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SRE CORE RECOVERY PROGRAM

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A DIVISION OF NORTH AMERICAN AVIATION, INC.

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SRE CORE RECOVERY PROGRAM

BY

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ABSTRACT

During an experimental nuclear power run at the Sodium Reactor Experiment (SRE), a leak occurred which allowed from 2 to 10 gal of organic material, commercially known as tetralin, to enter and decompose in the reactor core. Carbonaceous residue products reduced the sodium coolant flow in fuel channels to such an extent that 13 out of 43 fuel elements were damaged.

A substantial quantity of special equipment was developed, tested, and utilized to assess the situation, remove 81 loose fuel slugs plus other debris from the reactor core, and replace 16 moderator cans, 12 of which contained portions of fuel elements.

On-site recovery operations were safely and successfully performed by SRE operating and maintenance personnel. Work progressed 24 hours per day with the crews following a rotating schedule. In no instance did radiation exposure exceed standard AEC tolerances. On the average, exposure was less than a third of this tolerance.

I. INTRODUCTION

A. OBJECTIVE

Objective of the Sodium Reactor Experiment (SRE) Core Recovery Program was to assess extent of reactor damage, remove damaged fuel element components and other material from the reactor core, and to replace all defective moderator cans.

B. PURPOSE

Purpose of the project was to place the SRE reactor core into a condition which would allow a continuation of research and development operations with new loadings of reactor fuel.

C. DISCUSSION

The SRE, Figure 1. (illustrations are grouped at back of report), was designed, constructed and is operated by Atomics International for the U.S. Atomic Energy Commission. It is a graphite-moderated, sodium-cooled thermal reactor having many of the plant features of a full-scale, central-station, sodium graphite reactor. The SRE was built as a flexible development facility, with major portions of the research activity being concentrated on the investigation of fuel materials, sodium process technology, the canned graphite moderator concept, and overall plant design.

In the course of a research power run during the summer of 1959, a small leak occurred which introduced an organic liquid, known as tetralin, into the reactor core.[1] Carbonaceous decomposition material was produced and reduced the sodium coolant flow in a number of fuel channels. As a result, 13 of the 43 uranium fuel elements sustained damage.[2,3] Although great care was exercised during fuel element removal operations, 10 elements broke and various parts fell back on top of the reactor core. In addition, 2 complete fuel elements remained tenaciously lodged within the moderator region.

Special equipment such as optical scopes, lights, fishing and grappling tools, fuel slug containers, cutters, probes, and other accessories were developed to inspect the damaged reactor core, and to remove loose fuel slugs plus other material. To replace, transport, and store defective moderator cans, most of which contained portions of fuel elements, shielded casks, moderator grapples, and other gear were designed, fabricated, tested, and used.

Construction of the recovery equipment was complicated by the necessity of preventing the escape of radioactive fission gas and particles from the reactor, and of preventing the entrance of air to the highly radioactive core region which contained residual scattered sodium droplets even after the core tank was drained. Metallurgical characteristics of zirconium required maintaining a temperature range of 250 to 350°F in the core. Protecting personnel from radiation and contamination was an additional basic requirement.

Before the described program was concluded, 81 miscellaneous fuel slug pieces, numerous bits of stainless steel, and approximately 2 lb of low-density, frothy, carbonaceous material had been removed from the reactor core; then 16 moderator cans were removed and replaced. Two of the removed cans contained whole fuel elements, 10 held substantial portions of broken elements, and the other 4 moderator units were defective because of leaks.

Three of the four leaky moderator cans had not been affected by the fuel element separation episode, but sustained damage while pieces of uranium fuel were being removed. In addition, when two fuel slugs fell from the grappling tools and into the lower plenum beneath the core, an additional amount of attention and effort was required for extraction.

General descriptions of the SRE reactor core facility, recovery equipment, associated procedures, and program organization required to accomplish the desired objective successfully, are contained in this report.

II. DETERMINATION OF RECOVERY EFFORTS REQUIRED

A. DESCRIPTION OF SRE CORE AND FUEL ELEMENTS

The stationary portion of the SRE core (Figures 2, 3, 4, and 5) consisted of 119 moderator and reflector cans, approximately 10 ft long, containing graphite logs. The moderator cans are hexagonally shaped in cross section and 11 in. between parallel faces. Each moderator assembly is individually enclosed by 0.035-in. thick zirconium panels which are welded together. The reflector cans around the periphery of the core are covered by thin sheet metal sections of Type 304 corrosion-resistant steel (CRS). Most of the moderator units (in the center part of the core) were built with a 2.80-in.- ID central process coolant tube for insertion of fuel elements and other assemblies. A number of moderator cans also contained corner-channel cut-out holes for installation of control and safety rods, instrument tubes, etc.

The basic components of the SRE fuel element assembly (Figures 3 and 6) were the fuel rods, hanger rod with holddown tube, orifice plate, and retaining hardware with guide vanes. The assembly was attached to a shield plug, lowered through ports in the reactor top shield, and inserted into the reactor core region.

A typical fuel element in the SRE at the time of the difficulty was made up of seven 0.791-in.-diameter fuel rods, 7 ft, 9-1/8 in. long. The fuel rods contained twelve 3/4-in.-diameter, enriched uranium (2.78 wt %) slugs, each 6 in. in length. The seven rods as a cluster were uniformly spaced by means of 0.90-in.-diameter CRS spacer wire spirally wound, with a pitch of 10 in. around each of the six perimeter rods. By means of special hardware, the seven rods were held together at the upper and lower ends, and the orifice plate was mounted at the lower end of the fuel element.

B. INVESTIGATION OF DAMAGE SUSTAINED

Initially, probes were inserted into the core to learn which coolant channels were blocked by portions of damaged fuel element assemblies (Figures 7, 8, and 9) and to determine the possible condition of affected moderator cans. Development of viewing apparatus and lights allowed a more accurate determination of the extent of the damage and location of materials which had to be removed from the reactor. Numerous photographs were taken to supplement visual observations. With the information obtained, it was possible to plan recovery work and establish what equipment and scope of effort would be required to return the reactor to operating condition.

The observations and photographs (Figures 10, 11, and 12) of the SRE core (after it had been drained of sodium) indicated the presence of 81 fuel slug pieces and miscellaneous bits of stainless steel fuel rod cladding plus wire wrap on top of the moderator cans. The existence of a dark amorphous substance, particularly covering the peripheral reflector cans (Figure 13), was also noted. Concerning the latter deposit, depths ranged from a fraction to 3 in. and when the material was disturbed with a probe, it behaved like a thin, frothy carbonaceous sediment.

Two whole fuel elements were seen to be tightly held in the two associated moderator cans, and the process tubes of 10 other cans contained lodged portions of broken fuel elements. The thirteenth fuel element affected by sodium flow blockage had suffered only minor damage and was successfully removed from the reactor as an entire assembly.

Later metallurgical examination of the damaged fuel elements indicated that high temperatures generated within the fuel had caused formation of an iron-uranium eutectic which destroyed the fuel jackets and distorted the fuel slugs.

It was also determined that a moderator can which was not involved in the fuel element trouble was defective because of a sodium leak.

Detection of the leaky moderator can was accomplished in three ways. First, by measuring the length of the cans. When graphite is saturated with sodium, the graphite expands 1%. Thus, a moderator can with a 10-ft length of graphite would expand longitudinally about 1.2 in. Second, by determining induction properties of the cans.[4] An enclosed tubular assembly containing induction and pickup coils was inserted into the central process coolant tube of the moderator can. A significant increase in the output of the pickup coil as compared to the results with known to be normal cans indicated the likely presence of sodium within the can. Finally, a close visual and photographic examination showed split seams in the zirconium cladding at the top end of the can (Figure 14).

III. EQUIPMENT, PROCEDURES AND ORGANIZATION FOR RECOVERY PROGRAM

A. GENERAL EQUIPMENT

For determining the condition of the core, removing loose fuel slugs and miscellaneous material, and maintaining the desired temperature in the reactor tank, various pieces of special equipment were devised which were used throughout the recovery program. These items are described as follows:

1. Gas Lock

As a result of the SRE fuel damage, reactor core gas activity was initially 10^{-3} μ c/cc, but after extensive purging plus normal decay, activity stabilized around 10^{-6} μ c/cc. A substantial portion of the activity after decay of Xe^{133} came from Kr^{85}. Since these values greatly exceeded tolerance levels, only a very small amount of reactor cover gas could be allowed to pass into working areas. An analysis of the problem indicated that double containment would be required for all penetrations into the reactor. With such an arrangement, the cavity between the two containing walls could be purged to a vent system and greatly reduce the escape of radioactive gas. Likewise, the entrance of air into the reactor would be prevented.

To meet these criteria, a gas lock assembly (Figure 15) was developed, tested, and standardized which could accommodate different sizes of scopes, lights, heaters, tools, etc. with a maximum diameter limitation of 3-1/8 in. Such locks were installed over ports in the reactor top shield (Figure 16) and proved very effective in achieving the desired results when double containment gaskets were properly adjusted.

In general, the gas lock assembly comprised of an adapter fitting for sealing to reactor face ports or similar openings in other equipment, a commercial vacuum system gate valve, an upper chamber (tube) to hold the heads of tools and other devices being inserted, and a sealing gland on the top end. The sealing gland was primarily a compound packing gland with two square-cut synthetic rubber rings separated by a lantern spacer ring, a packing nut, and a housing case. Tightening of the packing nut placed an axial load on the rubber rings which resulted in an exaggerated inner bulge by the rubber since the peripheral surfaces of both rings were restricted by the housing. Thus, the two ring gaskets would bear against the smooth tubular shafts attached to grapple mechanisms, lights, viewing heads, etc., resulting in a method to control the passage of concerned gases while applying linear and rotary motion to the tubular shafts. A gas fitting provided connection to the space between the two gasket rings, which space was partially filled by the lantern ring. To assure that the direction of gas passage would be from the gland to the core and from the gland to the external atmosphere when the packing nut was loosened to permit movement of the tubular shaft, inert gas at slightly above core pressure was maintained in this space.

Once a lock was properly secured, the shield plug involved could be removed from its port and a tool or other device could be inserted to operating position. Upon removal of the item inserted into the core (optical device, light, grapple, etc.), the shield plug could be replaced and the gas lock moved to another location. In some cases, it was possible to remove the gas lock and leave an inserted assembly, designed for the purpose, in the reactor. Shielding and attenuation features incorporated in the gas lock construction also provided adequate biological shielding for operating personnel.

2. Optical Devices, Photographic Equipment, and Lights

Visual observation (Figure 17) of all operations during the core recovery program and inspection photographs (Figure 18) required that special types of viewing scopes, port windows, camera accessories, and lights be developed. These components have been made the subject of a separate report because of the specialized nature of the equipment.[5]

Optical equipment (Figures 19, 20, 21, 22, 23, 24, 25, 26,and 27) which resembled long telescopes with small diameter tubes, was used for panoramic and detailed observation and photography of the reactor core. Each such unit was integrally sealed and constructed to tolerate temperatures above 400°F, and was lowered through a gas lock assembly into the core region for operation. Provisions were made for adjusting the length and replacing eyepieces or objective heads to allow angular as well as variable distant fields.

Lighting in the reactor tank was provided by attaching special incandescent and vapor bulbs onto lengths of metal tubes (Figures 17 and 28) and inserting the completed assembly through the same type of gas lock used in conjunction with the viewing equipment. Each bulb was protected by a metal guard to prevent breakage, and the component was sealed as a unit to aid prevention of gas leakage. When space limitations presented problems, it was necessary to install bulbs on some of the scope arrangements. Anywhere from one to six light assemblies were employed at a time for adequate illumination of the core, depending on circumstances involved.

3. Grappling Equipment for Miscellaneous Objects (Figure 29)

Grappling tools, which varied in length between 21 ft and 30 ft, with two different types of grappling heads were used to remove debris which rested on top and in the core. One type which employed a standard vise grip plier for grappling was built in two models. On one (Figure 30), the grapple arm could be rotated through 360° and positioned at various angles, whereas the grapple arm on the second assembly was limited to hinge action (Figure 31). The other style (Figure 32) utilized four fingers of 100-mil piano wire with a collet device to effect opening and closing action. The latter type grapple head was attached to arms with one and two joints to allow a variety of positions.

Another type of tool (Figures 33 and 34) was fabricated at a later date to remove two fuel slugs which accidentally had been dropped into the lower plenum beneath the core. This tool was approximately 35 ft long and operated with a clam-shell grappling action.

Rods and cables, located inside the tubular shafts of the tool assemblies, were operated at the top end of the tool shafts to actuate the various grappling heads.

The gas lock was employed when installing grappling tools in the reactor.

4. Debris Containers

Except for the two cases where the clam-shell head was used, tubular containers approximately 4 ft long and 2-1/2 in. OD (Figure 30) were lowered into the reactor core to receive the highly radioactive fragments retrieved by the grappling tools. This equipment eliminated the need for removing a grappling tool from the core each time a piece was picked up. Material removed from the reactor was sealed in special tubes and deposited at a radioactive waste storage facility.

The fuel handling machine (Figure 35) was brought into operation when inserting and removing the debris containers.

5. Vacuum Cleaning Equipment

A closed-circuit vacuum cleaner (Figure 36) was fabricated to remove the dark flocculent deposits (Figure 13) from the tops of the moderator and reflector cans. The suction head was attached to an appropriate flexible hose which was connected to a metal tube for insertion through a gas lock and into the core region. Positioning and moving the suction head was performed by employing the vise-grip grappling tool which had been used to recover loose fuel slugs. Radioactive gases and foreign substances pulled from the reactor were routed from the suction tube through a trap to remove solids (including incidental sodium) before reaching the vacuum cleaner blower inlet. Discharge gases from the blower were returned to the reactor atmosphere. The sealed motor which powered the fan was enclosed within the blower unit. The estimated maximum gas circulation was 90 cfm at a pressure differential of 6 in. (water). Approximately 2 lb of flocculent carbon were removed from the core by this method.

6. Core Heating Equipment

In order to retain adequate metallurgical characteristics in the hydrided zirconium and prevent solidification of surface-coating sodium deposits which could bind moderator cans together, it was necessary to maintain the reactor at an elevated temperature. A temperature of 250°F was considered a reasonable minimum and 350°F a practical maximum. Above this range, substantial problems would have been encountered in attempting to maintain gas seals of available materials in the recovery equipment.

Although external heaters had been installed to heat the bottom of the core tank as a permanent feature of the plant facility, these were unable to supply the 6000 to 8000 watts of heat required to maintain the desired isothermal temperature condition. During the course of the recovery effort, four different types of heaters mounted on shield plugs were used. In commercial nomenclature, these were known as cal rod (Figure 29), strip, fire rod, and glow coil heaters. For all practical purposes, the cal rod and strip heaters gave the best performance. At rated capacity, the other two types characterized by higher heating surface temperatures, would fail soon after installation in the reactor. Apparently a slow rate of heat conduction, even at 50% of heater power capacity, was mainly responsible for the short operating life experienced.

B. MODERATOR CAN REPLACEMENT EQUIPMENT

The possibility of replacing moderator cans in the core had been under consideration since the inception of the SRE and some basic equipment had been designed and built. However, to obtain numerous other pieces of equipment in addition to modifying the assemblies on hand in a short period of time, an accelerated program was required. The highly radioactive and contaminated condition of the reactor atmosphere had changed the gas control requirements originally considered adequate for moderator replacement operations. Alterations made were primarily concerned with improving the gas-tight characteristics of various components, providing additional vent connections, and installing a larger number of ports for insertion of tools, lights, viewing devices, etc.

To unify this presentation, a brief resume of the available equipment will be included which will be followed by a description of the other items which had to be developed after the immediate moderator replacement problems were defined. (Figures 37 and 38)

1. Available Equipment

a. Moderator Handling Cask (Figures 39, 40, 41, 42, 43, 44, and 45)

The shielded cask for hoisting and moving moderator cans weighed about 31 ton, was 28 ft in overall length, and had effective interior dimensions of 19 in. diameter by 21 ft long. The four main subassemblies were (1) hoist section, (2) shielded body sections, (3) viewing section, and (4) a lower closure section. The cask was hoisted, moved, and positioned by the main high bay crane and could be readily disengaged from the crane, as required. Guy wires and direct mechanical attachment to a building column provided safe and adequate interim storage for the cask when not in service. A hoist and pneumatic lines inside the cask were employed to raise, lower, and actuate the grapples used on the moderator cans.

In the original concept of this cask, cylindrical shielded sections from the mid-section of the fuel handling cask were to be used as a body part for the moderator handling cask. During the recovery program, it was recognized that the cost and inconvenience of disassembling and reassembling the fuel handling cask exceeded the economies connected with dual utilization of such components. Accordingly, an additional mid-section tube assembly was fabricated and employed in the final version of the moderator handling cask. Shielding for this section was provided by welding an outer steel casing around the inner tube and filling the enclosed annulus, which was several inches thick, with lead shot.

b. Support Bridge and Sliding Shield (Figures 22, 41 and 45)

The support bridge and sliding shield was essentially a massive, movable biological shield platform which could be made gas-tight over the large diameter (40-in.) access holes located in the reactor top shield. The sliding shield contained a 43-in. diameter stepped plug which could be removed, as required, and rotated for location. A number of smaller portholes containing plugs were provided in the 43-in. plug. Included were two 19-in. diameter holes which were adequate in size for moderator cans and a number of smaller holes which could receive lights, tools, etc. Two 30-in. web I-beams with rails on the respective bottom facing flanges were the structural members which supported the heavy sliding shield and allowed linear travel by this component.

The substantial construction of the support bridge and sliding shield assembly also gave physical protection to the reactor should crane brakes fail at a time when a heavy object (such as a cask) was suspended over the reactor, and particularly if positioned over a 40-in.-diameter access hole after removal of the associated plug.

c. Plug and Pump Cask (Figures 46, 47, and 48)

Designed as a multipurpose container, the plug and pump cask could handle components up to 41 in. in diameter and 14 ft long. It was originally intended for the removal and storage of large access plugs from the reactor top shield and pumps used to circulate the primary, radioactive sodium coolant. Other possible uses later became apparent.

Positioning and moving of the 12-1/2 ton cask was performed by the high bay overhead crane (90 ton capacity); a 10-ton hoist, interior to the cask, was used to pull objects into the cask. During the recovery program, the cask was used to handle the 40-in.-diameter access plugs from the reactor top shield. Glass-covered viewing ports plus glove box holes allowed observation and manipulation of the suspended plug or rigging inside the cask. The bottom of the cask was sealed by an inflatable seal which seated against a sliding door. When not in operation, the entire cask plus contents were placed on a gasketed plate located in a storage area.

d. Moderator Transport Casks (Figures 49, 50, 51, 52, and 53)

Built for transporting radioactive moderator cans, sealed in capsules, between facility sites, the moderator transport cask consisted of a shielded body with an interior hoist and a detachable bottom shield cap. An exterior trunnion at the lower end of the assembly permitted the cask to be raised from horizontal to vertical position and vice versa by an overhead crane when the gudgeons were rotated in pivot blocks. The assembly was not made completely gas-tight since contaminated and radioactive materials to be transported within the cask would always be sealed in gas-tight steel capsules.

e. Trailer Dolly for Moderator Transport Cask (Figures 49 and 50)

To support the moderator transport cask, a cradle equipped with heavy duty casters and pivot blocks was fabricated. This cradle could be mounted on a large commercial truck trailer. Tracks installed on the trailer bed permitted movement of the dolly and contents at a dock facility, when desired.

f. Spreader Assembly and Cask (Figures 54 and 55)

Although not required for replacing most of the moderator cells, equipment was fabricated for pushing adjacent moderator cans slightly away from the unit to be removed and maintain the cavity while a new moderator can was installed. Briefly described, a spreader ring, equipped with wedges projecting from the lower end, was attached to a collar which in turn was connected to three flexible cables sheaved in a short shielded cask. When indexed over the selected moderator can in the core, the spreader assembly could be lowered into the core and forced downward to spread the cans apart.

After remote detachment from the collar, the ring would remain in place and the collar would be hoisted back into the spreader cask which in turn would be removed for subsequent operations. At a later time, the procedure would be reversed and the spreader ring removed from the core. Another feature worthy of comment was a rotable indexing device on the spreader ring which would facilitate initial positioning of the ring and orientation of the new moderator can during installation.

g. Moderator Can Grapples (Figures 22, 56, and 57)

Several different types of grapples were constructed for handling the vatious shapes of moderator cans in the moderator handling cask during the replacement process.

The bottom center channel grapple (Figure 57) was used for extracting moderator assemblies from which all fuel had been removed and for installing new cans. It was inserted through the center process coolant channel of a moderator can and was characterized by a tubular shaft, longer than a can, with an expandable tip at the lower end which would engage the bottom stainless steel support casting of the can. As finally developed, the grapple was fail-safe with the jaws in the tip held in the expanded position by a compression spring which pulled a tapered mandrel into an internal collet. The tapered mandrel was forced out of the collet by a pneumatic piston to close the jaws and disengage the grapple from a can.

A top casting grapple (Figure 57) was employed to remove cans in which the center process coolant channel was obstructed (by damaged fuel) and the zirconium-side panels of the moderator can were not damaged. Multiple fingers installed in circular configuration were designed to grip a ledge or land existing on the top stainless steel casting of a moderator can. The fingers of the grapple jaw were locked in closed position by movement of an external sliding sleeve which would compress the fingers together. A design feature provided that reverse movement of the sleeve would force the jaw fingers open to allow disengagement of the grapple from a can. Power to actuate the sleeve was furnished by a double acting pneumatic piston.

The side or corner channel grapple (Figures 22 and 56) was employed for the removal of defective moderator elements in which the center channels were obstructed. A fail-safe slide latch (opened by pneumatic power) at the lower end of the grapple locked onto an outer ledge at the bottom casting of a moderator cell. A retaining tube at the upper end of the grapple assembly would interlock with part of the top casting of a can to complete the connection. For installation, the grapple could be lowered down either a circular channel formed by corner cutouts on certain types of moderator cans, or down the flat side of a can. For the latter case it was first necessary to remove an adjacent can.

Another grapple (Figures 22 and 56) was specially built to remove two instrumented moderator cans which were surmounted by a tube structure which extended 6 ft above the top surface of the cans. The same general design arrangement which characterized the side or corner channel grapple also held true for the instrumented can grapple except the upper section was lengthened to clear the described tubular obstructions.

Although never utilized inside the moderator handling cask, another grapple was employed when hoisting, transporting, and positioning new cans with one of the high bay cranes. It was somewhat similar to the described top casting grapple except the jaw fingers were opened and closed by applying manual force to a mechanical latching device.

h. Hoist Bails for Casks (Figures 52 and 53)

A hoist bail with two hook arms was designed which could be used for connecting the moderator handling cask, moderator transport cask, or spreader assembly cask to the hook of an overhead crane. Two such bails were ordered as one was required at the SRE and the second was needed to handle the moderator transport cask at the radioactive waste storage facility. Safety bars were installed on both hooks of each bail to prevent accidental disengagement under a no-load condition. For handling convenience, a rack equipped with casters was constructed for holding the bail when it was not in use.

i. Moderator Cask Adapter Ring (Figure 41)

To provide the proper degree of gas sealing and side clearance for inserting tools, a special adapter ring for mating with the moderator cask was machined to be set on the support bridge sliding shield when replacing moderator cans.

j. Storage Capsules for Moderator Cans (Figures 58 and 70)

Gas tight tubular steel containers were built to receive defective moderator cans removed from the reactor. For each unit, 15-in.-OD steel casing was rolled for the shell and a ring flange was welded on the top end to receive a blind flange top lid. Gasketing was provided by a soft steel ring to assure against radiation deterioration and subsequent leakage of radioactive and contaminated gas. A tapered sheet metal shroud was welded onto the bottom of the storage capsule to facilitate insertion into storage holes. Permanent gas-tight bottom lids were welded onto the capsules except for a few which were modified with removable bottom covers for hot cell examination purposes.

k. Tubing Cut-Off Tool (Figures 59 and 60)

Before the first defective moderator can could be removed from the reactor, it was necessary to cut two 1/2-in.-diameter tubes which connected the two instrumented moderator cans with plugs in the top shield. Ceramic insulated thermocouple lead wires were inside both tubes. These tubes prevented rotation of the top shield.

A special tool was developed for performing the described operation which utilized a standard hydraulic squeeze-riveting cylinder head. A blade and anvil fabricated from tool steel replaced the rivet dies and a remotely controlled hinged connection with pressure fittings was attached to a tubular shaft for lowering and positioning the shearing mechanism within the reactor. The cut-off tool was smaller than 3-in. in diameter and in order to pass through a fuel element shield plug hole, was inserted through a standard gas lock for application in the reactor. A silicone base hydraulic fluid was used to transmit 8000 psi to the pressure cylinder, equipped with special retaining rings, when the tool was properly situated for action.

l. Strongback for Top Shield (Figures 61 and 62)

In the original construction of the SRE, a strongback assembly, shaped like a wheel with six heavy spokes, was used when hoisting and positioning the 75-ton reactor top shield. This shield is 140-in. in diameter and 81-1/2 in. thick. During the recovery program, this same equipment was used as a lifting rig when it was necessary to rotate the top shield. Six cables, each equipped with load equalizing turnbuckles, connected the strongback to the swivel hook suspended from the 90-ton overhead high bay crane.

2. Additional Equipment Required

Although the items which required the longest procurement lead time were generally available when steps were taken to institute the moderator can replacement project, numerous other pieces of equipment were needed before operations could commence. These were developed and tested over a two-month period of time. The following descriptions will serve to explain briefly how such items were designed and the function each performed.

a. 40-in. Gate Valve, Cap, and Seal Ring (Figures 41, 42, and 63)

It was essential that a closure device be provided for covering the 40-in.-diameter access ports. To serve the purpose, a gate valve with a rectangular shaped body was fabricated with an effective opening which exceeded 40 in. In use, the steel gate moved in a horizontal plane; the gate was 2 in. thick to provide structural stability and a measure of biological shielding. Four rollers supported the gate on machined tracks within the valve body and allowed ease of operation. Two concentric pneumatic gaskets were located on the top side of the gate. By inflating the gaskets to seat against an interior surface of the valve body and pressurizing the space between the two gaskets with inert gas, escape of radioactive gas from the reactor and leakage of air into the core atmosphere was prevented. The valve stem was a hollow tube through which inert gas supply lines (for inflating seals, etc.) were passed. The gas seal gland between the valve bonnet and stem was similar to the double-gasket seal glands employed on the gas locks (Figure 15). Several purge and vent connections on the valve body provided the means for adequately circulating inert purge gas through various active and inactive spaces associated with the valve.

A steel cap, several inches thick, was fabricated which could be placed over the top valve port, as required. An "O" ring gasket attached to the cap prevented gas leakage at the interface with the valve, and gas fittings allowed purging of the dead space between the cap and valve gate.

A two-piece steel adapter assembly with special "O" ring gaskets was engineered for connecting and sealing the gate valve lower surface to either of the top-shield 40-in. access ports. This component was termed the "40-in. seal ring."

An adapter ring arrangement could also have been built for the top shield 20-in. access port had it been necessary to work through this hole during the recovery program. This operation proved unnecessary.

b. Dummy 40-in. Plug (Figure 48)

As a precautionary measure and to conduct a detailed final examination of the core top in a minimum of time, a dummy plug was constructed which would fit in either of the 40-in. top shield access ports after removal of a regular shield plug. The 40-in. dummy plug was hollow and resembled an inverted cup. Four large ports in the top of the plug allowed installation of lights, windows, and other parts, as required. A tapped blind hole in the center of the plug top was used to connect a long steel shaft employed to hoist and handle the dummy 40-in. plug.

c. Cask for Dummy 40-in. Plug (Figure 22)

In order to install the large dummy plug conveniently into the top shield, an economical cask was assembled. Essentially, it was a steel tank without a bottom. The flat top was externally reinforced to prevent bulging from gas pressure. A gas seal gland similar to the variety installed on the gas locks (Figure 15) was spotted in the center of the top plate of the cask. A smooth tubular steel shaft penetrated the gas seal gland and was screwed into the dummy 40-in. plug for hoisting purposes. A rubber gasket along the lower circular edge of the cask allowed the cask to be sealed when mated with a flat surface. Vent and purge connections were also provided.

d. Rework Equipment for 40-in. Plug (Figure 64)

Prior experience in plug removal indicated that a rigid, tapered, guide ring would have to be installed on the bottom peripheral edge of each 40-in. access plug before the 40-in. plugs could be replaced in the top shield from the plug cask. Tight clearances for radiation shielding on the bottom of the plug made plug replacement difficult. Besides positioning and fitting each guide ring, other steps such as drilling, burring, countersinking and blind riveting had to be performed. The work had to be done in an inert atmosphere with the 40-in. plug shielded for protection of the operating personnel concerned.

For the guide ring installation, a holding fixture was attached to the bottom of a plate steel tank which resembled a large pan. Viewing and tool ports were located in the bottom and around the curved sides of the enclosed assembly. Electric lighting was also installed within the unit. Holes with drill bushings and stoppers were placed at predetermined locations in the walls of the container to facilitate the power tool work. Large bar scrapers which passed through rubber bellows in the cylindrical wall of the fixture cask were used to remove sodium residue from the lower surfaces of the 40-in. plugs. The guide rings were installed remotely using the equipment and techniques described.

e. <u>Encapsulating Equipment (Figures 48, 58, 65, 66, 67, 68, 69, 70 and 71)</u>

Encapsulating equipment was developed for the insertion of radioactive moderator cans, removed from the reactor, into cylindrical gas-tight, argon-filled capsules before shipment to a waste storage facility. The main components were a rotary cap, a 19-in. gate valve, a shield ring, and a long tubular cell liner topped by a chamber which was larger in diameter and which possessed a number of radial ports.

The rotary cap had a steel outer ring (10-in. thick, 31-in. OD, 18-in. ID) and an inner plug which carried socket extensions, viewing ports, and fixtures for holding and prepositioning the lid on a capsule. The inner plug of the cap rotated on 1-in. steel balls located in a race formed by the mating steps of the plug and the outer ring. A flared ring gasket, made of synthetic rubber, was pulled over the inner cylindrical, lubricated, surface of the plug and attached to the ring to form a gas seal which was effective under both stationary and rotation conditions. Tools which penetrated the plug were sealed by neoprene gaskets compressed radially to form a sliding seal.

The 9-in.-thick shield ring had gaskets on the top and bottom faces. It was placed above the 19-in. valve to provide connections for vent and purge lines, and to act as an indexing template for positioning the moderator handling cask and moderator transport cask as well as the rotary cap assembly.

Except for size, the 19-in. valve was similar to the previously described 40-in. valve (Figure 63) used on the reactor face.

The gas-tight, tubular steel chamber (Figure 66) in which moderator capsules were prepositioned to receive moderator cans was located under the 19-in. valve and was 20 ft long. It was installed vertically in a concrete-lined cylindrical storage cell existing in the reactor room floor. Welded to the top end of the chamber was a steel doughnut ring which was bored radially to provide openings for viewing devices, tools, radiation instruments, lights, etc. All such openings or ports were sealed by gaskets or sliding seals to maintain an inert (argon) atmosphere inside the encapsulating assembly.

Blocks of lead shielding were provided for alignment with the radial ports, which were slightly above floor level, to protect personnel when radioactive materials were lowered from the moderator handling cask or when the sealed capsules and contents were being removed from the encapsulating equipment by the moderator transportation cask.

f. Force Transmitting Tools (Figure 29)

Moderator cans in the SRE core lattice were fitted together in close arrangement with little accumulative horizontal tolerance. As expected, some of the moderator units were relatively snug. A steady, reasonable force was adequate in most instances for orderly extraction and insertion; however, vibrating motion was also required in two instances to move the cans.

In order to apply pressure and/or vibration to the stainless steel casting attached to the top of a moderator can, tools were constructed which could be inserted into the reactor core tank through access ports (equipped with gas lock assemblies) adjacent to the moderator access hole concerned. The lower end of each tool had a hinged extension arm which could be lifted upward by an attached flexible cable. A heavy-duty hinge knuckle with backstop allowed limited angular movement for the arm section. A downward push or vibration applied to the top end of the tool would be transmitted to a moderator can when the arm was pulled up firmly against the knuckle backstop.

A commercially available electric vibrator, normally sold to be attached to the walls of a dry-storage hopper, was used with satisfactory results for vibrating moderator cans when the unit was rigidly clamped onto the top end of the force transmitting tools.

g. Optical Apparatus and Lights for Moderator Replacement Equipment

As treated in more detail by separate report[5], scopes (Figures 72, 73, 74, and 75) were built for viewing and photographing the contents of the moderator handling cask and encapsulating assembly. Window devices were constructed for observing the core from various locations. A transparent port plug (Figure 76), employed when grappling and manipulating moderator cans (Figure 77) in the core, incorporated thick lead-glass window which furnished adequate biological shielding for operators. Other sleeve plugs which contained sealed window disks of transparent plastic materials were utilized with more desirable results when photographing the core top.

Light fixtures used in conjunction with the optical devices and transparent port windows are described in reference 5.

h. Miscellaneous Equipment

In addition to the items individually described, other pieces of equipment were developed or purchased which either played significant roles during the recovery activities or were available for possible emergency applications. These were:

1) Long (5-ft 15-ft) spool pieces for use on gas-lock assemblies when long components such as heaters were installed or removed from the reactor.

2) A manually operated winch for use on gas lock assemblies when lengthy spool pieces were employed.

3) Flexible bellows spool pieces for application as "upper chambers" on gas lock assemblies when various overhead and side clearance problems were present.

4) Adapter spools for connecting gas lock assemblies to the various types of ports in the reactor top shield and sliding shield.

5) Pads, pans and related equipment used when leak testing or supporting casks during periods of interim storage.

6) Clips for holding the surrounding moderator cans together should a cavity in the core lattice be created by the removal of two or more adjacent cans.

7) Jacks and chain hoists for use in rotating the reactor top shield.

8) Transits and related equipment for determining the rotation positions of the reactor top shield and indexing the proper locations for the support bridge and sliding shield components.

9) Leak test and gas monitoring instruments to assure the containment integrity of the recovery equipment installations and reactor system.

10) Heating and temperature regulating devices for use when melting the cerrobend metal seal located around the periphery of the reactor top shield.

11) Rigid backup gasket assembly for emergency installation over the cerrobend seal in case the latter failed to function properly as a gas seal upon solidification (a precautionary measure which did not have to be used).

12) Pressure sensing and regulating mechanisms to maintain proper inert gas pressure within the reactor tank during recovery operations.

13) Heating and circulating system for a silicone oil heat transfer system to melt sodium deposits around the lower periphery of the reactor top shield; (initially, it was not known if condensed sodium vapor and sodium oxide which deposited in the annulus between the top shield and the surrounding ring shield would hinder efforts to rotate the top shield. Although available, this system was not utilized as the top shield was rotated without undue difficulty).

14) A skid ring of 1-in.-thick carbon steel was manufactured for installation over the reactor ring shield. This skid ring, divided into three sections for handling convenience, provided a smooth, level bearing surface which supported the support bridge and sliding shield. Degree lines were scribed on the top surface of the ring for proper indexing of the support bridge.

15) Moderator can dolly for moving and prepositioning new can; straps with toggle clamps secured the moderator to a carriage which was connected to the dolly frame by pivot pins. The frame was mounted on casters. Moderator cans were raised to a vertical position by a crane before toggle clamps were released to allow disengagement from the dolly, and subsequent transportation of the can by the crane.

C. GENERAL PROCEDURES

All recovery work followed written procedures which were reviewed by SRE supervision and the AI Ad Hoc Reactor Safeguards Review Committee.

1. Inserting and Removing Core Devices (Tools, Lights, Scopes, etc.) Using Gas Lock Assembly (Figures 15, 17, 30, 33, 60)

a) By means of a clamp, attach 1 psi inert gas supply line (with check valve included) on gas seal fitting at upper end of device (tool, light, scope, etc.) tube after upper end of device tube has been installed through gas seal gland.

b) Move gas seal gland to lower end of device shaft.

c) Suspend device onto hoist by means of swivel hook and bail.

d) Raise device until it is vertical and device head is above floor level.

e) Test operation of device, as required. Lubricate moving joints with "Molykote," if necessary. When satisfied with device behavior, insert head of device into gas lock upper chamber and bolt upper chamber onto gas seal gland. Move gas lock unit which contains device over the 4-in. valve which is properly installed in "closed" position on an open port over the reactor.

f) Bolt flange at bottom end of gas lock upper chamber onto top 4-in. valve flange.

g) Scribe level mark and higher warning marks on side of device shaft tube to denote "up" position.

h) Attach inert gas supply to gas seal gland, gas lock upper chamber and device shaft tube, employing tube clamps, quick-disconnect fittings, and check valves. Use separate gas supply for each (inert gas at 1 psi) inlet fitting. Attach radioactive gas vent line onto bottom fitting on gas lock upper chamber.

i) Open valve to radioactive waste gas vent system and thoroughly purge interior of gas lock upper chamber and gas seal gland.

j) Close valve to radioactive gas system, tighten knurled nut on gas seal gland, and pressurize device shaft tube, upper chamber of gas lock assembly, and gas seal gland, at 1 psig.

k) Check to assure that entire gas lock assembly is secured to concerned port by means of bolts. Check to determine that reactor core gas pressure is less than 1/2 psig.

l) Check status of high bay area and personnel. Doors should be closed, supply fans turned off, and all personnel adequately clothed. Demand-type air masks must be readily available for emergency use. Monitor area for radiation and contamination levels.

m) Commence insertion operations after opening 4-in. gas valve. Maintain inert gas supply to gas lock upper chamber, device shaft tube, and gas seal gland. Loosen knurled pressure nut on gas seal gland.

n) Cautiously and slowly lower head of device until proper level is attained. Beware of hang-up; continously view core region, if possible.

o) Slowly and carefully adjust or manipulate device, as required.

p) Periodically check reactor core gas pressure and release excessive pressure, as required.

q) When operations through a particular port have been terminated, position device arm (if any) so that it hangs freely in a vertical direction, and close head jaws in the case of a grappling tool.

r) Cautiously raise device assembly with hoist and be particularly alert for hang-up. Due to thermal heat possessed by device after being in reactor, approximately thirty to forty minutes will be required to remove fully the device from the reactor interior. Avoid burning the rubber pads in the gas seal gland. Maintain inert gas flow to interior of device, gas lock upper chamber and gas seal gland.

s) During hoisting operations, continuously monitor radiation levels from the device and in gas lock vicinity. Should a piece of radioactive fuel adhere to the device, the radiation level from the gas lock might become excessive as the device is raised. In such case, apply external shielding.

t) Toward end of device raising operations, watch for "warning" scribe marks on device shaft tube. From this point, continue hoisting operations very slowly. When "up" level scribe mark becomes visible, immediately terminate lifting operations or else the gas seal gland may become damaged.

u) Open valve connecting the gas lock upper chamber to the radioactive vent system and immediately close the 4-in. valve. Lock 4-in. valve in closed position. Maintain inert gas flow to device tube, gas lock upper chamber, and gas seal gland until system is well purged. Tighten knurled pressure nut on the gas seal gland, close valve to radioactive vent system, and conduct 1-psig pressure test in upper section of gas lock tube to determine if 4-in. valve is adequately closed. On conclusion of test, release 1 psig to radioactive vent system and reclose valve to radioactive vent system. Terminate inert gas flow to all connections.

v) Remove flange bolts which connect gas lock cylinder to 4-in. valve. Using hoist, slightly raise device assembly and upper gas lock assembly; quickly cover bottom flange end of gas lock upper chamber with clean plastic sheeting which should then be tightly taped in place. Continuously monitor operation with radiation instruments.

w) Move device, gas lock upper chamber, and gas seal gland to next port prepared for device entry. Lower assembly onto valve flange, remove and dispose plastic sheeting (radioactive solid waste), and reinstall flange bolts. Continuously monitor operation with radiation instruments.

x) If a device is not to be reused immediately, it may be lowered into a storage cell or set horizontally on high bay floor. In the latter instance, adequate covering and shielding must be provided.

2. Handling of 40-in. Reactor Access Plug (Figures 47 and 64)

a) Install bridge support skid ring onto ring shield. Ring will remain installed until entire moderator replacement project has been completed.

b) Install seal ring onto 40-in. port where 40-in. reactor access plug is to be removed.

c) Install 40-in. valve onto seal ring in a leak-tight condition. Valve and seal ring will remain installed until 40 in. plug concerned has been replaced.

d) Install and align sliding shield bridge over 40-in. valve.

e) Remove 43-in. plug from sliding shield and replace with plug and pump cask after bolting lifting rig to 40-in. plug. Inflate seal between sliding shield and 40-in. valve and purge enclosed spaces including the plug and pump cask. Conduct gas seal tests.

f) Remove 40-in. reactor access plug from reactor top shield by using plug and pump cask.

g) Close cask door and inflate door seal.

h) Close 40-in. valve, inflate seals, and purge space between 40-in. valve gate and cask door.

i) When convenient, install guide ring on bottom of a removed 40-in. plug (Figure 64). This involves placing plug and pump cask on special installation container, and performing a number of fitting, drilling, burring, and riveting operations.

j) Reverse operations in steps "h" through "d" to replace 40-in. plug in reactor top shield.

3. Removing Moderator Can (Figures 41, 42, and 77)

a. Place 44-in. diameter "O" ring on top of 40-in. valve body, and install 43-in. plug into sliding shield; orient same so that proper 16-in. port will be indexed over concerned moderator can location. Remove 16-in. plug and replace with adapter ring. Install 4-in. valves and lights in 43-in. plug ports.

1) When it is necessary to use moderator spreader assembly, install lead glass window and 4-in. valves in spreader cask cover. Attach proper spreader onto spreader grapple hoist ring after first placing spreader cask on the particular spreader storage can which contains the concerned spreader.

2) Install spreader cask with cover over 16-in. open port in 43-in. plug.

3) Purge space between 40-in. valve and spreader cask cover. Deflate 40-in. valve seals, and open 40-in. valve. Insert necessary tools through 4-in. valves.

4) Lower spreader assembly over concerned moderator can, unlatch hoist ring (using grappling tool) which holds spreader and retract hoist ring into spreader cask. View operations through lead glass window.

5) Remove tools from 4-in. valve ports.

6) Close 40-in. valve, inflate valve seals, and purge space between 40-in. valve and spreader cask cover.

7) Remove spreader cask and place onto storage can. Remove lead glass window from spreader cask cover and place in proper 43-in. plug port.

b. Position moderator handling cask with proper moderator grapple therein over indexed 16-in. port (equipped with adapter ring) in 43-in. plug. Purge space between 40-in. valve and cask, deflate 40-in. valve seals and open 40-in. valve. Insert vise grip head grappling tool and force transmitting tools, if required, through ports in 43-in. plug and position same. Attach clips to moderator cans with grappling tool, if necessary.

c. Open moderator handling cask door and lower moderator grapple into reactor. Manipulate with vise grip head tool, as required, and attach to concerned moderator can.

d. Energize vibrators and apply weight to force transmitting tools, if necessary, and gradually lift moderator can from core lattice.

e. Raise moderator grapple and can into moderator handling cask, close cask door, and inflate door seal.

f. Remove tools from reactor, close 40-in. valve, inflate valve seals, and purge space between cask door and 40-in. valve.

4. Capsulating Moderator Can (Figures 65 and 70)

a) Install moderator capsule in encapsulating assembly, close 19-in. valve and purge encapsulating unit.

b) Move moderator handling cask with defective moderator can contents and position over encapsulating assembly 19-in. valve. Purge space between 19-in. valve and moderator handling cask. Open cask door and 19-in. valve. Lower moderator can into capsule, release grapple and retract grapple into moderator handling cask. Close cask door and inflate seal. Close 19-in. valve, inflate valve seals, and purge space between 19-in. valve and cask door.

c) Move moderator handling cask to storage area and set on special pad. Attach cask to building column, fix guy wires and disconnect cask from crane.

d) Position rotary shield cap over 19-in. valve and seal to valve (capsule lid in cap). Purge space between 19-in. valve and rotary cap.

e) Deflate seal and open 19-in. valve. Lower capsule lid onto capsule, position, and tighten lid bolts with extension wrench.

f) Purge encapsulating assembly interior, close 19-in. valve (do not inflate seal) and remove rotary shield cap.

5. <u>Transporting and Disposing of Encapsulated Moderator Can (Figures 50 and 70)</u>

a) Move trailer into high bay area with moderator transport cask positioned on cradle.

b) Attach crane to cask, raise cask upright, lower to floor, remove bottom end plug, and position cask over 19-in. valve. Open valve.

c) Lower cask grapple to engage mushroom head on moderator capsule. Hoist capsule into cask.

d) Remove cask and contents from encapsulating area and position over bottom end plug. Lower cask onto plug and pin plug into place.

e) Hoist cask onto cradle and position gudgeons in yoke. Lay cask down on cradle on trailer, and disconnect crane.

f) Haul trailer and load to radioactive waste storage facility and deposit capsule in storage vault. Return trailer to SRE.

6. <u>Replacing Moderator Can (Figures 41, 42, and 77)</u>

a) Connect moderator handling cask onto crane, and use grapple inside cask to pick up new moderator can from storage hole (use moderator grapple previously used for removal, if possible). Close cask door and inflate seal.

b) Align moderator handling cask over 16-in. port in 43-in. plug on sliding shield and lower cask until sealed onto adapter ring "O" ring. Open cask door. Purge cask and space above 40-in. valve.

c) Deflate seals and open 40-in. valve.

d) Install required tools into reactor through 4-in. valves installed on 43-in. plug.

e) Lower moderator can into core tank. Orient moderator can axially by rotating moderator handling cask which is sealed to adapter ring by means of a greased "O" ring.

f) Lower moderator can into core lattice. Energize vibrators on force transmitting tools, if necessary.

g) After seating can, disengage moderator can grapple and retract into cask. Close cask door. Remove tools from reactor. Close 40-in. valve, inflate valve seals and purge space between 40-in. valve and cask coor.

h) Remove moderator handling cask to storage on special pad, etc.

i) If spreader assembly was used in replacing the moderator can, use crane to place spreader cask over 16-in. port (complete with cover) and purge space enclosed. Deflate 40-in. valve seals and open 40-in. valve.

j) Lower spreader grapple hoist ring and latch onto spreader. Raise spreader into spreader cask.

k) Close 40-in. valve and inflate seals. Purge enclosed space above 40-in. valve.

l) Move spreader cask to storage can, and disconnect from crane.

7. Rotating 140-in. Top Shield (Figures 61 and 62)

a) Use crane to remove support bridge from reactor face; disconnect from crane.

b) Place special cover on 40-in. valve, as a precaution. Install six spacer studs in 140-in. top shield plug and install strong-back lifting assembly. Install screw jacks under strong-back arms, as required.

c) Melt cerrobend seal.

d) Employing crane and jacks, raise top shield slightly, remove jacks and rotate top shield while suspended from crane. Employ chain hoists and rigging, if necessary, to rotate top shield.

e) Lower top shield and remove strong-back rigging, solidify cerrobend seal and test integrity. Remove cover from 40-in. valve.

8. Changing Moderator Cask Grapple (Figures 22, 56, and 57)

a) Align moderator handling cask over storage hole containing grapples and grapple rack. Install cribbing under moderator handling cask.

b) Deflate door seal and open cask door.

c) Lower grapple into storage hole and position onto rack. Disconnect grapple from cask hoist.

d) Attach next grapple by reversing steps in item c) above. Raise attached grapple into moderator handling cask, close door and inflate seal.

D. PROJECT ORGANIZATION

In final form, the SRE core recovery program was organized on a project basis with discretionary authority and responsibility assigned to one engineer who assumed the temporary position of Chief Supervisor reporting to the SRE Group Leader. Six staff engineers and four shift recovery engineers reported directly to the Chief Supervisor. The shift recovery engineers each supervised a crew of technical operating personnel of four to six men. The recovery crews worked on a scheduled rotating shift basis which allowed the project to be conducted on a 24-hour basis, seven days per week. Routine overlap of shift schedules and a reasonable amount of overtime provided double strength coverage for certain heavy duty operations which occasionally required more manpower than could be supplied by one crew.

Work associated with the design, fabrication, procurement, and alteration of equipment was largely performed by personnel in other departments at the request, direction and approval of the project Chief Supervisor.

The six staff engineers were assigned various technical areas of responsibility and were required to coordinate activities with supporting departments.

IV. CONCLUSIONS

Aside from design and fabrication of special equipment, the recovery operation work was performed by a relatively small group of personnel who prepared and followed approved procedures. Although a variety of sizes and shapes of highly radioactive and contaminated substances had to be removed from the reactor, no one on the recovery crews received more than the standard AEC permissible radiation dosage. Most personnel accumulated substantially less than the weekly tolerance level established by the AEC.

The SRE core recovery project was completed with a perfect safety record in all respects, and a preplanned plant experimental modification program was conducted concurrently with the recovery effort. It was coincidental that the latter program was in the design and procurement stage when the core difficulty occurred at the SRE.

Major damage to the core of any nuclear reactor represents an undesirable situation. However, the fact that recovery was achieved with a reasonable degree of effort without overexposing plant personnel to radiation, or releasing more than permissible activity to the atmosphere demonstrates that maintenance may be performed on the entire plant complex of a sodium-cooled nuclear power reactor. The development of equipment, tools, and techniques required to accomplish these results are an important phase in the current research and development effort directed toward the ultimate utilization of nuclear energy for peaceful purposes.

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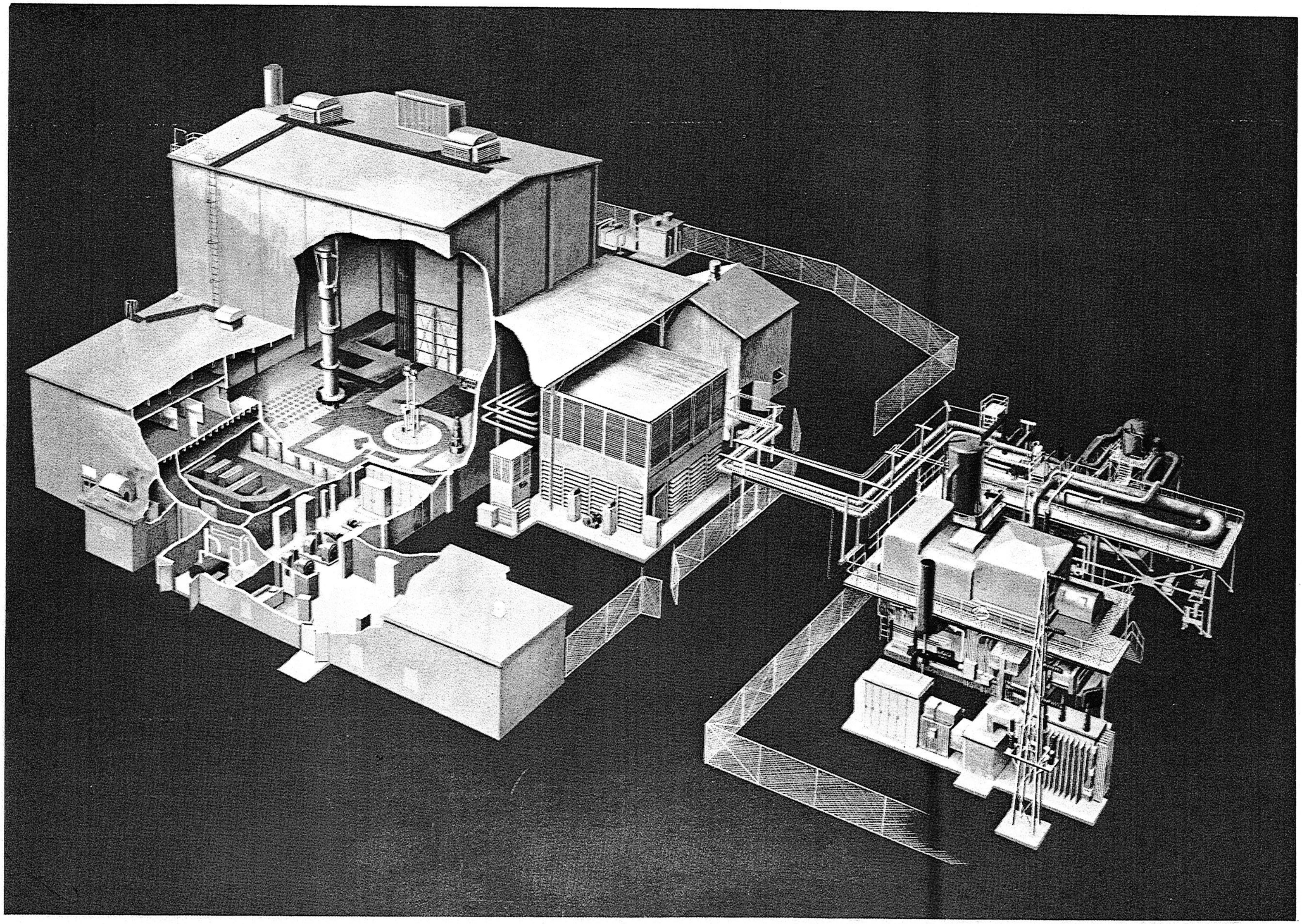

Figure 1. Sodium Reactor Experiment

Figure 1. Sodium Reactor Experiment

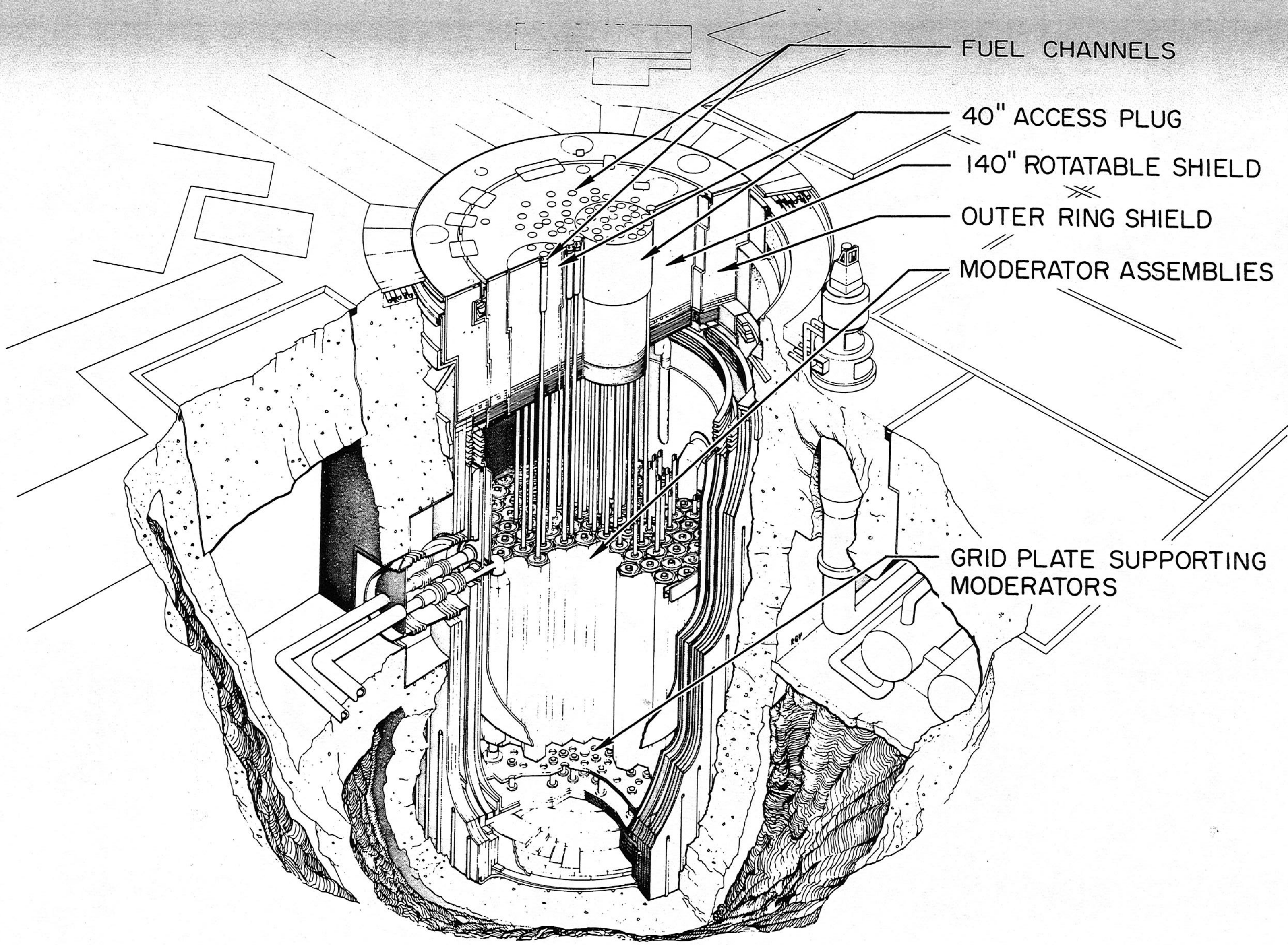

Figure 2. SRE Core

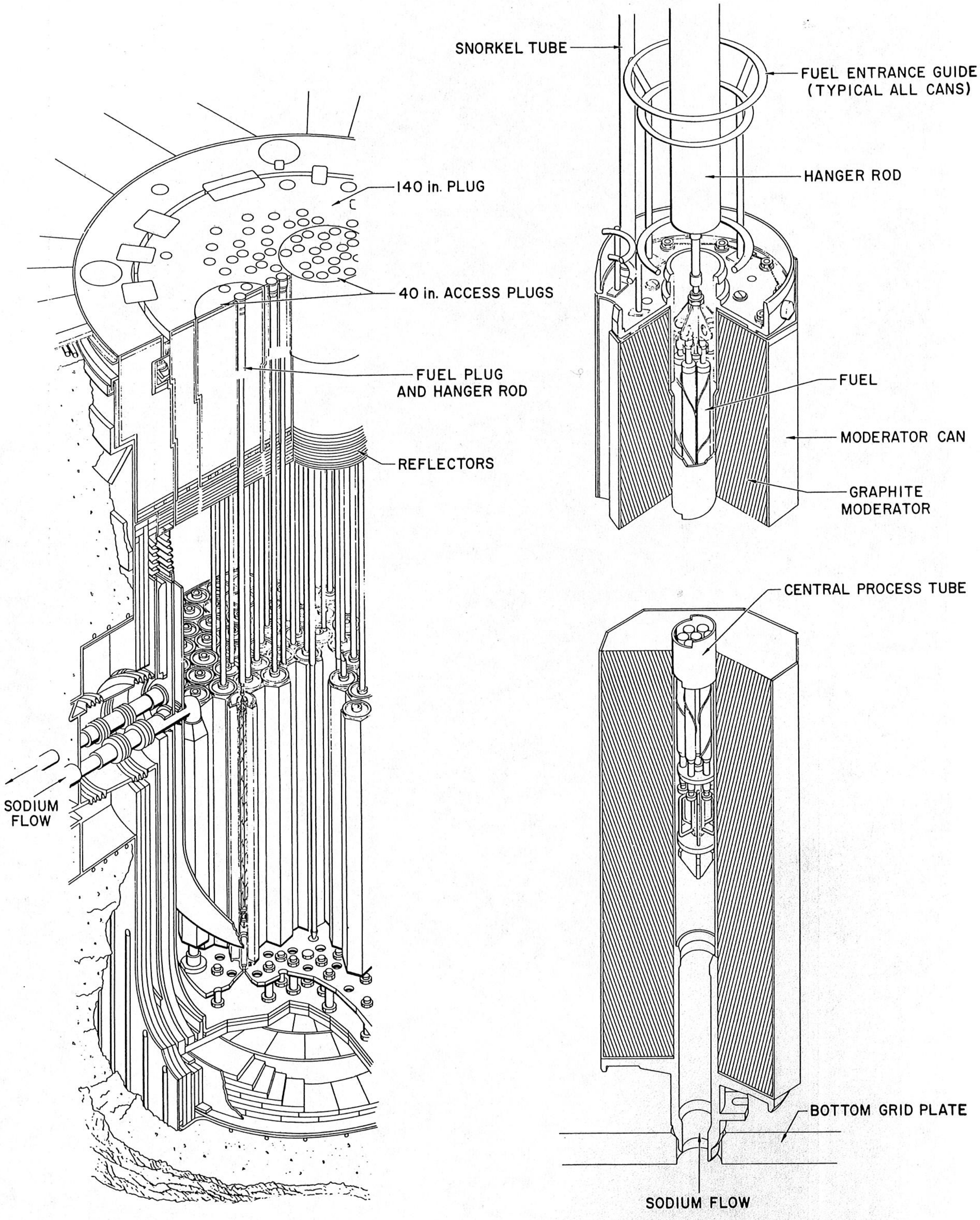

Figure 3. SRE Core and Components

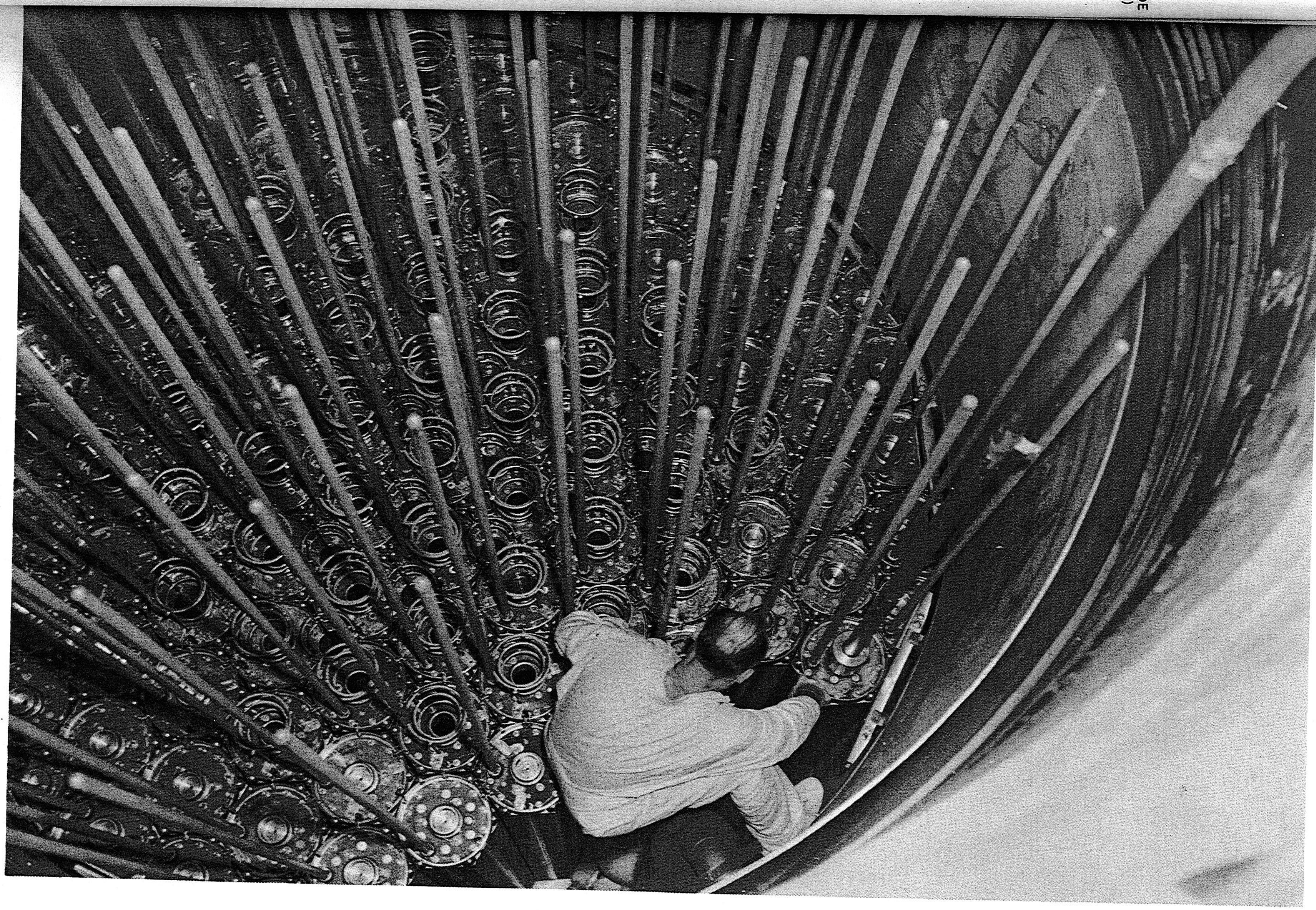

Figure 4. SRE Core During Construction

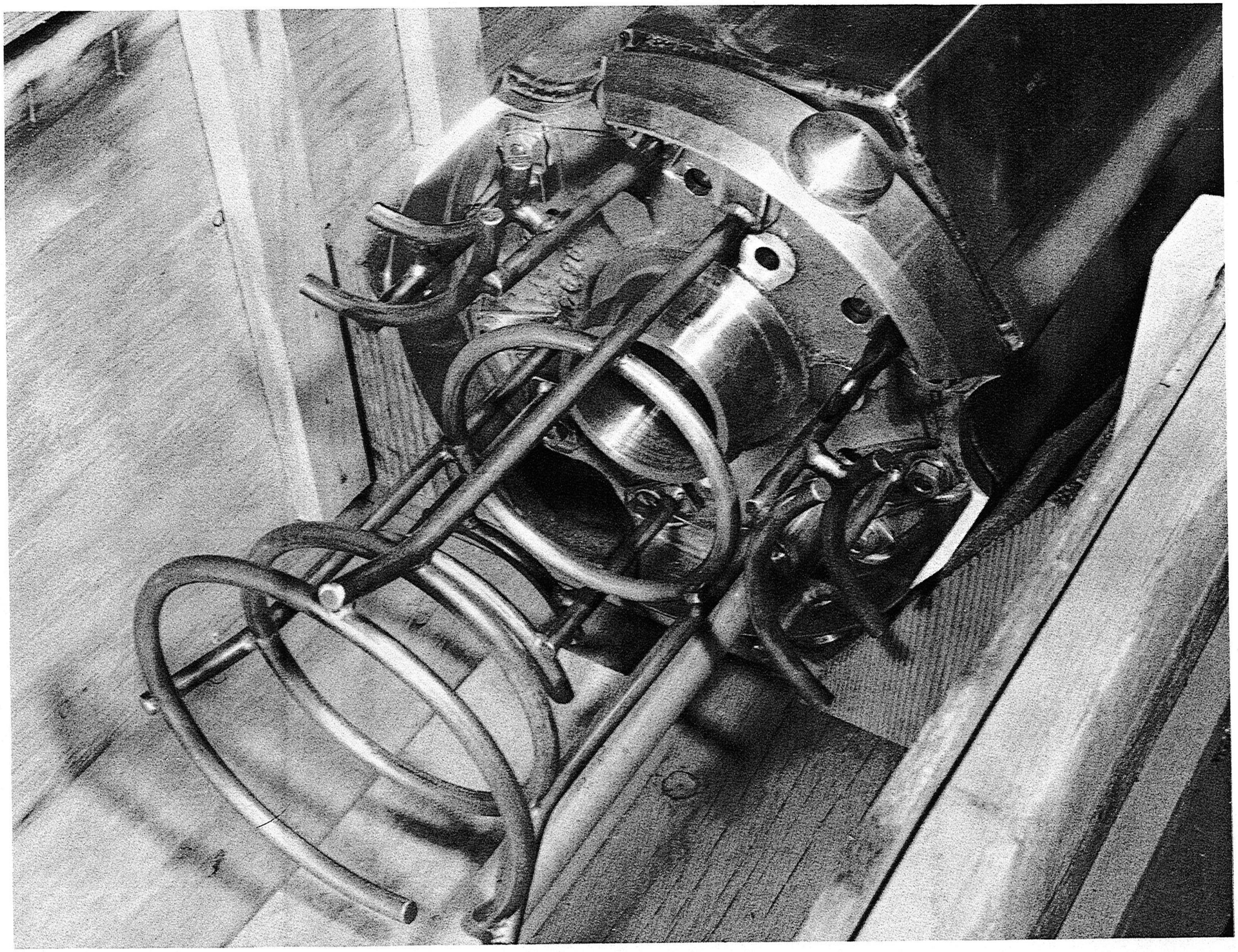

Figure 5. New Moderator Can in Crate

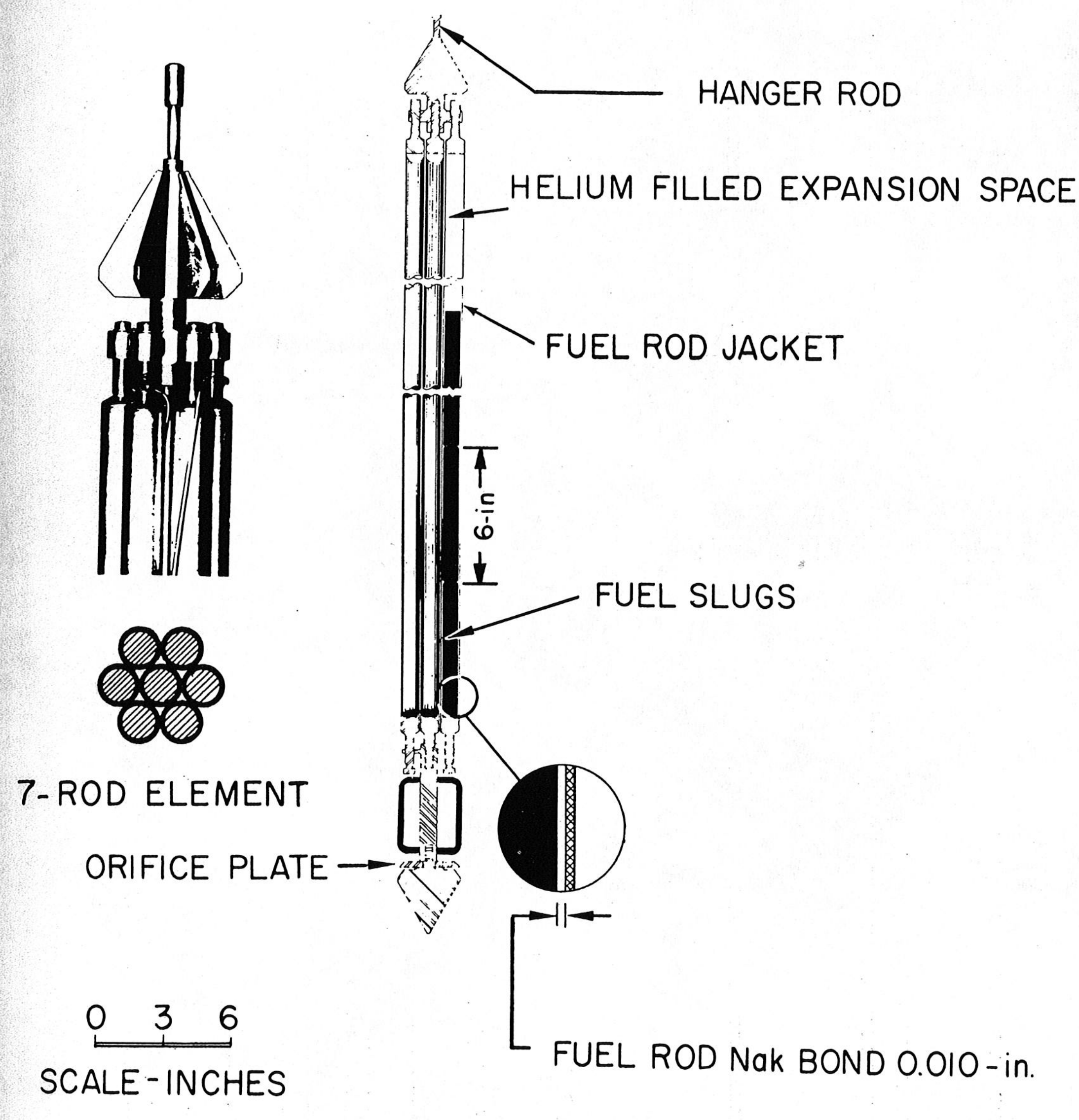

Figure 6. SRE Fuel Element

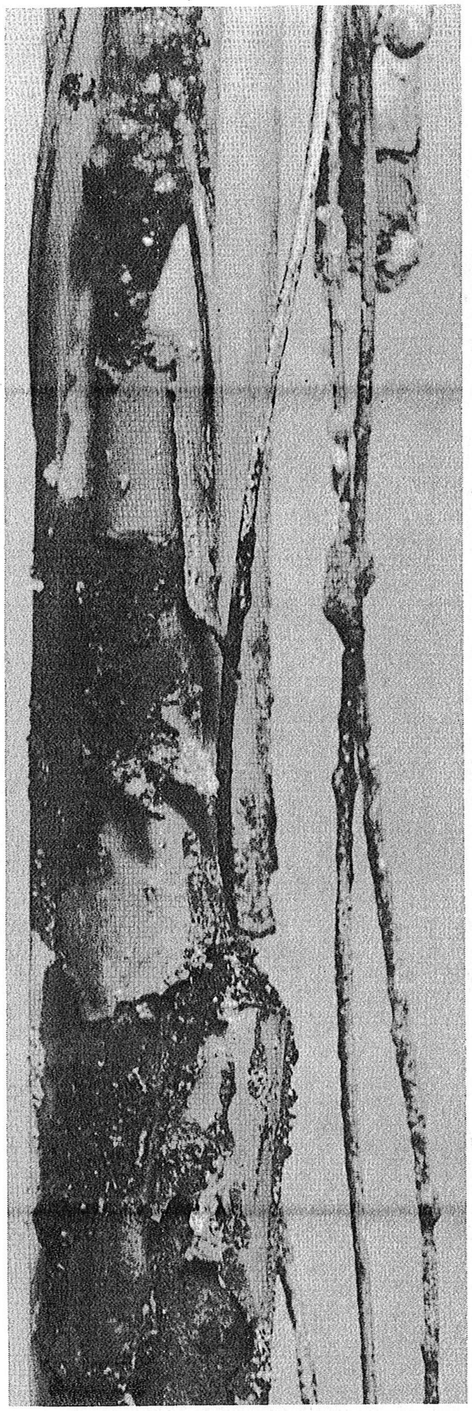

Figure 7.
Damaged Fuel Element
Middle Section

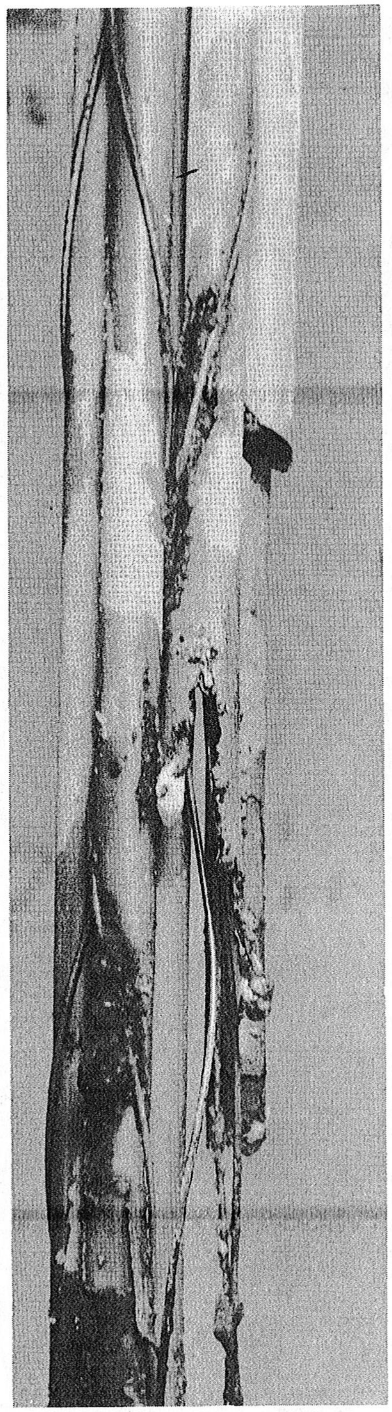

Figure 8.
Damaged Fuel Element
Portion Between Middle
and Bottom Sections

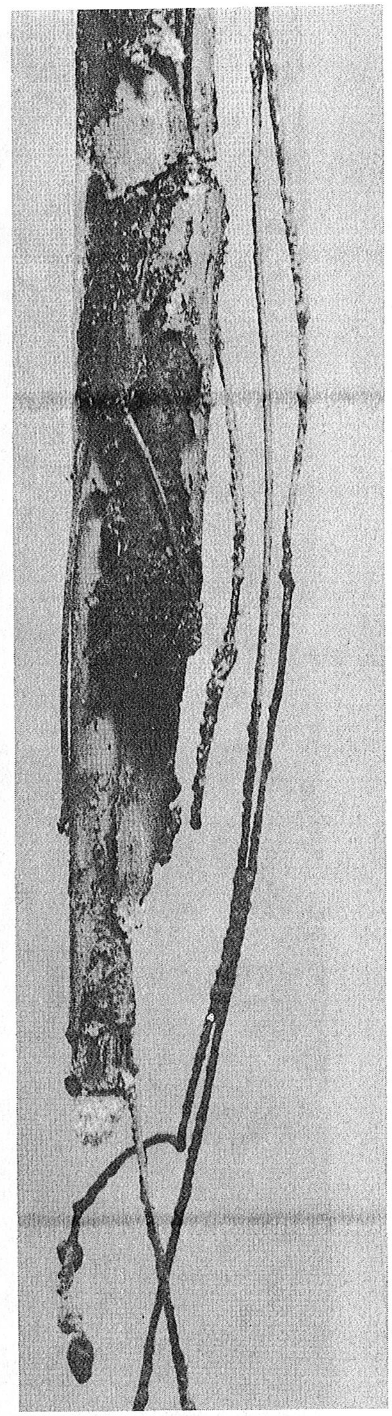

Figure 9.
Damaged Fuel Element
Bottom Section

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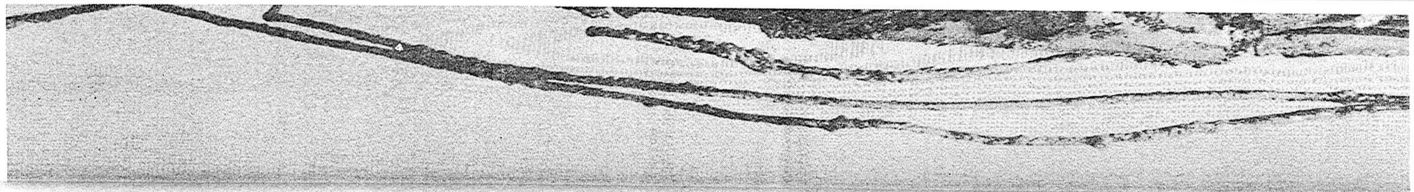
Fuel Eleme
n Section



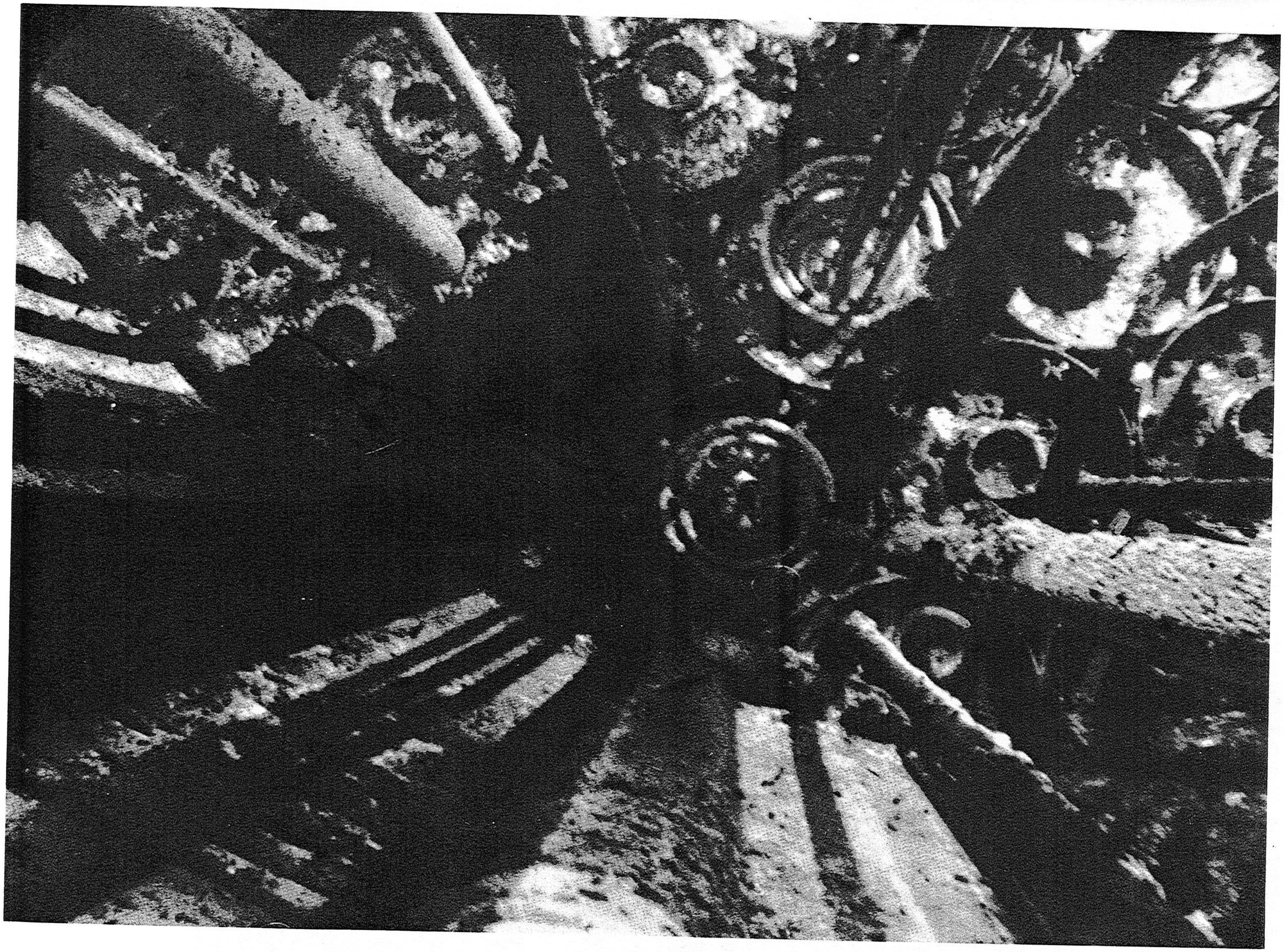
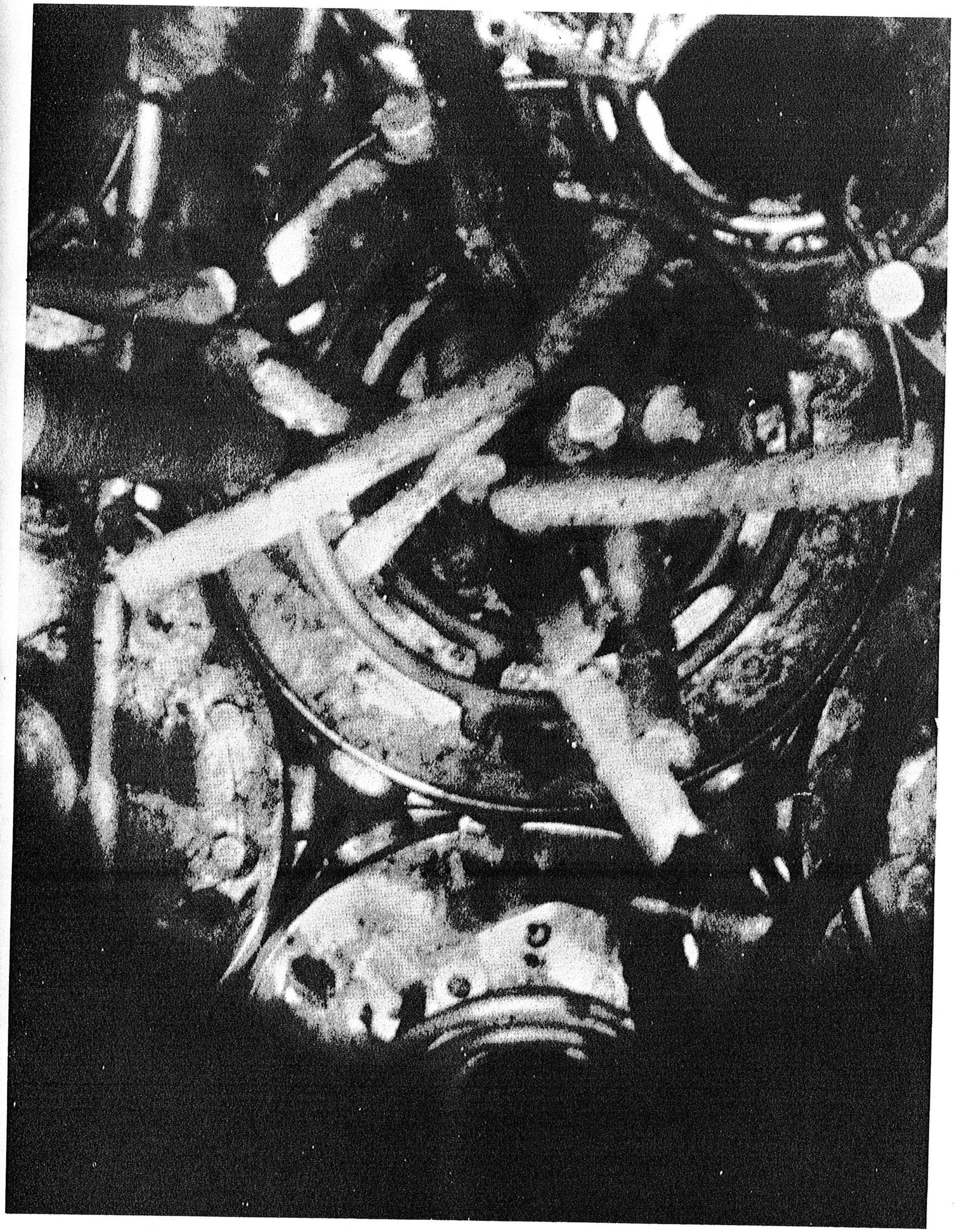


Figure 10. SRE Core Top Before Recovery Effort

Figure 11. Portion of Fuel Elements on SRE Core



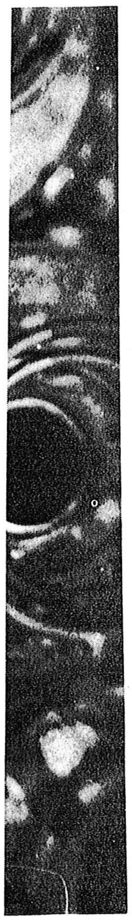


Figure 12. Fuel Slugs on Top of Core

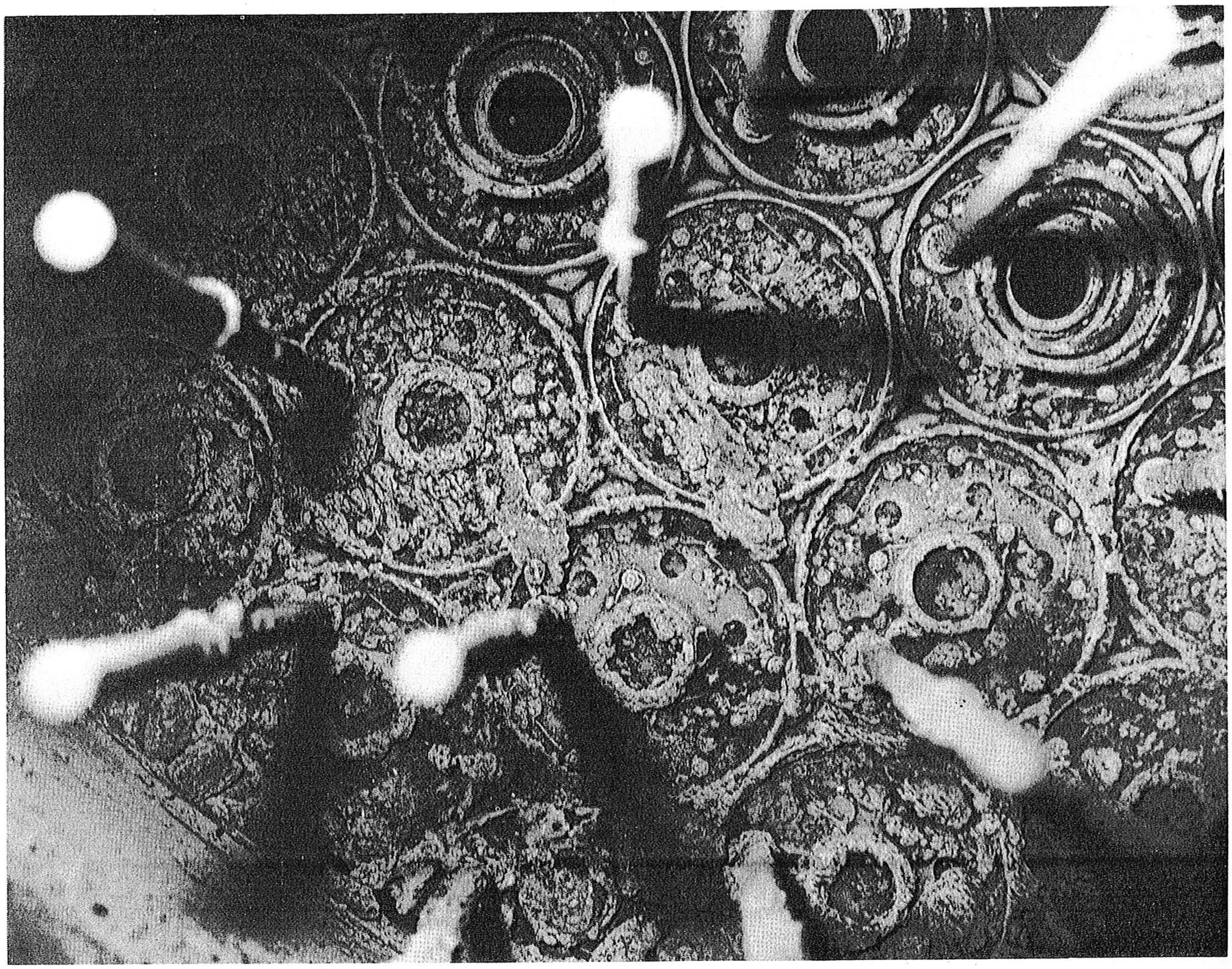


Figure 13. Carbonaceous Froth on Reflector Cans

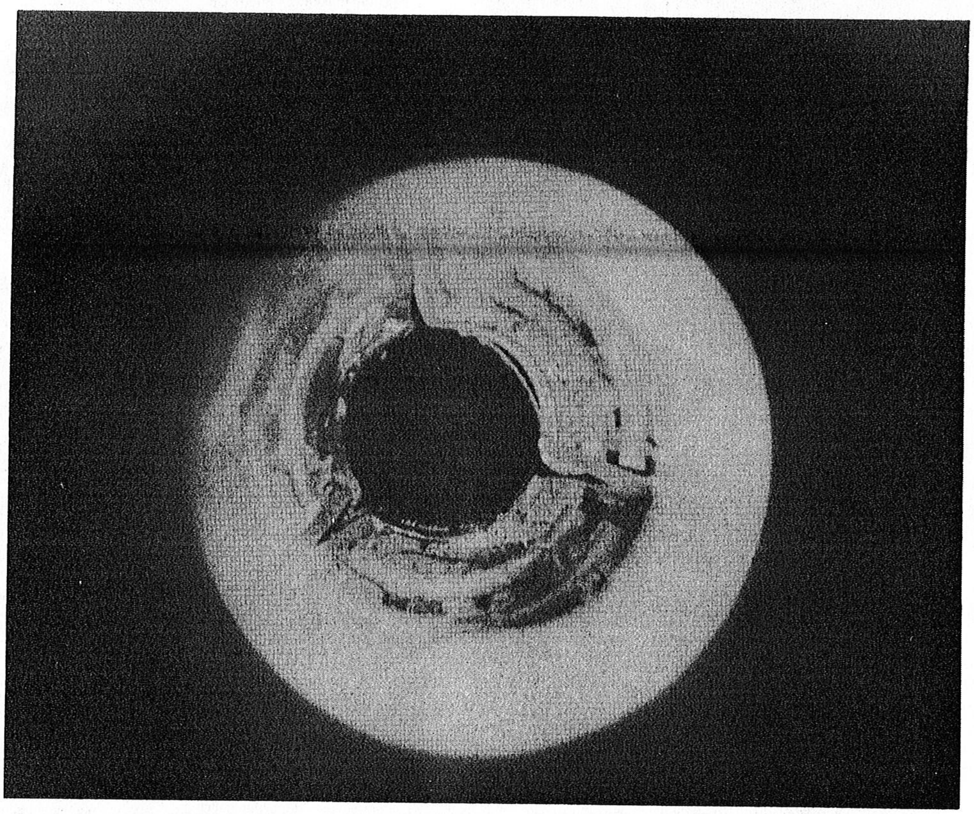


Figure 14. Split Seam on Leaky Moderator Can

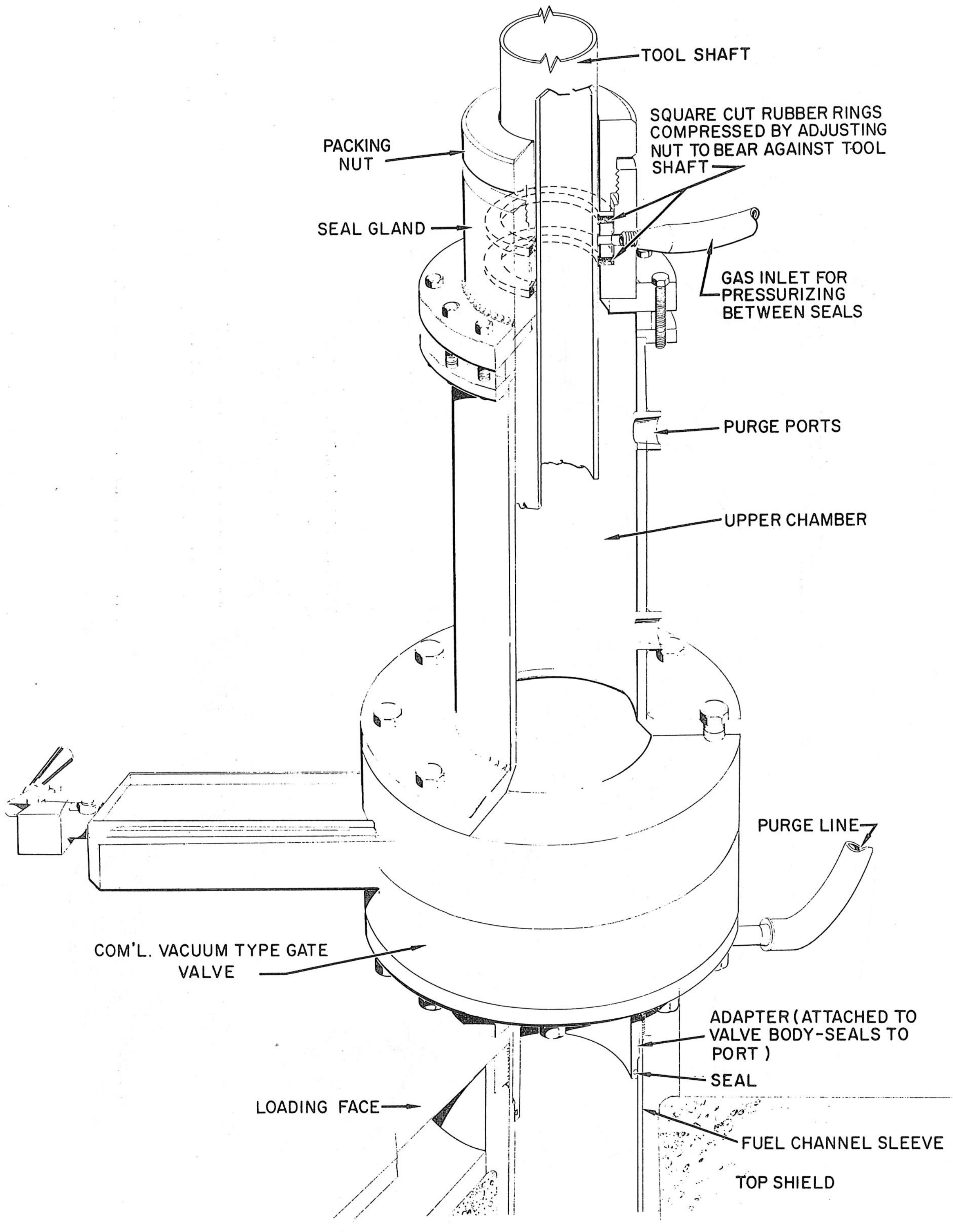


Figure 15. Gas Lock Assembly

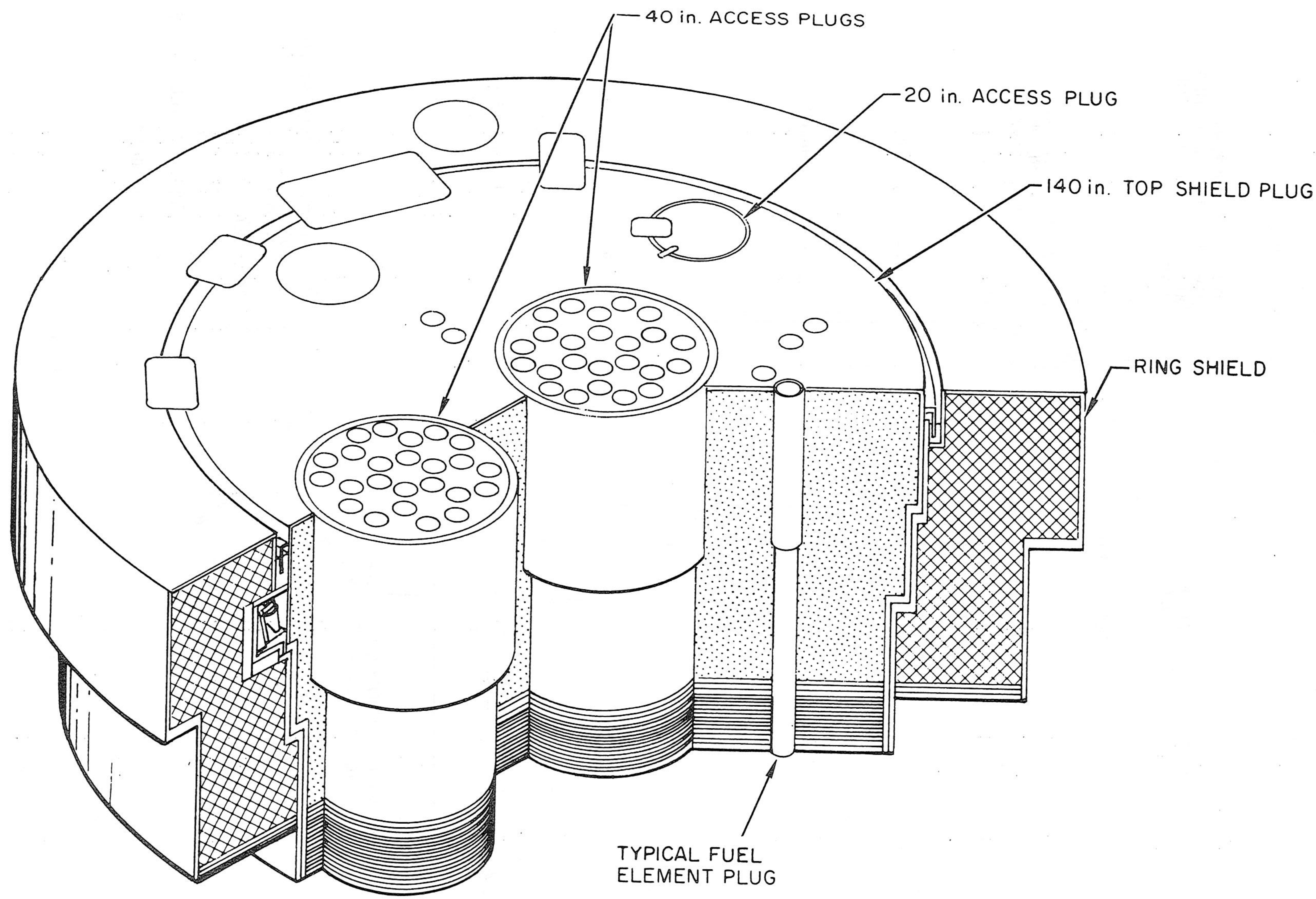


Figure 16. SRE Loading Face Shield

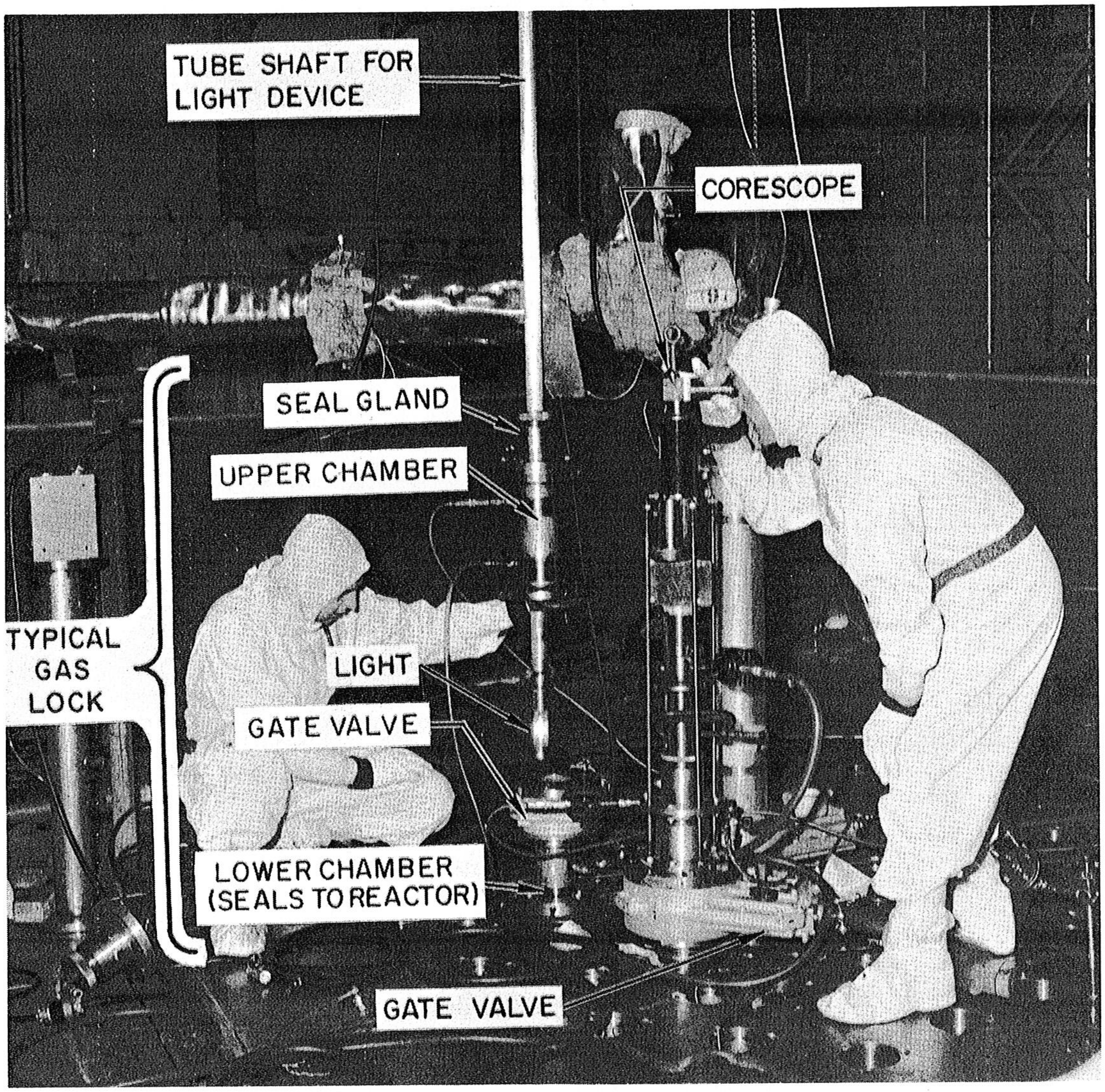


Figure 17. Observing Core Through Optical Device

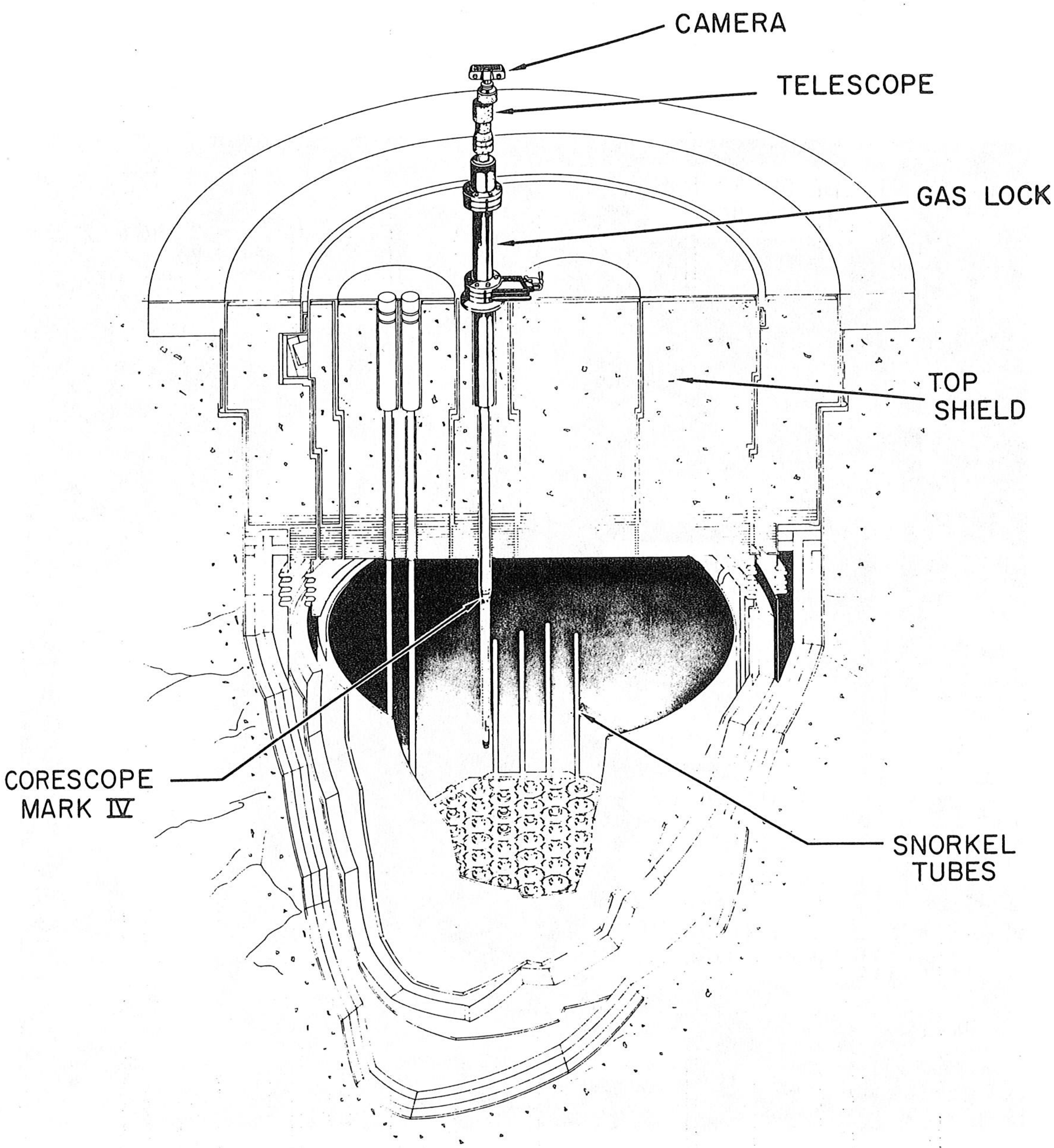


Figure 18. Photographing Top of Core