SRE MARK II
FUEL HANDLING MACHINE

AEC Research and Development Report

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Price $3.00
Available from the Office of Technical Services
Department of Commerce
Washington 25, D. C.
SRE MARK II
FUEL HANDLING MACHINE

By

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ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED: 2-2-1959
DISTRIBUTION

This report has been distributed according to the category "Engineering and Equipment" as given in "Standard Distribution Lists for Unclassified Scientific and Technical Reports" TID-4500 (38th Ed.), January 1, 1965. A total of 565 copies were printed.
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ABSTRACT

The Sodium Reactor Experiment Mark II Fuel Handling Machine has been modified to ensure fuel and gas containment during Core III operation. A new control system has been designed for the fuel handling machine. The design, operation, and hazard aspects of the fuel handling machine are discussed in this report. It is concluded that the Fuel Handling Machine will safely and reliably handle SRE Core III fuel.
I. INTRODUCTION

The SRE Mark II Fuel Handling Machine (FHM) is a large, lead-lined cylinder (equipped with internal lifting devices) designed to safely and reliably handle SRE fuel and other core elements. The design objectives have been demonstrated through successful use during hundreds of SRE Core I and Core II fuel transfers. Many damaged Core I fuel elements were removed from the reactor with the Mark II FHM. These damaged elements were successfully handled without incident, demonstrating the versatility and inherent safety of the FHM.

The FHM as described in this report will be used during the SRE Power Expansion Program (PEP). Four additional safety features have been added for PEP.

1) An intermediate (travel) position for the empty guide tube over the vacuum valve is provided to prevent fuel slugs from dropping onto the valve.

2) A new control system has been designed to prevent inadvertent deviation from the proper operating sequence.

3) A radiation detector installed near the bellows region prevents lifting the bellows seal if radioactive material is present in the bellows region.

4) Mechanical and electrical interlocks installed on the vacuum valve prevent its operation out of sequence.

With these modifications, the fuel handling machine will maintain fuel and gas containment under all operating conditions and permit safe handling of either normal or severely damaged fuel.
II. DESCRIPTION OF SRE MARK II FUEL HANDLING MACHINE

The SRE Mark II Fuel Handling Machine (FHM) is a gas-tight lead-shielded cylinder weighing about 52 tons. It consists of a hoisting assembly (dome), shielded body sections, a viewing section, a lower adapter assembly with a vacuum tight gate valve (see Figure 1) and internal mechanisms for fuel pickup and guidance. An inert atmosphere is maintained in the FHM by the use of O-ring joints between each section and a 6-in. gate valve at the opening in the bottom of the machine. A telescoping bellows seal is used to seal the FHM to an adapter seal ring (index ring) on the reactor loading face. The FHM is supported by a bail assembly pinned to the SRE 75-ton bridge crane hook.

The top section of the FHM is the hoist assembly, "dome" (see Figure 2). Two specially designed cable drums driven by separate grapple hoist motors with integral brakes are enclosed within the sealed dome. These element hoists are supported on a turntable which can be rotated 90° with respect to the FHM body section. With the use of both hoists an element can be removed from the reactor by using Hoist 1 and rotating Hoist 2 over the reactor channel. The replacement element may then be inserted without opening the reactor or the FHM to the atmosphere.

The element grapples travel in guide tubes, which protect the fuel assembly, maintain alignment, and prevent element hangup. These grapples serve as the connection between the hoist motors and the core elements. Springloaded latching fingers on the grapple tip engage the element lifting adapter for pickup (see Figure 3). The grapple latching fingers are normally in the latch position, and the fingers must be retracted to the release position by a gas-operated piston. The loss of gas pressure to the grapple cannot actuate the grapple fingers. Also, the element lifting adapter has safety lips which prevent accidental release of a fuel element during transfer, even if gas pressure is accidentally applied to the piston.

The grapple cable is attached to a cable drum, threaded through the grapple pulley, and terminated at a seal rod which leads outside the FHM to load-detecting devices. A slack cable switch provides underload protection for the grapple cable by deenergizing the hoist motors before the cable can be unwound from the cable drum. Grapple load switches indicate which grapple is loaded, and prevent movement of the FHM if the operating grapple (over the vacuum valve) is loaded.
Figure 1. Cutaway of Entire Fuel Handling Machine
SRE FUEL HANDLING MACHINE - MARK II

UPPER SECTION

Figure 2. Cutaway of Upper Section, Fuel Handling Machine

7519-5186B

NAA-SR-10817

11
Figure 3. Grapples for Fuel Handling Machine
FHM internal mechanisms consist of a centrally located torque tube which fastens to the bottom of the hoist assembly and two guide tubes in which the element grapples travel. The guide tubes provide a continuous tube from the face of the reactor which is free of steps and shoulders. Rotary motion of the hoist assembly is transmitted to the guide tubes by the torque tube and guide plates. The vented portion of the guide tubes permits heat dissipation of the fuel afterglow heat during transfer by means of radiation and convection cooling (see Figure 4).

During operation of the FHM, the guide tubes have three normal elevations:

1) A top position for rotation, where the grapples support the guide tubes,
2) A travel position, where the empty guide tube blocks the area over the valve, and
3) A down position where the guide tube is seated in the guide funnel, (see Figure 5).

Four shielded body sections are bolted together with O-ring seals between the sections to form the body of the FHM. Nine inches of lead shielding on the lower 10 ft of the FHM provide radiation protection to personnel from the 6-ft active fuel region. The viewing section, mounted below the body section, contains a replaceable periscope for observation of core elements as they are being raised or lowered (Figure 6). This sectional construction permits dis-assembly for repairs or decontamination.

The lower adapter assembly contains a 6-in. vacuum-tight gate valve surrounded by 9 in. of lead shielding. The manually operated valve is both mechanically and electrically interlocked to prevent operation out of sequence. A telescoping tube contained in a metal bellows is attached just below the gate valve. The lower end of the tube seals the FHM to the index ring, which is placed over the storage cell port.

The biological shield, which fits around the lower adapter section, is lowered during element transfers to shield the gap between the FHM and the floor. During travel, the shield is raised to the upper position.

The FHM controls and interlocks are designed to prevent contamination of the SRE reactor building and to provide maximum safety for SRE operating
Figure 4. Guide Tubes for Fuel Handling Machine

NAA-SR-10817
14
Figure 5. Guide Tube Positions in Lower Section of Fuel Handling Machine
Figure 6. Cutaway of Lower Section, Fuel Handling Machine
personnel, core elements, and FHM components. Table 1 shows a list of FHM interlocks which must be satisfied for each operation.

The control console is energized when electrical power is applied to the 75-ton crane controls. However, the FHM motors are not energized until power is transferred from the bridge crane to the FHM through a key-lock switch. This key-lock switch is mounted on the vacuum valve. A mechanical interlock prevents insertion of the key into the lock when the vacuum valve is open. This switch and cover prevent motion of the machine unless the valve is closed.

A selector switch (an electrical check sheet) with positions for all normal FHM operations is mounted on the control console. The selector switch circuit automatically samples the interlocks required for the selected operation, and a light is energized if they are satisfied. If the "OK" light is not illuminated, a check of the interlock indicating panel will reveal which interlocks are not satisfied. The interlocks prevent accidental deviation from the proper operating sequence.

Element protection is provided by grapple load cells. Each load cell (mounted in the cable dead leg) is adjustable and is set for a narrow operating band. Any element hangup will exceed the operating band and stop the grapple hoist motor. If the load cell fails to function, a disconnect plug attached to the weak link will be pulled apart and will deenergize the hoist motors.

Protection of the FHM components is provided by interlocks connected to the grapple upper-limit switches, grapple rotation limit switches, bellows travel switch, vacuum valve position switches, and biological shield limit switches. A mechanically blocked power transfer switch prevents movement of the 75-ton crane during FHM operation.
# TABLE 1

## FUEL HANDLING MACHINE INTERLOCKS

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[X] Indicates interlock may be bypassed
III. OPERATION OF MARK II FUEL HANDLING MACHINE

The SRE Mark II FHM is used to transfer core elements between the reactor, wash cells, storage cells, and the maintenance cell. Before any element transfers are initiated, an element transfer request form (ETR) is issued which must be approved by the SRE shift supervisor and the operations supervisor. A separate form, the negative reactivity transfer request, is used for the transfer of poison rods from the reactor. A fuel transfer operation is started by installing a lifting adapter in the element shield plug and placing the index ring over the reactor port containing the element to be removed. The FHM containing the replacement element is located over the index ring. The bellows seal is sealed to the index ring and the bellows region is evacuated and purged with helium. The biological shield is lowered and the vacuum valve opened. The element is picked up while being observed through the FHM periscope to check for abnormalities and to receive a visual indication of hangup. It is raised to the upper limit of the grapple hoist, the hoist assembly is rotated, and a new element is lowered into position. After closing the vacuum valve and lifting the biological shield and bellows seal, the power is transferred to the bridge crane and the FHM is then moved to the next location on the ETR.

The control system interlocks ensure that the above operations are carried out in this exact sequence, and that each operation is successfully completed before the next can be started.

An operator can move about 10 fuel elements from the reactor to the storage cells in a regular 8-hr shift. Personnel radiation exposure is limited to 300 mr/week and an operator could move about 20 fully irradiated fuel elements before receiving the maximum weekly exposure. The PEP core loading will contain an estimated 33 fuel elements. See Appendix, Section D, for a detailed description of operator radiation exposure during fuel transfers.

During all element transfers the oxygen content of the helium inside the FHM is kept below 1%, as determined by an $\text{O}_2$ analyzer mounted on the FHM. All exhaust gases from the FHM are vented to the plant radioactive vent system.
IV. CONSEQUENCES OF CREDIBLE ACCIDENTS INVOLVING FUEL HANDLING MACHINE AND HANDLING OF DAMAGED FUEL

A. HANDLING OF DAMAGED FUEL IN THE FUEL HANDLING MACHINE

The purpose of the FHM is to remove core elements from the reactor safely. At times during operation of the SRE Mark II FHM it may be necessary to handle damaged fuel. The FHM will provide total containment for damaged fuel and the FHM atmosphere at all times during the transfer operation. The FHM will retain fuel slugs and particles from a severely damaged fuel element and prevent this material from reaching the highbay floor.

The following sections discuss possible problems which might be encountered in handling damaged fuel.

1. Broken Fuel Element In the FHM

A broken fuel element (fuel rod completely severed) or an element with severe cladding damage (fuel slug exposed) is the most potentially dangerous type of damaged fuel element normally handled in the FHM. Other types of fuel element damage include a bent lower guide, a broken thermocouple, dented cladding, or a pinpoint hole in cladding.

Broken fuel has been successfully handled in the Mark II FHM during the SRE recovery program and shipped to storage in the fuel transport cask. Both undamaged and damaged fuel are removed from the reactor in the same manner. The debris from an element damaged in the reactor would remain in the reactor, whereas the debris from an element broken in the FHM would be contained in the FHM. This report will not discuss removal of debris from the reactor. Experience during the SRE recovery program has already shown that fuel slugs may safely be removed from the reactor.

After reviewing the safety features of the FHM used during Core II operations, additional safety features were added for Core III operation to assure containment of broken fuel in the FHM. The possible problems postulated during the review of the FHM safety features along with the solutions are shown in Figures 7 and 8. Additional explanation is given below.

FHM fuel and gas containment is maintained by a mechanically and electrically interlocked vacuum valve which may be opened only after the FHM has been properly sealed to the reactor, wash cell, or maintenance cell (see Figure 9).
How to contain loose fuel slugs in FHM

1. Provide a slug containment guard.
2. Provide a travel position for guide tube blocking hole over vacuum valve, in case slug bounces, and interlock FHM, so that guide tube over closed vacuum valve is empty.

Problem:

When vacuum valve is open, fuel slug would drop into reactor room floor.

Solution — Tests show that slugs don't bounce, but even so:

1. Provide a slug containment guard.
2. Provide a travel position for guide tube blocking hole over vacuum valve, in case slug bounces; and
3. Interlock FHM, so that guide tube over closed vacuum valve is empty.

Figure 7. Containment of Fuel Slugs by Fuel Handling Machine

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Figure 8. Containment of Fuel Particles by Fuel Handling Machine
DOME CONTAINING ELEMENT LIFTING DEVICES

FUEL ELEMENT BEING REMOVED FROM CORE

OPERATING GUIDE TUBE AT BOTTOM POSITION

BELLOWS SEAL SHOWN SEALED TO REACTOR. BELLOWS MAY NOT BE RAISED UNLESS AN ELEMENT IS IN REACTOR AND VACUUM VALVE IS CLOSED.

REACTOR FACE PLATE

FMH WILL SEAL ONLY TO INDEX RING AT REACTOR, RASH CELL, STORAGE CELL, OR MAINTENANCE CELL.

HELIUM COVER GAS

VACUUM VALVE OPEN

GUIDE TUBE CONTAINING REPLACEMENT ELEMENT IN ROTATE POSITION

FMH SHOWN SEALED TO REACTOR WITH AN ELEMENT BEING REMOVED FROM IT

D-RINGS PROVIDE GAS-TIGHT SEAL

VACUUM VALVE CANNOT BE OPERATED UNLESS FMH IS SEALED TO REACTOR

VACUUM VALVE CLOSED, THEREBY CONTAINING GAS IN FMH

BELLOWS SEAL MAY NOT BE RAISED UNLESS RADIATION DETECTOR IS NORMAL

FUEL SLUG CONTAINMENT GUARD

PERISCOPE

PLATE COVERS POWER TRANSFER ORTIX WHEN VALVE IS OPEN, PREVENTING OPERATION OF CRANE

VACUUM VALVE CANNOT BE OPERATED UNLESS FMH IS SEALED TO REACTOR

BELLOWS SEAL IN "UP" POSITION

FMH SHOWS READY FOR TRANSPORT TO STORAGE CELLS

Figure 9. Fuel Handling Machine Gas Containment

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A broken fuel element removed from the reactor might have exposed fuel slugs which could become dislodged in the FHM. During the fuel removal and grapple rotation operation, the vacuum valve is open and the FHM is open to the reactor. Any dislodged fuel slugs, fuel particles, or fuel cladding would fall into the reactor as the element is raised; and any fuel dislodged during rotation would either fall into the reactor or onto the FHM drip pan (see Figure 10). Fuel on the drip pan would remain there until retrieved, since it is retained by the lip (slug containment guard) on the drip pan.

After the replacement element is inserted into the reactor, the guide tube and empty grapple return to the travel position (see Figure 3), at which time the vacuum valve is closed. The empty guide tube in the travel position effectively blocks the hole over the vacuum valve, so that only fuel particles smaller than 1/16-in. diameter could reach the dished top of the vacuum valve. (Particles are still contained in the FHM when on top of the vacuum valve.) The guide tube may not be lifted above the travel position unless the FHM is indexed and an open hole to reactor or storage is below the FHM. The FHM may not be moved unless the vacuum valve is closed, the operating grapple (grapple over valve) is empty, and in the travel position. (See Table 1, Fuel Handling Machine Interlocks.) Only one element is carried in the FHM during transport.

If fuel particles (less than 1/16-in.) from a broken fuel element fall between the FHM and guide tube into the bellows region before the valve is closed, a radiation detector (range 1 mr/hr to 1000 R/hr) would open an interlock immobilizing the FHM and preventing exposure of personnel to radiation. Particles reaching the bellows region would be contained by the FHM bellows seal. Interlocks prevent lifting the bellows seal and movement of the FHM unless the radiation detector is normal. Special procedures would be required to recover the fuel particles. The FHM may be moved if fuel particles from a broken element are on the drip pan (but not in the bellows region), since they are safely contained within the FHM.

Pieces of fuel or fuel slugs may be fished from the drip pan of the FHM after unloading the machine by separating the viewing and lower adapter sections from shielded section 4. The fuel is then remotely encapsulated. Special maintenance procedures would be necessary for the removal of fuel particles from the FHM and of damaged fuel from the reactor.
Figure 10. Fuel Handling Machine Drip Pan and Slug Containment Guard
2. Bowed Element in FHM

The FHM guide tubes are smooth on the inside, but a badly bowed fuel element could be pulled into a guide tube and might become wedged. The Mark II FHM grapple motors cannot push, and depend upon the weight of the element for lowering operations. The FHM would provide containment for a bowed element wedged in a guide tube until special maintenance procedures could be written for removal of the guide tube and the wedged element from the FHM.

3. Dropping a Fuel Element in the FHM

The probability of dropping a fuel element in the FHM (as explained in Appendix, Section F.) is very slight due to the "normally extended" grapple latching fingers, the safety lip on the element latching device (see Figure 3), the grapple motor "springloaded" brake, and the grapple cable weak link. However, should such an accident occur, the element would still be completely and safely retained within the shielded machine.

B. CONSEQUENCES OF EQUIPMENT FAILURES DURING FUEL HANDLING OPERATIONS

The SRE Mark II FHM contains interlocks and special design features which ensure operational safety of the machine, but equipment failures or operator errors are not impossible. Each postulated accident is discussed in Appendix, Section F., under the FHM operation during which it could occur.

The most difficult equipment failure to repair (of all the failures or errors described in Appendix, Section G.) is the vacuum valve jammed partly open with an irradiated fuel element in the FHM. If the vacuum valve, gear reducer, or extension shaft breaks, the valve could jam in a partly opened position and prevent unloading of the fuel element. The bellows seal is interlocked to prevent its operation until the vacuum valve is closed. The 75-ton crane is also interlocked to prevent movement unless the vacuum valve is closed. (See Table 1, Fuel Handling Machine Interlocks.) Special maintenance procedures would be required for the repair of the valve. Complete containment of fuel element and FHM atmosphere would be maintained at all times while the procedures were being prepared. (The integrity of the reactor would not be disturbed since the element swap has already been performed or has not started.)
During normal fuel handling operations, irradiated fuel is allowed to remain in the reactor until the heat generation has decayed to a level which limits fuel element temperature rise above 1200°F in the FHM.

Due to a series of operational errors, a special test fuel element could be pulled from the reactor 10 hr after reactor shutdown (10 hr are required to prepare the reactor for fuel handling operations) from extended high power operation. Such an element pulled into the FHM could increase in temperature from the sodium temperature of 500°F at an initial rate of 170°F/min. If the fuel change was made normally, the temperature would not have time to increase above 1200°F; but if the element remained in the FHM longer than usual, the temperature could rise to 1700°F.

Cladding temperatures in the range of 1700°F during fuel handling operations could result in cladding failure, releasing fission gases and sodium bonding to the FHM. (See PEP hazards report, NAA-SR-9516, for gas activity.) Containment of the gases and the sodium would be provided by the FHM. The gases would eventually be purged to the radioactive vent system through the vent hose connected to the FHM. See previous section for handling of damaged fuel.

In these and other instances of mechanical failures or operator errors (see Appendix, Section F.), containment of a fuel element and FHM atmosphere would be maintained within the FHM and FHM bellows seal by the system interlocks and the safety features of the machine.
V. CONCLUSIONS

Past performance of SRE Mark II FHM has shown that it can handle and provide containment for damaged fuel being removed from the reactor. Much of the Core I fuel was severely damaged with exposed fuel slugs and loose debris projecting in various directions. During normal transfers of Core II fuel, the efficiency and reliability of the Mark II machine were again demonstrated.

For the SRE Core III operations (SRE-PEP), the FHM has been modified to insure complete containment of fuel or particles of damaged fuel within the machine. Modifications such as mechanical and electrical interlocks on the vacuum valve, the travel position for the operating grapple, a selector switch which performs the function of an electrical check list, a new interlock circuit which will prevent accidental deviation from the proper operating sequence, and a radiation detector to prevent movement of the FHM if fuel is in the bellows region have been made for Core III operation to afford even greater reliability and safety during fuel handling.

The Mark II FHM will provide safe and reliable transport of SRE Core III fuel. Safety of the public and SRE personnel is ensured by the fuel and gas containment features of the FHM.
APPENDIX

A. FUEL HANDLING MACHINE COMPONENTS

As supplementary material to Section II, FHM General Description, the major components are individually discussed below. Figure 11 shows the components, and Table 2 (see page 76) gives the Atomics International drawing numbers.

1. Hoist Assembly

The top section of the FHM (Figure 2) is the hoist assembly, which consists of a 4-ft-high, 7-ft-diameter dished head attached to a 7-ft-diameter flat plate. The dished head was constructed to ASME code and designed for 15 psi external pressure (full vacuum inside) and 4 psi internal pressure. A 34-in. manhole centered on the top of the dished head (dome) is provided for access. Lights are located in the dome to aid in viewing through dome windows.

Enclosed within the dome are two cable drums driven by the grapple hoist motors with integral brakes, the necessary idler pulleys, springloaded hose reels for the grapple release helium hoses, electrical power connections, controls, and limit switches. The grapple cables and pneumatic hoses extend through the hoist assembly base plate to each grapple. The cable extends from the cable drum, through the dome base plate, around the grapple pulley, up through the base plate again, over idler pulleys, and anchors to the seal rod. The seal rod extends to the outside of the dome and is connected to load-detecting mechanisms which form the "dead-leg" of the cable. The grapples are enclosed in separate guide tubes in the FHM body. Each grapple supports the weight of its guide tube when the tube is in travel position or top position. (See Figure 5 for guide tube positions.)

A hard chrome-plated sliding surface plate resting on the top shielding section supports the hoist assembly. A rubber O-ring provides a gas seal, and grease fittings are provided for lubrication. The alignment of the dome with respect to the FHM body sections is accomplished by three equally spaced rollers. A spur gear mounted on a gear motor, fixed to the FHM body, drives a large sector gear on the hoist assembly. This permits 90° rotation of the hoist assembly with respect to the body sections. Rotation is transmitted to
Figure 11. Illustrated Components of Fuel Handling Machine

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the guide tubes and grapples by a centrally located torque tube attached to the
dome base plate. Welded to the torque tube are top and bottom guide plates with
holes bored at 90° through which the guide tubes protrude. Limit-switches stop
the internal hoists when the grapples reach travel position and top position (see
Figure 5), and prevent rotation of the assembly if guide tubes are not fully
retracted. All electrical and pneumatic leads are sealed at wall penetrations
to maintain an inert atmosphere inside the cask.

2. Grapples

The lifting assemblies, called grapples, serve as a connection between
hoist motors and core elements. Three springloaded latching fingers spaced
radially 120° apart on the grapple tip engage the element lifting adapter for
pickup (see Figure 3). The grapple latching fingers are normally in the latch
position, and the fingers must be retracted to the release position by a gas
operated piston. Therefore the loss of gas pressure to the grapple cannot
initiate release of the grapple fingers. The element lifting adapter has safety
lips which prevent accidental release of the grapple even when gas pressure is
accidentally applied to the piston. The grapple can be released only when the
weight of the element has been removed. The grapple may be manually re-
leased by rotating a cam lobe in the grapple 90°, which will push the release
piston downward and retract the latching fingers.

Lead and stainless steel weights attached to the grapple mechanism,
increasing the total weight to 92 lb, ensure that the grapple assembly will
descend as required. Also the added weight eliminates slack in the hoist cable
when the grapple is empty. Grapple speed is about 8 ft/min.

3. Guide and Torque Tube Assembly

The guide and torque tube assembly (see Figure 4) consists of two guide
tubes in which the element grapples travel and a central torque tube which
fastens to the bottom of the hoist assembly. The guide tubes provide protection,
maintain alignment, and prevent hangup of the core elements while in the FHM.
The guide tubes provide a continuous tube from the face of the reactor free of
steps and shoulders, permitting removal of badly damaged or broken fuel
without danger of hangup.

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The guide tubes, each about 25 ft long, are divided into three sections. The top section is a smooth tube about 15 ft long, with a flat plate bolted at the top and a flange at the bottom. The top plate slips down over the grapple cables and gas hose to bolt to the guide tube. The grapple engages this flat plate when it lifts the guide tube (see Figure 12). The middle section of the guide tube is bolted to the lower flange of the top section (see Figure 13). It is fabricated from 1-in.-wide stainless steel strips circumferentially arranged with the minimum gap of 0.3 in. at the ID, and are supported by interlocking bands around the outside diameter. The vented portion of the guide tube permits heat dissipation of the fuel afterglow heat during transfer by means of radiation and convection cooling. The FHM body acts as a heat sink. The bottom section of the guide tube is a solid tube, which protects the fuel cluster from accidental closure of the vacuum valve during entry or removal from the machine. An opening (window) in this section is aligned with the periscope so that core elements may be observed during transfer. When the guide tubes are installed in the FHM, the windows are located at 90°.

Alignment of the guide tubes during removal or replacement of elements in the reactor is insured by the guide plates and a guide funnel at the entrance to a mating socket. During operation of the FHM, the guide tubes have these three normal elevations.

1) A top position for rotation, with the grapples supporting the guide tubes at upper limit of travel

2) A travel position, at which the empty guide tube blocks the area over the valve

3) A down position, with the guide tube seated into the guide funnel (see Figure 5).

The guide tubes which are lifted and supported by the grapples in the travel and up positions may be removed from the FHM without extensive disassembly. The guide tubes are smooth on the inside and, although the chances of wedging a core element are small, a wedged core element would render the FHM inoperative. To remove a guide tube the lower adapter section is removed, the open bottom FHM is moved over a disposal hole, and a tube containing an element is lowered into the hole. A new guide tube may be installed.
Figure 12. Upper End of Guide and Torque Tube Assembly, Fuel Handling Machine
Figure 13. Ventilated Guide Tubes, Fuel Handling Machine
and the FHM placed back in service. Special procedures must be prepared before performing this operation. Removal of a guide tube from the FHM is not a normal operation, and careful supervision with health physics coverage would be required.

4. **Shield Section 1**

The top shielded section is 84 in. long and has a 19-in. ID. The section has 3 in. of lead shielding, and O-ring joints are used for gas containment. Section 2 is attached to the lower end of Section 1 by a V-joint clamp.

5. **Shield Section 2**

Shield Section 2 is 96 in. long with 4 in. of lead shielding surrounding the 19-in. ID tubing.

6. **Shield Sections 3 and 4**

These sections are 72 in. long, with 6 in. of lead shielding. Section 3 is bolted to the bottom of Section 2, and Section 4 is bolted to the bottom of Section 3. O-ring seals are used between these sections. Three-in.-thick auxiliary shielding extends 10 ft up from the lower end of Section 4. This provides 9 in. of lead shielding in the fuel region for personnel protection.

This sectional construction permits disassembly for repairs, decontamination, or transportation. If unexpected difficulties are encountered during operation, the equipment may be separated at any of the connections, allowing access to the interior for repairs.

7. **Viewing Section**

The viewing section (see Figure 14) contains a replaceable periscope for observation of core elements as they are being raised or lowered. The periscope consists of a sealed rectangular tube containing two front-surface mirrors whose reflected image gives a true color picture of the FHM contents. Mirror width is adequate to permit normal binocular vision, therefore depth perception is good. Sufficient lighting is provided for photographing elements in the FHM through the periscope (see Figure 6). The viewing section contains 9 in. of lead shielding and serves as a mounting for the operating console, gas manifold, vacuum pump, electrical panels, motor starters, and biological shield hoists.
Figure 14. Viewing Section of Fuel Handling Machine
8. **Lower Adapter Assembly**

The lower adapter assembly (see Figure 6) contains a 6-in. vacuum-tight gate valve surrounded by 9 in. of lead shielding. The valve is manually operated with the hand wheel through an electromagnetic clutch to prevent operation out of sequence. A telescoping tube contained in a metal bellows is attached just below the gate valve (see Figure 15). The lower end of the tube incorporates a sealing face and indexing shroud to permit sealing of the FHM to the reactor or storage cells. Pneumatic cylinders controlled by a 4-way, dual solenoid valve, are used to extend or retract the bellows. A guide funnel (slug containment guard) for the guide tubes and a sodium drip pan are attached to the top of the section. A V-clamp is used to join the adapter assembly to the viewing section.

Penetrations through the shielding are made either tangentially or through embedded, helix-wound conduits.

9. **Biological Shield**

The biological shield is lowered during element transfers to shield the gap between the FHM and the floor. This gap is necessary to permit movement of the FHM from the reactor to storage or wash cells. The shield fits around the lower section and is suspended from three pneumatic cylinders which supply the vertical movement (see Figure 6).

10. **Bail Assembly**

The bail assembly, pinned to the 75-ton bridge crane hook, consists of a cross-member of two steel plates 114 by 15 by 3 in. wide, welded together with spacers between. Extending down from the cross-member are two support beams pinned to the FHM.

11. **FHM Auxiliary Equipment**

a. **Index Ring**

An index ring containing O-ring seals is placed over a port in the reactor top shield before the fuel handling machine is located over the fuel channel. The FHM, suspended from the 75-ton crane hook, is moved over the indexing ring and the telescoping tube (bellows seal) is lowered to seal against the index ring. The pendulum suspension of the FHM from the crane hook
Figure 15. Fuel Handling Machine Bellows Seal
permits visual indexing of the machine within ±1/4 in. Perfect alignment of the FHM is obtained when the telescoping tube slides down the conical surface on the index ring.

b. Carriage Assembly

The FHM carriage assembly is used to move the FHM into its storage area. The 75-ton crane hook and bridge are then free to perform other operations. The "ears" of the FHM bail rest on the top of the carriage which consists of a box frame with four 2-wheel trucks at the edges of the frame. The eight wheels ride on rails installed on the 75-ton bridge and in the storage area. Pivoted transfer links make the connection between the bridge crane and the storage area. One end of the carriage frame is a swinging beam allowing the FHM to enter the center of the carriage. The beam is then closed to form a part of the frame. The carriage is chain-driven by a 2-hp motor, underslung due to limited headroom. Carriage speed is 5 ft/min (see Figure 16).

c. Fuel Handling Machine Gas System

The FHM gas system is divided into two headers, namely a high pressure (100 psig) supplied from a nitrogen bottle, and a low pressure (10 psig) supplied from the plant helium supply header. The high-pressure nitrogen is used to operate the grapple release pistons and the pistons operating the bellows seal. The bellows seal is operated by a 4-way dual solenoid valve which will not change position if the power is lost. Rupture disks are included in the high-pressure header.

The low-pressure helium system is used for purging the inside of the FHM. The bellows region and the main FHM body may be evacuated and purged separately or together. A vacuum pump mounted on the FHM is used to evacuate the cask. This pump exhausts through a vent hose to the plant radioactive vent system.

The FHM gas system P & I is shown in Figure 17.

d. The 75-Ton Bridge Crane

The 75-ton bridge crane is used to transport the FHM in the SRE high-bay area. The bridge provides east-west travel at 34.5 ft/min, and a trolley mounted on the bridge provides north-south travel at 55 ft/min. Crane controls are mounted on a hanging pendant operated from the highbay floor. Each direction of travel is controlled by a separate button. The crane is normally moved
Figure 16. Fuel Handling Machine Carriage
Figure 17. Fuel Handling Machine Gas System P & I
in only one direction at a time, but in an emergency it may be operated in two
directions. Two men are present during operation. In an emergency, one man
can trip the crane power supply breaker located on the highbay wall, thereby
stopping crane operation.

B. FUEL HANDLING MACHINE INSTRUMENTATION

Instrumentation for the FSM consists of grapple travel indicators, grapple
load cells, an interlock indicating panel, a radiation detector, an oxygen ana-
lyzer, and pressure gauges. Switches, lights, instrumentation readout gauges,
etc., are located on a console attached to the FHM viewing section. See Fig-
ure 18 for control console layout.

1. Grapple Travel Indicator

Grapple travel indication is provided by a selsyn transmitter connected
to the grapple hoist motor. Signals from the transmitter are sent to the selsyn
receiver mounted in the control console. The receiver is connected through a
gear train to a veeder counter calibrated in inches of grapple travel. A separate
selsyn is provided for each of the two grapples.

2. Grapple Load Cells

A load cell is connected to the dead-leg of each grapple cable outside the
FHM dome. A load applied to the grapple is transmitted to the load cell, which
produces a voltage signal linearly proportional to the grapple load. The signal
voltage (0 to 10 mv) from the load cell is connected to the amplifier, where its
value is increased to 0 to 5 volts. The amplifier output signal is then sent to
the underload controller, overload controller, and load meter. The load meter
is connected to the 0 to 5-volt output from the amplifier, and is calibrated to
read load directly from 0 to 2000 lb.

The overload controller will stop grapple travel if the grapple load
exceeds the setpoint; and the underload controller will also stop grapple travel
if the grapple load becomes less than the setpoint. Both controllers compare
the output signal from the amplifier with an internally generated signal. An
adjustable control on the front of the controller is graduated from 0 to 100%,
Figure 18. Control Console Layout, Fuel Handling Machine
and is used to vary the internally generated signal. When the difference between the amplifier output signal and the generated signal approaches zero, the control relay is energized.

3. Interlock Indicating Panel

The interlock indicating panel consists of small instrument lights mounted on a panel under each named interlock on the FHM interlock table (Table 1). These instrument lights are energized when each interlock has been satisfied and are used as an operational aid for troubleshooting of the FHM during actual operation.

4. Console Indicating Lights

In addition to the interlock indicating panel, selected duplicate lights are mounted on the control console. These lights indicate: Grapple 1 or 2 in operating position, vacuum valve open or closed, bellows seal up or down, power to FHM, biological shield up or down, Grapple 1 or 2 in travel position, and Grapple 1 or 2 at upper limit switch. A light test circuit is provided for immediate testing of all FHM control console and interlock indicating panel lights.

5. Radiation Detector

A radiation detector is located in the biological shield to detect high radiation in the bellows region. This detector is replaceable without disassembly of the FHM. The read-out meter (1 mr/hr to 1000 R/hr) is mounted in the control console. The detector is included in the interlock circuit of the FSM to protect the operator and plant personnel by locking the bellows seal and biological shield in place if abnormal radiation readings are detected in the bellows region.

6. Oxygen Analyzer

An oxygen analyzer mounted on the viewing section of the FHM is used to continuously monitor the atmosphere in the machine. The oxygen content of the machine is maintained below 1% to prevent contamination of the reactor cover gas and to prevent oxidation of the sodium film remaining on elements removed from the reactor.

C. FUEL HANDLING MACHINE CONTROLS AND INTERLOCKS

The FHM controls and interlocks are designed to permit ease of operation and to provide maximum safety for SRE operating personnel, core elements,
and FHM components. The FHM electrical control schematic is shown in Figure 19.

Electrical power is applied to the bridge crane and FHM through contact shoes mounted on the 75-ton bridge which contact three 480-volt rails mounted on the building supports. A key lock switch is used to transfer power from the FHM motors to the crane controls. A mechanical interlock prevents insertion of the key into the lock unless the vacuum valve is closed. The control console is energized when electrical power is applied to the rails. Instruments, lights, and meters are energized but the motors are not, unless power is transferred through the key lock switch.

A selector switch with positions for all normal FHM operations is mounted on the control console. The selector switch circuit samples the interlocks for the selected operation and a light is energized if the required interlocks are satisfied. The selected operation may then be performed. If the "OK" light is not illuminated, a check of the interlock indicating panel will reveal which interlock is not satisfied.

Element protection is provided by grapple load cells. Each load cell (mounted in the cable dead leg) is adjustable and is set for a narrow operating band. As an element is being raised, any hangup will cause the load to increase. The overload relay (each grapple has a separate relay) will then be energized, causing a contact in the grapple circuit to open, thereby stopping the grapple hoist motors. Conversely, as an element is being lowered, any hangup will cause the load to decrease. The underload relay (each grapple has a separate relay) is energized, opening contacts in the grapple lower circuit stopping the element travel. The slack cable switch (mounted in the cable dead-leg) provides underload protection for the grapple by preventing the cable from unwinding from the drum. This switch consists of a springloaded plunger which opens a limit switch if the load is removed from the grapple and stops grapple travel. Element protection is also provided by a grapple cable weak link which consists of a short section of 1/8-in. wire cable. A disconnect plug attached to the weak link will be pulled apart if the weak link cable breaks due to an element hangup. This plug is connected in series with a relay which would open contacts in the 480-volt power supply, deenergizing the hoist motors on the FHM.
Protection of the FHM components is provided by interlocks (see Table 1) connected to the grapple upper limit switches, grapple rotation limit switches, bellows travel switch, vacuum valve position switches, biological shield limit switches, and a mechanically blocked power transfer switch which prevents movement of the 75-ton crane during FHM operation.

Grapple upper limit switches will stop the grapple at the topmost position of travel and will close a contact in the grapple rotation circuit. Both grapples must be in the top position before rotation is permitted. This protects the elements and guide tubes from damage due to rotation with guide tubes down. The grapple rotation limit switches will stop rotary motion when the selected grapple is in operating position. Interlocks prevent grapple rotation unless both grapples are loaded, the vacuum valve is open, the bellows seal is down, and the biological shield is down.

The 75-ton bridge crane is interlocked to prevent movement if either the bellows seal or biological shield is not at its upper limits or if the transfer links are down. These interlocks prevent damage to FHM components during travel.

The protection of personnel from radioactive elements and the prevention of radioactive contamination of the building are accomplished by interlocks which prevent the transfer of elements unless the bellows seal and the biological shield are at their lower limits. Interlocks prevent opening the vacuum valve unless the FHM has been properly indexed and the bellows region evacuated. Radioactive material is prevented from leaving the machine at all times by a system of interlocks that maintains an empty guide tube in the travel position, plugging the funnel to the gate valve. The guide tube is raised from the travel position only when the FHM is over an empty hole in the reactor or storage cells. Interlocks prevent movement of the 75-ton bridge crane unless the vacuum valve is closed and an empty guide tube is in the travel position. Additional operator protection is provided by a radiation alarm system which interlocks the 75-ton bridge crane, the biological shield and the bellows seal, thus preventing their operation if radioactive material is present in the bellows region. If the radiation detector is above normal, the biological shield and the bellows seal may not be raised.
Only three bypass switches are provided in the FHM control circuit. These bypasses allow raising of the operating grapple from the travel position to the topmost position, and rotation of the grapples if either or both of the grapples are not loaded. These bypasses permit unloading of the FHM before placing in temporary storage, or loading after removal from storage. All other interlocks may be bypassed only by rewiring the FHM control circuits.

D. OPERATION OF THE MARK II FUEL HANDLING MACHINE

1. Description of a Typical Fuel Transfer

SRE Standard Operating Procedures 40 and 41 present the step-by-step directions for operation of the FHM; however, a sequence of operations for one complete transfer cycle over the reactor is presented below. The operations are listed according to the selector switch positions from 1 to 13. The selector switch must be positioned for each desired operation and the "OK" light must be energized before the operation can be performed. The interlocks which must be satisfied before the selected operation can be performed are shown in Table 1.

At the position where the transfer is to be performed, the element number and position number are checked against the element and position number given in the ETR. The proper lifting adapter is attached to the element shield plug and the index ring is positioned over the element.

a. Position 1. Operate 75-Ton Bridge Crane

The FHM is indexed over the element by sighting with a mirror, moving the FHM in north-south and east-west directions until the bellows is centered over the index ring within \( \frac{1}{4} \) in.

b. Position 2. Lower Bellows Seal

Power is transferred from the bridge crane by a key lock switch, and a solenoid valve is energized to lower the bellows seal.

c. Position 3. Evacuate Bellows Region

The bellows region is evacuated to check the seal between the FHM and the reactor by opening the valve to the vacuum pump and allowing the pressure to decrease to 25 in. of mercury vacuum. The bellows region is then pressurized with helium to 3 psig.
d. **Position 4. Lower Biological Shield**

The biological shield is lowered until it rests on the highbay floor.

e. **Position 5. Open Vacuum Valve**

The vacuum valve is opened by turning a hand wheel on the side of the FHM which is interlocked to prevent operation until the preceding sequence has been completed.

f. **Position 6. Lower and Engage Grapple 1 or 2**

The empty guide tube is lowered by the grapple from the travel position until it is supported in the mating socket below the valve with none of its weight hanging on the grapple. The setting on the underload controller dial is decreased to a position that will just permit downward travel of the empty grapple. The empty grapple is then lowered. As the grapple nears the core element the grapple release valve on the control console is pressed, retracting the grapple fingers while simultaneously lowering the grapple until it indicates underload. The grapple release valve is released, thus allowing the grapple fingers to engage the element.

g. **Position 7. Raise Grapple 1 or 2 to Rotate Position**

The overload controller dial is set to a point that will just permit upward travel of the loaded grapple. The element is observed through the periscope and its condition is noted as it is being raised. When the grapple reaches the pick-up position of the guide tube, the overload controller dial setting is increased to a position that will permit the grapple to raise the guide tube to the upper-limit switch. The grapple is then raised to the upper limit.

h. **Position 8. Rotate Grapple Positions**

The hoist assembly is rotated 90° until the alternate grapple and element are in the operating position.

i. **Position 9. Lower Grapple 1 or 2**

The alternate grapple with the replacement element is lowered until the guide tube supports itself in the mating socket below the valve with none of its weight hanging on the grapple. The setting on the underload controller dial
is decreased to a position that will just permit downward travel of the element and grapple. The grapple is continuously lowered until the element is seated in the reactor loading face. The element is observed in the periscope while it is being lowered and any abnormal condition is noted.

j. Position 10. Release and Raise Grapple 1 or 2 to Travel Position

The grapple is released by pressing the grapple release valve on the control console which retracts the grapple fingers. The grapple is simultaneously raised and the load indication checked to verify that the element has been released. The overload controller dial is set to a point that will just permit upward travel of the grapple. When the grapple reaches the pickup position of the guide tube, the overload controller dial setting is increased to permit the grapple to raise the guide tube to the travel position. The empty grapple is then raised to the travel position where it automatically stops.

k. Position 11. Close Vacuum Valve

The vacuum valve is closed by turning a hand wheel on the side of the FHM.

l. Position 12. Raise Biological Shield

The biological shield is raised to its upper limit. The bellows region is evacuated to 25 in. of mercury vacuum and purged with helium to atmospheric pressure.

m. Position 13. Raise Bellows Seal

The solenoid valve is energized to raise the bellows seal. The power is then transferred back to the 75-ton bridge crane by a key lock switch.

2. Radiation Dose to Personnel During Fuel Transfers

The radiation shielding on the FHM consists of an equivalent of 9-1/2 in. of solid lead for a height of over 10 ft (more than adequate to cover the 6-ft active fuel section). Assuming that the cask contained a Core III fuel element which had been operating at the highest power \((1.60 \text{ Mwt})^2\) for a period of 1 yr and then cooled for 2 wk prior to placing the element in the FHM, the maximum radiation level at the surface would be 370 mr/hr\(^2\). The average fuel element would give a maximum radiation level at the FHM surface of 220 mr/hr\(^2\). The
dose rate to personnel as the distance from the FHM increases is shown in Figure 20. Personnel radiation exposure is limited to 300 mr/wk and as the distance from the cask is increased, the radiation level drops and the allowed operating time increases. During operation of the FHM, the operator stands at the control console for about 10 min while raising or lowering core elements. At this time, he is about 2 ft from the surface of the cask and has an additional 4 to 8 in. of lead shielding mounted on the viewing section behind the control console. During the rest of the operation, the operator handles the crane at about 10 to 15 ft from the cask, but with only the normal shielding.

![Diagram](image)

**Figure 20. Radiation Dose to Personnel During Fuel Transfers in Fuel Handling Machine**

An operator can move about 10 fuel elements from the reactor to the storage cell in a regular 8-hr shift, and he could work two 8-hr shifts before receiving 300 mr. Since the planned reactor fuel loading is 33 elements, the entire core could be unloaded in less than four shifts; thus normally no one operating crew would handle more than 13 elements during a complete fuel change.
E. FHM DESIGN AND SAFETY FEATURES

Special features of the Mark II FHM which contribute to the usefulness and safety of the machine deserve further attention.

1. Radiation Detector

A radiation detector mounted in the biological shield indicates any abnormally high radiation levels in the bellows region. The detector tube is accessible for service or replacement without disassembly of the machine. This detector is connected to the FHM control circuit and immobilizes the machine if an abnormal radiation condition exists in the bellows region. This prevents the release of radioactive material from the FHM and also protects the operator from exposure to radiation from any material which might fall into the bellows region.

2. Interlocks on Vacuum Valve

The vacuum valve is mechanically and electrically interlocked to prevent its operation unless the FHM is sealed to the reactor, storage cell, wash cell, or maintenance cell. The valve cannot be opened during transport of the FHM over the highbay floor. Radioactive material is positively contained within the FHM by the vacuum valve.

3. Travel Position for Operation Grapple

When the operating grapple is in the travel position, the lower end of the guide tube blocks the hole over the vacuum valve. The guide tube cannot be raised above the travel position unless there is an open hole below the FHM to the reactor, storage cells, or wash cells. This prevents loose material from a damaged element on the other grapple reaching the top of the vacuum valve and eventually the highbay floor. The FHM may be moved only if the operating grapple is empty and in the travel position.

4. Pendulum Suspension of the FHM

The pendulum suspension of the FHM has the advantage of allowing greater tolerances for indexing than would a rigidly mounted machine. This free suspension permits visual indexing of the FHM over a core element within ±1/4 in. As the telescoping tube is lowered, the lower end of the FHM is automatically adjusted to the proper index by the taper on the index ring which is fitted over the core element port.
5. **Sectional Construction**

The sectional construction of the FHM permits disassembly for repairs, decontamination, or transportation. If unexpected difficulties are encountered during operation, the equipment may be separated at any of the connections, thus allowing access to the interior for repairs.

6. **External Mounting of Load Control Equipment and Limit Switches**

All load control equipment and, whenever possible, limit switches are mounted externally for easy adjustment and repair. The load cells, load switches, slack cable switches, and the cable weak links are attached to the free ends of the lifting cables (called the dead-leg). In the event of a hoist motor failure during a fuel handling operation, outside hoisting equipment may be attached to the free cable ends for continuation of the lifting operation.

**F. HANDLING OF DAMAGED FUEL IN THE FHM**

The purpose of the FHM is to safely remove core elements from the reactor. At times during the operation of the SRE Mark II FHM it may be necessary to handle damaged fuel. The safety of the FHM operator, SRE personnel, and SRE equipment must be assured during fuel-handling operations. To prevent releasing contamination to the atmosphere, any broken fuel must be contained at all times during the transfer operation in the inert atmosphere of the FHM.

The following sections discuss possible problems involved in handling damaged fuel.

1. **Broken Fuel Element in the FHM**

A broken fuel element (fuel rod completely severed) or an element with severe cladding damage (fuel slug exposed) is the most potentially dangerous type of damaged fuel element to handle in the FHM. Other types of fuel element damage include a bent lower guide, a broken TC, dented cladding, or a pinpoint hole in the cladding.

Broken fuel has been successfully handled in the Mark II FHM during the SRE recovery program and shipped to storage in the fuel transport cask. The debris from an element damaged in the reactor would remain in the reactor,
whereas the debris from a broken element in the FHM would be contained in the FHM. This report will not discuss removal of debris from the reactor. Experience during the SRE recovery program has shown that fuel slugs may be removed from the reactor.

After reviewing the safety features of the FHM used during Core II operations, additional safety features were added for Core III operation to assure containment of broken fuel in the FHM. The possible problems postulated during the review of the FHM safety features are shown in Figures 7 and 8. The solutions are shown in the same figures. These possible problems are: (1) the FHM vacuum valve could be opened out of sequence, thereby releasing the FHM atmosphere; (2) fuel from a broken element could drop to the top of the vacuum valve and be released from the machine when the valve was opened; (3) small fuel particles from a broken element could drop undetected into the bellows region and be exposed to the atmosphere. The following modifications provide solutions to these problems: (1) mechanical and electrical interlocks for the vacuum valve maintain the proper operating sequence; (2) a travel position for the operating grapple blocks the hole over the vacuum valve; and (3) a radiation detector constantly monitors the bellows region.

Both undamaged and damaged fuel are removed from the reactor in the same manner. (See Appendix, Section D., for fuel removal procedures.) A broken fuel element removed from the reactor could have exposed fuel slugs which might become dislodged in the FHM. During the fuel removal and grapple rotation operation, the vacuum valve is open and the FHM exit hole is open to the reactor. Any dislodged fuel slugs, fuel particles, or fuel cladding would fall into the reactor as the element is raised; and any fuel dislodged during rotation would fall either into the reactor or onto the FHM drip pan (see Figure 10). Fuel on the FHM drip pan would remain there until retrieved at a later date. Such fuel could not reach the closed vacuum valve due to the lip (slug containment guard) on the drip pan around the opening to the vacuum valve, and would be contained in the FHM. After the replacement element is inserted into the reactor, the guide tube and empty grapple return to the travel position, at which time the vacuum valve may be closed. The guide tube in the travel position effectively blocks the hole over the vacuum valve, so that, only fuel particles smaller than 1/16-in. diameter could reach the dished top of the
vacuum valve. (Particles are still contained in the FHM when on top of the vacuum valve.) The guide tube may not be lifted above the travel position unless the FHM is indexed and an open hole to the reactor or storage cell is below the FHM. The FHM may not be moved unless the operating grapple (grapple over valve) is empty and in the travel position (see Table of Interlocks, Table 1). If fuel particles (less than 1/16 in.) from a broken fuel element should fall between the FHM and guide tube into the bellows region, a radiation detector would immobilize the FHM, preventing exposure of personnel to radiation and the release of fuel to the highbay. Particles reaching the bellows region would be contained by the FHM and the bellows seal. Interlocks prevent movement of the FHM and special maintenance procedures would be required to recover the fuel particles. The FHM may be moved if fuel particles from a broken element are on the drip pan (but not in the bellows region) since they are safely contained in the FHM.

Pieces of fuel or fuel slugs may be fished from the drip pan of the FHM after unloading the machine by separating the viewing and lower adapter sections from shielded section 4 and remotely encapsulating the fuel. Special maintenance procedures would be necessary for the removal of fuel particles from the FHM and of damaged fuel from the reactor.

2. Bowed Element in FHM

The element guide tubes are smooth on the inside with a 6-in. ID, but a badly bowed fuel element could be pulled into a guide tube, becoming firmly wedged. The Mark II FHM grapple motors cannot push, and depend upon the weight of the element for lowering operations. The FHM would provide containment for the bowed element wedged in a guide tube until special procedures could be written for the removal of the guide-tube. To provide an operational escape in such a case, the guide-tube with the lodged fuel may be lowered into a disposal hole and released.

To remove a guide-tube, after preparing special procedures, the FHM is lowered by the 75-ton bridge crane until the lower adapter assembly rests on the floor. The lower assembly is detached by a quick disconnect clamp, the open-bottomed FHM is moved over a disposal hole, and the guide tube containing the fuel is lowered therein. The grapple may be salvaged by disconnecting the top plate on the guide tube and removing the grapple.
A new guide tube may be raised into position in the FHM, the lower adapter section reattached, and the FHM is ready again for operation.

3. Dropping a Fuel Element in the FHM

Mechanical failures which could lead to dropping a fuel element have been discussed in Section G. of the Appendix, but the preventive features of the FHM will be mentioned again.

The three grapple latch fingers are spring-loaded in the latched position, and a lip on the element prevents their release unless the load is removed from the grapple. The grapple hoist motor has a spring-loaded brake which is engaged when the motor is deenergized. Friction in the hoist motor and the gear reducer will also prevent travel even with a fully-loaded grapple. The grapple cable is in series with a weak link which would break and stop the hoist motor before the cable would break. When the weak link cable breaks the grapple would be allowed to drop no more than 1 in.

G. CONSEQUENCES OF CREDIBLE ACCIDENTS TO THE FHM CAUSED BY OPERATOR OR EQUIPMENT FAILURES DURING FUEL HANDLING OPERATIONS

The SRE Mark II FHM contains interlocks and special design features which ensure operational safety of the machine, but accidents caused by equipment failures or operator errors are not impossible. Each credible accident is discussed under the corresponding FHM operation where it could occur. The 13 basic operations for one complete fuel transfer cycle over any of the normal locations (reactor, storage cell, or wash cell) are listed in sequence as follows.

1. Move FHM With the 75-Ton Bridge Crane
   a. Loss of Gas Pressure to Telescoping Bellows During Travel

   Loss of gas pressure to the FHM could be caused by a damaged nitrogen supply hose. The telescoping bellows is held in the up position by two gas pistons. A springloaded checkvalve in the high pressure line prevents loss of gas pressure to the bellows gas pistons, and would prevent the bellows from relaxing and dragging on the floor as the FHM is moving. A damaged nitrogen hose would not result in a damaged bellows, and the only repairs necessary would be those to the nitrogen hose.
b. Lower FHM Onto the Index Ring

During indexing, if the FHM is lowered until it rests on the index ring, the telescoping tube guide may be bent, resulting in binding of the bellows seal. The tube guide and bellows seal must be removed and repaired before attempting fuel transfers. Special procedures would be required, but the tube guide and bellows seal can be removed from the FHM with an irradiated fuel element in the machine. Containment of the FHM atmosphere would be maintained during this operation.

c. Fuel Overheating in FHM

Before performing fuel handling operations, irradiated fuel is allowed to decay in the reactor (special test element full power generation is approximately 1.24 Mw) to a heat generation level which limits fuel element temperature rise to 1200°F in the FHM. (This decay time is calculated before removing fuel from the reactor.)

Due to a series of operational errors, a fuel element could be pulled from the reactor 10 hr after reactor shutdown (the time required to complete operational procedures for fuel handling operations after full-power operation). This element could increase in temperature from the sodium temperature of 500°F at an initial rate of 170°F/min. If the transfer is made normally, the temperature would not increase above 1200°F (normal reactor temperature), but if the element remained in the FHM longer than usual, the temperature could rise to 1700°F. Heat generated in a fuel element is transferred to the FHM body by radiation and free convection. The helium temperature would reach about 170°F, and, as the internal pressure increased, gas would be vented through a hose connecting the FHM to the radioactive vent system.

Cladding temperatures of 1700°F during fuel handling operations could result in cladding failure, releasing fission gases and sodium bonding to the FHM. (See PEP hazards report, NAA-SR-9516, for the gas activity.) Any cladding failures would be the result of decreased cladding strength and increased gas pressure at 1700°F within the individual fuel rods. Containment of fission gases, sodium, and any fuel particles would be provided by the FHM as shown in Figures 7, 8, and 9. See Appendix, Section F., for the handling of damaged fuel.
2. Lower Bellows Seal
   a. Power Lost to Solenoid Valve After Lowering Bellows

      The 4-way dual solenoid valve on the supply line to the bellows seal contains two solenoids which operate a main valve. This valve opens when one solenoid is energized, and remains in position when the solenoid is deenergized. The opposite solenoid must be energized to return the valve to its original position. The loss of power to the FHM will not affect the position of the bellows seal during FHM operation.

3. Evacuate and Purge Bellows Region
   a. Bellows Region Does Not Seal After Lowering Bellows

      The bellows region is evacuated to check for gas leaks after lowering the bellows seal. A leak in that area could be due to a damaged O-ring on the index ring or a crack in the bellows. The O-ring can be easily replaced by moving the FHM and checking O-rings on the index ring. Interlocks prevent proceeding to the next operation unless a vacuum can be established in the bellows region. This insures that a gas-tight seal has been established between the reactor and the FHM. A cracked bellows would be easily detected thereby, preventing subsequent operations. Reactor and FHM atmospheres would be maintained. Special procedures for replacement of the bellows would be necessary if the FHM contained an irradiated fuel element. Containment of the FHM atmosphere would be maintained during replacement of the bellows.

4. Lower Biological Shield

   No credible accidents are postulated for this operation.

5. Open Vacuum Valve
   a. Vacuum Valve Jams Partially Open

      If the vacuum valve, gear reducer, or extension shaft breaks, the valve could jam in a partially opened position and prevent unloading of a fuel element. Containment of the fuel element and the FHM atmosphere would be maintained by the FHM and the bellows seal. The bellows seal which has already been sealed to the reactor is interlocked to prevent movement unless the vacuum valve is closed. (See Table 1, "FHM Interlocks.") Special maintenance procedures would be required for repair of the valve. Containment
of the fuel element and the FHM atmosphere would be maintained at all times while the procedures were being prepared.

6. **Lower and Engage Grapple 1 or 2 (Empty Grapple)**

   a. **Hoist Motor Fails**

      The grapple hoist motor could fail during lowering but no damage would occur since the motor is equipped with a spring-loaded brake. After preparing special procedures, a hoisting device could be attached to the free end of the cable (dead-leg) outside the machine to raise the guide tube to the rotate position. The fuel element may be removed before replacing the grapple hoist motor. Spare parts are stocked for this type of equipment failure.

   b. **Unwinding Excess Grapple Cable From Hoist Drum**

      Should the load be removed from the grapple, safety devices prevent unwinding cable from the hoist drum. A load cell, adjusted by the operator during the lowering operation, opens a set of contacts in the grapple motor circuit if the weight on the grapple cable is less than the setpoint. The operator errs if he does not correctly set the load cell, but a slack cable switch will also open contacts in the hoist motor circuit if the weight is removed from the cable. The hoist motor brake immediately stops the cable drum when the motor is deenergized.

   c. **Loss of Gas Pressure After Engaging Element**

      The grapple fingers are spring-loaded and designed to remain in the normally open (latch) position. Gas pressure is required to retract the fingers. If a sudden loss of gas pressure occurs due to grapple helium hose failure inside the FHM after engaging the element, it would not be possible to remotely disengage the grapple (the manual release must be used) until gas pressure is again restored. The loss of gas pressure could not cause an accidental release of an element by the grapple.

   d. **Actuation of Grapple Release Valve With Core Element Suspended on Grapple**

      The grapple and core element adapter ring have been designed to prevent the accidental release of an element from the grapple. The grapple cannot be released unless the weight of the element has been removed. The grapple fingers are kept in place by a lip on the element adapter ring (see...
Figure 3). The operator would err if he actuates the grapple release valve before the element is in the proper position, but the element would not be released. If through some incredible set of circumstances a fuel element was dropped in the FHM, the fuel element and cask atmosphere would be contained within the FHM. (See Appendix, Section F.)

7. Raise Grapple 1 or 2 to Rotate Position (Grapple-Loaded)

a. Grapple Hoist Motor Fails

If the grapple hoist motor fails or a power failure occurs, the spring-loaded motor brake will immediately stop the grapple travel. During fuel transfers, the temperature of an irradiated fuel element could approach 1200°F (normal reactor temperature) if left in the FHM for several hours. If the element-lifting operation is interrupted with the fuel region of an element next to the index ring, the high fuel element temperature could damage an O-ring seal on the index ring. The FHM operator would have an estimated 1/2 to 3/4 of an hour to resume the lifting operation or cool the index ring. The index ring may be cooled by purging the FHM with helium from the plant helium supply at 40 cfm and venting the reactor atmosphere, thereby cooling the element for about 1 hr. The vent and purge lines are connected during FHM operation. The element could probably be moved within 1.5 hr but, if not, damage to the O-ring could release reactor cover gas to the highbay. Since the fuel element temperature would not exceed the temperature of the operating reactor, no cladding damage would occur. The released material would not present an undue hazard to operating personnel and the consequences would be less severe than those described in the "SRE PEP Reactor Safety Analysis Report," NAA-SR-9516, Section XIV. E. 1, since purging the reactor cover gas with helium during the 1-hr cooling period would sweep most of the gaseous fission products out of the reactor to the radioactive decay tanks.

The series of accidents leading to the inadvertent pulling of a fuel element before sufficient cooling time, followed by sticking, overheating, and cladding failure with the release of core cover gas is considered incredible due to the number of independent failures or errors required.

b. Element Hangs up During Lifting Operation

The FHM guide tubes provide a smooth bore which is continuous from the face of the reactor, offering little chance for element hangup. The
operator sets the overload controller before pulling an element, so that the load cell will deenergize the grapple hoist motor, should the element hang up. If the operator fails to properly set the overload controller and the element hangs up, the cable weak link would break disconnecting power to the FHM before the grapple cable could break or before seriously damaging the element. The case of a stuck fuel element will be discussed in Appendix, Section F. A motor overload switch protects the grapple hoist motors.

   c. **Upper Limit Switch Failure**

   The failure of the upper limit switch to deenergize the grapple hoist motor would result only in damage to the limit switch and actuating rod. The grapple overload switch would stop the grapple hoist motor. If the operator did not properly set the overload controller, the grapple cable weak link would break disconnecting power to the FHM hoist motors. The weak link could be repaired and the fuel elements unloaded from the FHM before repairing the switch.

   d. **Loss of Gas Pressure to Bellows Seal**

   Interlocks prevent operation out of sequence of the solenoid valve which controls the bellows seal. A springloaded check valve in the helium supply line prevents loss of gas pressure to the gas pistons which operate the bellows seal. During the FHM operation, the bellows seal will remain sealed to the reactor providing containment for the reactor and FHM atmospheres, and may be operated only in the proper sequence. The loss of helium supply pressure will not initiate operation of the bellows seal.

8. **Rotate Grapple Positions**

   a. **Rotation Motor Fails**

   No accident could occur as the result of loss of power to or failure of the externally mounted rotation motor. Rotation simply would be interrupted while the motor was repaired or replaced. Spare parts are in stock.

   b. **Rotation Motor Limit Switch Fails**

   Limit switches mounted on the FHM body deenergize the dome rotation motor at the desired position. A failure of one of these switches would permit the rotation motor to continue to rotate the dome until the spur gear ran
off the rack. The fuel elements inside would not be damaged, and neither would
the rotation motor. Only the externally mounted limit switch would be damaged,
and could be easily replaced.

9. **Lower Grapple 1 or 2 (Loaded Grapple)**
   a. **Hoist Motor Fails**

   The grapple hoist motor could fail during element lowering but no
damage would occur since the motor is equipped with a springloaded brake.

   b. **Element Hangs Up During Lowering Operation**

   Core elements have been designed with special guides and smooth
edges which offer little chance for element hang up during the lowering opera-
tion. The operator sets the underload switch before lowering the element, so
that the load cell will deenergize the grapple hoist motor should the element
hang up. If the operator fails to set the underload controller and the element
hangs up, the slack cable switch will deenergize the hoist motor before un-
winding the grapple cable from the cable drum. If the operator properly sets
the underload controller, the fuel element would not be damaged due to a hang-
up. The grapple travel speed is 8 ft/min. Minor damage to a fuel element,
such as a bent lower guide, could result should the operator fail to set the
underload controller.

10. **Release and Raise Grapple 1 or 2 to Travel Position (Unloaded Grapple)**
   a. **Hoist Motor Failure**

   The grapple hoist motor could fail during lifting but no damage would
result since the motor is equipped with a springloaded brake. A hoisting device
could be attached to the free end of the cable (dead-leg) outside the machine,
and the empty guide tube raised to the rotate position. Using special procedures,
the fuel element may be removed before replacing the grapple hoist motor.

   b. **Limit Switch at Travel Position Fails**

   The unloaded grapple is always stopped in the travel position. The
guide tube in the travel position blocks the hole over the vacuum valve, prevent-
ing foreign material from entering the bellows region. If this limit-switch fails
in the open position, the grapple would be allowed to pass the travel position but
would be stopped at the upper limit. The FHM interlocks would not be satisfied for subsequent operations, and the light on the interlock indicating panel would not be energized. Special electrical hookups would be required to unload the fuel element before replacing the limit switch.

Conversely, should the travel position limit-switch fail in the closed position, power would be interrupted to the hoist motor. The light on the control console would indicate that the grapple is in the travel position. The vacuum valve could not be closed, and a visual check of the periscope and grapple position indicator would reveal the true position of the grapple. Special electrical connections could be made to unload the FHM before replacing the faulty switch.

c. Loss of Gas Pressure Before Disengaging Element

The springloaded grapple fingers which are actuated by a gas piston remain the normally open (latched) position. To release the grapple, all weight must be removed from the grapple and gas pressure must be applied to the gas piston. The loss of gas pressure would prevent remote release of the fuel element from the grapple. This loss of pressure could be caused by a grapple hose failure in the FHM. After preparing special procedures, the element could be released by lifting the biological shield and the bellows seal and operating the manual release. The other element could be removed from the machine and the faulty hose repaired.

11. Close Vacuum Valve

a. Vacuum Valve Jams Partially Open

See Section 5a. (The integrity of the reactor would not be disturbed since the element swap has already been performed.)

b. Vacuum Valve Closed Against Fuel Element

The FHM vacuum valve cannot be closed against a fuel element in the cask. The guide tube which is lifted from its mating socket by the grapple blocks the path of the vacuum valve until the guide tube and element are lifted above the valve.

12. Raise Biological Shield

No credible accidents are postulated for this externally mounted equipment.
13. Raise Bellows Seal

a. Bellows Seal Fails to Raise

A loss of gas supply, faulty gas piston, or a binding telescoping tube could prevent the lifting of the bellows seal. Special procedures would be written to permit lifting of the FHM with the 75-ton bridge crane to permit movement away from the reactor for repairs. Gas containment of the FHM would be maintained during repair to the bellows seal or gas pistons.

H. MAINTENANCE OF FHM

1. Disassembly of Unloaded FHM

The disassembly sequence for the major FHM sections is divided into disassembly positions (see Figure 21) as follows.

a. Position I (FHM Resting on Highbay Floor)
   1) Remove biological shield
   2) Remove lower adapter section
   3) Disconnect all plumbing and electrical gear from lower adapter section

b. Position II (FHM Resting on Highbay Floor)
   1) Remove upper auxiliary shield segment
   2) Remove lower auxiliary shield segments
   3) Remove viewing section

c. Position III (FHM Over Empty Moderator Can Storage Cell)
   1) Remove shielded sections 3 and 4 as one unit, as follows.
      a) Unbolt upper flange
      b) Raise upper part of cask until flange joints on guide tubes are visible
   2) Remove guide tubes as follows.
      a) Clamp lower guide tubes in place
      b) Unbolt lower guide tubes
      c) Raise upper section of FHM 6 in.
DISASSEMBLY SEQUENCE

POSITION I (HIGH BAY FLOOR)
1. REMOVE MOBILESHEILD.
2. REMOVE LOWER ADAPTOR SECTION.
3. DISCONNECT ALL PLUMBING AND ELECTRICAL GEAR.

POSITION V (HIGH BAY FLOOR)
1. REMOVE VIEWING SECTION.

POSITION III (CASK OVER MODERATOR CAN STORAGE CELL, OR PIPE TRENCH BETWEEN WASH AND STORAGE CELLS)
1. REMOVE (2) 9693-7858-4 SECTIONS AS ONE UNIT AS FOLLOWS.
   A. UNBOLT Upper FLANGE.
   B. RAISE Upper END OF CASK UNTIL FLANGE JOINTS ON GUIDE TUBES ARE VISIBLE.

2. REMOVE GUIDE TUBES AS FOLLOWS.
   A. CLAMP LOWER GUIDE TUBES IN PLACE.
   B. UNBOLT LOWER GUIDE TUBES.
   C. RAISE Upper SECTION OF CASK 6 IN.
   D. BOLT UPPER GUIDE TUBES TO LOWER TORQUE TUBE ASSEMBLY.

POSITION IV (CASK OVER 4-FT-WIDE TRENCH EAST OF MODERATOR CAN STORAGE CELL)
1. LOWER CASK ONTO SPECIAL STAND POSITIONED OVER PIPE TRENCH.
2. SECURE CASK TO BAIL SO IT CANNOT SWING.
   A. LOWER END OF TORQUE TUBE ASSEMBLY WILL BE BELOW FLOOR LEVEL.
3. REMOVE LIFTING ARMS.
4. REMOVE "J" CLAMPS.
5. LIFT CASK UNTIL TORQUE TUBE ASSEMBLY CLEARS THE 8 FEET SECTION.

POSITION VII (CASK OVER SHIPPIING CASK STORAGE CELL)
1. REMOVE MILLER BEARINGS.
2. LIFT CASK UNTIL UPPER END OF TORQUE TUBE IS VISIBLE.
3. INSTALL 2 BY 4 CRIBBING UNDER TORQUE TUBE PLATE.
4. REMOVE BOLTS THAT HOLD TORQUE TUBE IN PLACE.
5. REMOVE GUIDE TUBES FROM GRAPPLES.
6. REMOVE Pins THAT HOLD BAIL ARMS.
7. LIFT DOME ASSEMBLY OUT OF WAY.
8. REMOVE TORQUE AND GUIDE TUBE ASSEMBLIES FROM UPPER SHIELD SECTION, USING 5-TON CRANE.
9. REINSTALL DOME ON UPPER SECTION.
10. REPLACE BAIL PINS.
11. REPLACE MILLER BEARINGS.
12. SET DOME AND UPPER SHIELD SECTION IN STAND PROVIDED.
13. REMOVE BAIL ASSEMBLY (NOTE: STEP 13 MAY BE OMITTED IF DOME IS NOT REMOVED FROM HIGH BAY AREA).
d) Bolt upper guide tubes to lower torque tube assembly

d. Position IV (FHM Over 4-ft-Wide Pipe Trench East of Moderator Can Storage Cell)

1) Lower FHM onto shoring positioned over pipe trench

   Note: Lower end of torque tube assembly will be below floor level.

2) Secure FHM dome to bail so it cannot swing

3) Remove lifting arms

4) Remove V-clamp between shielded section 1 and 2

5) Lift FHM until torque tube assembly clears shielded section 2

e. Position V (FHM Over Shipping Cask Storage Cell)

1) Lower FHM onto shoring over shipping cask storage cell

2) Remove hoist assembly roller bearings

3) Remove pins that hold bail arms

4) Lift FHM until upper end of torque tube is visible

5) Install 2 x 4 cribbing under torque tube plate

6) Remove bolts that hold torque tube in place

7) Remove guide tubes from grapples

8) Lift hoist assembly out of way

9) Remove torque and guide tube assemblies from upper shield section, using the 5-ton crane

10) Reinstall hoist assembly on shielded section 1

11) Remove bail assembly

2. Assembly of FHM

   Reassemble in reverse order.

3. Routine Maintenance of FHM

   Maintenance of the FHM is a regular part of the SRE preventive maintenance program. This program includes inspection and lubrication of the FHM motors, lubrication of the vacuum pump, and inspection of the control panel light bulbs.
TABLE 2
AI DRAWING NUMBERS

I  FHM Assembly Drawing
   9693-782258  Assembly – FHC

II FHM Subassembly Drawings
   9693-782189  Shield Section Assembly, FHC – Upper
   9693-782192  Adapter Assembly – FH Cask – Lower
   9693-782198  Moveable Shield Assembly – FHC – Lower
   9693-782199  Turnbuckle Assembly – FHC Lower Adapter
   9693-782203  Pan – FHC Drip
   9693-782204  Adapter Assembly – Loading Face Seal
   9693-782205  Hoist Assembly – Fuel Handling Conversion
   9693-782207  Ring – FHC – Hoist Base Plate Seal
   9693-782214  Bracket Assembly – Index Motor Support
   9693-782217  Bracket Assembly – Index Limit Switch
   9693-782219  Block – Seal Ring Bearing
   9693-782221  Drive Gear – FHC Hoist Assembly – Indexing
   9693-782242  Pickup Assembly – FHC (grapples)
   9693-782262  FHC – Electrical Equipment Mounting Details
   9693-782263  Collar – FHC – Cask Lower Pickup
   9693-782264  Spreader Assembly – FHC Cask Pickup
   9693-782265  Pin – FHC – Cask Pickup Hinge
   9693-782266  Bar – FHC – Cask Pickup
   9693-782267  Fittings – FHC – Cask Pickup Bar End
   9693-782287  Viewing Section – FHC
   9693-782291  Bail Assembly – FHC Cask
   9693-782293  Tube Assembly – Air Cooled FHC – Torque and Guide
   9693-782299  Shield Segment – FHC – Lower Auxiliary
   9693-782300  Shield Segment Assembly – FHC – Upper Auxiliary
   9693-782302  Details – FHC Cask – Flange and Gasket
   9693-782313  Sketch Periscope Assembly – FHC Cask
   9693-78587-4 Shield Section Assembly – Moderator Can Cask Center
   9693-785100 Shield Section Assembly – Moderator Can Cask – Upper
   7642-HM005  Mark II FHM Modification Control Console

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### TABLE 2 (Continued)

#### III FHM Electrical Drawings
- 7602-94002  FHM Overhead Power Installation
- 9693-9782337  Underload Switch — SRE
- 7642-HM001  Mark II FHM Electrical Control Schematic
- 7642-HM002  Mark II FHM Modification Wiring Diagram
- 7642-HM006  Mark II FHM Modification Control Console Layout
- 7642-HM004  Mark II FHM Modification — Key Lock Switch Interlock
- 7642-HM007  FHM Modification Relay Cabinet Layout

#### IV FHM Gas System Drawings
- 7642-HM003  Mark II FHM Modification Gas System P&I
- 7642-HM008  Mark II FHM Modification — High Pressure Gas System Header

#### V FHM Carriage Drawings
- 303-143-S78  General Arrangement
- 303-143-S79  Truck Beam Details
- 303-143-S80  Details
- 303-143-M26  Drive Arrangement and Details
REFERENCES


8. Internal Letter to C. W. Griffin from C. G. Johnson, "SRE-PEP Safety Analysis of Index Ring," 7602-1370-717-897