

I. INTRODUCTION

The Hallam Nuclear Power Facility (HNPF)¹ has been authorized by the United States Atomic Energy Commission as part of the program to demonstrate the technical and economic feasibility of using nuclear reactors for central station power. The HNPF consists of a 240-Mwt Sodium Graphite Reactor (SGR) and the associated equipment for producing superheated steam. By use of the SGR concept for this facility, it is intended to utilize and extend the knowledge gained from the operation of the Sodium Reactor Experiment (SRE), which Atomics International (AI) built and has operated successfully for the AEC since July 12, 1957.

Highly radioactive core components such as fuel rods, control rods, reflector filler elements, and moderator elements must at times be removed and replaced in the Hallam reactor without releasing radioactive contaminants into the reactor building. The removal and replacement of fuel elements will be a routine necessity established by the fuel management program. The removal and replacement of reflector-filler and moderator elements will be predicated upon any abnormal situation occurring in the reactor which warrants their removal and replacement. The fuel-handling requirements are characteristic of most reactors, and vary in complexity and mode of operation depending on the type of reactor serviced. A common requirement is that the handling operations be absolutely safe and that the equipment be dependable throughout its expected range of operations.

To accomplish the HNPF handling needs, a fuel-handling machine (FHM) and the accessory equipment for other core component handling were designed and fabricated. The designs were based on the existing SRE handling system² and the experience gained from the use of that equipment.

Confirmation of the satisfactory operation of the core component handling equipment and the handling techniques was obtained by a program of testing performed in the HNPF Fuel Handling Test Installation (FHTI). This report describes the general equipment and covers in detail the results of the test program.

II. DESIGN OF EXPERIMENT

The basis for the design of the experiment was the necessity for core component handling equipment at the HNPF. Although the equipment design was based on that used at the SRE, the Hallam equipment was larger, many improvements were incorporated, and the operating conditions were somewhat different. For these reasons, both verification of the proper functioning of the equipment and development of the handling techniques were sought. Performing the desired test program at the reactor site would have resulted in conflicts with the plant construction (and preoperational test program), with consequent delay in reactor startup. To reduce testing at the site to a minimum, the important features of the reactor installation pertinent to core element handling were constructed in a mockup system, the FHTI. A brief description of the reactor system is presented to introduce the design of the experimental installation.

A. DESCRIPTION OF REACTOR SYSTEM (Figure 1)

The nuclear reactor of the HNPF is a sodium cooled and graphite moderated thermal reactor with a nominal full power rating of 240 Mwt. The reactor core consists of graphite moderator elements into which are suspended fuel elements, control rods, and miscellaneous elements. The core and its supporting structure are contained in a stainless-steel reactor vessel surrounded by a thermal shield, a reactor outer vessel, thermal insulation, gas-tight, water-cooled cavity liner, and a concrete biological shield. The core tank is flooded with sodium to a level approximately 5 ft below the thermal reflector of the loading face shield. Core tank inlet and outlet nozzles connect the tank to the heat transfer loops for transferring the energy of the core-heated sodium to the secondary loops and steam generating equipment. Within the reactor building, facilities are provided for receiving, handling, maintaining, and storing of fuel elements, control rods, moderator elements, and other core components.

Figure 1. Cutaway View of Reactor Structure

1. Reactor Core Components

a. Fuel Element Assembly (Figure 2)

Each fuel rod consists of solid cylinders of U-10 wt% Mo, encapsulated within a Type 304 stainless steel tube. The fuel rods are assembled into a bundle by hanger castings at each end. The upper hanger casting joins the bundle to a hanger support which in turn connects the bundle to the hanger tube. A Zircaloy-2 process tube encloses the bundle and is separately connected to the hanger support by three disconnect pin assemblies to permit removal of the tube without disturbing the rod bundle. The process tube serves to confine the reactor coolant flow to the fuel bundle. It seals the element to a nozzle in the lower grid plate by means of two piston rings carried on a lower extension of the process tube.

The hanger support, with the fuel bundle and process tube attached, is joined to the hanger tube by a disconnect device so that the process tube can be removed from the fuel element assembly, leaving the fuel attached to the hanger tube; or both the fuel cluster and process tube can be removed as a unit by operation of the disconnect device. The hanger tube with the attached fuel element and process tube are secured to the bottom of a reactor shield plug for support during cell storage or reactor service. An internally threaded end-piece at the top of the shield plug permits the attaching of adapters for lifting and handling purposes.

The overall fuel element assembly weighs approximately 1000 lb, and occupies a space envelope equivalent to a 6-in.-diameter cylinder with a 39.5-ft length.

b. Moderator-Reflector Element (Figure 3)

Each moderator element consists of a log of graphite enclosed within a stainless steel sheath. The graphite is a prism of hexagonal cross-section measuring 16 in. across flats, with a longitudinal scallop on each edge. Overall length of a moderator element is 17 ft, and its weight is 2400 lb. A total of 141 elements makes up the core and reflector graphite assembly. The edge scallops form circular process channels when the moderator elements are assembled together in the core.

Figure 2. Fuel Element Assembly

Figure 3. Moderator-Reflector Element

Moderator elements are positioned and supported at the bottom by individual pedestals on the grid plate. The weight of each element is sufficient to hold it on the pedestal. The nominal gap between elements at temperature is 0.160 in. This gap and proper alignment are maintained by the spacer castings fastened to the top head of each element. Core clamps surrounding the moderator matrix support the element top heads to prevent movement.

c. Reflector Filler Element

The reflector filler element is a cylindrical log of mold-grade graphite canned with stainless steel. They are installed in the outermost rings of core process channels and serve to eliminate columns of sodium in the reflective region and to add graphite to the reflector. Each reflector filler element is supported at its base by individual pedestals on the grid plate. The upper end of the element is equipped with a female bayonette socket and a rotation restraining lug which hooks over an adjacent moderator element spacer-casting. Because their installation is semipermanent, there are no process channel openings in the loading face shield above the reflector filler openings.

d. Core Element Shield Plug

The core element shield plug is a seal-equipped stepped cylinder filled with reflective insulation and steel-shot grout. It is used to seal and shield the core element openings in the reactor loading face and similarly sized openings in the accessory cells when these cells are not occupied by an integrally shielded core component. The plugs are single-stepped, 6-1/4 in. diameter at the top and 4-3/4 in. diameter below the step. They have an overall length of approximately 7 ft, and weigh approximately 280 lb. The transition step occurs 32-1/2 in. from the top of the plug and supports the plug weight during incell installation. Each plug has a double Quad ring seal and an internally threaded endpiece at its upper end.

e. Moderator Removal Plugs

In addition to the core position holes, the loading face shield has three large circular openings of 58-1/4 in. diameter at the bottom, through which moderator and reflector elements can be removed or maintenance

operations performed. These holes are filled with moderator removal plugs which are 58-1/16 in. diameter and stepped down to 56-3/8 in. at a distance of 40-1/2 in. below the top of the loading face. Each moderator removal plug is pierced with 25 core position openings which must align with the core process channels when the plug is installed in the loading face shield. Since the plug openings are not symmetrical about any plan centerline, the rotary orientation of the plug while installed in the loading face shield is critical.

Two O-ring seals near the upper end of the plug prevent the escape of the core cover gas through the clearance annulus between the plug and the mating loading face surfaces. Handling provision is provided by three equally spaced tapped holes in the upper face of the plug.

2. Reactor Cell Facilities

a. Cleaning Cells

The cleaning cells consist of four steel-lined wash cells approximately 40 ft deep. Three of the cell cavities are equipped with removable liners which enable the cells to be used for washing fuel elements and other small core components. Fuel wash cells (Figure 4) have cooling water jackets to remove decay heat from irradiated fuel elements. The cooling jackets have a capacity of 73,000 Btu/hr, which is based on the heat generated in a center element 10 hr after shutdown.

All the washing cells have pipe connections providing steam, water, nitrogen, helium, vacuum, and vent services. A pressure-regulating valve reduces 150 to 15-psig steam for steam wash purposes. Steam-flows up to 600 lb/hr are possible for cooling of fuel elements. The wash cell liners have corresponding pipe connections to extend the services into the cell interiors.

Radiation shielding for the top of the wash cells is provided by steel-encased, stepped concrete plugs. In the case of the fuel wash cells, steel shot is used to fill the annular space between the plug and the fuel wash cell. Below the plug, a steel plate serves as a seal to contain the shot just below and around the piping connections and between the wash cell and cavity liner. A cover plate is fastened over the fuel element shield plug to hold the element securely in place during cleaning.

Figure 4. Fuel Wash Cell

Fuel wash cells have an inner basket of perforated stainless steel to permit retrieving of damaged or broken fuel elements.

b. Storage Cells

Shielded storage cells are provided for storage of fuel elements and other small core components. The storage cells consist of 40.5-ft-long thimbles, provided with plugs and cover plates, suspended into three vaults below the reactor room floor. The top section of the thimble has two steps machined inside, to fit and support the shield plug. The inside surface is also machined to make a seal with the Quadrings. The sealing surfaces on the upper portion of the cells are identical with the sealing surfaces of the sleeves in the reactor loading face shield. When the storage cells are not in use, the cells are plugged with storage cell plugs dimensionally the same as the reactor plugs.

There are 10 moderator storage cells, fabricated from carbon steel plate and pipe, and which are provided in case of need to store damaged radioactive moderator elements. A fixture is installed in the moderator storage cell to convert the cell for reflector filler storage. Six reflector filler elements can be supported in the cell fixture. An aligning fixture is also provided to position new moderator elements in the same orientation as those of the reactor core. The cells are sealed at the top by steel-encased concrete shield plugs, and will maintain an inert atmosphere.

c. Maintenance Cells (Figure 5)

The maintenance cell is designed for the disassembly, reassembly, and packaging for shipment of radioactive components, such as fuel elements, moderator elements, control rods, pumps, and the internals of the fuel-handling machine. It consists of two defined areas which may be designated as the incell area and the operating area.

The incell area is 7 ft wide, 9 ft long and 54 ft deep from the reactor room floor level. An offset area 18 ft deep from the reactor room floor level extends the basic cell to 7 ft wide by 12 ft long. A storage area, 2 ft by 7 ft by cell depth, is located at the end opposite the viewing windows. A recessed area located at the top of the cell is provided for installation of the incell crane.

There are two large stepped plugs (58-in. diameter) located in the cell roof. These plugs are large enough to allow the internal mechanism of the

Figure 5. Maintenance Cell

fuel-handling machine or a primary sodium pump to be lowered into the maintenance cell. Within each of these plugs is a medium-sized plug (30-in. diameter) which is large enough to allow moderator elements to pass into the maintenance cell. Within each of these medium-sized plugs are two small plugs. One is the same size as a storage cell plug and will support a fuel element and shield plug assembly. The second is slightly larger (7-in. diameter) and will permit passage of a fuel element and shield plug assembly into the maintenance cell.

The maintenance cell is equipped with master-slave manipulators and other tools for working on fuel elements and control rods. A tool positioner mounted on vertical tracks on a wall of the cell is capable of being located at any cell depth by a ball screw. A gripping tool is furnished for use on the tool positioner; and when equipped with suitable jaw inserts, it can grip the various diameters of fuel elements and control rods without crushing.

B. DESCRIPTION OF FUEL-HANDLING TEST INSTALLATION

A test installation was constructed to permit the operational checkout of the core component handling equipment under conditions simulating field service. This facility duplicated either by mockup or actual full scale construction the major reactor high-bay cells that would be serviced by the handling equipment, and in particular by the fuel-handling machine. In some instances, equipment slated for installation at Hallam was installed in the facility so that its primary operation as well as its interaction with the handling equipment could be demonstrated during the associated test program. The test facility complex consisted of a building 50 by 60 by 70 ft high with a 48-ft-deep equipment pit (20 by 25 ft) located approximately in the center of the facility floor. Within the pit were a mockup core vessel, fuel wash cell, auxiliary test cells, and an integrated sodium system. Steam, water, gas, and vacuum services were piped to the pit from a service pad outside the building. Hoisting service was provided by a 20-ton bridge crane which carried a 2-ton auxiliary. Rails and bumper stops for the fuel-handling machine were installed at the facility to accommodate the gantry-mounted fuel-handling machine.

1. Test Facility Core Components

a. Fuel-Element Assembly

The fuel-element assembly used in the development test program was a full-scale prototype of the 19-rod cluster originally proposed for the Hallam reactor. It contained U - 10 wt% Mo fuel rods, and was instrumented with thermocouples for test purposes. In a subsequent design change, the center rod was eliminated, reducing the fuel cluster to 18 rods.

b. Moderator-Reflector Element

A prototype model of the Hallam moderator-reflector element was used for the demonstration tests of the handling equipment.

c. Reflector Filler Element

Three prototype models of the Hallam reflector filler element were used in the development program. At installation, it was found that the torque-restraining lugs would not engage the moderator element spacer-casting because of length discrepancies. Extension pieces were added to the lugs so that the intended engagement with the spacer casting was obtained.

d. Core Element Shield Plug

Six production shield plugs destined for Hallam were retained for use at the FHTI. At conclusion of the test program they were shipped to Hallam.

e. Moderator Removal Plug

The moderator removal plug mockup used at the FHTI contained only three core element openings and none of the reflective or biological shielding of the Hallam plugs. Its overall geometry, however, was an exact facsimile of the Hallam plugs.

2. Test Facility Cells

a. Core Mockup Vessel

The core mockup vessel was a 42-ft-long, vertically suspended tank structure with a 3-ft-diameter lower section and a 10-ft-diameter upper section. Mounted at the bottom of the smaller section was a circular grid plate containing a centrally located moderator element support stand, three fuel nozzles, and three reflector filler support stands. The fuel nozzles and reflector filler

supports were equally spaced on an 18-1/2-in. base circle to duplicate the grid spacing of the Hallam reactor. Completing the core mockup were the prototype moderator element and six concrete-filled half-cans which together formed a matrix of six process channels. The moderator removal plug (without concrete) containing three shield plug openings was mounted flush with the top of the 10-ft-diameter section to complete the core mockup vessel. The vessel was electrically heated, insulated, instrumented, and connected to the sodium system.

b. Fuel Element Wash Cell

The wash cell used in the FHTI was one of two fuel-element wash thimbles destined for installation in the reactor facility at Hallam. It was fitted with an upper support section at the FHTI so that its upper end was at the same elevation as the top of the core mockup vessel. Steam, helium, nitrogen, water, and vacuum services were piped to the wash cell to duplicate the services that would be available at Hallam. Installed in the wash cell was the basket, a tubular sieve which served to catch debris that might otherwise fall to the bottom of the wash cell. A standard shield plug was inserted into the top of the wash cell to complete the installation.

c. Sodium Test Cell

This cell was a 6-in. Schedule 40 stainless steel pipe adapted to take a shield plug at its upper end and a single fuel-nozzle at its lower end. The cell was equipped with electric heaters, insulation, and thermocouples, and was connected to the facility sodium system. The cell could be heated independently of the main sodium system to a temperature of 1000°F. Conventional sodium system accessories such as level indicator, regulated cover-gas supply with pressure relief, and a cold trap for sodium oxide removal were incorporated in the sodium test cell.

d. Observation Cell

The observation cell was a window-equipped tube which permitted a limited visual inspection of fuel elements and similar reactor components being lowered into the cell under an inert atmosphere. The 2-by-9-in. sealed window was located approximately 2 ft below the bottom of the cell shield plug. Because of its vacuum and cover-gas provisions, the cell was used chiefly as a storage cell for a sodium-contaminated fuel element.

e. Moderator Storage Cell

The moderator storage cell was a cylindrical structure designed to receive the full-size Hallam moderator element and its handling fixture. The cell used at the FHTI was a carbon steel mockup of the proposed Hallam units and closely duplicated the internal geometry of those units. A full-size shield plug, fabricated without concrete shielding, was used to mock up the shielding seal plug of the Hallam moderator storage vessel. Inert gas service was piped to the cell for storage of elements under inert atmosphere.

f. Maintenance Cell

The 48-ft-deep pit at the fuel-handling test facility served as a maintenance cell for the handling tests. One corner of the pit was clear of equipment so that fuel elements and other core components could be serviced from scaffolding within the pit.

III. FUEL HANDLING

A. EQUIPMENT DESCRIPTION

The fuel-handling machine (Figures 6 and 7) consists of a shielded cylinder with two internal hoists and grapple mechanisms to raise and lower core

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Figure 6. Cutaway View of HNPF Fuel-Handling Machine

components, a gas-lock to prevent the escape of any radioactive gases from the machine, and an indexing device for proper positioning of the fuel-handling machine over the reactor core and storage cells. The machine is supported and transported by a trolley which rides on a gantry crane. Maximum speed of travel of the gantry on its rails is 80 ft/min.

The machine-shielding consists of lead shot confined between steel walls of the machine body; the greatest shield thickness surrounds the lower section. The shielding around the upper section is tapered. A movable lead-shot-filled skirt provides shielding whenever an element is entering or leaving the machine.

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Figure 7. HNP Fuel-Handling Machine at
FHTF

The skirt is raised and lowered by four hydraulic cylinders. Protection against free fall is provided by flow control valves on the cylinder hydraulic fluid connections. Handling machine shielding is designed to limit radiation to the operator to 7.5 mr/hr during fuel transfer.

Internally there are two grapples, each suspended between two continuous roller chains. Each grapple is capable of picking up fuel elements (and similar items) when it is rotated into the pickup position directly above the port in the bottom of the machine. When the machine is traveling, the fuel element is carried in the position 180° away from the pickup position, and the empty grapple is kept in "traveling" position above the port at the bottom of the machine. As a safety measure, grapples can be released only when they are in the port at the bottom of the machine. Thus, only one element can be in the machine while it is moving. Each grapple operates in a guide tube which runs the full height of the machine. The tubes are continuous except for two lengthwise slots. The chains which support the grapples are outside the guide tubes, and a bar between the chains passes through the slots in the guide tube to support the grapple inside the tube. The grapples are provided with fingers that are normally operated by means of the air cylinders located on the lower end of the gas lock. The grapple fingers may also be operated by applying helium pressure to the grapple center body, which actuates an internal piston that releases the grapple fingers.

Two hoists, one for each grapple, are located at the top of the machine (Figure 8). Each hoist mechanism is outside the machine, and the chain-sprocket driveshaft passes through a seal in the machine body. A variable-speed electric motor supplies power for the hoist mechanism. The motor is equipped with a brake for quick stopping. Power is transmitted through a slip clutch, gearbox, and torque load cell. In case of motor failure, an auxiliary motor drive system can be energized. A limit-switch assembly with a selsyn and counter is driven from the output side of gearbox. The limit-switches stop the grapple at various predetermined positions. The selsyn and its receiver on the control panel are used to drive a counter which indicates the grapple position to the operator. The hoist mechanism counter is mechanically driven, and used to check the operation of the selsyn-driven counter on the control panel. A torque load cell is connected to the slow-speed shaft of the gearbox. This cell indicates to the operator which load is on the grapple.

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Figure 8. Fuel-Handling Machine — Top

At the bottom of the machine (Figure 9) are located the gas-lock, helium blower, photoelectric cell, gate valve, and three television cameras. One camera is for viewing the fuel; the other two, one of which is a spare, for indexing. As the machine is positioned near the given station, the downward-facing television camera transmits a picture which shows the operator how accurately the machine is positioned. The gas-lock sleeve is normally carried about 4 in. above the floor. When the machine is positioned, this sleeve can be driven down to make a seal between the machine and the index ring. (The index ring is manually positioned and sealed to the reactor face prior to positioning the handling machine.) A vacuum pump and helium supply are provided to evacuate the gas-lock and fill it with helium. A photoelectric cell, at the bottom of the gas-lock sleeve, "sees" if anything is left attached to the grapple

Figure 9. Fuel-Handling Machine - Bottom

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when it is in the travel position. A gage valve is actuated by an air cylinder to a position underneath the gas-lock sleeve to seal the chamber and to catch debris that may fall.

A cooling system is built into the fuel-handling machine to provide cooling for the contained fuel element. This system consists of a helium blower, which is located outside the machine body at the bottom but inside the movable shield, with a nozzle protruding upward into the machine. After a hot-fuel element has been raised into the machine and rotated 180° from the pickup position, it is lowered to a position directly above the blower nozzle. Helium is drawn from the machine body and blown upward through the fuel element. The heat picked up by the helium is transferred to the machine body walls where it is dissipated by means of cooling coils in the upper and lower body. Two separate pumps circulate water through the upper and lower body coils and through a finned heat exchanger. A fan circulates air over the exchanger to exhaust the heat to the atmosphere.

B. OPERATING PROCEDURE

Figure 10, "Fuel-Handling Machine Control Console," depicts the arrangement of controls and instruments associated with the fuel-handling machine. The gantry and trolley controls and instruments are located on the left side of the fuel-handling machine control console.

An operator will employ the gantry controls to position the fuel-handling machine over the desired north-south location. The trolley will then be moved

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Figure 10. Fuel-Handling Machine Control Console

to a more accurate east-west location. Digital readouts for both the gantry and trolley appear on the console. The operator will approach a desired position by obtaining a correct reading on the trolley and gantry digital readouts. Several gantry-trolley movements may be necessary to precisely orient the machine after it has been moved to the desired vicinity. The normal or standby television sets, located on the upper vertical portion of the control console, show the position of the fuel handling machine gas lock with respect to the index ring over which the machine is to be placed. The television set will be employed by the operator for the precision orientation after the machine is brought within the vicinity of the desired location. Prior to approaching the desired location, an appropriate core element pickup cup (Figure 11) and index ring will have been manually placed at the station. The index ring serves as a locating target for cask positioning, while the pickup cup adapts the core element for grappling by the handling machine.

Numerous fuel-handling machine operations are common to all the cycles that the machine performs. There are, however, some operations peculiar to the individual cycles. The method of exchanging new fuel for spent fuel in the reactor employs many of the more frequent and common machine operations. A description of this method will therefore explain many of the functional characteristics of the machine.

The initial conditions that must exist before the fuel-handling machine is employed for exchanging new fuel for spent fuel are that: (1) the new fuel element and shield plug assembly must be in a storage cell which contains a helium atmosphere; and (2) the fuel-handling machine must contain a helium atmosphere with a storage cell plug positioned above the helium blower, and the second grapple must be in the port at the bottom end of the cask.

When the fuel-handling machine is in motion, the gas-lock sleeve is raised to approximately 4 in. above the floor, the gate valve is in the closed position under the gas-lock sleeve, serving as a seal, and the movable shield is raised about 4 in. above the floor.

The following basic operations, all performed by the fuel-handling machine, are accomplished by controls located on the control console unless otherwise specified.

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Figure 11. Core Element Pickup Cups

- 1) The machine is brought into position over a storage cell containing a new fuel element by the operation of gantry and trolley controls as described earlier.

Note: An indexing ring has been previously placed manually on the storage cell.

- 2) The gas-lock sleeve is lowered to seal the gate valve against the index ring.
- 3) The shield up-lock pins must be manually removed before lowering the shield. The shield is then lowered to the floor.
- 4) The gas-lock is evacuated. The operator will observe the gas-lock pressure indicator to determine when the operation is complete.
- 5) The gas-lock is filled with helium. Its pressure gage will be employed to determine when this operation is sufficiently complete.
- 6) The gas-lock gate valve is opened.
- 7) The grapple in the port at the bottom end of the machine in the travel position (assume it is No. 1 grapple), is lowered, and engages the top end of the fuel element and shield plug assembly. The grapple position counters, and lights on the console indicate when contact is made.
- 8) No. 1 grapple is raised. The operator observes the No. 1 grapple torque meter to ensure that the assembly is free for withdrawal from the storage cell. The fuel element and shield plug assembly are raised into the machine to the UP position as indicated by the grapple counter and lights.
- 9) The cask hoist-grapple turntable is rotated to exchange the positions of the fuel-element assembly and the storage-cell plug. The turntable position indicator and lights are employed to determine when the transfer is complete.
- 10) No. 2 grapple, holding the storage-cell plug, is lowered and the plug fitted into its hole.

- 11) The grapple release button is pushed to release the plug when the grapple is in the down position as indicated by the grapple counter and position indicator lights.
- 12) No. 2 grapple is raised to the travel position. The grapple load-cell and the photoelectric cell will indicate that the grapple has released the plug.
- 13) The gate valve is closed and the gas-lock evacuated to the gas storage vessel mounted on the gantry. This vessel has the capacity for 50 such evacuations and is periodically exhausted to the radioactive vent system.
- 14) The gas-lock is filled with helium.
- 15) The movable shield is raised to about 4 in. above the floor.
- 16) The gas-lock sleeve is raised to about 4 in. above the floor. The helium contained below the gate valve is dispersed to the building atmosphere. The fuel-handling machine is now prepared for moving to the reactor.
- 17) The machine is moved to and positioned over a fuel element in the reactor.
- 18) The operations described above are now performed with respect to the spent fuel element positioned in the reactor and the new-element assembly supported by the No. 1 grapple. An additional operation associated with the spent fuel element is that while in the cask storage position (180° away from the gas lock) the element may be lowered (18 in.) into the helium blower nozzle for cooling. This is done only with a fuel element, as the other elements have no passages for helium flow. Before rotating the inner mechanism, the element must be raised out of the blower nozzle to the UP position.
- 19) At the completion of the operation for installing the fuel-element assembly in the reactor, the fuel-handling machine is ready to return to the storage area to deposit the spent fuel and to pick up another new fuel element.

C. OPERATIONAL TESTS

Testing of the fuel-handling equipment was performed in accordance with a generalized test agenda.³ This agenda outlined in detail seven experiments through which confirmation of the satisfactory operation of the handling equipment and techniques was demonstrated. The nature of these experiments and significant results are summarized under the appropriate headings.

1. Preoperational Qualification of Gantry

Equipment specifications⁴ for the fuel cask gantry-trolley described in detail the characteristics of the gantry-trolley control system. The qualification tests consisted of time and/or distance measurements to determine if the intent of the specifications had been met. Six principle items under the equipment details were compared with the gantry-trolley performance. These were concerned with the ability of the power and control equipment to accomplish the following.

- a) Movement of gantry with cask smoothly along the runway with continuous speed variation in either direction between 1/4 and 100 ft/min.
- b) Movement of trolley with cask smoothly along the bridge with continuous speed variation in either direction between 1/4 and 30 ft/min.
- c) Having controls and drives of such type that operator can locate cask within $\pm 1/32$ in. in either direction.
- d) Provide dynamic braking on both the gantry and trolley drives.
- e) Provide position indicators to indicate position of gantry or trolley within ± 0.1 in. over entire travel.
- f) Ensure gantry drive design to automatically prevent racking of gantry on the runway.

The maximum speeds for both the gantry (100 ft/min) and trolley (30 ft/min) were found to be acceptable, but the slower 1/4 ft/min speed could not be maintained for either the gantry or trolley. The control lever positions more nearly corresponded to acceleration values than to fixed velocity positions. In spite of the discrepancy in the low speed control, the cask could be positioned

within $\pm 1/32$ of a point inside the bounds of travel. However, many inadvertent stops were encountered in the approach to a reference position. The operator, in attempting to reduce speed to a minimum, invariably eased the control lever to the center OFF position. Here, a limit switch was actuated to deenergize the dynamic brake coils (brakes spring-loaded to engage position), bringing the gantry or trolley to an abrupt halt. With practice, the operators were able to reduce the number of jolting stops to minimum.

Dynamic braking equipment for the gantry and trolley drives was found to be within specifications, based on the abrupt stops experienced in the positioning tests. However, some concern arose over the possibility that decelerating forces resulting from sudden stops might cause serious structural damage to a fuel element within the cask. This prompted the performing of deceleration tests which consisted of releasing the gantry dead-man switch (interrupts all gantry power) when the gantry reached the top speed of 100 ft/min. The maximum gantry deceleration as recorded with accelerometer instrumentation was 0.1 g, which was not objectionable.

Negotiations with the gantry designer/builder over the discrepancies in the slow-speed control resulted in control circuit changes which reduced the top speed of both gantry and trolley by approximately 20%. This decrease improved the slow-speed (1/4 ft/min range) control characteristics to an acceptable condition. In addition to this change, the center OFF limit switch in the speed controllers were eliminated, permitting operators to use drive motor plugging to decelerate the gantry or the trolley. The foot-operated "dead man" remained in the circuitry for emergency stopping.

Position indicators as listed under the equipment specifications were provided to numerically display the position of the gantry and trolley over the entire range of travel. The specifications stated that an accuracy of ± 0.1 in. was desired. It was found that the selsyn-driven counters accumulated a 0.5-in. error when totaling 20 ft of travel. The position indicators consistently repeated this error to within ± 0.1 in. This nonconformity to specifications was found to be acceptable during subsequent operations of the fuel-handling machine.

Measurements were taken to determine the amount of skew between the gantry and its rails. Using a perpendicular to the parallel rails as a reference, the gantry was found to be racked 10-1/2 in. This was reduced to approximately

1 in. by repeatedly ramming the gantry against the spring-loaded bumper stops. Slow-speed rams reduced the rack distance only slightly, with greater reductions obtained with higher speeds. It is estimated that ram speeds of up to 70 ft/min were used in correcting the rack. No damage occurred in the fuel-handling equipment as a result of the ram operations. Examination of the bumper stops revealed, as expected, that the honeycomb shock cylinders were crushed beyond reuse. These were replaced with new cartridges.

2. Preoperational Qualification of Cask

It was the objective of this testing category to demonstrate that the cask interlocks and controls operated as intended. The basis for the test was the specifications for the assembly and checkout procedure for the FHM at Santa Susana.⁵ At the time these operations were performed, the cask gas-lock was equipped with a pivoted drip pan which served as a debris container as well as a secondary seal at the bottom of the cask. A more suitable gate-valve closure had been designed, but fabrication delays prevented its installation on the cask at this time.

During the course of testing, several difficulties were encountered which necessitated changes or additions to the equipment of the handling cask. The more significant of these are discussed under appropriate headings below.

a. Grapple Drive System

The grapple drive motors are 1-1/2-hp standard dc units. Variable grapple speed (0 to 16 ft/min) is obtained by regulating the ac input to the motor field and armature rectifiers. Burnout of all four rectifiers (one field and one armature rectifier in each of the two grapple control circuits) was experienced early in the preoperative tests. Minor increases in rectifier current ratings reduced the frequency of rectifier failure, but when failure did occur again, it was accompanied by burnout of the motor shunt windings. The winding burnout was extremely severe, in that the coils were completely charred. This led to modifications in the electrical control circuitry to reduce voltage surges during motor start, stop, and jog to a minimum. In addition to these changes, the failed motors were rewound using glass insulation. These revisions corrected the grapple circuitry problem, but the very occurrence of the problem revealed another drive system inadequacy.

A manually operated backup drive had been provided for the grapple system in the event of motor failure. This backup consisted of a hand crank adaptation for the unused input shaft of the double-ended drive gearbox. When motor failure occurred, the hand crank was utilized as a temporary drive for the purpose of checking grapple limit switches. With two men, working in relays, it required 45 min to lower a grapple 45 ft (maximum working stroke); this is a speed of 1 ft/min. In view of the 30 min required for an uncooled fuel element (hottest core element) to reach the cladding meltpoint,⁶ the hand-cranking time could result in fuel meltdown.

An electrically driven nut runner was adapted in an attempt to speed the backup drive, but the impulsing torque resulted in the shear of all the slip clutch studs after a few minutes of operation.

Ac motors were mounted on the grapple drive cover plates and belt-connected to the hand-crank shaft. The pulley combination in conjunction with the existing gear reduction resulted in a constant grapple speed of approximately 8 ft/min. With improvised controls mounted at the operators console, the auxiliary a-c drives permitted resumption of testing without serious delays. The auxiliary drive system worked so well that it was included in the fuel-handling machine design.

b. Cask Vacuum System

Operational procedures for the purging of air from the fuel-handling cask outlined two steps for the process: (1) evacuate cask to 28 in. Hg vacuum with the 1-hp cask pump; and (2) backfill with helium to a pressure of 1-1/2 psig. This procedure required 70 min to accomplish, 40 min for pump down and 30 min to backfill with helium. One full bottle of helium was consumed in the backfill sequence. Since helium was introduced through the single bottle manifold fold carried by the cask, considerable time and manhandling of gas bottles were required. This was reduced significantly by indexing the cask to a cell serviced by the facility vacuum and helium system. The 5-hp facility pump combined with the high flow helium system reduced purging operations to about 12 min. This same technique can be utilized at the reactor site by indexing the cask to one of the fuel wash cells.

c. Cask Nitrogen System

A single nitrogen bottle carried by the cask supplied all the auxiliary air-operated equipment. This equipment included the gas-lock gate valve, grapple release cylinders, gas-lock lift cylinder, and the vacuum valve operators. The nitrogen bottle invariably became exhausted when handling operations were in progress. An air compressor was installed on the trolley deck and connected to the nitrogen circuit for primary operating service. The nitrogen bottle was left in the circuit to serve as a backup system to the air compressor.

3. Fuel Cask Indexing

The feasibility of using closed circuit television as a means of indexing the fuel cask had been established by subcomponent tests⁷ using a jury rig. These tests demonstrated that the apparent superposition of orthogonal tangents (index bars) to a floor-mounted target ring (index ring) resulted in the superposition of the gas-lock centerline to within 0.041 in. of the index ring centerline. The downward-facing camera was aligned so that its centerline and the two index bars formed a righthanded system of axes. By adding a third index bar and a second TV camera, a backup system of indexing was obtained.

Design changes in the gas-lock area of the fuel cask required that the TV cameras be positioned nearer the intersections of the index bars than was recommended by tests. This resulted in a loss of view, as illustrated in Figure 12-a. Replacement of the existing 1/2-in. wide angle lens with a 3/8-in. lens improved the view area only slightly. By rotating the camera 45°, equal lengths of the index bars appeared on the monitor (Figure 12-b). Operator difficulty in correlating the gantry-trolley motions to the monitors rotated axis resulted with this change. A 3-point system was devised, using one index bar with two indicator buttons (Figure 12-c). Parallax was encountered when viewing the two outboard indicators, but this was not objectional. Once the equipment (Figure 13) was properly adjusted, the cask operator could index the gas-lock to a cell with assurance. This was due primarily to the fact that the monitor image was a 3X magnification of the actual equipment. If a way could have been found to conveniently orient a radial scribe mark on the index ring such as shown on Figure 12-d, a superior indexing system, free of parallax and capable of up to 5X magnification could have been obtained.

1a

2b

3c

4d

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Figure 12. Television Indexing Arrangements

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Figure 13. Cask Indexing Equipment

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4. Fuel-Element Dry Cycling

The fuel-element dry cycling test was a familiarization exercise in the operation of the fuel-handling machine. A full-size Hallam prototype fuel element complete with U - 10 wt % Mo fuel was used in this exercise. Handling operations were performed using the sodium test cell which had not been loaded with sodium at that time. During the handling operations, periodic difficulty was encountered in seating the fuel-element piston rings in the cell nozzle. The ring type had been selected as the reference nozzle seal because its leakage rate as a function of differential pressure (2 to 6 psi) was the lowest of several candidate rings tested.^{9,10} No difficulty in seating the rings was experienced during the bench-testing.

Since the sodium test-cell did not duplicate the complete process channel configuration, it was assumed that the lack of proper guiding permitted the willowy fuel-element assembly to bow on ring contact with the nozzle, which in turn resulted in ring cocking. On the basis of this assumption, fuel-element dry cycling in the empty sodium test cell was terminated. The exercise served its primary purpose in that operating personnel gained sufficient experience to make indexing and machine operations routine procedures.

5. Fuel Handling in Dry Core Mockup Vessel

The purpose of this test was to determine the general operating characteristics of the FHM through the practice of inserting the fuel element into a fuel process channel. The three full-scale process channels of the core mockup vessel were used for this test. A 5/16-in. offset between the shield plug opening and the nozzles below were designed into the core mockup to duplicate the maximum eccentricity expected in the reactor as a result of thermal expansion.

Initial attempts to seat the fuel element in all three of the gridplate nozzles were unsuccessful. An examination of the rings and guide assembly revealed that the groove depth was shallower than recommended from ring bench tests. Depth alterations improved seating somewhat; however, in over half the tries, jamming occurred. The machining of a slight bevel at the bottom of both rings further improved the seating operations, but not to the extent of acceptability. A more thorough examination of the rings revealed that if the expanded ring (free diameter) were held in a position of maximum eccentricity with the guide assembly, one section of the ring would protrude completely out of the ring groove (Figure 14). In this position of least support, even slight

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Figure 14. Fuel-Element Guide
Assembly With Piston Rings

axial loads were sufficient to deflect the ring over the edge of the groove. To minimize this situation, a centering shoulder was added at the base of the groove. With this change, consistent ring entry into all three gridplate nozzles was obtained. An average seating force of 320 lb was required to seat the rings. Twenty typical fuel transfer operations were performed in the core mockup vessel without further ring seating problems.

A different problem arose which required a design change in the lock sleeve of the fuel-element disconnect. Upon withdrawal of the fuel element from the core, the disconnect sleeve periodically caught the underside of the loading face shield plug liner. The lock-sleeve bevel was increased to reduce the upper face land from 0.143 in. to approximately 0.03 in., which eliminated this problem.

Once the above discrepancies were corrected, fuel-handling operations were reduced to a routine. Operator performance improved with practice, as was evidenced by the decrease in the time (24 to 18 min) required to exchange

a fuel element for a shield plug. The time sequence started with the cask indexed over the plug and ended with the cask indexed over the fuel element at the same station.

6. Fuel Element Wet Cycling

The purpose of the fuel-element wet cycling tests was to establish the fuel-element cleaning technique and to provide a basis for evaluating the relative amount of sodium deposited in the fuel-handling cask. Cleaning operations were performed in a production wash cell assembly installed at Hallam at the conclusion of testing. Operating procedures for the test followed a pattern which included these basic steps.

- a) Soaking of the fuel-element assembly in the sodium test cell until its temperature equalled that of the cell sodium. Soak-temperatures of 400 and 700°F were used.
- b) Transferring of fuel element from test cell to wash cell with the fuel-handling machine.
- c) Cleaning fuel-element assembly, using steam, water, nitrogen, vacuum, and helium in a sequence that yielded the most effective cleaning.
- d) Inspecting the element for cleanliness by removing it from wash cell with overhead crane. Replace the element in wash cell after inspection, and change cell atmosphere to helium at 1-1/2 psig.
- e) Transferring of fuel element from wash cell to test cell with the fuel-handling machine and repeat of Step a.

The pattern, repeated throughout 40 washings of the prototype fuel element, resulted in establishment of an acceptable cleaning cycle for the Hallam U - 10 wt % Mo fuel elements. The recommended cycle consists of introducing saturated steam (212°F) into the wash cell at a rate of 100 lb/hr for a period of 15 min. At the conclusion of the steaming operating, the cell is first flushed with nitrogen to remove the bulk of the water vapor, and then vacuum-dried. A detailed report of the wash cell proceeding can be found in Reference 8.

Except for a few minor problems, the fuel-element wet cycling tests were conducted successfully.

During the removal of the fuel element from the sodium test cell (sodium at 400°F), considerable sodium splatter accumulated on the anodized aluminum index ring. This sodium rapidly hydrolized in the moist atmosphere that prevailed at the test site and resulted in severe pittings of the index ring. Since decontamination of a pitted ring would be extremely difficult, it was recommended that a nickel plate be used on the Hallam rings to protect the aluminum from caustic attack.

Periodic replacement of the grapple Quad ring seals was required because of rollover and sodium accumulation in the ring grooves. On two occasions a ring was lost and presumably dropped into the sodium test-cell. It was suggested by the ring manufacturer that a looser-than-standard ring squeeze would improve the life expectancy without jeopardizing the sealing characteristics. Deepening the groove to reduce the cross-sectional squeeze to 0.003 to 0.004 in. did not significantly improve the service life, which was completely unpredictable. Some rings (there are four per grapple) performed adequately for over 30 handling operations, while others lasted but one fuel change. A contributing factor to the seal problem was the fact that the gas-lock bore had several deep score marks in the area where sealing was required. The scoring had occurred during construction of the FHM, and a replacement part was not available at the time of testing. By periodically checking the grapple seals during idle machine times (the grapples can be driven out of the gas-lock for close ring examination) inservice failures were considerably reduced. It should be recalled here that the gas lock was equipped with the drip pan which, when opened, placed the burden of cask gas containment solely upon the frequently moved grapple seals. The gate-valve closure, which was destined to replace the drip pan, to some extent obviated the need for tight grapple seals. In view of the foreseeable improvements that would be gained by the addition of the gate-valve, no further concern was given the grapple seal problem. Testing of the gate-valve is discussed elsewhere in this report.

Handling of the sodium-covered fuel element after soaking in 700°F sodium was initially inconsequential. The element appeared to drain well, (Figure 15) and as viewed by the TV camera presented a very bright shiny

appearance somewhat similar to a bright chrome plate. With each wash test, progressively larger quantities of sodium remained on the fuel element. The piston ring area (Figure 16) and the disconnect area held large concentrations of sodium. Difficulties were experienced in seating the piston rings, and on two occasions the fuel element became frozen in the cell sodium during insertion. The oxide concentration in the sodium cell apparently increased with each succeeding test until capacity of the cell cold-trap was exceeded. By emptying and then refilling the cell with filtered sodium, the excellent drainage obtained earlier was regained.

Large pieces of sodium (15 to 30 grams), which apparently dropped off the fuel element during transfer operations interrupted testing by causing the grapple to jam in the gas lock. The pieces were dislodged by forcing the grapple up and down several times.

Fogging of the gas lock TV port by condensed sodium vapor began to impair visibility about the 35th fuel transfer. The window was easily cleaned with a damp cloth during machine idle time.

Tests performed in conjunction with the wash cell development effort indicated that the expected sodium carryover from a well wetted fuel element would amount to approximately 1.12 lb. These measurements were made without the benefit of afterglow heat, which would tend to reduce sodium carryover from the reactor.

7. Cleaning and Disassembly of Fuel Cask

a. Fuel Cask Cleaning

A limited examination of the fuel cask interior at the conclusion of the wet-cycling tests revealed little to no condensed sodium vapor at the top of the cask, and only a slight film on the lower cask components. Since the internals were scheduled for removal in the next series of tests, preparations were made for cleaning the cask while all internals were still within the cask structure. The fuel-handling cask was indexed to the wash cell, and as a precaution all important gas-lock equipment dismantled. These included the TV equipment, the helium circulator, and the photoelectric cells. Removal of the circulator left the inlet and outlet ports of the cask open to atmosphere. Steam was introduced into the cask by closing the wash cell exhaust valve, which

Figure 15. Fuel-Element Guide After Adequate
Sodium Drainage

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Figure 16. Fuel Element After
Poor Sodium Drainage

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forced the steam to rise up into the case body. After about 10 min of steaming (100 lb/hr), light puffs of what is believed to have been sodium hydroxide smoke appeared at the cask ports. A series of muffled detonations were heard which increased in both magnitude and frequency. Escaping hydrogen gas ignited at the ports in momentary bursts of flame. Some molten sodium flowed out the helium inlet port and half filled a small bread pan. When no more reactions could be discerned within the cask, steaming was stopped and the cask flushed with water introduced through a port at the top of the cask.

The three following design changes in the lower cask area were initiated as a result of the cleaning operation: (1) A cleanout port was added to the helium piping by replacing an existing elbow with a tee (Figure 17). The port permits periodic cleaning of the line to prevent large accumulations of sodium as occurred in the tests, (2) The cast-lead bricks used for shielding the inlet line at entry to the cask were replaced with lead-shot shielding. A containment box permits draining of the shot for access to the cleanout port, and (3) A drain manifold connecting the cask helium inlet and outlet ports to the gas-lock for condensate draining during future cleaning operations was designed.

b. Disassembly of Fuel Cask

The cask-mounted fuel-handling mechanisms were designed for removal to convert the machine for moderator handling. In addition to this, a criterion in the design of the inner cask mechanisms was that provisions be incorporated to contend with a fuel element securely lodged within the cask. In meeting these requirements, features were incorporated in the cask which permitted the entire inner mechanism and gas-lock assembly to be removed from the cask by methods consistent with the hazards present. The need to disassemble the cask in preparation for moderator handling presented an opportunity to evaluate the disassembly procedure for stuck fuel element retrieval.

The method used in the disassembly operation conformed to the following sequence.

- 1) Remove the shield plug from the top of the cask to expose the upper drive sprocket assembly.
- 2) Remove one-half of the inner coupling bolts on each drive shaft.

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Figure 17. Cleanout Port – Helium Inlet to Cask

- 3) Install the bail on the sprocket assembly to lock both sprocket shafts and remove the rest of the coupling bolts.
- 4) Connect the bail to the overhead crane, take up slack, and then remove the four bolts which connect the hoist assembly to the upper cask flange.
- 5) Position the movable shield so that the integral wrench lines up with the Marman clamp disconnect. Engage the lock nut with the wrench and release the clamp. The entire gas-lock assembly will creep down approximately 1 in. until its weight is sustained by the hoist chains.
- 6) Lower the entire inner assembly with the overhead crane until the upper sprocket assembly emerges from the bottom of the cask.

The only difficulty encountered with the above procedure involved the removal of the coupling nuts. Individual hex nuts on the coupling bolts required the use of another wrench, in a cramped location, to remove the bolt. A one-piece nut plate was designed to eliminate the need for a second wrench.

Examination of the inner cask assembly revealed all components in excellent condition. The lower sprocket bearings were rough in spots and completely void of grease. These were most likely degreased in the cask steam-cleaning operation. After cleaning and regreasing, the bearings were restored to a serviceable condition.

Removal of the upper cask body to complete the disassembly required for moderator handling was routinely accomplished with the special lifting bail provided.

IV. MODERATOR HANDLING

A. EQUIPMENT DESCRIPTION

1. Moderator Plug Removal Container

The moderator plug removal container (Figure 18) is basically a cylinder large enough to accommodate one moderator removal plug from the top shield of the reactor. Three plug-lifting rods pass through the top of the cannister and extend to the bottom. The lower ends of the rods are threaded for engaging three lift-holes tapped in the face of the plug. A bail assembly connects to all three lift-rods above the canister top so that all three rods are simultaneously lifted when the centrally located bail is hoisted by an overhead crane. The bottom of the canister has a support flange, a rubber gasket, a rubber skirt, and electromagnets. The support flange distributes the weight of the canister and its contents to the floor when not being moved by the crane. The rubber gasket (refrigerator type) provides a gas seal when the container is resting on the floor, and the rubber skirt provides a partial gas seal when the container is lifted off the floor a short distance. The electromagnets are used to pick up and hold a 5-1/2-ft-diameter metal sheet over the bottom of the moderator plug removal container for gas containment during transfer operations. A 100-ft extension cord supplies the electromagnet power during transit.

2. Moderator Removal Machine

The partial disassembly of the fuel-handling cask results in the removal of all fuel cask components excepting the lower cask body and its movable shield. A television camera assembly consisting of two cameras with telephoto lenses and lighting equipment is installed on the lower cask face. Rubber seals are installed to provide a gas barrier between the movable shield and the handling machine lower body. These seals consist of two flat rubber rings. One of the seals is attached to the top of the movable shield; the other, to the bottom of the handling machine body. The upper seal wipes the inside surface of the movable shield. A large refrigerator-type seal is installed at the bottom of the movable shield to provide a gas seal when the shield is lowered to the floor. A 122-in.-diameter steel sheet is available for clamping to the bottom of the movable shield for gas containment during machine transfer operations.

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Figure 18. Moderator Plug Removal Container

A remote control station consisting of gantry, trolley, and movable shield controls is connected to the machine control cab by a 100-ft extension cable. The station permits remote control of the moderator handling cask during the approach to and departure from the open reactor vessel.

Accessory equipment is added to the moderator removal cask as required for reflector filler or moderator element handling. Features of the accessory items are discussed below under the specific element handled.

a. Reflector Filler Equipment

For reflector filler handling, a flanged shield plug is inserted inside the top of the moderator handling cask body, with the flange extending across the upper cask face. Six holes, spaced and oriented the same as the reactor process channel, penetrate the shield plug. Through each hole passes a bayonet-type grapple for engaging the female socket at the top of each reflector filler element. Wiper seals are provided for each rod that passes through the plug. When the cask is in the position for reflector filler removal, extension rods are connected to the short grapple rods to permit the bayonets to reach the tops of the reflector filler elements. The extension rods are received from a storage fixture (Figure 19) and transferred to the top of the moderator cask by a single hoisting bail. Connection of the extension rod to the grapple rod is made by two roll pins through the socket joint. All extension rods, regardless of length, have both a male and female end for joining to other rods.

b. Moderator Element Equipment

For moderator element handling, the reflector filler equipment is removed from the cask, and the moderator handling plug and grapple assembly installed. The moderator plug caps the top of the cask as did the reflector plug, and similarly contains six penetration holes and seals. Although the holes accept the same size rods (2-1/2 in.), they are not all on the same base circle. One set of three holes (3 at 120°) are on the same base circle as the reactor process channels, while the second set of three are on a slightly smaller circle. Rods passing through the holes of the larger circle screw into the spreader ring with the three remaining rods connecting to the grapple assembly. Extension rods are added to the spreader ring in multiples of three to lower the 3-pronged ring about the moderator element to be removed. When installed, the three

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Figure 19. Extension Rod Storage
Fixture

prongs exert an outward force on the surrounding six moderator elements to prevent crowding of the element during removal.

The grapple assembly consists of three grapple rods and a guide section. Each grapple rod passes through a tube of the guide section and terminates in a bullet-nosed hook. A triangular bracket ties the guide tubes together at their tops and spaces the tubes on the process channel base circle. Since the grapple rods are on the smaller base circle, they enter the guide tubes with a 5/8-in. eccentricity. The grapple rods can be positioned to bring the hooks into concentricity with the lower end of the guide tubes, or they may be rotated to place the hooks in the pickup position.

Extension rods added to both the spreader ring and grapple rods are transported to and from the storage fixture by a special lift fixture. The rod adapters are positioned on the two different base circles to accommodate both assemblies with three rods at the same time.

3. Miscellaneous Equipment

Moderator handling equipment is remotely positioned over the various stations by placing the equipment at the intersection of orthogonal lines of sight. Two jig transits provide sight control with permanent bench marks and targets referencing the location of pertinent cells. Each in-core moderator element is assigned a locating index consisting of two bench marks and two targets.

The Hallam high-bay crane is normally operated from a bridge cab. In order to eliminate operator exposure to radiation streaming during moderator removal plug handling, a remote control station is provided to permit operation of the crane from the reactor floor. A 60-ft distance can be maintained between the console and the open reactor vessel during handling operations.

B. HANDLING PROCEDURE

All core components suspended by the reactor loading face must be removed prior to a moderator handling operation, to permit loading face shield rotation. Preparations for moderator handling require the conversion of the fuel-handling machine. The internal mechanism and the upper half of the fuel-handling cask body are removed. Seals are installed to seal the movable shield to the lower machine body and to the floor. Television cameras and lights are installed to permit operator viewing down into the reactor. The appropriate grapple assembly (moderator can or reflector filler) is then installed in the top of the lower body. It will be assumed that the reflector filler grapple is to be used first for the description given here. The procedures enumerated are supplemented with appropriate figures depicting the action described. The photographic figures were taken during operational tests in the FHTF, and are presented under this section for clarity.

- 1) The moderator plug container is placed over the plug in the loading face shield with the building crane (Figure 20) and its position referenced with two jig transits at 90 degrees to each other. The container is purged with argon, and the lift rods are lowered and screwed into the plug. Operating personnel remove themselves to a distance of about 60 ft from the moderator port. The building crane is remotely operated to lift the plug into the container, and then until the container is about 1 in. above the floor. The only seal between the container and the floor is provided by the flexible rubber skirt. Argon is slowly bled into the container to leak out at

a

b

LEGEND

1. BUILDING FLOOR
2. MODERATOR REMOVAL PLUG
3. MODERATOR CAN
4. BUILDING CRANE
5. PLUG GRAPPLE

6. PLUG CONTAINER
7. INERT GAS
8. COVER (MAGNETIC)
9. COVER (NONMAGNETIC)
10. LEAD BRICK SHIELD

c

d

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Figure 20. Moderator Removal Plug Handling

the bottom. Two 16-gage metal sheets are then pulled over the plug port and under the plug container. The metal sheets consist of a 5-1/2-ft-diameter sheet on top of a 10-ft² sheet. The metal sheets are properly positioned, and the container is lowered. The electromagnets are energized, and the 5-1/2-ft-diameter sheet is picked up to seal the bottom of the container. The container and plug are transported to and stored in a suitable location where temporary shielding is erected around the container. The 10-ft² metal sheet covers and partially seals the port in the loading face shield.

- 2) The moderator handling machine is remotely positioned over the port and indexed by means of transits (Figure 21 and 22). The movable shield is lowered to within an inch of the 10-ft² sheet of metal. The flexible rubber skirt now effects a seal. The machine is purged with Argon, and the metal sheet is withdrawn. The movable shield is lowered to seal the floor over the open port. Operating personnel may now approach the machine for viewing the TV monitor and further operation (Figure 23). Extension rods are coupled to the reflector filler grapple rods, and the grapples are lowered into the tops of the reflector fillers. Each individual grapple rod is manually rotated to engage the reflector filler. The fillers are then raised into the handling machine (Figure 24) with the extension rods being removed and stored as they are pulled out.

The movable shield is raised about an inch from the floor, the flexible rubber skirt still maintaining a partial seal. The 10-ft² metal sheet with a 112-in.-diameter steel sheet on top is pulled into position under the machine. The shield is lowered, and the top metal sheet is manually secured to the shield with clamps (Figure 25). The machine is then driven to a convenient temporary position, and the movable shield is lowered to the floor.

- 3) The container with the moderator removal plug is now brought back over the port. The container is lowered to the floor and the electromagnets are deenergized to release the bottom cover plate. The container is raised about an inch, and the metal sheets are removed. The container is set down on the floor, and the plug is lowered into place. The container is left in position with lift rods attached to plug.

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Figure 21. Moderator Element Handling

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Figure 22. Indexing Moderator Removal Cask with Jig Transit

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Figure 23. Television View of Core During Moderator Handling

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Figure 24. Reflector Filler Elements Raised into Moderator Removal Machine - Movable Shield Up

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Figure 25. Movable Shield Down For Clamping of Cover Sheet

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- 4) The reflector filler storage cell is prepared by lifting out the plug, covering the open cell with a 10-ft² sheet of metal, and filling the cell with argon.
- 5) The moderator handling machine is positioned over the storage cell. The movable shield is lowered, and the clamps removed to release the bottom cover plate. The movable shield is again lowered, and the reflector filler are lowered into the cell fixture (Figure 26). The movable shield is again raised an inch and the two metal sheets are pulled over the port. The machine is then driven to a convenient place.
- 6) The reflector filler storage cell plug is picked up by the building crane and positioned over the cell by remote control. The metal cover sheets are then pulled off the cell, and the plug is lowered in as quickly as possible to minimize diffusion of air into the cell.
- 7) The reflector filler grapple assembly is removed from the moderator handling machine, and the moderator element grapple (Figure 27) and spreader ring assembly (Figure 28) are installed.
- 8) The moderator removal plug is raised up into its container. The container is raised about an inch from the floor, the two metal sheets are pulled into position under the container, and the container is lowered. The magnets are energized to pick up the 5-1/2-ft-diameter top sheet. The container and plug are moved remotely to a convenient storage location.
- 9) The moderator handling machine is positioned over the moderator removal port by remote control. The movable shield is lowered and the machine is filled with Argon. The movable shield is then raised about 1 in. and the 10-ft² sheet is pulled from underneath the machine. The movable shield is then lowered, permitting personnel to approach the machine for final positioning and grappling operations. Extension rods are brought to the machine (Figure 29) and coupled to the spreader ring rods, and the spreader ring is lowered to the tops of the moderator elements (Figure 30). The three prongs of the spreader ring are inserted in three of the vacant fuel channels to ensure that adjacent

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Figure 26. Lowering Reflector Filler Elements Into Storage Fixture

Figure 27. Installing Moderator
Element Grapple Into Moderator
Removal Machine

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Figure 28. Spreader Ring Assembly
Connected to Extension Rods

Figure 29. Transferring Extension
Rods to Moderator Removal
Machine

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Figure 30. Spreader Bar Lowered to Top of Core

cans do not crowd into the empty space remaining after a moderator element is removed. Additional extension rods are coupled onto the moderator element grapple rods (Figure 31), and the grapples are lowered to the bottom of the moderator element through the remaining three vacant fuel channels (Figure 32). Then each individual grapple rod is rotated through 180° to engage the moderator element. The moderator element is then raised up into the machine (Figure 33 and 34), with the extension rods being removed and stored as they are pulled out. The spreader ring rods are unscrewed from the spreader ring, and are pulled up into the machine with the extension rods being removed and stored as they are pulled out. The spreader ring itself is left in place in the core. With the moderator element in the machine, the movable shield is raised about 1 in., and the 10-ft² and 112-in. circular sheets are pulled underneath the machine. The movable shield is lowered, and the 112-in. circular sheet is attached to seal the bottom of the machine. The 10-ft² is left in place over the reactor. The machine is now moved to some convenient spot and the movable shield lowered to the floor.

- 10) The container with the moderator removal plug is now brought back over the port. The container is lowered to the floor and the electromagnets are deenergized to release the bottom cover plate. The container is raised about 1 in. and the metal sheets are removed. The container is set down on the floor, and the plug is lowered into place. The container is left in position with lift rods attached to plug.
- 11) The moderator element storage cell is filled with Argon, and the plug is lifted out with the building crane. The 10-ft² metal sheet is positioned over the cell.
- 12) The moderator handling machine is then positioned over the moderator element storage cell. The movable shield is lowered and the bottom cover sheet is released (112-in. circular). The movable shield is then raised about 1 in., and both the 10-ft² and the 112-in. circular sheets are pulled from underneath the machine. The movable shield is lowered and sealed to the floor. The moderator element is then lowered into the cell. The grapple rods are released and pulled up,

Figure 31. Moderator Element
Grapple Prior to Lower-
ing Into Core

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Figure 32. Moderator Element Grapple Installed About Incore Element

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Figure 33. Top of Grappled Moderator Element During Removal Operation

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Figure 34. Bottom of Grappled Moderator Element When Completely in Moderator Removal Machine

the movable shield is raised, and the 10-ft² and 112-in. circular metal sheets are pulled in under the machine. The movable shield is lowered, the 112-in. sheet is picked up, and the movable shield is raised. The machine is then moved by remote control to some convenient spot.

- 13) The moderator storage cell plug is picked up by the building crane and positioned over the cell by remote control. The metal cover sheets are pulled off the cell and the plug is lowered into the cell as quickly as possible to minimize diffusion of oxygen into the cell.
- 14) The new moderator can shipping container is suspended vertically in the shipping cask loading pit and is prepared so that the new moderator element may be lifted out.
- 15) The moderator handling machine is positioned over the new moderator element shipping container and the grapples are lowered and engaged to the moderator element. The new moderator element is then lifted vertically out of its shipping container into the handling machine. The handling machine is open to air during these operations.
- 16) The moderator removal plug is raised up into its container. The container is raised about 1 in. from the floor and the two metal sheets are pulled into position under the container, and the container is lowered. The magnets are energized to pick up the 5-1/2 ft-diameter top sheet. The container and plug are moved remotely to a convenient storage location.
- 17) The moderator handling machine is positioned over the moderator removal port by remote control. The movable shield is lowered and the machine filled with Argon. The movable shield is then raised and the 10-ft² metal sheet is pulled out from underneath the machine. The movable shield is lowered permitting personnel to approach the machine for final positioning and grappling operations. Extensions are coupled to the moderator element grapple rods and the new moderator element is lowered into place in the core. After the element is lowered, the grapple rods are individually rotated through 180° to release the element. The grapple rods are then pulled up into the machine, with the extension rods being removed and stored

as they are pulled out. The spreader ring is also raised up into the machine, with the extension rods being removed and stored as they are pulled out. The movable shield is then raised about 1 in. and the 10-ft² and the 112-in. circular metal sheets are pulled in under the machine. The movable shield is lowered and the 112-in. circular sheet attached to the bottom of the machine to seal it. The 10-ft² sheet remains in place over the moderator removal port. The machine then is moved to a convenient location by remote control.

- 18) The container with the moderator removal plug is now brought back over the port, the container is lowered to the floor, and the electromagnets are deenergized to release the bottom cover plate. The container is raised about 1 in., and the metal sheets are removed. The container is set down on the floor, and the plug is lowered into place. The container is left in position with lift rods attached to the plug.
- 19) The moderator element grapple is removed from the moderator handling machine, and the reflector filler grapple is installed.
- 20) The reflector filler storage cell plug is removed with the building crane by remote control. After the plug is raised, the 10-ft² sheet is pulled over the cell.
- 21) The moderator handling machine is positioned over the reflector filler storage cell by remote control. Operating personnel may then approach for final positioning and grappling operations. The machine is filled with argon and the metal sheet pulled out from under the machine. Extension rods are attached and the grapples lowered to engage the reflector fillers. The reflector fillers are then raised up into the moderator handling machine. The movable shield is then raised and the 10-ft² and 112-in. circular sheets are pulled in underneath the machine. The movable shield is lowered and the 112-in. sheet is attached to seal the bottom of the machine. The machine is then moved to some convenient location.
- 22) The reflector filler storage plug is then picked up with the building crane and positioned over the reflector filler storage cell. The 10-ft² sheet is pulled off the cell and the plug lowered in.

- 23) The moderator removal plug is pulled up into its container. The container is raised about 1 in. from the floor and the two metal sheets are pulled into position under the container, and the container is lowered. The magnets are energized to pick up the 5-1/2-ft-diameter top sheet. The container and plug are moved remotely to a convenient storage location.
- 24) The moderator handling machine is positioned over the moderator removal port by remote control and indexed by means of transits. The movable shield is lowered and the 112-in. cover sheet released. The movable shield is then raised, and both the 10-ft² and the 112-in. circular sheets are pulled from underneath the machine. The movable shield is then lowered and sealed to the floor. Extension rods are coupled onto the reflector filler grapple rods, and the reflector fillers are lowered into the core and set into the lower gridplate. The grapples are then disengaged and pulled up into the machine, with the extension rods being removed and stored as they are pulled out. The movable shield is raised about 1 in., and the 10-ft² metal sheet is pulled under the cask. The machine is then moved away by remote control to some convenient location.
- 25) The container with the moderator removal plug is now brought back over the port. The container is lowered to the floor and the electromagnets are deenergized to release the bottom cover plate. The container is raised about 1 in., and the metal sheets are removed. The container is set down on the floor, and the plug is lowered into place. After the plug is lowered into the port the operating personnel may approach the container, unscrew the plug lifting rods, and move the container to its normal storage area.
- 26) The moderator handling machine is converted back to fuel-handling. The loading face shield is rotated back to its correct position and the cerrobend seal (Figure 1) made. All controls rods, fuel elements, etc., are reinstalled in the reactor. The sodium level is raised and the space above the core filled with helium to return the reactor to operating condition.

C. HANDLING TESTS

The test program for moderator handling was conducted in accordance with a test agenda¹¹ which paralleled the handling operations described under moderator handling procedure. Many of the operations were repeated up to four times, to verify the effectiveness of both the equipment and procedure. Two types of testing were planned in the agenda, dry (no sodium) and wet (sodium-wetted) moderator handling.

1. Dry Handling

Two minor difficulties were encountered in the test program for dry moderator handling. The first difficulty arose during attempts to index the moderator removal plug container with plug over the open core mockup vessel. Locating targets had been glued on the canister at the time of plug removal and bench marks in the test area referenced for plug reinsertion in the core mockup vessel. These references controlled both the axial alignment of the plug with its hole as well as its rotary position with respect to the hole. As the canister and plug (suspended from the overhead crane) neared the index position, sway and canister rotation hindered target alignment. A snubline was wrapped about the canister with the rope ends terminating at each transit site. This arrangement gave test personnel control of canister sway as well as a limited control of rotation. Consistent axial alignment was achieved on each of four plug replacement runs, but the rotary index could not be maintained. By removing the canister after plug insertion (rotary position still incorrect), and raising the plug slightly (gas seal not broken), it was found that one man could easily rotate the plug to its correct position.

The second problem was experienced when the moderator element grapping equipment displayed a tendency to deviate from plumb when suspended from the overhead crane. As the grapples neared the spreader ring, sufficient drift accumulated to allow the grapples to miss the spreader bar leadin chamfer so that the grapples struck the flat face area of the spreader. This problem was magnified when twisting of the grapple assembly accompanied the off-plumb condition. Initial correcting efforts were directed toward equipment adjustments and part rework. Only slight improvements were achieved with this effort. An improved guide system was devised which consisted of the addition of tapered bushings pinned to the spreader bar rods. In addition to this change, the token

leadin bevels at the upper face of the spreader bars were increased to funnel proportions. Immediate success was achieved in lowering the grapple assembly into the process channels. Both the twist and off-plumb conditions, though still present, were corrected at the spreader by the combined action of the bushings and leadin chambers. When the weight of a moderator element was sustained by the grapple assembly, the entire assembly hung more nearly plumb, with very little twist.

2. Wet Handling

This test of the moderator handling equipment was to have been performed after sodium had been added to the core mockup vessel. It was not accomplished because the cladding of the six concrete filled half elements used to complete the core matrix buckled during attempts to remove the excess water of hydration. The water was being removed by vacuum drying the heated (250°F) elements when the vacuum line broke away. Pressure generated by the formation of steam caused the deformation of the element scallops. The schedule did not permit the design and fabrication of more suitable half elements, so the test was abandoned.

V. FUEL ELEMENT DISASSEMBLY TESTS

The objective of this test was to establish the suitability of the equipment and procedures for the partial disassembly of a fuel element in the Hallam maintenance cell.¹² Two specific disassembly operations were evaluated. These were: (a) removal of the process tube from the fuel cluster while the cluster remains attached to the hanger rod; and (b) removal of the cluster and process tube as an assembly from the hanger rod. Component equipment involved in these operations include the hanger rod disconnect, the process tube disconnect, and the maintenance cell gripping tool.

A. EQUIPMENT DESCRIPTION

1. Hanger Rod Disconnect

The hanger rod disconnect is a mechanical joint (Figure 35) that couples the hanger rod assembly to the fuel rod hanger adapter. The joint components are aligned by a short male and female pilot and retained by a split retainer sleeve (elongated C cross-section) which spans over the flanges of the two joint parts. A lock-sleeve is slipped over the split retainer sleeve to prevent the two halves from separating. Movement of the lock-sleeve is prevented by trapping a deformable lock tab in a recess in the hanger rod. Initially, the lock-sleeve was retained by a separate lock ring, which was found to be unacceptable by the tests.

2. Process Tube Disconnect

The process tube is connected to the fuel-rod hanger casting by three disposable button assemblies that protrude into mating holes in the process tube. Each button assembly has a springloaded lock button with an elliptical flange. Prior to tube assembly, the buttons are placed into the hanger casting with the buttons depressed by lock-wiring. The wire is removed during the tube installation operation when the edge of the tube covers a portion of the depressed button. When the tube holes are positioned over the buttons, the spring forces the buttons into the holes. A one-quarter counterclockwise turn of the button shaft locks the assemblies in place by placing the elliptical button flange 90° to the elliptical clearance holes in the hanger casting. The springs simultaneously seat the button shaft keys into retainer slots machined in the body of the hanger adapter.

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Figure 35. Hanger Rod Disconnect and Process Tube Disconnect
Assembled on Fuel Element

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In order to disconnect the process tube from the hanger adapter, the buttons must be rotated 90° clockwise. This results in torsional deformation of the button shafts because the shaft keys are still retained. With the elliptical button flange now aligned with the adapter ellipse, the buttons may be depressed to clear the process tube for removal.

3. Hot-Cell Gripping Tool

The hot-cell gripping tool (Figure 36) is a power-driven clamp that can be mounted to the maintenance cell remote tool positioner. Removable jaw inserts are provided for the gripping tool so that fuel elements, control rods, and other similar core components may be securely clamped without crushing. During fuel element disassembly operations, the tool clamps the process tube guide section (lower end) to anchor the tube for fuel cluster removal.

B. DISASSEMBLY PROCEDURE

The most frequent need for fuel element disassembly will occur when spent fuel elements are disassembled in preparation for fuel shipment to the reprocessor. The operational procedure required to accomplish this disassembly is summarized as follows.

- 1) A spent fuel element is cleaned in the fuel wash cell and transferred with the fuel-handling machine to the maintenance cell.
- 2) The gripping tool, equipped for guide tube clamping, is positioned under the 8-in. -diameter plug of the maintenance cell.
- 3) The fuel-handling machine removes the 8-in. plug and lowers the fuel element into the open jaws of the gripping tool.
- 4) After clamping, the three process tube lock-buttons are released by the deformation of the shafts.
- 5) The fuel-handling machine lifts the hanger rod and attached fuel element out of the process tube. When the cluster of fuel rods clears the process tube, the tube is transferred by the incell crane from the gripping tool to a storage area. A spent fuel canister is then placed in the gripping tool after appropriate jaw inserts have been installed in the gripping tool.
- 6) The fuel-handling machine lowers the fuel cluster into the canister until the canister partially supports the fuel weight. Incell manipulators

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Figure 36. Hot Cell Gripping Tool Installed at the Fuel Handling Test Facility

bend the lock-sleeve tab out of its recess and slip the lock-sleeve off the split retainer sleeve. The two retainer halves are removed to complete the disassembly.

- 7) The fuel-handling machine raises the hanger rod assembly into the cask, replaces the maintenance cell plug, and relocates over a standard core element plug at the maintenance cell. The hanger rod is then discharged into the cell for reassembly to a new fuel element.

C. EXPERIMENTAL TESTS

Initial demonstration test of the disassembly procedure were based on the assumption that only clean fuel elements would be disassembled. The tests were

extended to cover the disassembly of unwashed elements because of the anticipated need to disassemble a ruptured fuel element without prior cleaning.¹² For the tests, the maintenance cell gripping tool was mounted to an I-beam within the facility pit. It was located at an elevation that placed the disconnect section of a gripped fuel element within reach of the facility scaffolding.

1. Clean Fuel Element Disassembly

Before the operational procedure was evaluated, a functional check of the participating components was made. It was found that the lock-ring used to retain the process tube lock-sleeve was much too rigid for the application. In order to compress the ring (the sleeve was slipped over the ring), a hose clamp with a worm-tightening screw was required. The ring-compressive force (not measured) was such that tearing of the worm teeth slots occurred. Drastic reductions in the ring cross-sectional area decreased the compressive loads, but the overall procedure was still much too involved for routine manipulator operation. It was recommended that the ring concept be discarded and a more suitable lock devised. This resulted in the bent tab design used for the Hallam fuel elements. Design and fabrication of the new lock could not be completed in time for retest under this program.

Process tube disconnect operations were found to be satisfactory. A torque of 16 ft-lb was required to lock the buttons while 15 ft-lb was required for unlocking. Although the button shafts were intended to be used but once, it was found that they could be operated up to five times before the shaft failed in shear.

Some difficulty was experienced in releasing the process tube guide from the gripping tool. The saw-cut made during fabrication of the two insert halves resulted in metal flow at the edges. This localized buildup caused the jaws to seize the guide tube with essentially line contact (Figure 14). When the gripping tool was opened, the guide would remain securely in one insert half or the other. This problem was eliminated by removing the metal buildup and rounding the insert edges slightly.

An average force of 750 lb was required to withdraw the fuel cluster out of the process tube. This was the weight of the test fuel element and hanger rod, so that essentially no friction was encountered.

2. Unclean Element Disassembly

Two fuel-element disassembly operations were attempted without benefit of prior cleaning. On the first test, an extremely large amount of sodium compound adhered to the fuel element assembly (Figure 37). It had been removed from 700°F sodium and permitted to cool to room temperature in the fuel-handling cask before exposing it to atmosphere. Unlocking of the process tube disconnect buttons went well after some sodium had been scraped out of the square wrench openings. However, when removal of the cluster from the process tube was attempted, the three hanger-adapter support hooks bent under the extracting load (1800 lb) and pulled free of the hanger casting (Figure 38). The cluster had not moved at all, and was left securely held by the sodium cast within the process tube. The fuel-element components were cleaned and repaired for another attempt at disassembly. Before proceeding further, the test-cell sodium was drained, and the cell flushed several times with filtered sodium before refilling. Once again the element was soaked in 700°F sodium, raised into the fuel-handling machine, and cooled to room temperature. This time, very little sodium covered the exterior surface of the fuel element (Figure 39). Release of the process tube disconnect was achieved as before, but now the cluster was pulled out of the tube by the fuel-handling grapple. The force required to extract the fuel cluster was 1500 lb. Very little sodium was found on the fuel rods, with slightly larger quantities accumulated on the spacers and lower casting (Figure 40). Sodium drainage during element removal from the test cell had been obviously very good. If any additional heat such as afterglow energy had been present, drainage would have been excellent.

The overall disassembly procedure was found to be acceptable in all respects with but one exception, the lock-sleeve ring. The ring was eliminated by incorporating a deformable tab in the lock-sleeve.

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Figure 37. Fuel Element Disconnect Heavily Coated with Sodium

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Figure 38. Failure of Hanger Adapter Hooks in Disassembly Test

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Figure 39. Fuel-Element Disconnect Lightly
Coated with Sodium

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Figure 40. Sodium Accumulation on Fuel-Element Lower
Casting and Spacer

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VI. MISCELLANEOUS TESTS

Many of the accessory tools and equipment required for the operation of the Hallam power plant were functionally tested at the FHTI before shipment to the reactor site. These items included frequently used service equipment as well as infrequently used special purpose, handling tools.

A. EQUIPMENT DESCRIPTION

1. Shuttle Rod

The shuttle rod is a plug-mounted (8-in. -diameter plug) grapple used for transfer of spent fuel canisters from maintenance cell to fuel shipping cask. It is manually (manipulator) coupled to the canister in the maintenance cell, and automatically uncouples when the canister is seated in the shipping cask. The grapple head consists of three pin-supported hooks that converge or diverge as an integral operator flange is lowered or raised. Loading-springs force the actuator to a normally closed position (hooks converged). A mushroom-shaped pickup knob is provided at the top of the canister for engagement by the shuttle rod grapple.

2. Grapple for Wash Cell Basket

A manually operated grapple in the shape of a shortened shield plug is provided for removal of the wash-cell perforated basket. The grapple employs the trapped ball technique commonly seen in quick disconnect couplings to engage a recess near the basket flange. Positioning of the three grapple balls is controlled by an actuator shaft that extends up through concrete shielding to the top of the grapple. Typical shield plug features such as seals and pickup cup threads are included in the upper grapple geometry.

3. Portable Purge Unit

The portable purge unit consists of a cylindrical glove box with a hydraulic pump, gloves, glove port cover plates, a compound pressure gage reading from 30-in. Hg vacuum to 15 psig, flexible hoses, storage reels, valves, and couplings. The hydraulic pump is carried on a cart which is also used to transport the glove box, hoses, etc. The upper part of the glove box is a polished cast acrylic section that permits vision within the box. Helium and vacuum connections on the glove box may be connected by means of the flexible hoses to helium and vacuum connections within the reactor building.

The unit may be used to purge storage cells, change Quad-rings on shield plugs, or take gas samples from storage cells. The hydraulic jack is used to lift fuel element and storage cell plugs. Coupling of the jack to the plug is made by a ball detent grapple mounted to the jack shaft.

4. Gas-Lock Gate-Valve

Advantages of a gate-valve closure over the initially installed drip pan for the FHM gas-lock became apparent before any tests were performed with the machine. Some of the obvious reasons for eliminating the hinged drip pan were: (a) to reduce the gas volume purged each time the cask arrives and leaves a station; (b) to obviate need for breaking the gas lock to index ring seal before closing the drip pan; and (c) to eliminate need for positive grapple seals. These reasons were later supplemented when other deficiencies in drip-pan operation were experienced during preoperative testing of the cask.

Construction of the gate-valve (Figure 41) is somewhat similar to those commercially produced by valve manufacturers. The gate translates into the valve body opening and then moves against the opening seat, due to the wedging action of ramps. A pneumatic cylinder provides the motive power, with limit switches signalling the fully open or closed positions. Partial seal protection from gas-lock debris is obtained by a depression in the gate.

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Figure 41. Gas-Lock Gate-Valve With Top Cover Removed

B. OPERATING PROCEDURE

1. Shuttle Rod

The shuttle rod is attached to an 8-in. -diameter maintenance cell shield plug and inserted into the 8-in. cell opening by the FHM. A spent fuel element has been placed within a canister, and the canister supported by the gripping tool. Coupling of the canister to the shuttle rod grapple is accomplished by raising the remote tool positioner until the pickup knob of the canister enters the lower end of the shuttle rod grapple. Incell manipulators are then operated to raise the grapple flange for completion of the coupling operation. The FHM removes the shuttle rod and attached canister from the maintenance cell and re-locates over the spent fuel shipping cask. During canister insertion into the cask, a shoulder within the cask will engage the grapple release flange when the canister is approximately 1 in. from being seated. As the last inch of travel is negotiated, the differential motion between the grapple body and the shouldered flange causes partial release of the canister. Overtravel of the grapple after the canister is fully seated completes the release. Springs within the grapple maintain the hooks in the release position until the raised grapple clears the pickup knob. Continued raising of the shuttle rod into the FHM returns the grapple to the engage position by unseating the grapple flange.

2. Grapple for Wash Cell Basket

Operating procedure for the basket grapple depends on whether or not a radiation hazard accompanies removal of the basket from the fuel wash thimble. If no radiation hazard is present, the core element shield plug may be removed and the grapple inserted by use of the overhead crane. The ball detent coupling is then manually engaged and the basket raised into the reactor high bay by the crane. Should radiation hazards prevent this approach, shield plug removal and grapple insertion would be performed by the FHM. After the grapple has been seated in the cell, the machine would be removed for manual operation of the grapple. The machine is then reindexed to the cell and the grapple and attached basket removed. These can then be deposited in the maintenance cell after indexing the machine to one of the core-element shield plugs located at the cell.

3. Portable Purge Unit

The portable purge unit will more frequently be required for the changing of core-element shield plug seals than any other service. For this operation,

the index ring and pickup cup must be installed as for plug removal by the FHM. The cart carrying the purge unit and its equipment are wheeled out to the plug area and new (prelubricated) seal rings slipped over the pickup cup. Placement of the unit atop the index ring is done, and connection of the helium and vacuum lines is made. The hydraulic jack is then released to allow the ball detent grapple to descend into the pickup cup. When the grapple enters the cup, the latching balls will automatically emerge to engage the cup. Pressure equalizing lines connected to the port plates are opened to allow equal pressure on both sides of the gloves. Purging of air from the unit is achieved by evacuating to 30 in. Hg, and backfilling with helium to 0 psig. Hand-pumping of the hydraulic pump raises the grappled core element plug to expose the worn seals. After replacing the seals, the hydraulic pressure is relieved to allow the plug to slip back gently into the cell. Overtraveling the grapple releases the coupling to free the grapple. Purging of the helium by evacuation and backfilling with air is performed to complete the operation.

4. Gas-Lock Gate-Valve

The gas-lock gate-valve serves the same function as the pivoted drip pan during operation of the fuel handling machine. Its functions have been discussed under the operational procedure for the FHM and will not be repeated here.

C. EXPERIMENTAL RESULTS

1. Shuttle Rod

A mockup of a spent fuel canister and a shipping cask were provided for the demonstration test of the shuttle rod.¹³ The canister mockup closely duplicated the proposed Hallam canister, and was loaded with 1000 lb of lead shot to simulate the weight of a spent fuel element.

Initial bench tests of the grapple and pickup knob revealed design discrepancies which required extensive part rework. Once the rework was completed, all operations of the shuttle rod were successfully demonstrated. However, some difficulty was encountered in the insertion of the canister into the cask when using the FHM. The flat bottom of the canister consistently struck the shoulders of the shipping cask during insertion operations. This problem was subsequently eliminated by changing the bottom edge of the canister to a bevel.

2. Grapple for Wash Cell Basket

Two situations occurred in the course of the fuel-element wet cycling test that required the use of the basket grapple before the formal tests of the grapple had been made. In one case, the basket had stuck to a washed fuel element and was inadvertently raised into the fuel-handling cask. It was safely lowered back into the cell while still attached to the element. Both components were slightly warm (200°F) at the time of the incident. When the element and basket had cooled to room temperature, the element was easily removed with the overhead crane. Concern over the incident prompted removal of the basket for close inspection. This was successfully accomplished with the aid of the grapple and the overhead crane.

The second opportunity to operationally test the grapple was afforded when it became necessary to retrieve equipment from the bottom of the basket. In this case, the FHM was used to insert the grapple and to remove the basket. The crane could have been used again for the operation, but wasn't, because of interest in further demonstrating grapple effectiveness.

On the basis of the foregoing experience, the grapple was considered to be suitable for its intended purpose.

3. Portable Purge Unit

The effectiveness of the portable purge unit was primarily established by use rather than by any specific test. Repeated exercises in fuel-handling accelerated shield plug seal wear at the FHTI, so that periodic seal replacement was required. These seal replacements were frequently performed using the portable purge unit. As could be expected, more improvements were generated by use than could be achieved by several limited tests. The units' gas lock function (permits the breaking of a cell shield plug seal without releasing the cell atmosphere to the reactor bay) was satisfactorily demonstrated through frequent use. Its initial utility, however, was diminished by the lack of internal accessory tools. This was exemplified during the first attempts to change slippery seal rings using only the rubber gloves provided. Experiences such as this led to the installation of tethered seal removal tools and shelving for other items within the unit. After these additions, the portable purge unit became an efficient device for the changing of core element shield plug seals.

4. Gas-Lock Gate-Valve

Preliminary bench tests were performed with the gate-valve to determine its general operating characteristics. These tests established the cylinder operating pressure (25 psig) and optimum vent positions for the cylinder cushion stops.

At the conclusion of the moderator handling program, the fuel-handling machine was completely reassembled for a final checkout before tear-down and shipment to the reactor site. The gate-valve was installed on the gas lock at the time of machine reassembly and operated in conjunction with several fuel-handling exercises. The gate-valve served its purpose well, but its addition required a change in operating procedure. Prior to the installation of the valve, the gas-lock was purged after the fuel-handling grapple had been driven down into the pickup cup. Purging (performed twice) was done by evacuating the air volume between the grapple seals and the index ring to 28 in. Hg and backfilling with helium. With the gate-valve installed, the grapple remains within the gas-lock and above the closed gate valve while purging is done. This resulted in the lifting of the shield plug and loss of vacuum due to the 15-psig pressure differential across the plug seals. To prevent plug-lifting during gas lock purging, the evacuation process was limited to 15 in. Hg vacuum. This limitation does not apply to fuel elements or similar core components with weights that exceed the differential pressure force at 28 in. Hg vacuum.

VII. CONCLUSION

Testing of the core component handling equipment and handling techniques demonstrated that the operating techniques were safe and that the equipment is dependable throughout its expected range of operation. Partial verification of this conclusion has already been established by operational use of the equipment at the reactor site. Both fuel and control rod handling in conjunction with reactor dry and wet criticality tests were routinely accomplished with the fuel handling machine. Minor problems with equipment adjustments were initially experienced, but these have been reduced to a minimum by regularly scheduled maintenance and equipment checkout programs.

It is unfortunate that wet testing of moderator handling equipment could not be accomplished. The tests would have provided information on the effectiveness of the sheet metal seals in excluding oxygen from the core atmosphere during handling operations.

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