LA-2761

C.3

LOS ALAMOS SCIENTIFIC LABORATORY

OF THE UNIVERSITY OF CALIFORNIA ○ LOS ALAMOS NEW MEXICO

MOLTEN PLUTONIUM PUMP EXPERIMENT

Printed in USA. Price $ 2.00. Available from the

Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

LA-2761
REACTOR TECHNOLOGY
TID-4500 (18th Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA LOS ALAMOS NEW MEXICO

REPORT WRITTEN: August 1962

REPORT DISTRIBUTED: December 24, 1962

MOLTEN PLUTONIUM PUMP EXPERIMENT

Work done by:	Report written by:
K-Division GMX-1 CMB-6 CMB-11	J. E. Deverall G. L. Caldwell

Contract W-7405-ENG. 36 with the U. S. Atomic Energy Commission

ABSTRACT

The Molten Plutonium Pump Experiment was a subcritical mock-up of a reactor core in which a plutonium-iron alloy was circulated by means of a sodium lift pump. Sodium for the lift pumping was circulated by an E.M. pump in an isothermal loop at 500°C. The purpose of the test was to study pump characteristics, instrumentation, sodium-fuel separation, and fuel transfer systems. Operational characteristics of the core and fuel transfer system were observed by a closed, gamma ray television circuit, radiographs, and a fuel reservoir level indicator. Motion pictures were taken of the TV screen to provide a permanent record. All phases of the study were completed before a leak at the core necessitated shutdown.

CONTENTS

CONTENTS (continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

1. INTRODUCTION

The feasibility of using a molten plutonium alloy as a mobile reactor fuel is now being studied by the Los Alamos Scientific Laboratory. Circulation of molten fuel in a reactor core would permit continuous flushing of fission gases generated and offer the potential for fuel reprocessing during operation. A further possibility with such a system is to use the pumping fluid as the primary heat exchange medium. This would provide excellent heat transfer by the mixing of two liquid metals and eliminate many of the problems of transferring heat through container walls. One method for circulating the fuel in the core is to use a lift or jet pump with sodium as the pumping fluid. One of the steps in feasibility studies of this system is to build and operate subcritical mock-ups to develop fuel transfer systems and pumps, fuel-sodium separation methods, and instrumentation to indicate core conditions under radiation fluxes. This experiment was one of a series of such experiments.

Before the core assembly was designed for this experiment, lucite mock-ups were constructed and tested using mercury and water to simulate the plutonium alloy and sodium, respectively. Copper pumps were built and dipped in mercuric nitrate to promote wetting by the mercury such as plutonium alloys wet tantalum. A lucite reservoir, attached to a motor-driven bellows, was also installed in the apparatus in order to study fuel transfer systems. After a suitable design had been determined from these tests, a core assembly, lift pump, and reservoir were constructed of tantalum.

2. DESCRIPTION OF APPARATUS

Although every effort was made to develop a simple apparatus, the associated equipment required for heating, control, radiographs, scanners, etc., was the major part of the system and resulted in a rather involved test setup as shown in Fig. 1.

The basic test section of this apparatus was a pot core assembly, lift pump, and reservoir submerged in sodium in a stainless steel container tank. This tank was connected to a sodium flow loop and a sodium bellows pusher system. The flow loop contained two E.M. pumps, a uranium hot trap, E. M. flowmeter, and a flow calorimeter. The bellows pusher system was essentially a static sodium leg attached to the reservoir to serve as a fuel transfer system. All these components were assembled on a portable unistrut frame, Fig. 2. Sodium was pumped upward by the E.M. pump through the hot trap and E.M. flowmeter to the lift pump in the tantalum test section where a mixed stream of sodium and fuel was formed. After the sodium separated from the fuel in the upper tantalum pot, it returned to the external loop, passing through the flow calorimeter and back to the E.M. pumps. Circulation of the fuel was confined to the tantalum core assembly. A stainless steel catch pan, filled with vermiculite, was installed at the bottom of the unistrut frame in case any sodium leaked out of the loop section.

2.1 Test Section

2.1.1 Tantalum Core Assembly

All parts of the test section which could contact the fuel were made of tantalum as it is one of the few metals capable of containing plutonium alloys. The assembly consisted of two parts: a lower pot to represent the core and an

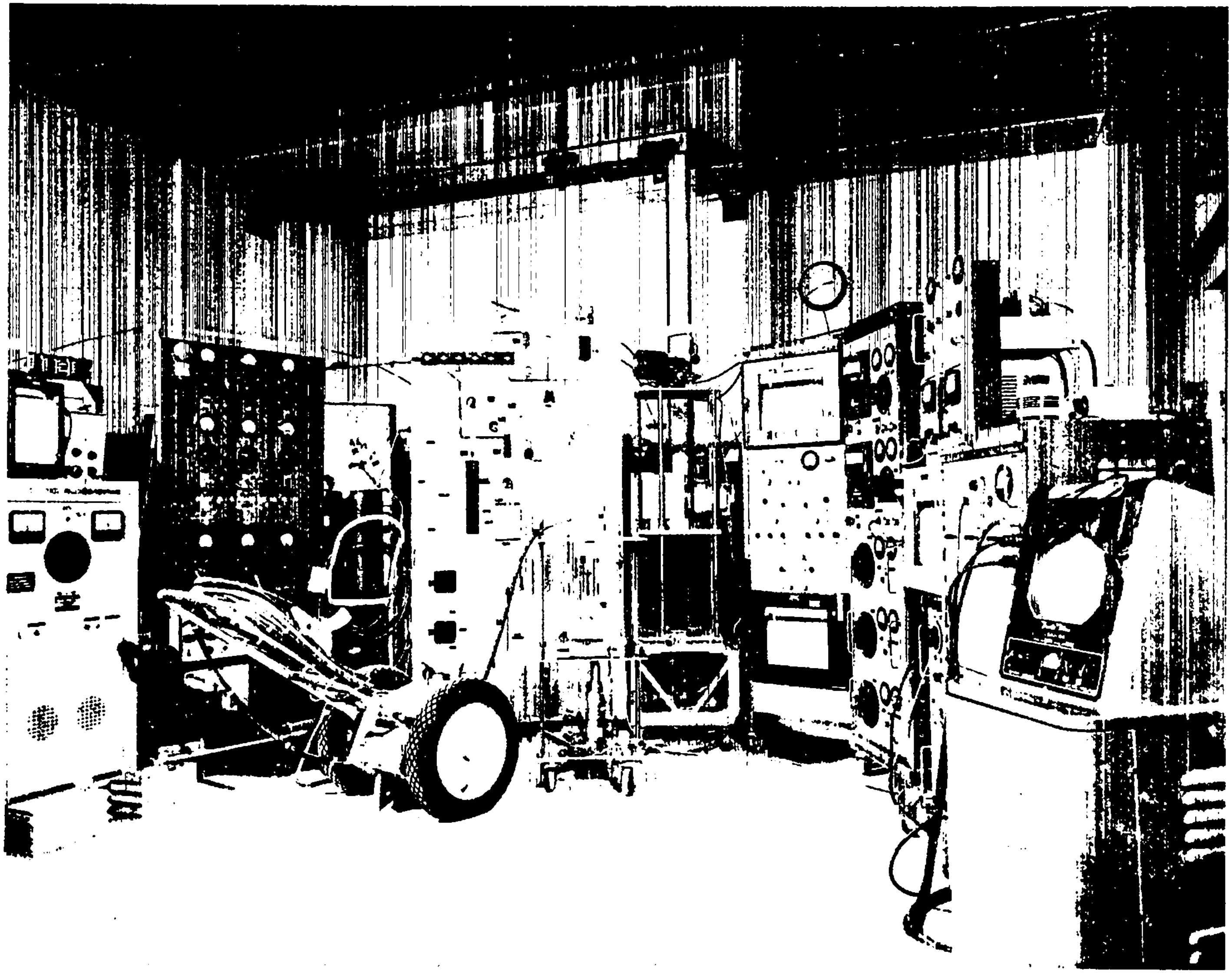


Fig. 1 Complete Test Setup

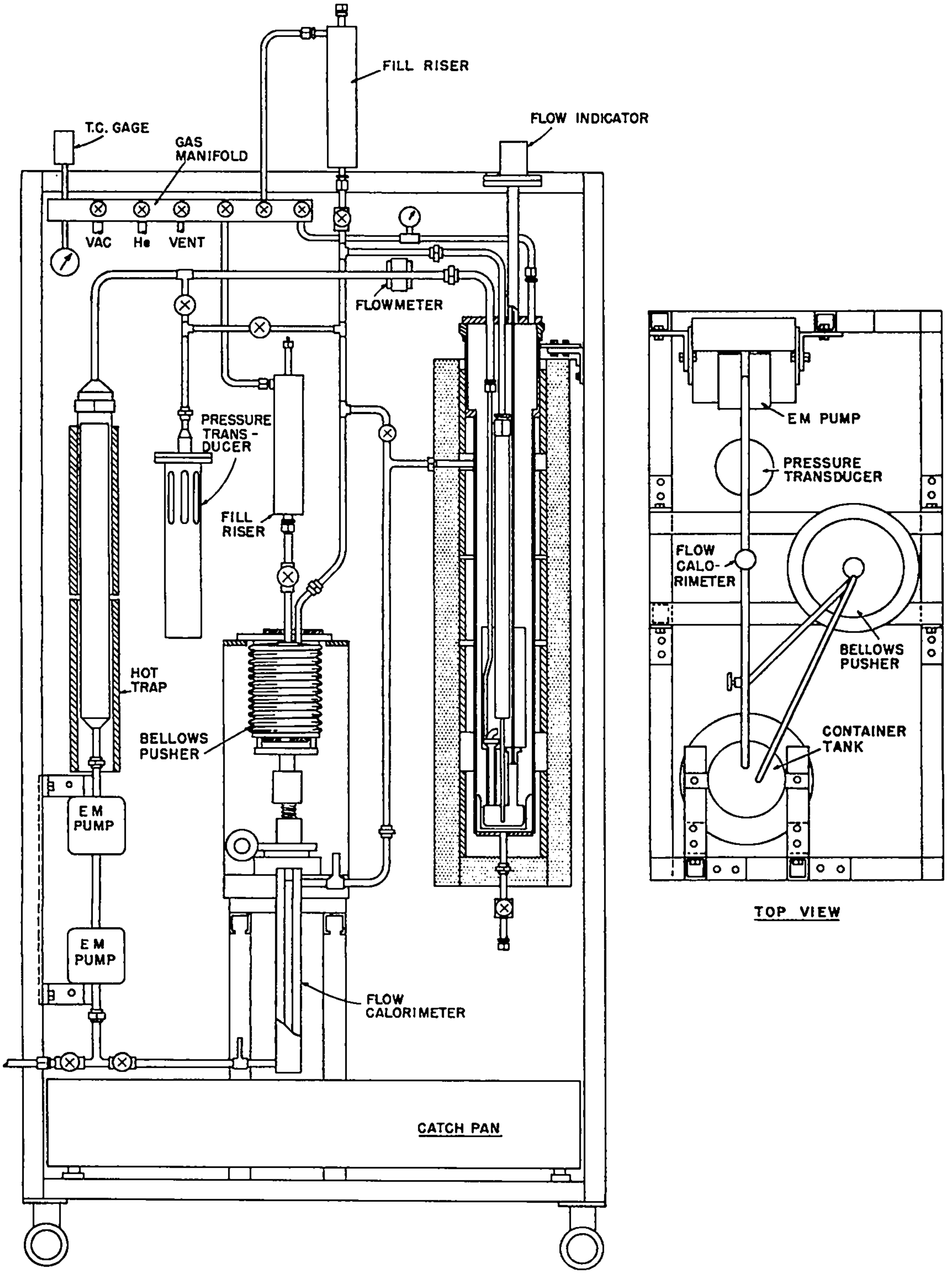
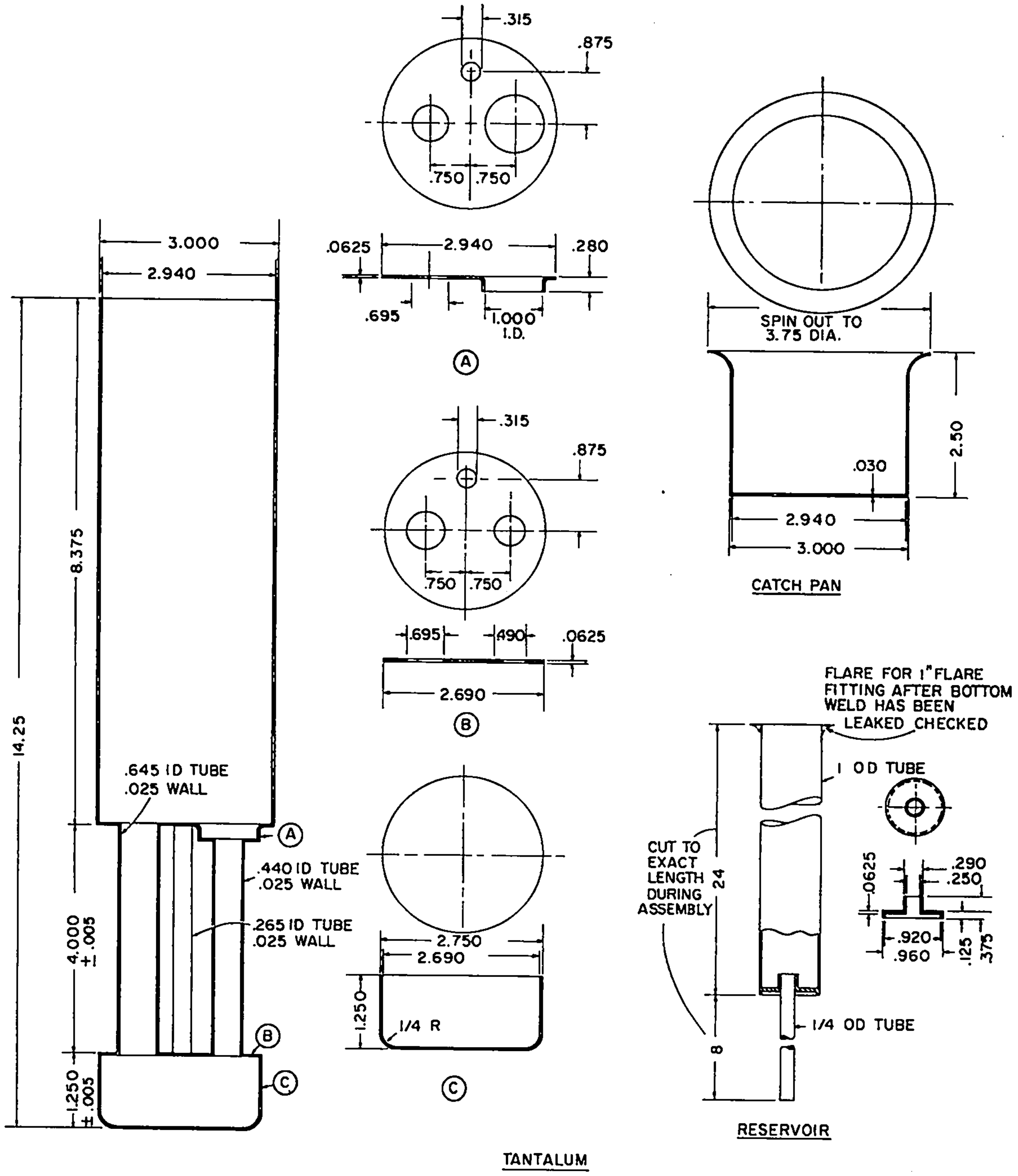


Fig. 2 Container Tank and Sodium Loop Layout

upper pot to provide for fuel-sodium separation. The two pots were connected together by three tubes, each 4 in. long. These tubes simulated what would normally be holes through a decoupler block for the lift pump, reservoir tube, and fuel return leg. The decoupler block in a reactor core would decouple the fuel in the separation pool from the core mass and also provide an operating head for the lift pump. The phantom tube structure was used to allow observation of fuel motion and mixed stream flow in the lift pump by radiography and gamma ray television. The upper pot was 3 in. in diam and 8-3/8 in. long. It was formed into a cylinder from 30-mil sheet and seam welded. The bottom was a 60-mil disc welded to the cylinder. A well, 1 in. in diam and 0.280 in. deep, at the top of the fuel return tube, was installed to form a deeper pool of fuel and help prevent sodium carry-back to the core. The lower pot was a 2-3/4-in.-diam cup 1-1/4 in. high formed from 30-mil sheet. The top was a 60-mil disc. The three tubes connecting the upper and lower pots were welded to the discs before the discs were welded to their respective pots. See Figs. 3 and 4.

2.1.2 Lift Pump

The tantalum lift pump consisted of two concentric tubes connected to a plenum chamber. The inner tube was 1/2 in. in diam with a necked section near the bottom containing eight 1/16-in.-diam holes. The bottom of the tube was flared out to the inside diameter of the outer tube and the two tubes seal welded together. The plenum chamber was formed by welding the outer pump tube to the bottom plate with the inner pump tube extending through to the top plate where it was welded. The plenum chamber was 1.210 in. in diam by 0.374 in. high. A 1/4-in. tube was welded to the top of the chamber for the sodium inlet as shown in Fig. 5. A 1/2-in. elbow attached to the inner pump tube directed the mixed stream flow horizontally for better separation. Lift pump action was obtained by forcing sodium down the annulus and injecting it into the fuel in the inner pump tube through the eight 1/16-in. holes. This created a lower density mixture which was displaced by fuel flowing down the fuel return tube. The mixed stream separated in the upper pot with the sodium returning upward to the sodium loop and the fuel falling into the separation pool and then returning to the core through the fuel return tube. See Fig. 6.



ALL DIMENSIONS IN INCHES

Fig. 3 Tantalum Core Assembly Detail

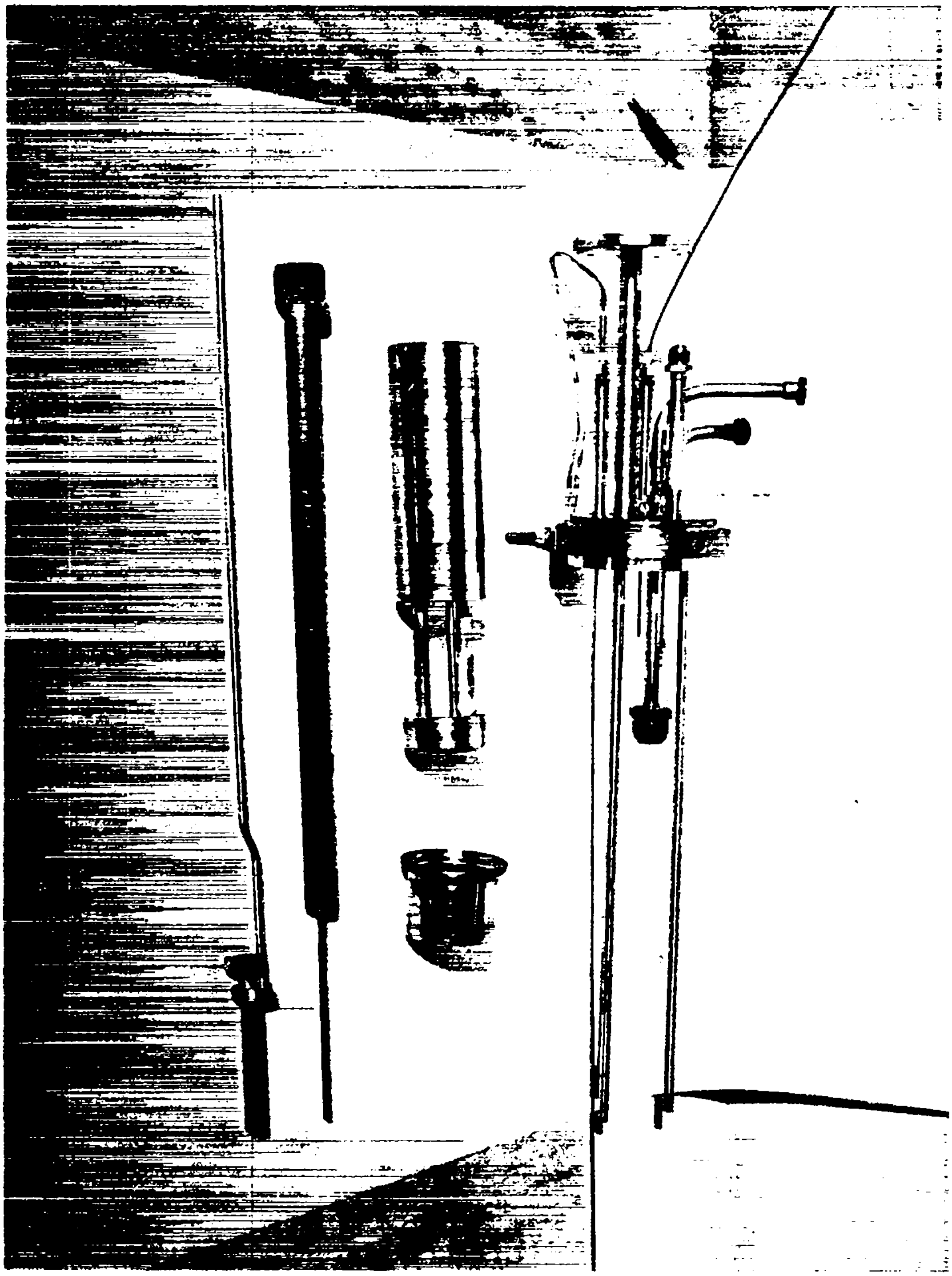
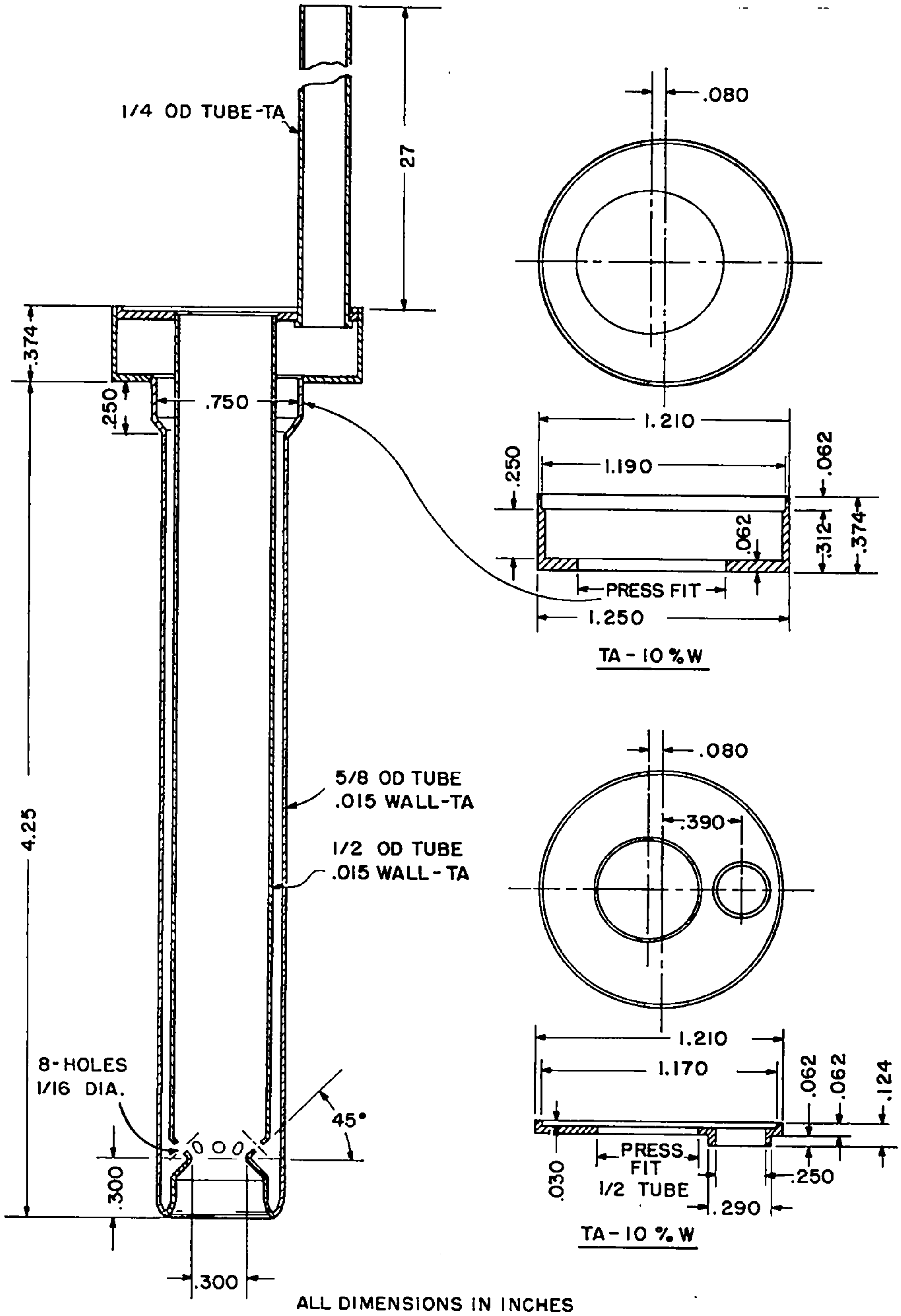


Fig. 4 Exploded View of Core Assembly



ALL DIMENSIONS IN INCHES

Fig. 5 Lift Pump Detail

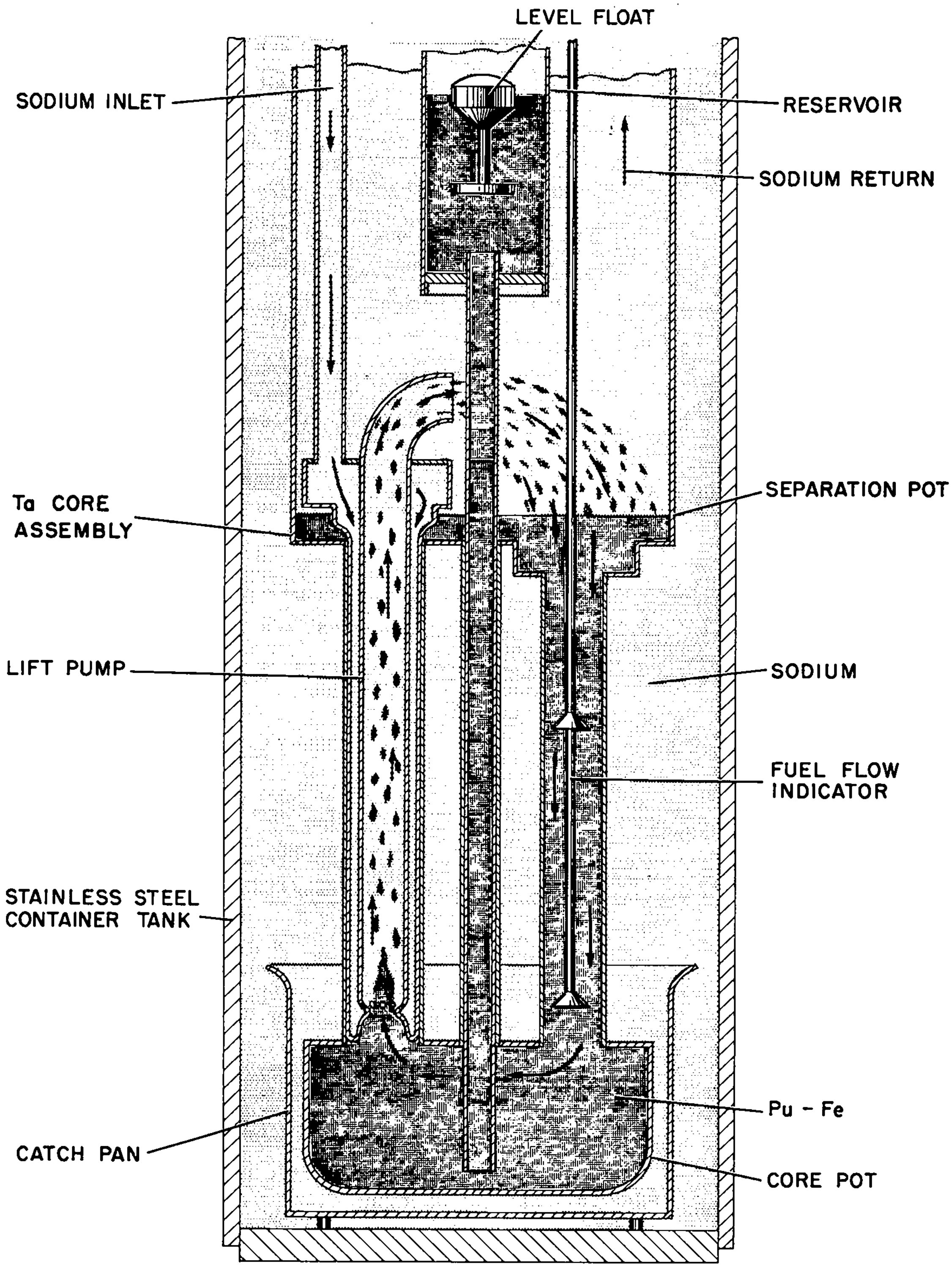


Fig. 6 Lift Pump Operation

2.1.3 Reservoir

The reservoir was a 1-in.-diam tantalum tube with a 15-mil wall. A machined bottom cap provided a re-entrant arrangement for the 1/4-in. tube which went down into the core. This bottom cap was welded into the 1-in. tube. At the top of the reservoir, a flare was made for attachment to a 1-in. stainless steel flare fitting. The main purpose of the reservoir was for transferring fuel into and out of the core and varying the level in the separation pot. It was also used to load the fuel slugs at the beginning of the experiment. See Figs. 3 and 4. A 5/8-in.-diam cap was placed over the re-entrant tube to prevent the solid fuel slugs from sealing the tube. The cap had scallops cut around the bottom of it so that when the fuel melted it could flow out of the reservoir into the core.

2.1.4 Catch Pan

In the event of a leak in the core, a tantalum catch pan was placed below the core assembly. This was a 3-in.-diam tube flared at the top to a 3-3/4 in. diam. A 60-mil disc was used for the bottom and had three legs to keep the catch pan from blocking the sodium drain tube at the bottom of the container tank. See Figs. 3 and 4.

2.1.5 Container Tank

The container tank was a 4-in.-diam, 1/8-in.-wall, stainless steel tube 29-1/2 in. long, with an enlarged section at the top, 5 in. in diam and 7 in. long. A 5-in. Conoseal fitting was the main seal with a 1/2-in. plate welded into the top half of the fitting and the lower half welded to the tank. See Fig. 7. Tubes penetrating the top of the tank were welded to the 1/2-in. plate. Three stainless steel hanger rods were screwed into tapped holes on the under side of the 1/2-in. plate to support the tantalum core assembly. See Fig. 8. The reservoir, pump tube, thermocouples, and fuel flow and level indicator were also attached to the 1/2-in. plate so that when the top half of the Conoseal fitting was lifted out the complete

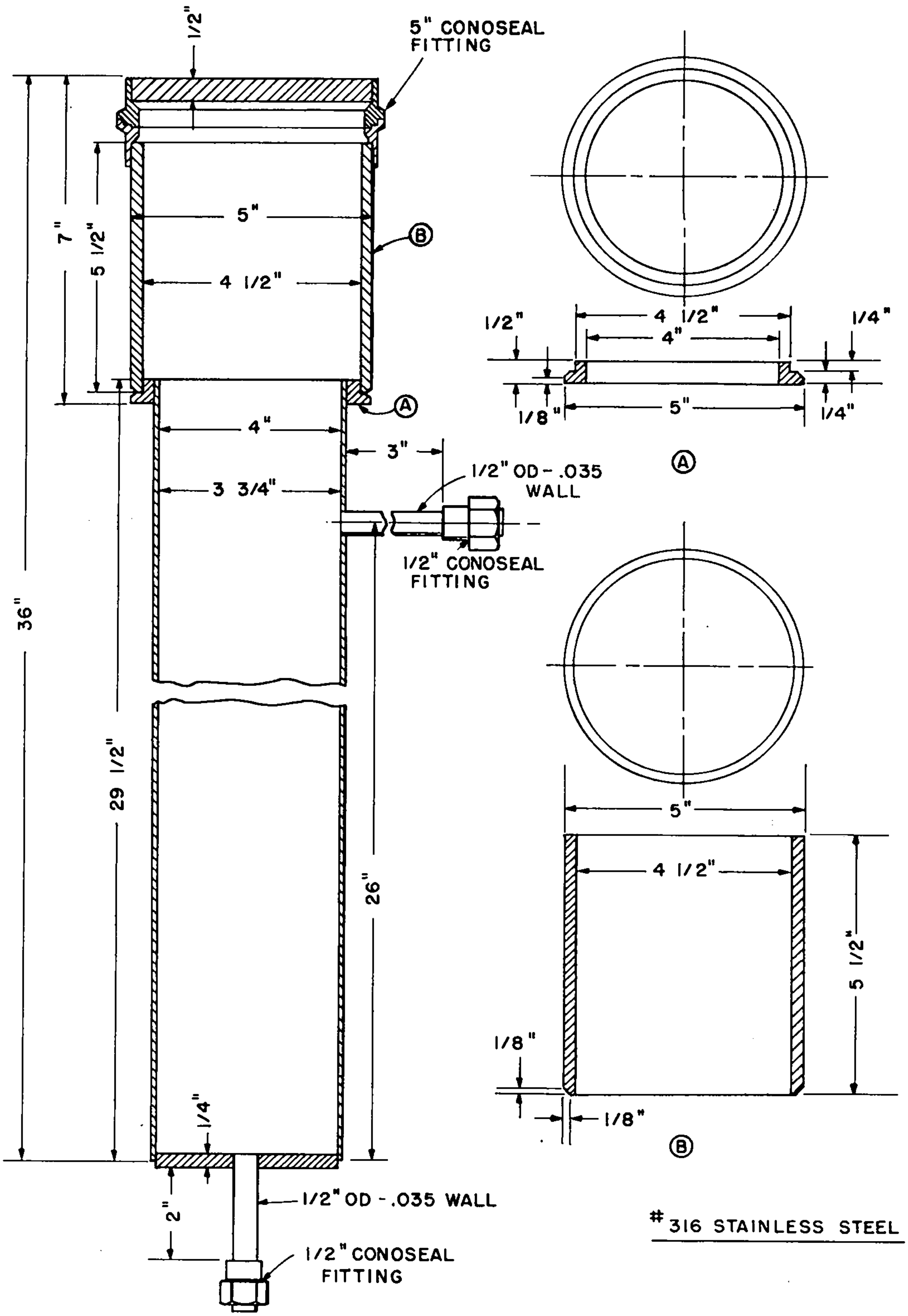


Fig. 7 Container Tank Detail

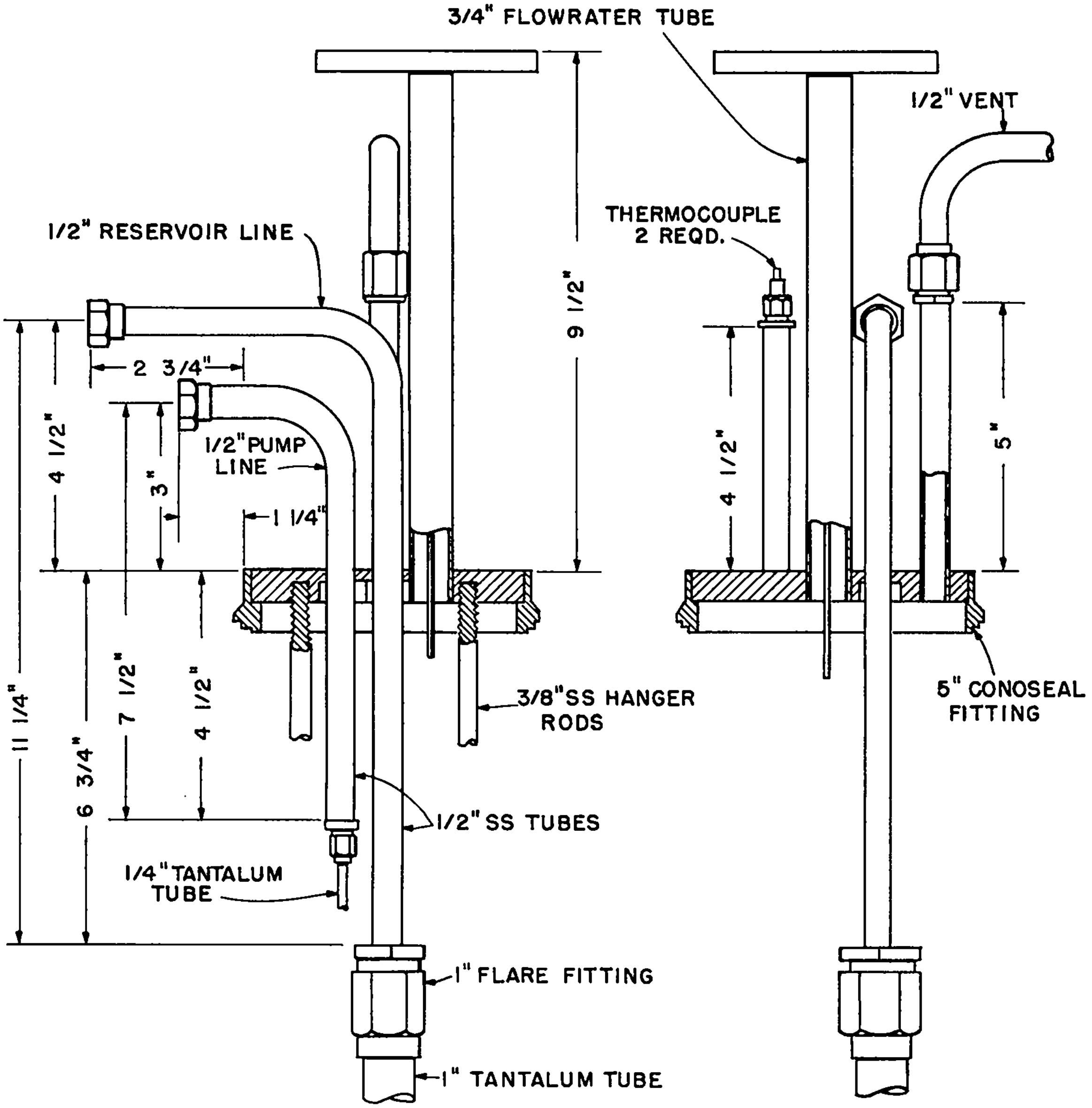


Fig. 8 Container Tank Lid Detail

test assembly was removed except for the catch pan. See Fig. 9. A 1/2-in. tube was welded into the side of the tank for the sodium return line and another 1/2-in. tube welded into the bottom for draining the sodium at the end of the experiment. See Fig. 10.

2.1.6 Fuel Flow and Level Indicator

This combination instrument was a tantalum rod with two cone shaped bobs suspended in the fuel return leg. When fuel rose up the fuel return leg and contacted the bobs, a buoyant force was exerted on the rod. The top of the rod was attached to a transducer system for an electrical readout of the forces. In this manner it was used as a level indicator. After the core had been filled, the transducer was rezeroed and when pumping of the fuel started, downward forces due to fuel flow past the bobs indicated flow.

2.2 Sodium Loop

2.2.1 E.M. Pumps

Two E.M. pumps were installed in the loop in order to have a spare in case one failed. These were dc pumps with the field current in series with the driving current. Each pump was attached to a 750-amp, dc power supply. These power supplies had motorized controls for remote operation while the gamma sources were exposed. The pumps mounted in the loop are shown in Fig. 11.

2.2.2 Hot Trap

To provide continuous sodium cleanup, a flow-through hot trap was installed in the loop. Corrugated uranium sheet was used as the gettering material and was contained in a stainless steel tube 2 in. in diam and 24 in. long. A 2-in. Conoseal fitting at the top provided a means for loading the uranium. See Fig. 11.

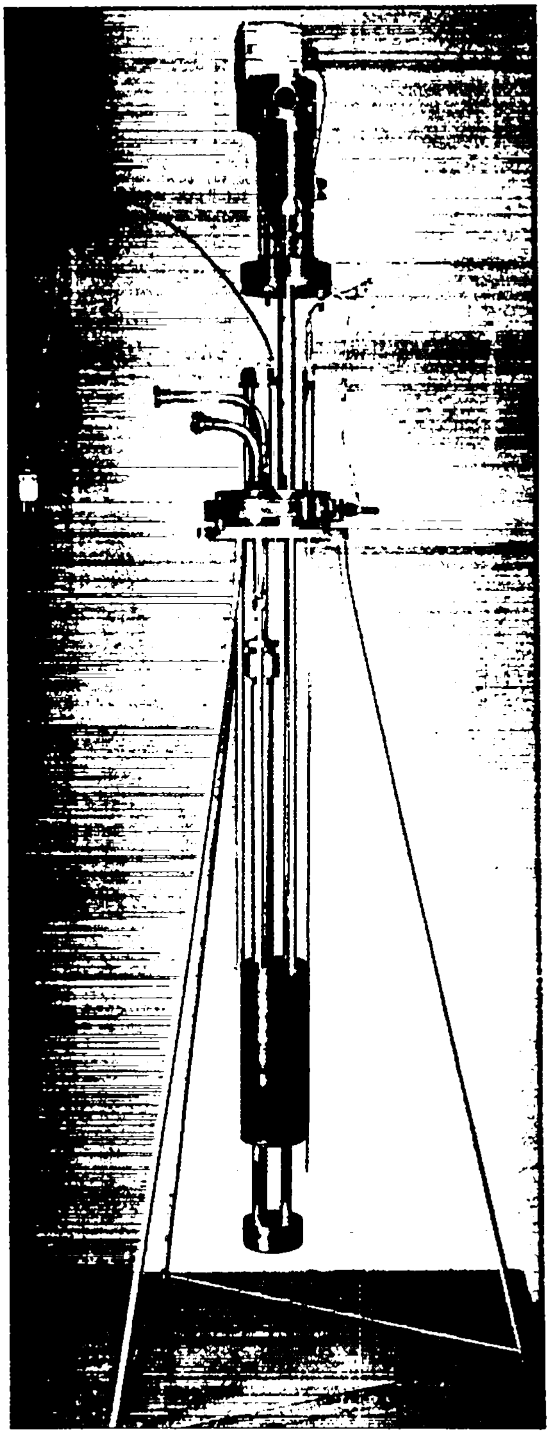


Fig. 9 Tantalum Core Assembled to Container Tank Lid

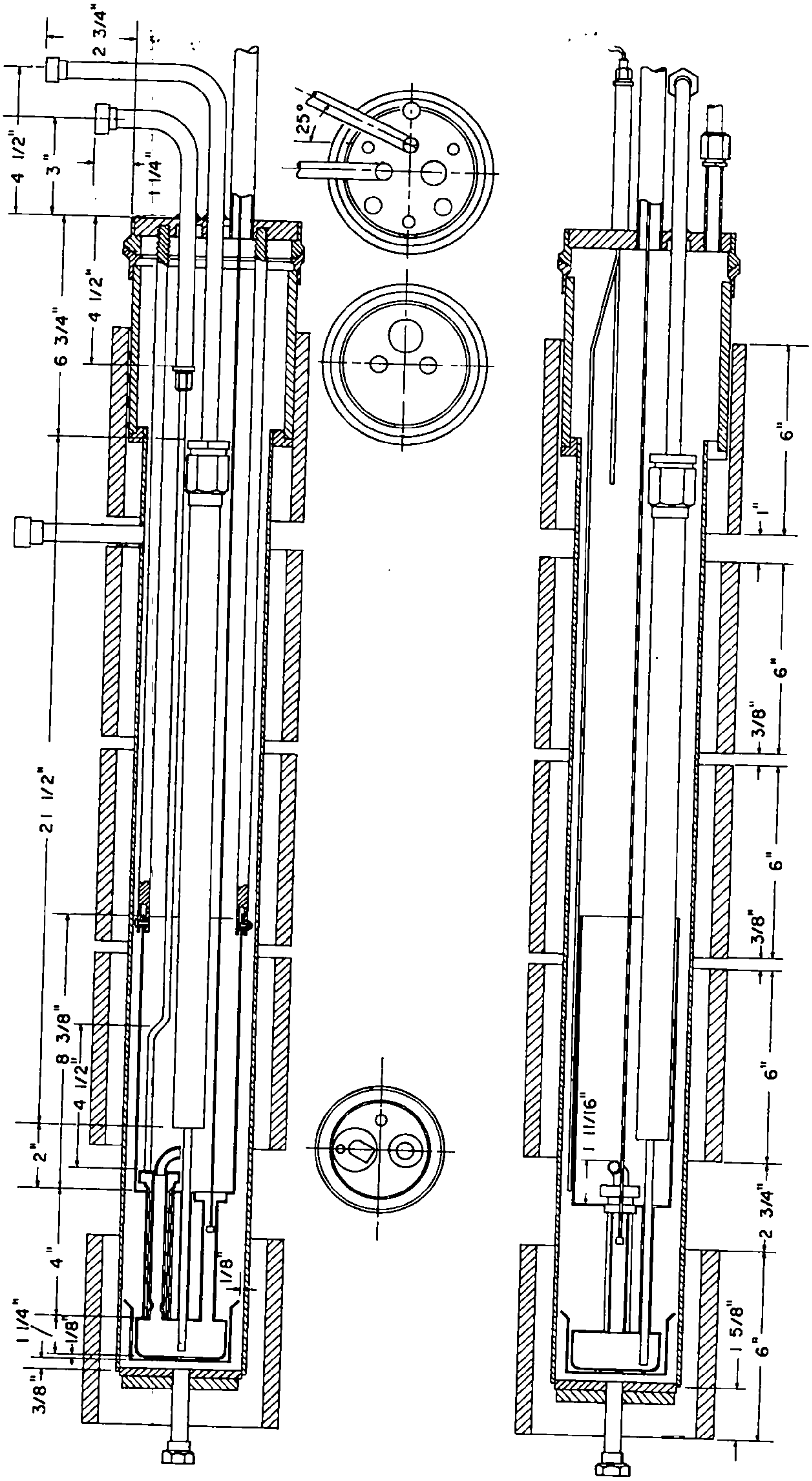


Fig. 10 Test Section Detail

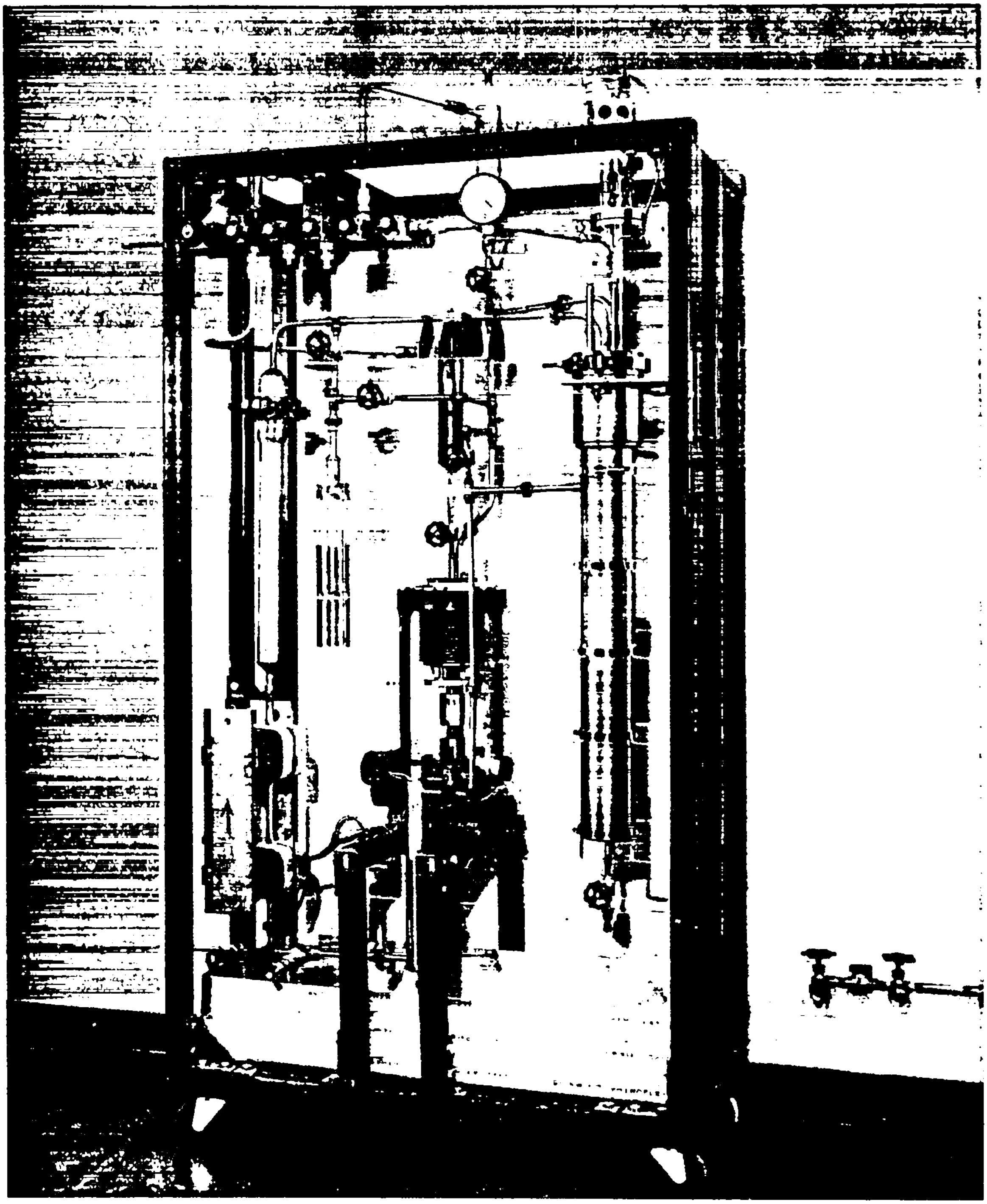


Fig. 11 Test Assembly Mounted on Rack

2.2.3 E.M. Flowmeter

Sodium flow was measured by an E.M. flowmeter, the output of which was paralleled to a Brown circular indicator for visual readout and an Esterline-Angus recorder for a continuous record. The magnetic field was measured as a function of temperature before installing the flowmeter in the loop. Two thermocouples were attached to the magnet to measure magnet temperature during operation. A calibration curve for a similar calibrated flowmeter was used to determine flow rate at any given temperature. See Fig. 12. The flowmeter section was placed between the hot trap and container tank as shown in Fig. 11. It was placed as far away from the E.M. pumps as possible to eliminate pump field effects.

2.2.4 Flow Calorimeter

In an attempt to develop additional sodium flowmeters, a flow calorimeter was built and installed in the loop for comparison with the E.M. flowmeter. This device was an enlarged section in the loop in which a heater well formed an annular flow path. A cylindrical tube heater was sealed into this well with alundum cement. Two thermowells, one at the inlet and one at the outlet, were used to measure the temperature difference across the flowmeter. An ac wattmeter measured the watts input to the heater. The assembly was insulated to reduce heat loss. Knowing the heat capacity of sodium, the flow rate could be calculated with measured values of wattage input and temperature difference.

2.2.5 Pressure Transducer

A pressure transducer was installed in the loop to measure inlet pressure to the sodium lift pump and the bellows pusher pressure. One unit was installed with appropriate valving so that either pressure could be measured but not both at once. The unit was calibrated as an absolute gage so that either pressure or vacuum could be measured. It was calibrated at temperature with helium against a Heise gage. For a complete description of this pressure transducer see L. H. Thacker's report, LA-2727, June, 1962.

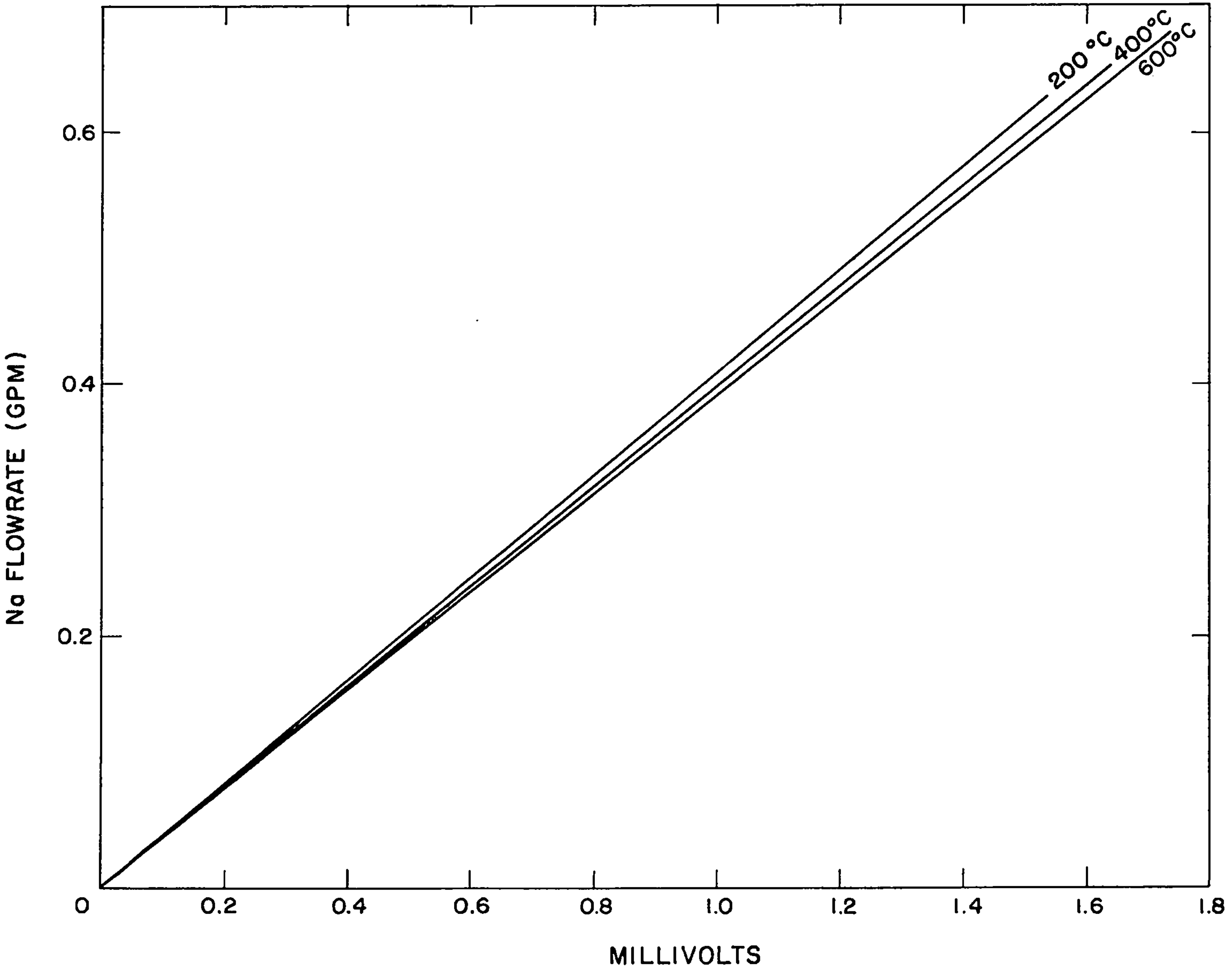


Fig. 12 E.M. Flowmeter Calibration Chart

2.2.6 Fill Risers

Two riser tubes were used during the loading of the loop with sodium to assure a complete filling with no void spaces. One of these risers was put on top of the bellows pusher system and the other at the highest point in the loop. These risers were 1-1/2-in. tubes, 10 in. long, and had Teflon gland thermocouple fittings at the top. A 1/2-in. flare fitting at the bottom provided for attachment to the loop. A 1/8-in. shielded thermocouple, through the gland at the top, served as an electrical level probe as well as measuring temperature. A shutoff valve was installed below each riser. When sodium completely filled a section, it would start flowing up into the riser. When it reached the probe, as indicated by a continuity meter, filling was complete and the risers were valved off from the system to prevent surge tank action when pumping with the E. M. pump or operating the bellows pusher system.

2.3 Bellows Pusher System

In order to control transfer of the plutonium alloy into or out of the core assembly and to have the ability to set the fuel level in the upper tantalum pot, a sodium pusher system was used. This system was comprised of a stainless steel bellows filled with sodium which could be expanded or contracted by a motor drive to force sodium into or out of the reservoir above the fuel level. A synchro readout indicated bellows position. As sodium is essentially incompressible at the pressures involved, fuel displacement by the sodium was a linear function of bellows travel at any given temperature. See Figs. 11 and 13.

2.4 Gas Manifold

During the several operations of degassing, sodium loading, etc., it was necessary to evacuate or fill with helium various parts of the loop and test section. To provide for this, a central gas manifold was installed with appropriate valving to the loop and attached to both a vacuum system and a helium

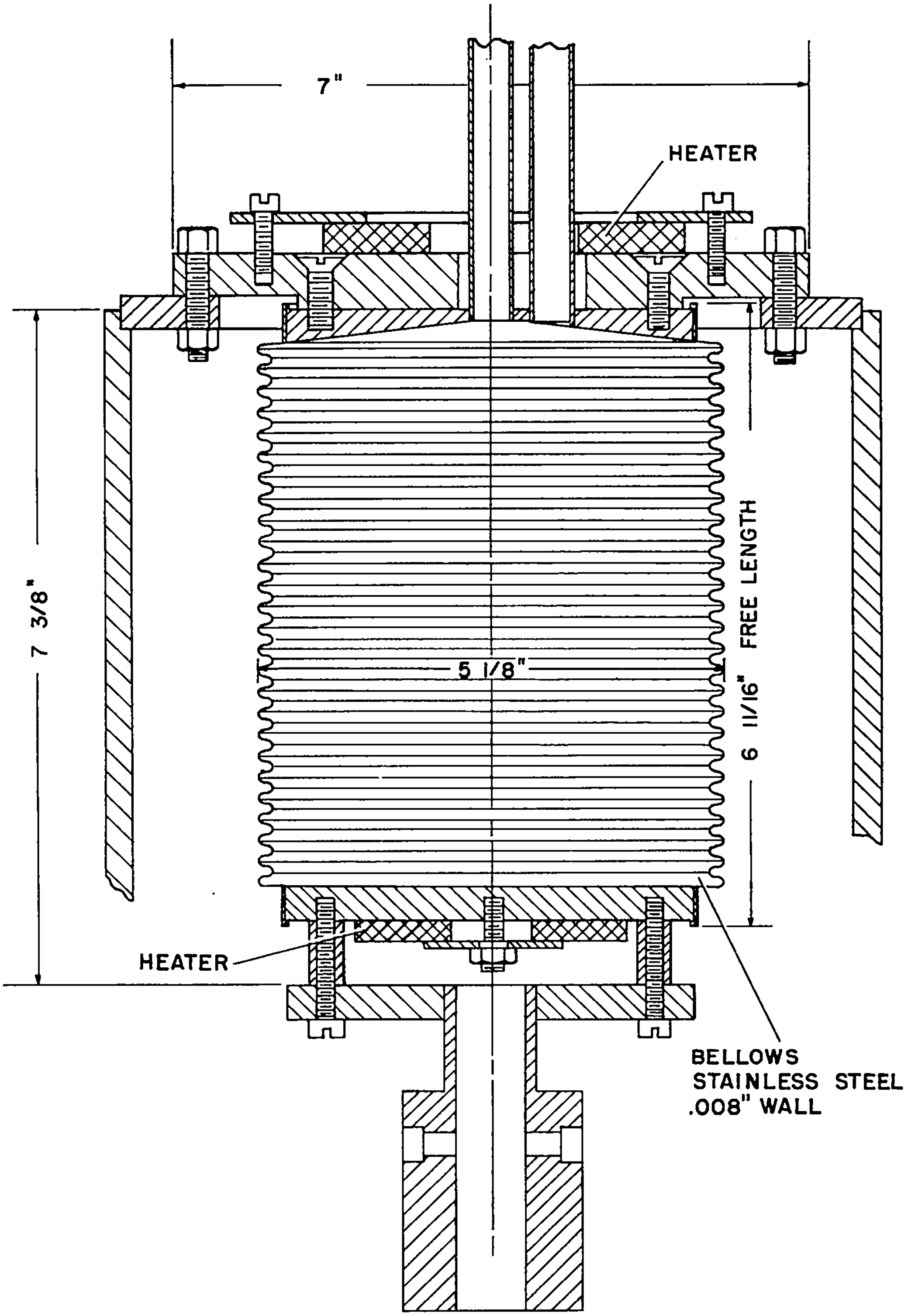


Fig. 13 Bellows Pusher System

supply. The manifold was a 3-in. copper tube with end caps soldered in and six brass bellows valves soldered on the side. This provided for evacuating or filling with helium any part of the loop including the fill risers. Pressure in the manifold was indicated by a bourdon tube pressure-vacuum gage as well as a vacuum thermocouple gage. See Fig. 2.

2.5 Heaters

The container tank was heated with three 5-in.-i.d. clam shell heaters. The top and bottom heaters were 6 in. long and the center heater 18 in. long. A 3-in. gap was left between the center and bottom heaters so that clear radiographs of the lift pump section could be taken without the presence of heater windings. To prevent oxidation of the lead wires, 1/16-in. iron wire was attached to the nichrome heater leads with stainless steel screws and led out of the hot region where they were then connected to copper wires. The iron wires were insulated with porcelain beads.

Two 12 in. long clam shell heaters were used to heat the hot trap. These heaters were connected in parallel and controlled by one 115-v Variac. Similar heaters were used to heat the fill risers with one heater on each riser. These were also connected in parallel and controlled by one 115-v Variac.

All 1/2-in. tubing forming the sodium loop was heated by calrod heaters bent to shape and clamped to the tubing. Various heater lengths were used depending upon the configuration of each section to be heated. In order to have good temperature control of the loop, heaters were mounted so that flow and non-flow sections were heated separately. Each calrod heater was controlled by a 115-v Variac.

The bellows pusher system was heated by two disc heaters and two tape heaters. The disc heaters were clamped to the bellows end plates, one at the top and one at the bottom. The two tape heaters were wound around the bellows and connected in parallel. As the resistances of the disc heaters and the two tape heaters in parallel were about equal, one 115-v Variac was used to supply the heaters through a switch system so that any one of the heaters could be added to or cut out of the circuit.

High temperature super-x insulation was used to cover all heated sections. Where feasible, split pipe insulation was used, the halves being held together with clamps. In areas where the pipe insulation could not be used, such as around valves, powdered super-x was used and coated with super-x cement to hold it in position. The container tank insulation was 6-1/2 in. i.d. by 12 in. o.d. In the area where radiographs were taken of the lift pump section, the insulation was cut away to a depth of 1 in. so that the film could be closer to the pump area. The insulated system is shown in Fig. 14.

2.6 Schematic Cover Plate

A full scale colored drawing of the system was made on the front cover plate with each component accurately located in position. A color code was used for clarity with the sodium shown in yellow , fuel in blue, and helium in green. Valve handles were extended through the lines on the cover plate which represented the actual sodium tubes in the system. All heaters were shown in red and marked with their numbers as well as the numbers of the Variacs which controlled them. Thermocouple locations were also shown with their respective numbers. This panel arrangement proved to be very useful when loading the system with sodium, controlling temperatures and flow during operation, and locating the gamma sources at any desired position for radiographs. See Fig. 15.

2.7 Thermocouples

All temperatures were measured with chromel-alumel thermocouples. The temperature of the sodium in the container tank was measured by two sheathed thermocouples. These thermocouples were clad in stainless steel and were immersed in the sodium through Teflon glands on the tank lid. With this arrangement, sodium level could also be determined, using the thermocouples as electrical probes the same as was done in the fill risers. The inlet and outlet temperatures of the flow calorimeter were measured by sheathed thermocouples which were placed in thermowells and spring loaded for good contact

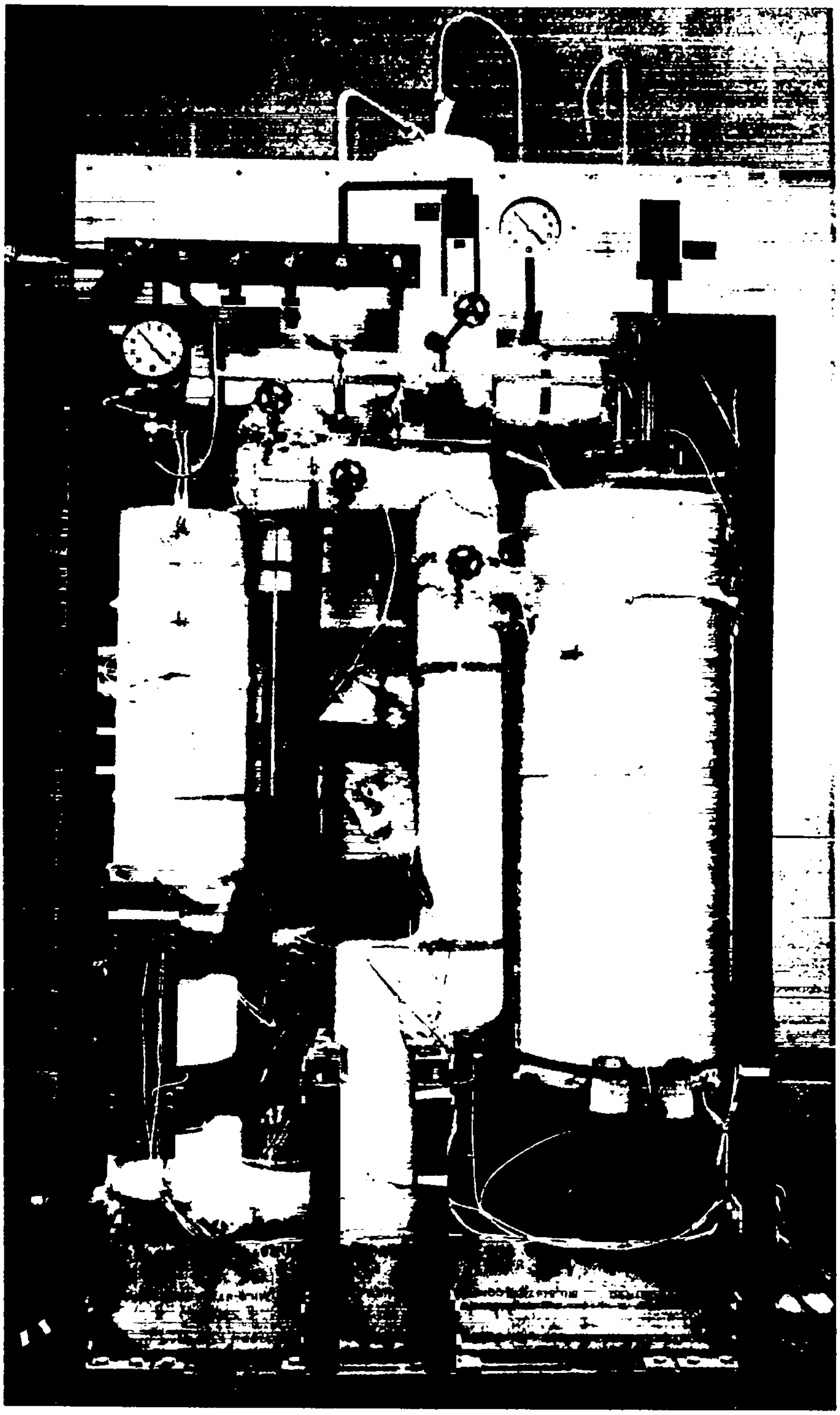


Fig. 14 Insulated Test Assembly

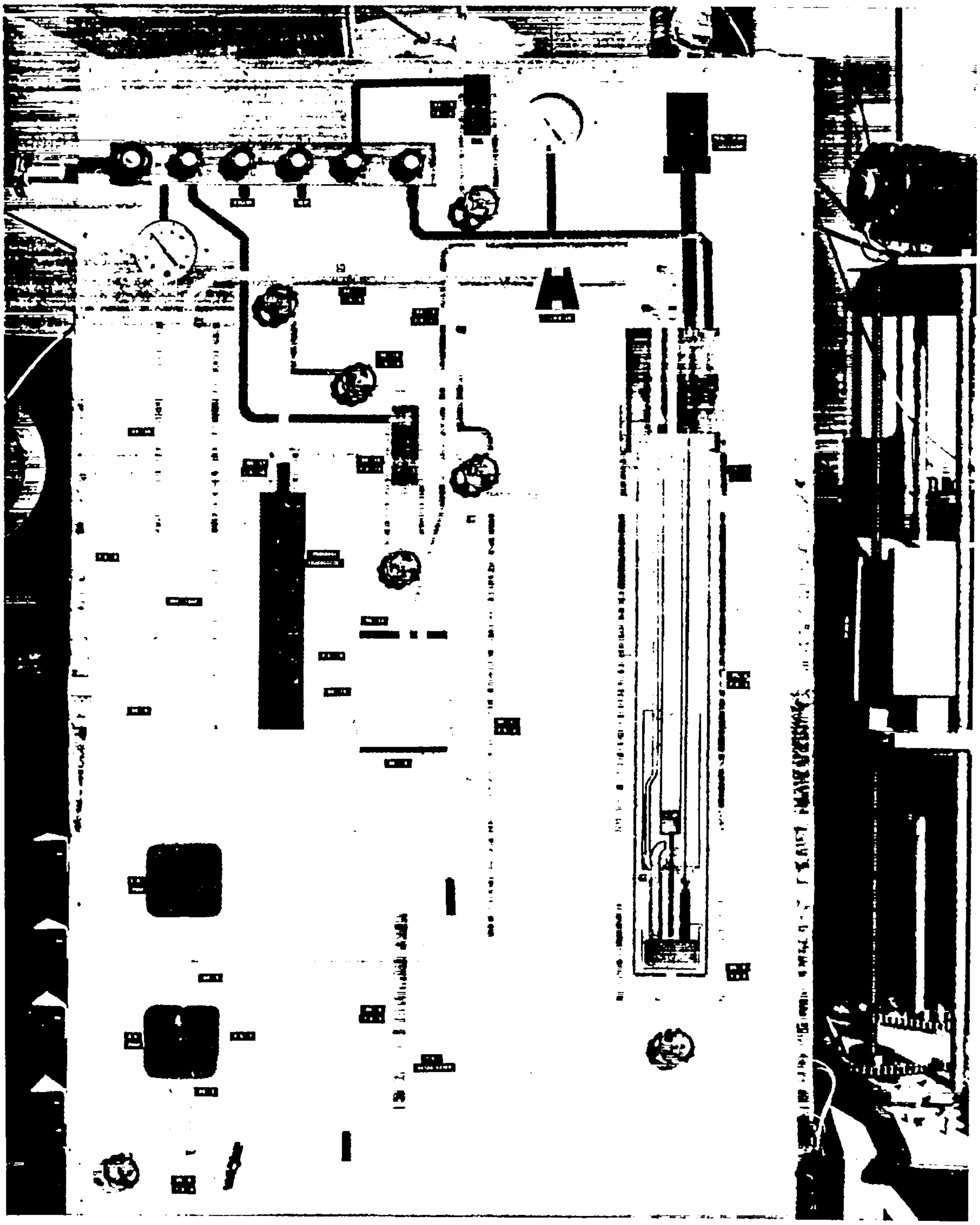


Fig. 15 Graphic Cover Plate

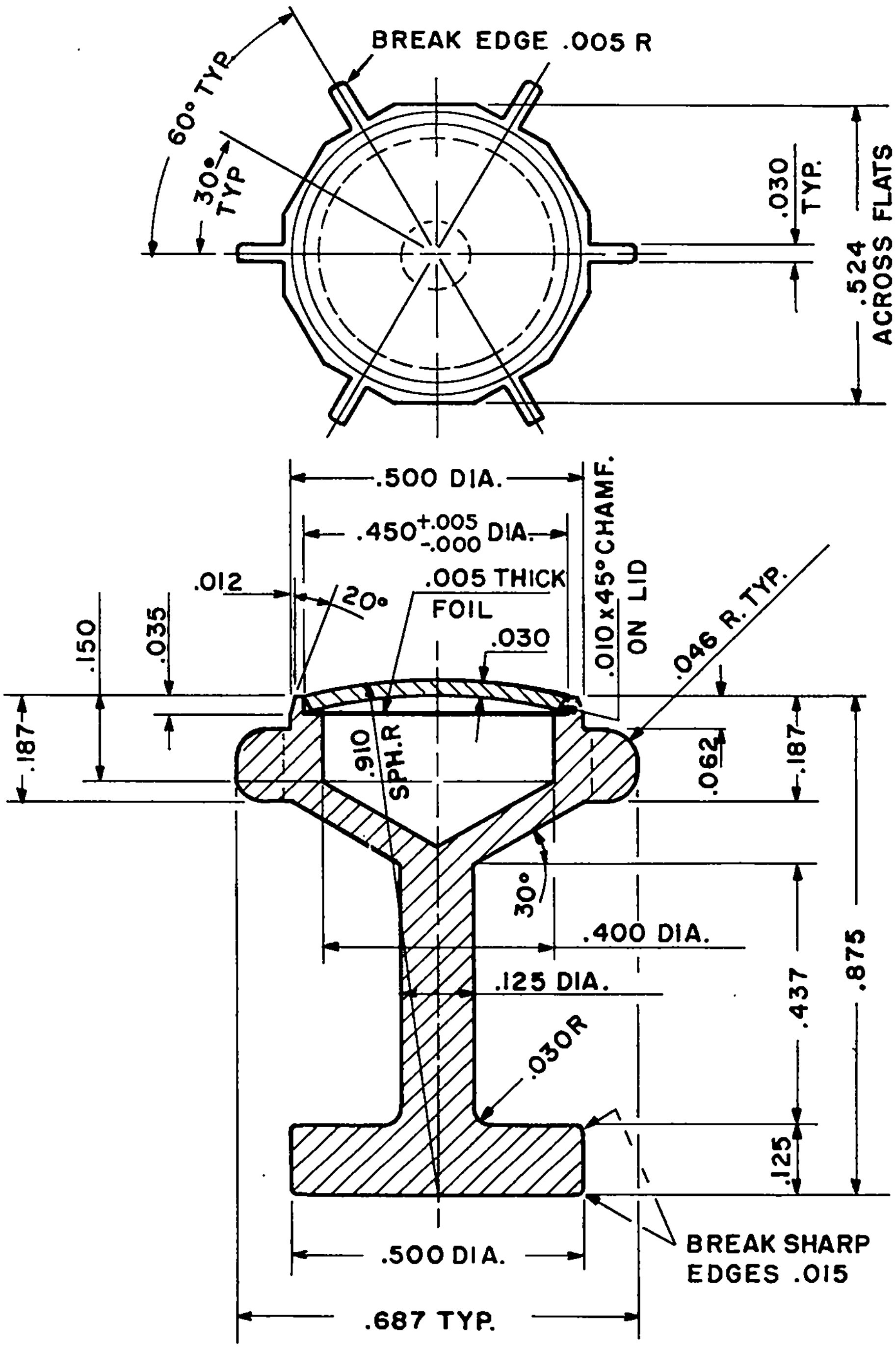
with the tube wall. All other thermocouples were made from standard duplex thermocouple wire. The junctions were made by twisting the wires and then arc welding them under oil to form a bead. These thermocouples were attached to the loop by clamps after first putting them in position and wrapping them with glass tape. All thermocouples were connected to one of two 16-point Brown recorders for continuous readout. In addition, the two thermocouples on the flow calorimeter were paralleled through a switch system so they could be read differentially on a Rubicon B potentiometer when making sodium flow measurements.

2.8 Vacuum System

A vacuum system was incorporated into the apparatus to evacuate the loop for degassing and sodium loading. A fore pump in series with a water-cooled, oil diffusion pump evacuated the loop through a liquid nitrogen cold trap. A protect circuit provided diffusion pump heater shutoff in the event of loss of vacuum, failure of cooling water supply,or pump over heating. The thermocouple gage mounted on the gas manifold provided the pressure signal to the protect circuit. A Philips gage was mounted at the inlet to the cold trap to indicate the vacuum in millimeters of mercury. Vacuums of better than 10^{-6} mm Hg were obtainable.

2.9 Reservoir Fuel Level Indicator

Fuel level in the reservoir was determined by locating a radioactive disc in a tantalum float with a crystal scanner. The float was machined from solid tantalum and had a cavity in the top section to provide sufficient buoyancy so that the activated disc, just under the lid, would float above the fuel surface. Six small fins equally spaced around the upper section reduced the tendency of the float to drag on the wall. See Fig. 16. The disc was 0.005 in. thick and irradiated in the Los Alamos Omega West reactor for 9.5 Mw-hr. The resulting intensity was high enough for detection by the crystal but produced only 20 mr/hr at 2 ft so it was safe to work in the vicinity of the test section. A sodium iodide crystal mounted



MATERIAL - TANTALUM

ALL DIMENSIONS IN INCHES

Fig. 16 Radioactive Tantalum Float

in a lead-shielded collimator was used as the sensing device. The collimator was mounted on four motor-driven lead screws which provided about 3 ft of vertical travel. A synchro readout indicated the scanner height in millimeters. The float position was determined by finding the scanner height which produced maximum crystal output as indicated by the count rate meter,as well as an audio count signal. This system was used as a fuel leak indicator by setting the scanner just below the float level. In the event of a leak in the reservoir, the float would drop through the scanner slit producing a maximum crystal output which tripped a relay, setting off an alarm bell as well as trigger a red light. The scanner assembly is shown in Fig. 1 just to the right of the pump test assembly.

2.10 Sodium Leak Alarm

The thermocouple probe at the top of the container tank was used to indicate loss of sodium from the system. This probe was set just below the sodium level in the tank and connected to a relay circuit by two leads: one from the insulated thermocouple sheath and the other to the grounded gland fitting. As long as the sodium contacted the probe, continuity was maintained and the relay held in. If the sodium level dropped due to a leak, the circuit was opened and the relay action would set off an alarm and trigger a red light. The probe was reset just below the sodium level any time the system temperature was changed to allow for expansion or contraction of the sodium.

2.11 Gamma Ray TV System

Lift pump action and fuel transfer operations were observed by a closed circuit,gamma ray TV system. A 35-curie iridium source was used to produce an image on an intensifier screen which was in turn transmitted through a TV camera to the monitor screen. Motion pictures were taken of the monitor screen for a permanent record of the action observed. This system was very useful for dynamic studies as, due to the high sensitivity of the intensifier screen, instantaneous fuel motion could be observed. This was not possible with radiographic films which required integrated time exposures. For a complete description of this system see N. G. Wilson's report (now in preparation).

2.12 Radiographs

For detailed studies of the test assembly involving static and steady state condition such as float location, fuel level, sodium in the lift pump annulus while pumping, carry-over of fuel out into the stainless steel tank, etc., the radiographs proved invaluable. The definition obtained with Type N film and the iridium source showed excellent detail of the system. When it was desirable to use two sources at fixed positions, the Co-60 source was also used though it did not produce as good definition and contrast as the iridium source. In order to get the best radiographs possible, masses of excess material in the areas to be radiographed were reduced to a minimum, and object-to-film distances were kept as short as possible when designing the test section. A 1/8-in. wall tube was used for the container tank and a 3-in. space was left between tank heaters in the lift pump area to eliminate excess material. The tantalum core assembly was designed and oriented in the tank so that the three tubes connecting the core with the upper pot were in the same plane and parallel to the film. This prevented any overlap of tubes in the radiographs which could make interpretation of the films difficult. Exposure times were in general 20 minutes with a source-to-film distance of 24 in. When Co-60 was used, the exposure time was reduced to 15 minutes because of the higher energy.

The iridium source was contained in a tungsten collimator and exposed by removing the front plug. The shielding and collimation were sufficient to allow personnel to remain in the area behind the source during exposure. The Co-60 source was contained in a lead-shielded cart and exposed by a crank driven cable which moved the source out to the end of a flexible tube. The end of this tube was mounted in a lead block with a cone shaped opening in the front. This was not sufficient shielding; so lead bricks were piled around it until the radiation level was reduced to 20 mr/hr at 1 ft. The shielding also collimated the beam so that it would not affect the scanner crystal. The two sources were mounted on a double platform table. Both platforms were adjustable in height by hydraulic jacks. See Fig. 1.

A gamma alarm was placed behind the test section so that when the sources were exposed, a red light mounted above the test section came on to warn personnel not to go behind the unit and be exposed to the gamma beam.

3. FUEL AND SODIUM LOADING PROCEDURES

In the loading of sodium and plutonium alloys, it is essential that the systems be clean and thoroughly degassed. It is also important to have the system relatively free from oxygen. This can be achieved by loading under vacuum, in the case of sodium, and using argon in sections into which solid fuel pieces are loaded. Steps involving exposure of the plutonium alloy to the air should be done as rapidly as possible, particularly if the air has a high moisture content. Water vapor will hydride plutonium very rapidly and is a more serious problem than oxidation.

Experience has shown that detailed planning of a fuel loading procedure, along with several practice dry runs, will usually result in a successful loading with a minimum of fuel contamination.

3.1 Cleaning

All stainless steel parts of the loop were scrubbed and rinsed with acetone to remove any grease or particulate matter prior to welding. The seats of the flare fittings were polished to remove any scratches or nicks. As various sections of the loop were welded, they were again rinsed in acetone before final assembly. Helium back-up gas was used during all welding to prevent oxidation of the inside surfaces of the hot zones.

The tantalum parts were bright dipped in an acid solution and then washed with acetone before welding. All tantalum welding was done by heliarc in a helium atmosphere.

3.2 Degassing

After the loop was assembled and helium leak checked, it was evacuated and heated to 650°C for 4 days to degas the system.

The bellows pusher system was heated to only 250°C, which was about 100°C higher than its expected operating temperature, to prevent any damage to the bellows by excessive heating.

During this process, none of the tantalum core parts or uranium hot trap material was in the system as they would getter the gases driven out of the stainless steel.

Upon completion of the degassing run, some of the sections of the loop were opened up and bright inside surfaces indicated that a good vacuum had been maintained during the run.

3.3 Hot Trap Loading

Two kilograms of uranium sheet were used as gettering material in the hot trap for sodium cleanup. Half of the sheets were corrugated and half were plain. The sheets were 6 in. wide. A plain sheet was placed on top of a corrugated sheet and then the two rolled together to form a cylinder. The plain sheet between the corrugations formed flow paths with a large surface area of uranium exposed to the sodium. Three cylinders were made in this manner and pushed down into the hot trap. A 1/2-in. stainless steel rod was pushed down the center of the cylinders to fill the space left after the cylinders had sprung into position in the hot trap.

The uranium was electropolished before loading to remove all oxide and grease. It was loaded as soon as it was received to prevent any additional oxidation. When the hot trap was loaded, the 2-in. Conoseal fitting at the top was sealed and rubber corks put in the tubes leading to the container tank. After this part of the system was sealed and leak checked, it was kept on a vacuum system to prevent oxidation of the uranium while other work was done on the rest of the loop.

3.4 Hydrogen Removal from Uranium

Since the uranium was electropolished before loading, it was necessary to degas the material to remove hydrogen. This was done by running the system at 350 °C, while being evacuated, for a period of 3 days. The temperature was brought up slowly so that a good vacuum was maintained at all times.

3.5 Fuel Loading

The fuel used in this experiment was 97.5 w/o plutonium and 2.5 w/o iron alloy which has a melting point of ~ 415 °C. The original casting was 1 in. in diam and 22 in. long. From this casting three pieces were machined 0.90 in. in diam with lengths totaling up to 16-1/2 in. The weight of the three finished pieces was 2.8 kg. Samples were taken of the casting at each end and between the pieces for chemical analysis to check for homogeneity of the casting.

In order to keep oxidation of the alloy to a minimum, all loading preparations were made prior to final machining. As soon as the pieces were machined and weighed, they were sealed in capsules that had been flushed with argon, and sent to the loading area. At the loading area, the reservoir was flushed with argon and the bottom outlet sealed to retain as much argon as possible. The fuel pieces were then pushed into the reservoir through a thin stainless steel sleeve to prevent contamination of the reservoir inlet. After the pieces were pushed to the bottom with a rod, the tantalum float was inserted and the stainless steel sleeve removed. The reservoir was then attached to the container tank lid and the flare connection tightened. The seal at the bottom of the reservoir was removed and the core assembly completed. After the tank had been flushed with argon, the complete core assembly was lowered in and the Conoseal fitting tightened. As soon as the remaining fittings were made and the loop sealed, a helium leak check was made of the entire system. When this step was completed, radiographs of the container tank were taken to assure that all core components were in their proper positions. See Figs. 17 and 18. The loop was kept under vacuum to protect the fuel and uranium from oxidation until the sodium was loaded.

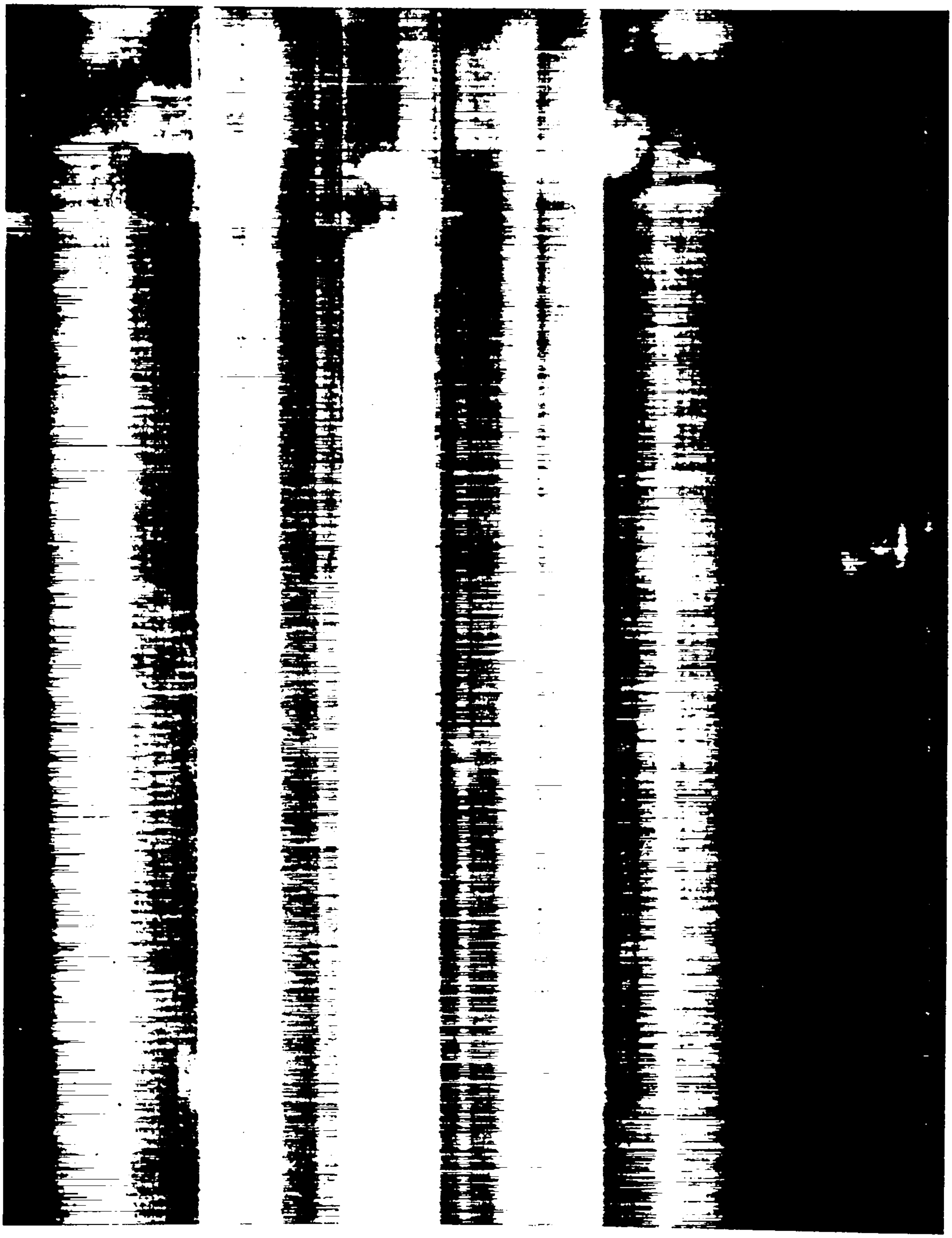


Fig. 17 Radiograph of Unmelted Fuel Slug and Float

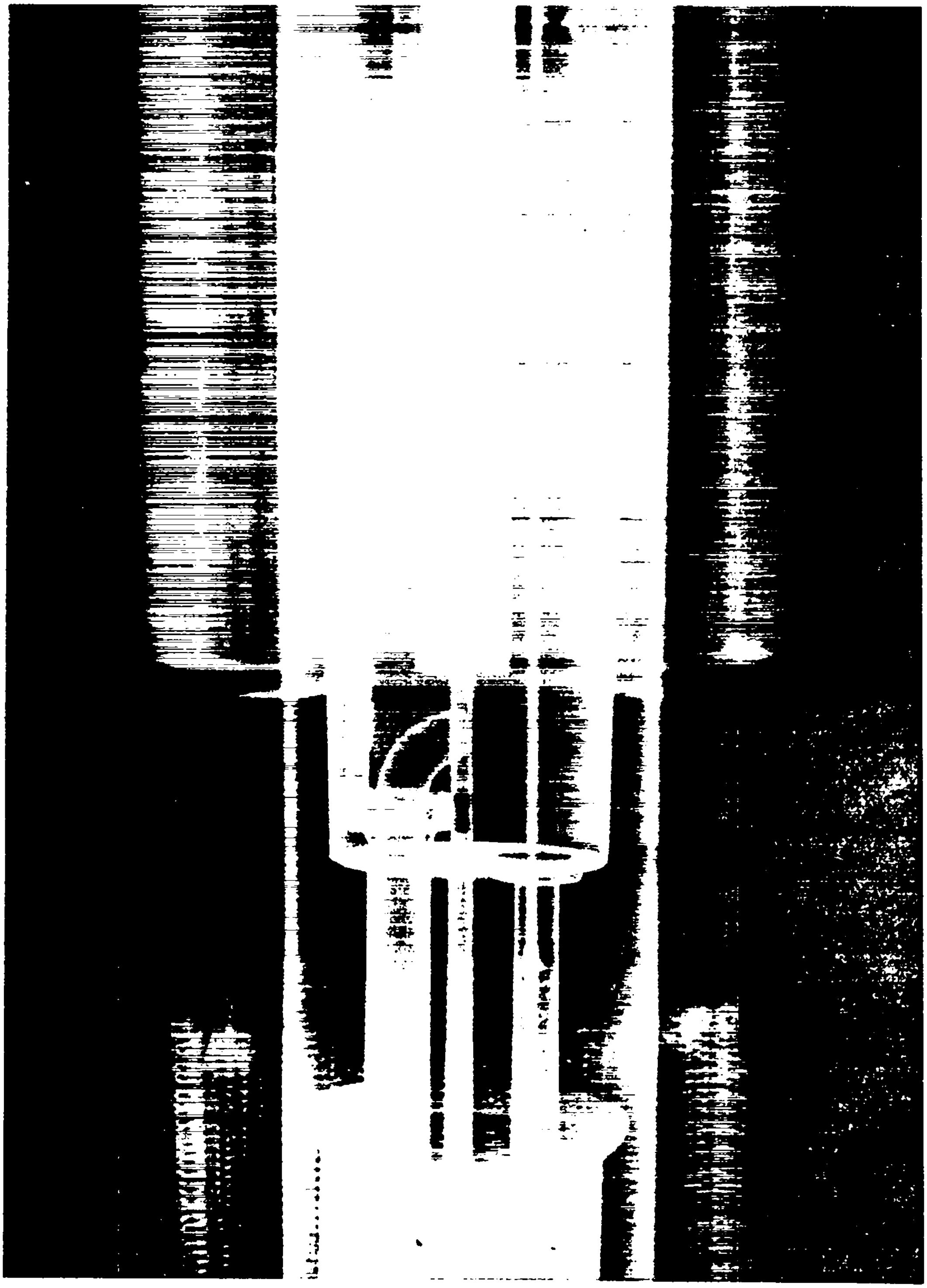


Fig. 18 Radiograph of Core Section before Melting Fuel

3.6 Sodium Loading

Sodium was loaded, with the loop under vacuum, from a standard 55-gal sodium drum. The drum temperature was maintained about 20 °C above the melting point of sodium. A low supply temperature was desirable as it reduced the amount of dissolved oxide carried into the system and also made it possible to locate the sodium as it entered different parts of the loop by a sudden drop in loop temperature. The loop temperature prior to loading was maintained at ~ 250 °C. Sodium was loaded into the system at the bottom connection below the E. M. pumps. It was fed slowly into both the vertical line containing the E.M. pumps and the horizontal line containing the flow calorimeter. This was done so that the lines would fill from the bottom up and prevent any gas traps in the flow calorimeter line. When the calorimeter line was filled up to the container tank outlet tube, this line was valved off so that all the rest of the sodium loaded would go through the hot trap for some cleanup before it entered the container tank and contacted the fuel. Filling was continued until the bellows pusher was full as indicated by the probe in its riser tube. The valve for this riser was then shut to seal the riser off from the bellows. More sodium was then added until the probe in the container tank showed that it was at the desired level. At this point, the vacuum system was valved off and the volume above the sodium in the container tank filled with helium at 5 psi. This gas overpressure was used to push sodium into the upper portion of the loop until the probe in the top riser tube indicated that filling had been completed. The valve below this riser was then shut and helium allowed to flow into the volume above the sodium in both risers. After the line from the loader was frozen, it was disconnected from the system and the fitting capped to supplement the seal obtained by the loading valve.

3.7 Sodium Hot Trapping

Hot trapping of the sodium was done at 350 °C by circulating the sodium over the uranium at 0.3 gpm for a period of 4 days. This temperature was chosen so that there would be no possibility of melting the plutonium alloy during the cleanup. As the fuel was in the reservoir, which was a static leg during this process, flowing sodium contacted the uranium for oxygen removal rather than the fuel.

4. OPERATIONAL PROCEDURE

When a new concept such as this experiment is being tested, it is difficult to predict the behavior of all the various system components. Where possible, it is advisable to design the system so that more than one run can be made, using the first run for familiarization and study of system characteristics. This resolves mainly to a provision for freezing the system without damage to the fuel containment. In this experiment, it was planned to transfer the fuel to the reservoir before freezing in the event a shutdown was necessary. A second run would then be possible even if the reservoir were damaged and leaked. This would, of course, eliminate the fuel transfer capability; however, lift pump tests could still be made.

As it turned out, a shutdown was required, and by freezing the system as planned, it was possible to make a second run. The first run proved very educational and, knowing the characteristics of the system, the second run was planned based on the information obtained. The detailed operational procedure established for the second run made it possible to obtain all data, radiographs, and motion pictures required before a leak in the core necessitated termination of the experiment.

4.1 Run No. 1

A radiograph was taken of the container tank at catch pan level before the fuel was melted to have a reference film when checking for leaks. See Fig. 19. After checking out all the instrumentation, the loop temperature was raised to the melting point of the alloy. The first sign of melting was when the float in the reservoir started to drop as indicated by the scanner system. When the fuel started to

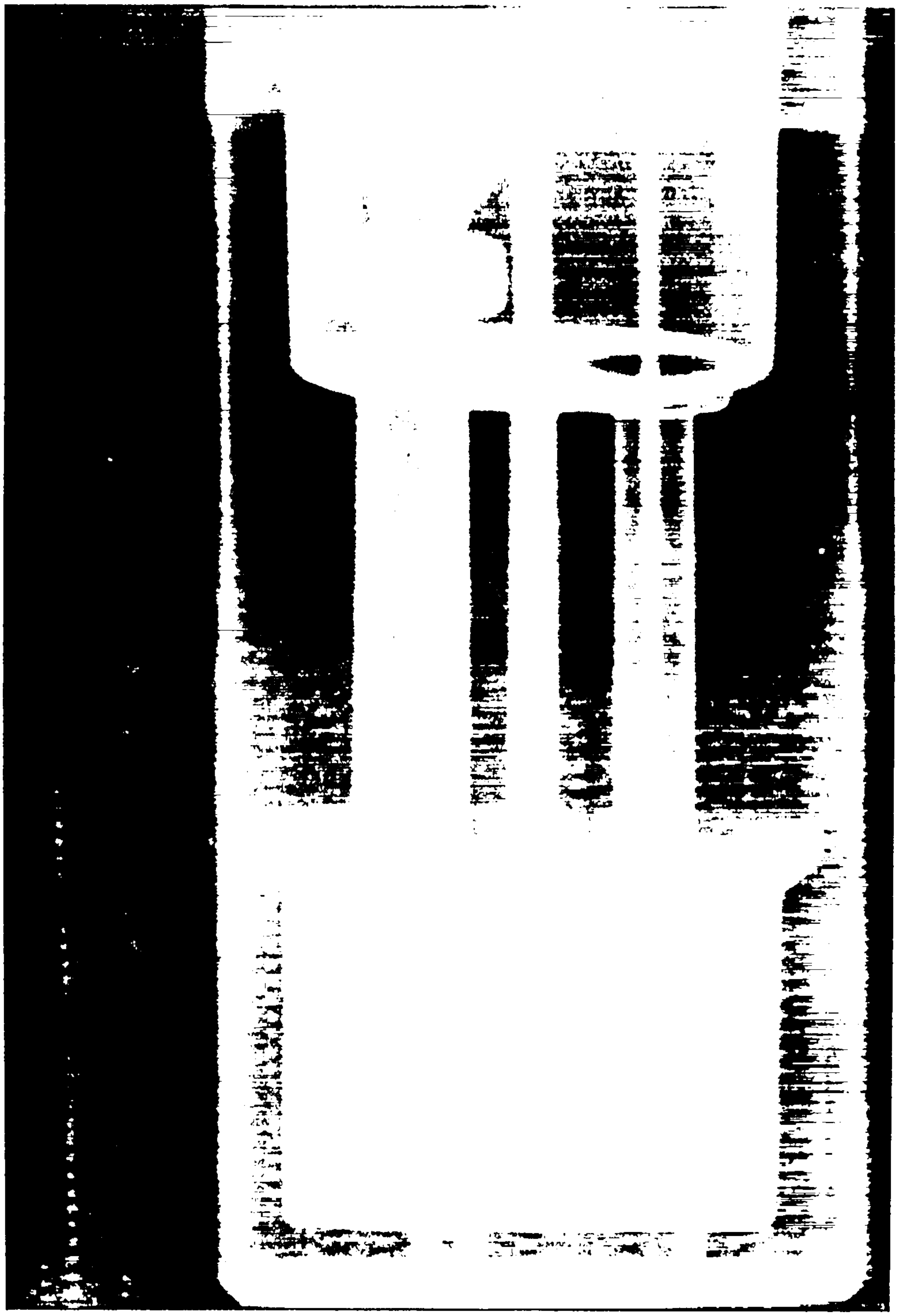


Fig. 19 Radiograph at Catch Pan Level before Melting Fuel

cover the reservoir outlet in the core the bellows pusher pressure started to drop as sodium could no longer replace the fuel and allow it to run down into the core. When all the fuel was melted, a vacuum was created in the bellows pusher system corresponding to the head of fuel from the surface in the core to the level in the reservoir. The final equilibrium pressure was 3.2 psia and when no further pressure changes were noted it was assumed that all the fuel had been melted. Figure 20 shows the equilibrium level in the core with liquid fuel in the bottom of the reservoir and outlet tube except for a trapped sodium section just below the reservoir. After melting, the system temperature was raised to 500°C and the fuel liquated in the reservoir overnight to force any impurities to the surface. During the melting and liquation, sodium was circulated continuously at 0.2 gpm. The next day a radiograph was taken at the fuel level in the reservoir (see Fig. 21) and it can be seen that the float was tipped and not floating properly. This was apparently due to a skin formation left after melting.

When the fuel was transferred into the core by compressing the bellows pusher, it was found that the float was stuck and did not move down with the fuel level. However, evidence that the transfer was being made was shown by the gradual increase of the sodium pressure in the pusher system. When the core was full and fuel started up the lift pump tube, it was noted that sodium flow rate dropped and more E.M. pump current was needed to bring it up to the original value. Further evidence of fuel transfer was given by the fuel level indicator bobs as when the level reached the bobs, pulses were noted on the indicating meter. When the transfer was completed, a radiograph was taken at the lift pump area as shown in Fig. 22. This film shows that the core was full and fuel was being pumped up into the upper pot with a sodium flow rate of 0.2 gpm. Figure 23 shows that a section of the fuel was hanging up in the reservoir about 3 in. from the bottom. The cap for the re-entrant tube had come loose and had been carried up under this fuel section when fuel was drawn up into the reservoir (see arrow). Subsequent figures show that this fuel section gradually decreased in size and eventually disappeared. It was not determined whether this was an unmelted portion of fuel which was off eutectic or a liquid contained in some sort

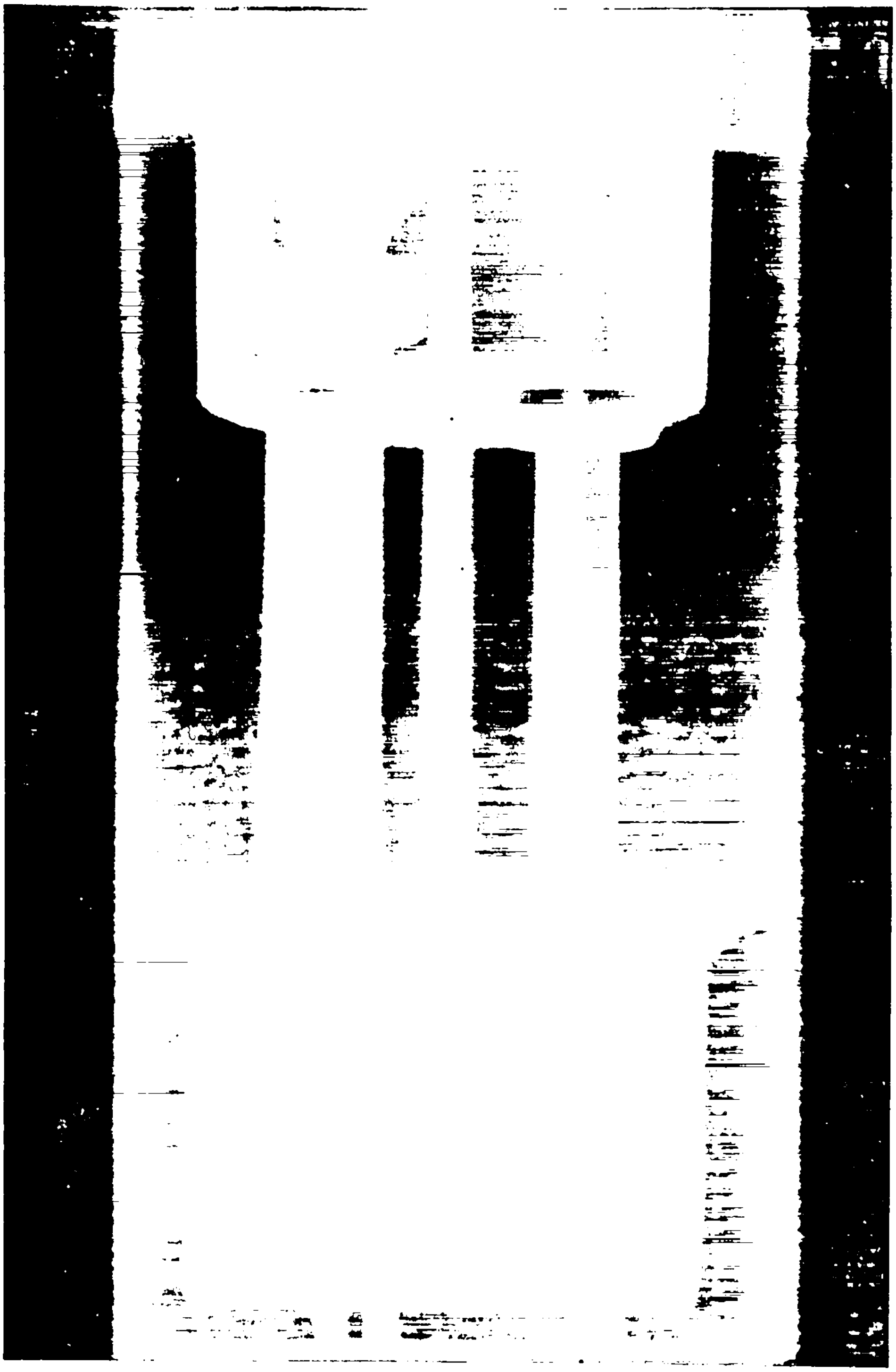


Fig. 20 Radiograph of Core after Melting Fuel

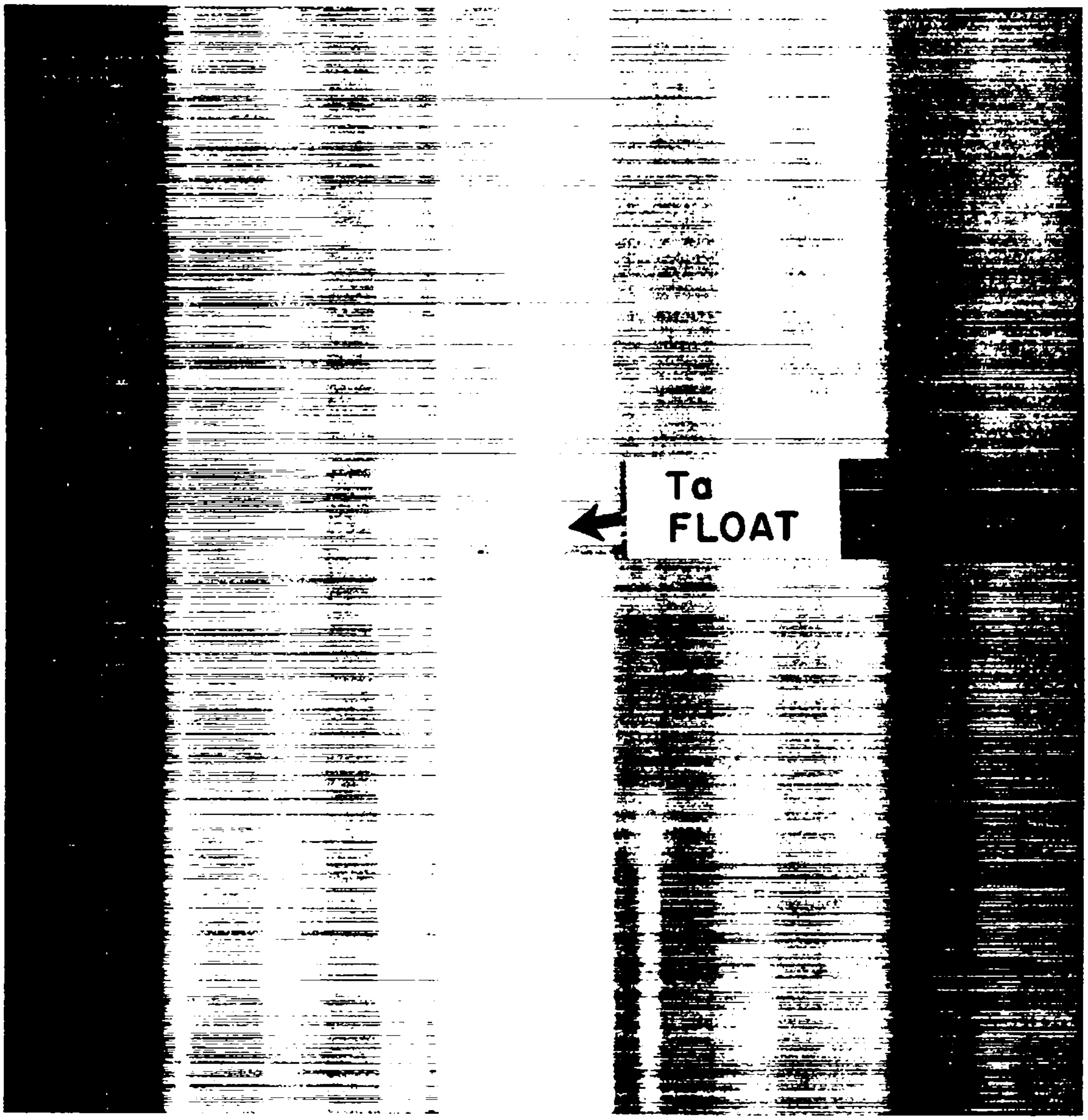


Fig. 21 Radiograph of Upper Reservoir Section with Float Stuck

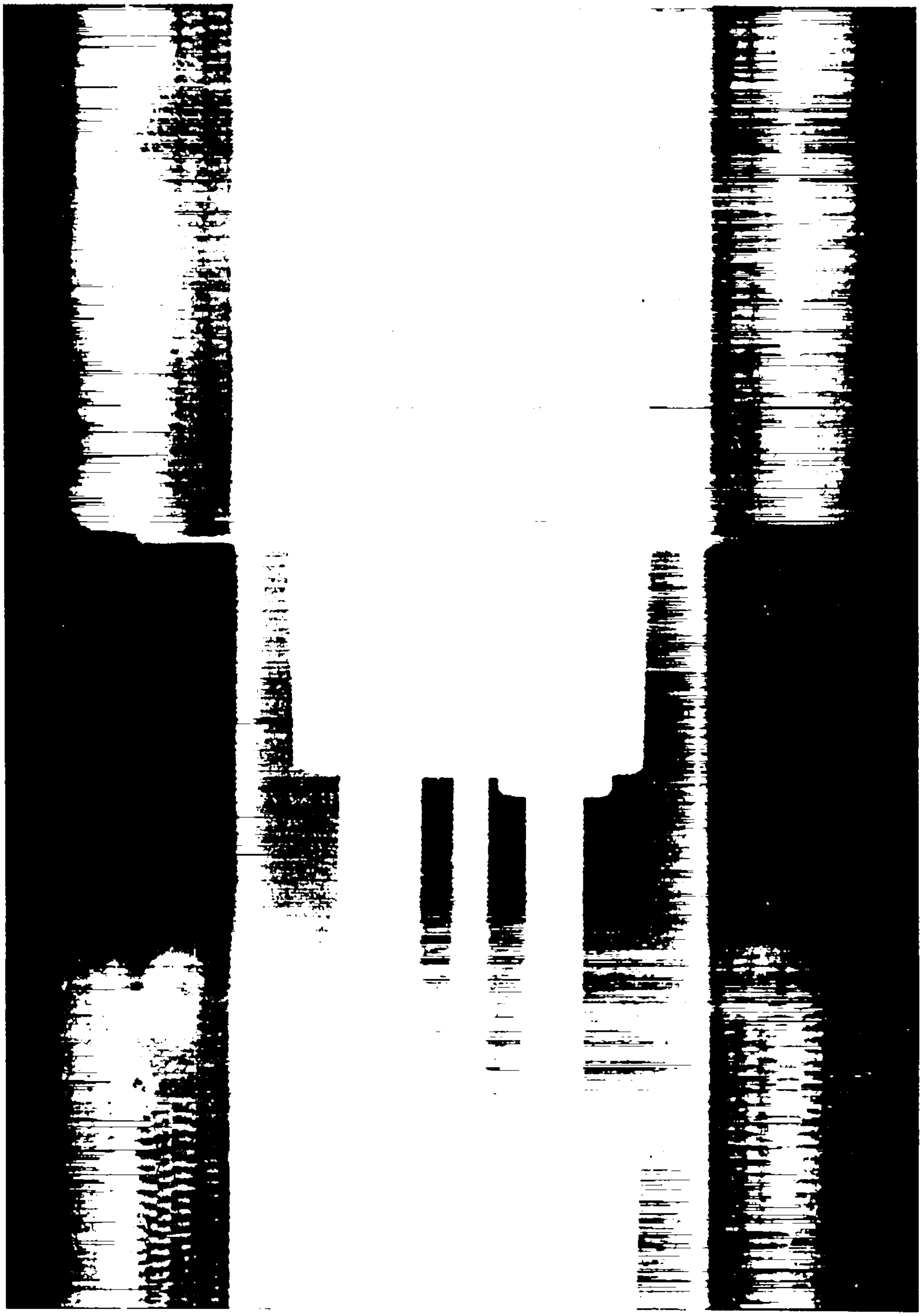


Fig. 22 Radiograph of Core-Fuel Being Pumped by 0.2 gpm Sodium Flow

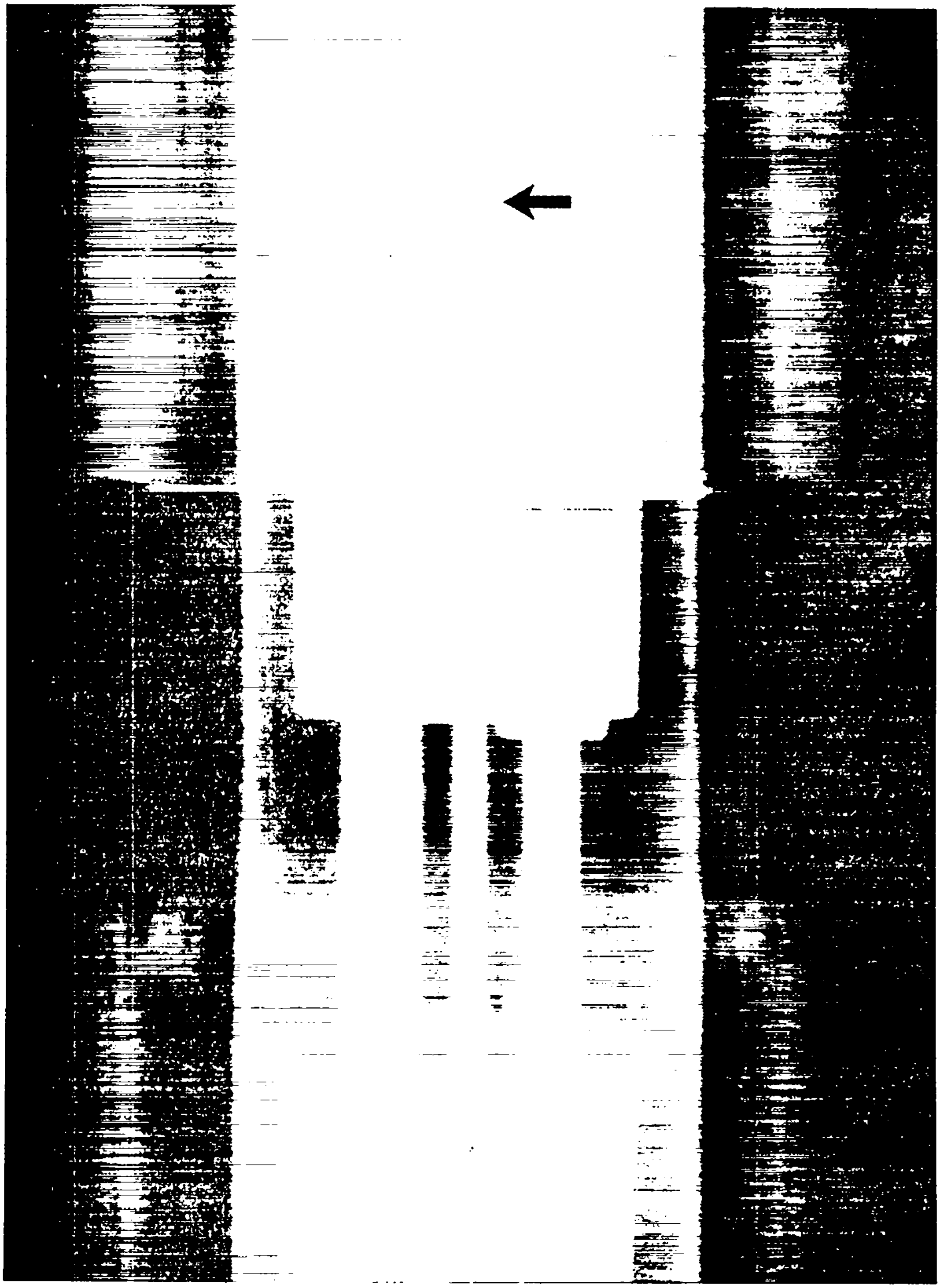


Fig. 23 Radiograph of Core-Fuel Being Pumped by 0.4 gpm Sodium Flow

of bubble formed by a skin-like material. This fuel section disappeared after a period of 2 days running and numerous fuel transfers into and out of the reservoir. Figure 23 was taken with fuel being pumped with the sodium flow at 0.4 gpm. The higher sodium flow made the pump annulus and necked fuel entrance more visible.

After numerous transfers of fuel into and out of the reservoir and vibration of the tank with an air vibrator, the float was freed and dropped down to a point just above the upper tantalum pot as shown in Fig. 24. In dropping down, however, the float again became tipped and stuck in this position. A slight wetting of the tantalum by the fuel is now apparent as shown in this film by the slight curvature of the fuel up the wall. Figure 25 is an over-all view of the upper tantalum pot and reservoir showing the float, remainder of the fuel portion hung up in the reservoir, and the re-entrant cap stuck just below it. This film was also taken at 0.4 gpm sodium flow.

Sodium flow was increased to 0.51 gpm and a radiograph taken as shown in Fig. 26. In this film there is evidence of sodium being carried back down the fuel return leg (see arrows) and being trapped below the two flowmeter bobs. When sodium flow was reduced to 0.2 gpm the carry-back of sodium stopped and the trapped sodium worked back up into the upper pot. This is shown in Fig. 27. The film also shows that the float became free again and was resting on top of the remaining fuel portion hung up in the reservoir.

A transfer of fuel was made from the core back into the reservoir and a radiograph taken of the core area after the transfer. Figure 28 shows the empty core except for the fuel below the level of the reservoir outlet tube. It can also be noted that the bobs of the flowmeter were held against the tube wall by the fuel wetting both surfaces (see arrows). The fuel was held in the reservoir for almost an hour to help dissolve the remaining fuel section above the re-entrant tube cap. During the transfer the float appeared to move freely, and when the fuel was transferred back to the core the float resumed its former position on the still smaller fuel section and re-entrant tube cap as shown in Fig. 29.

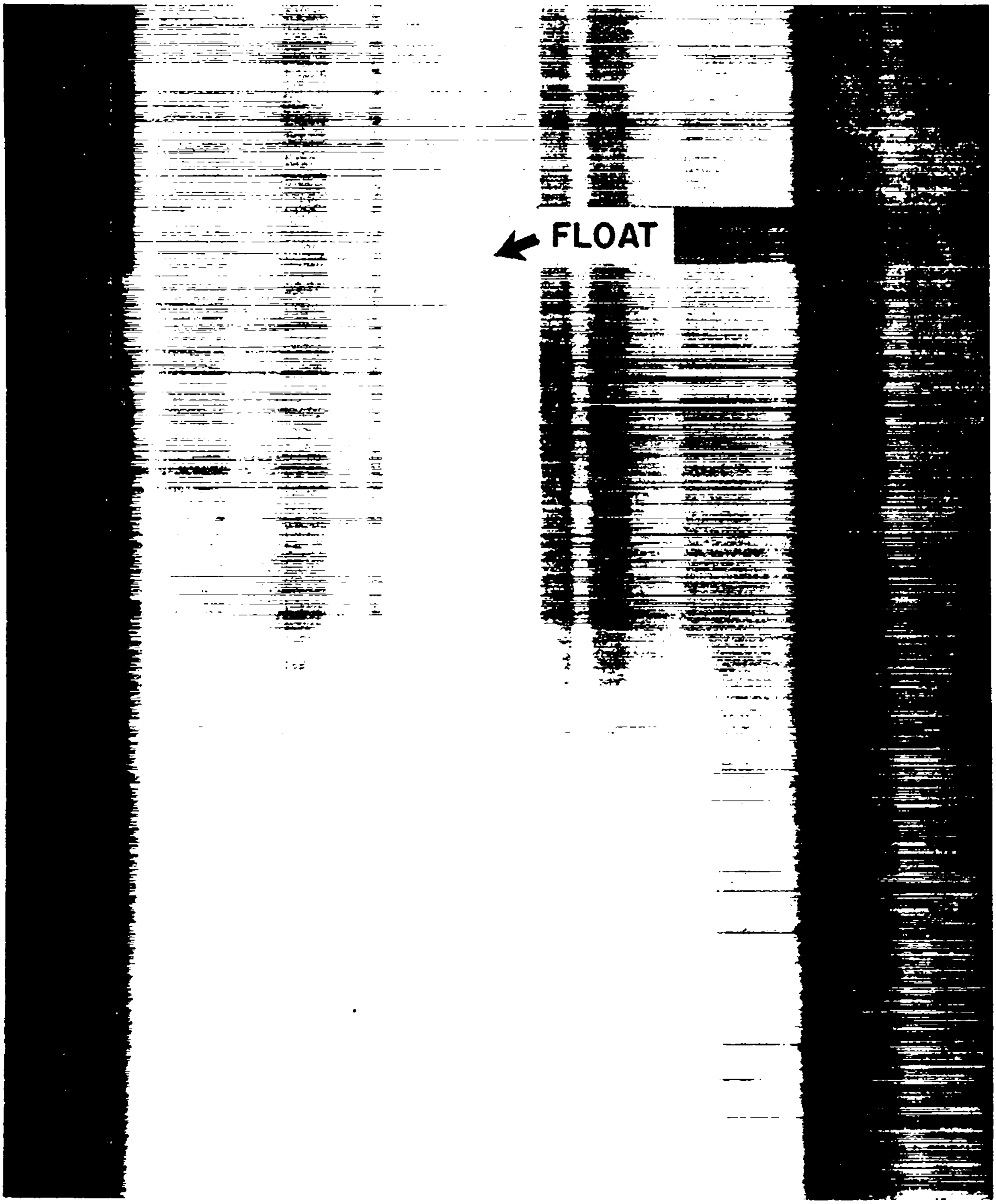


Fig. 24 Radiograph of Float Stuck in Reservoir

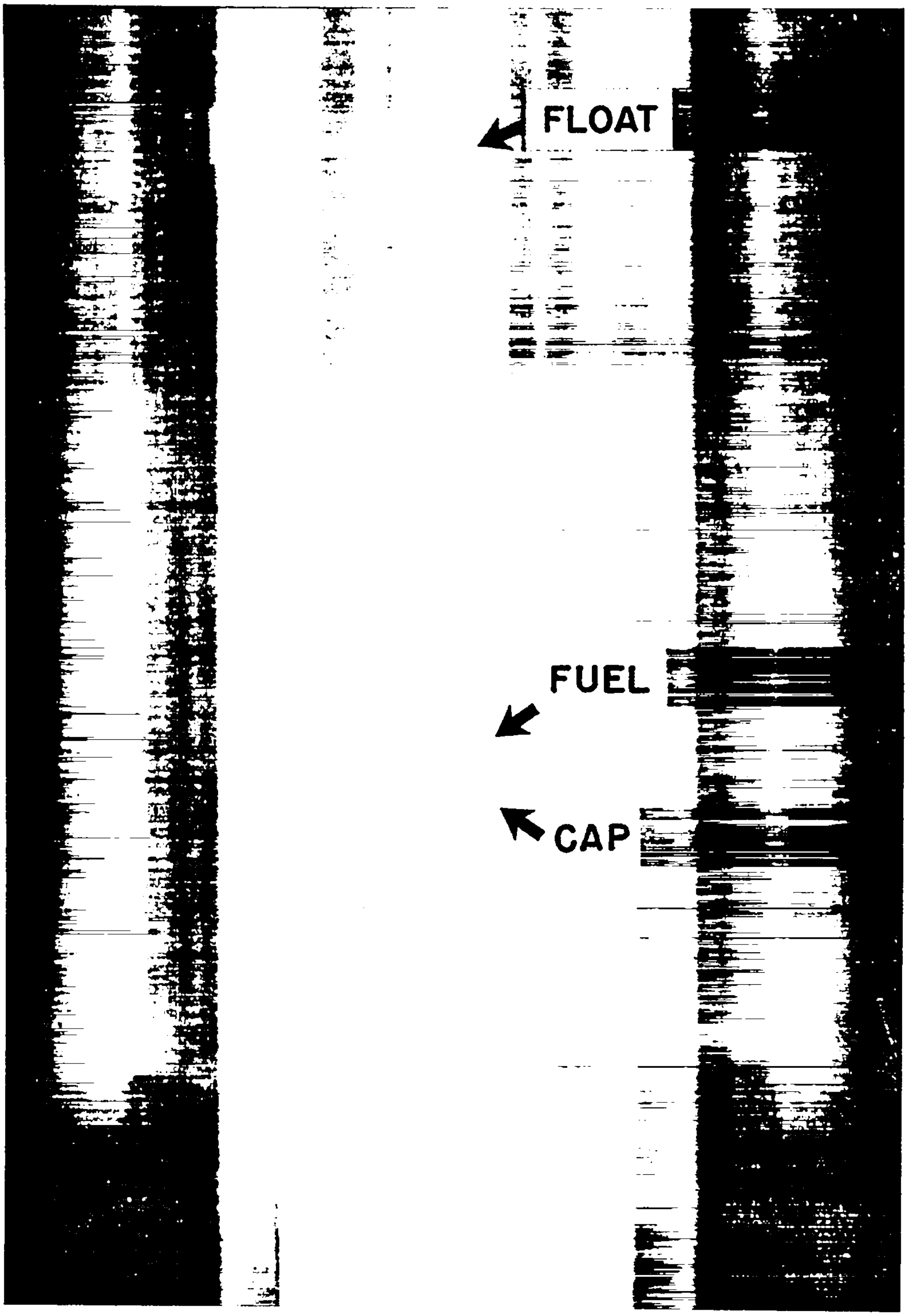


Fig. 25 Radiograph of Upper Tantalum Pot Assembly

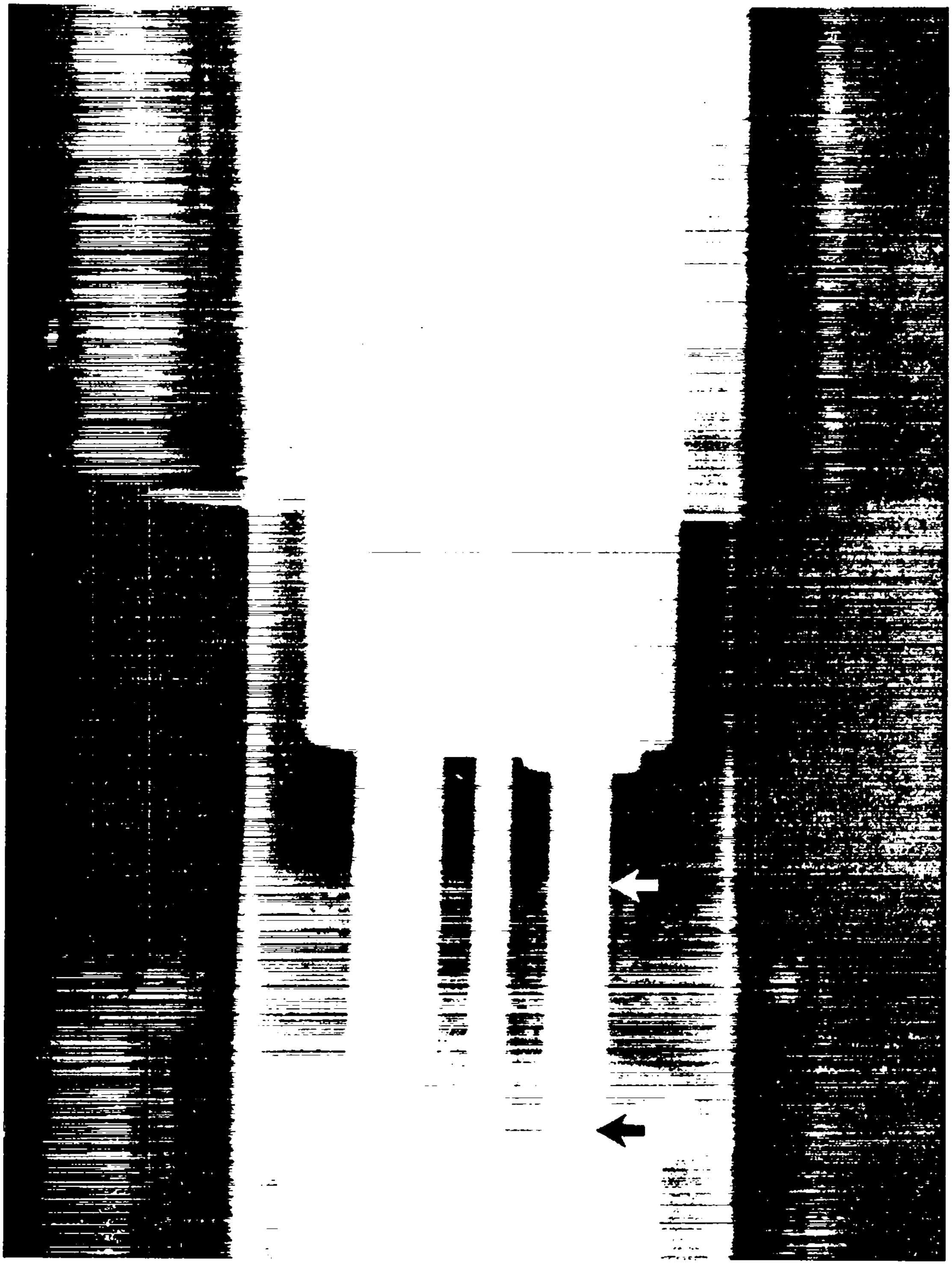


Fig. 26 Radiograph of Core-Fuel Being Pumped by 0.51 gpm Sodium Flow

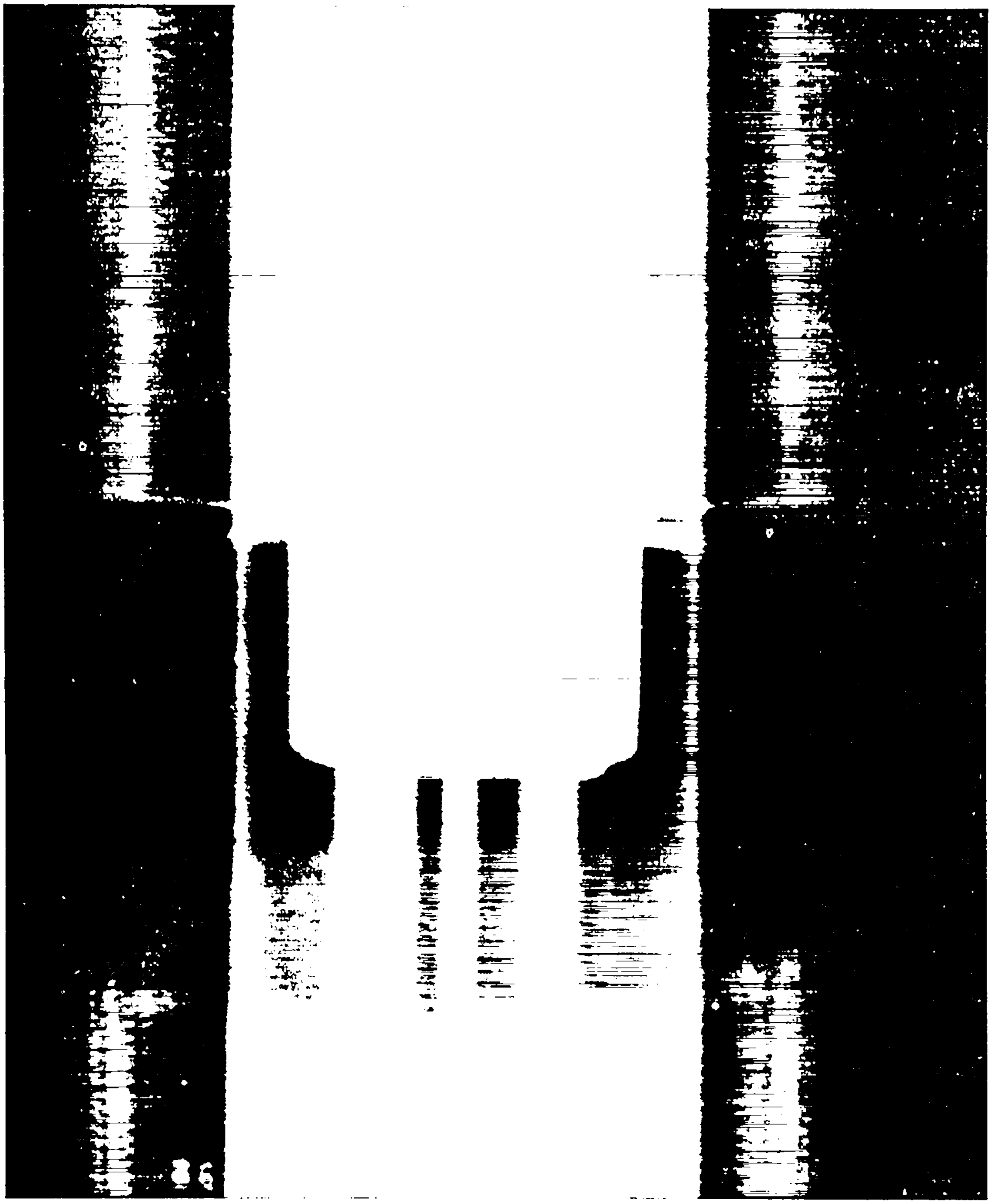


Fig. 27 Radiograph of Float Resting on Unmelted Fuel Section

Fig. 28 Radiograph of Core-Fuel Transferred Back to Reservoir

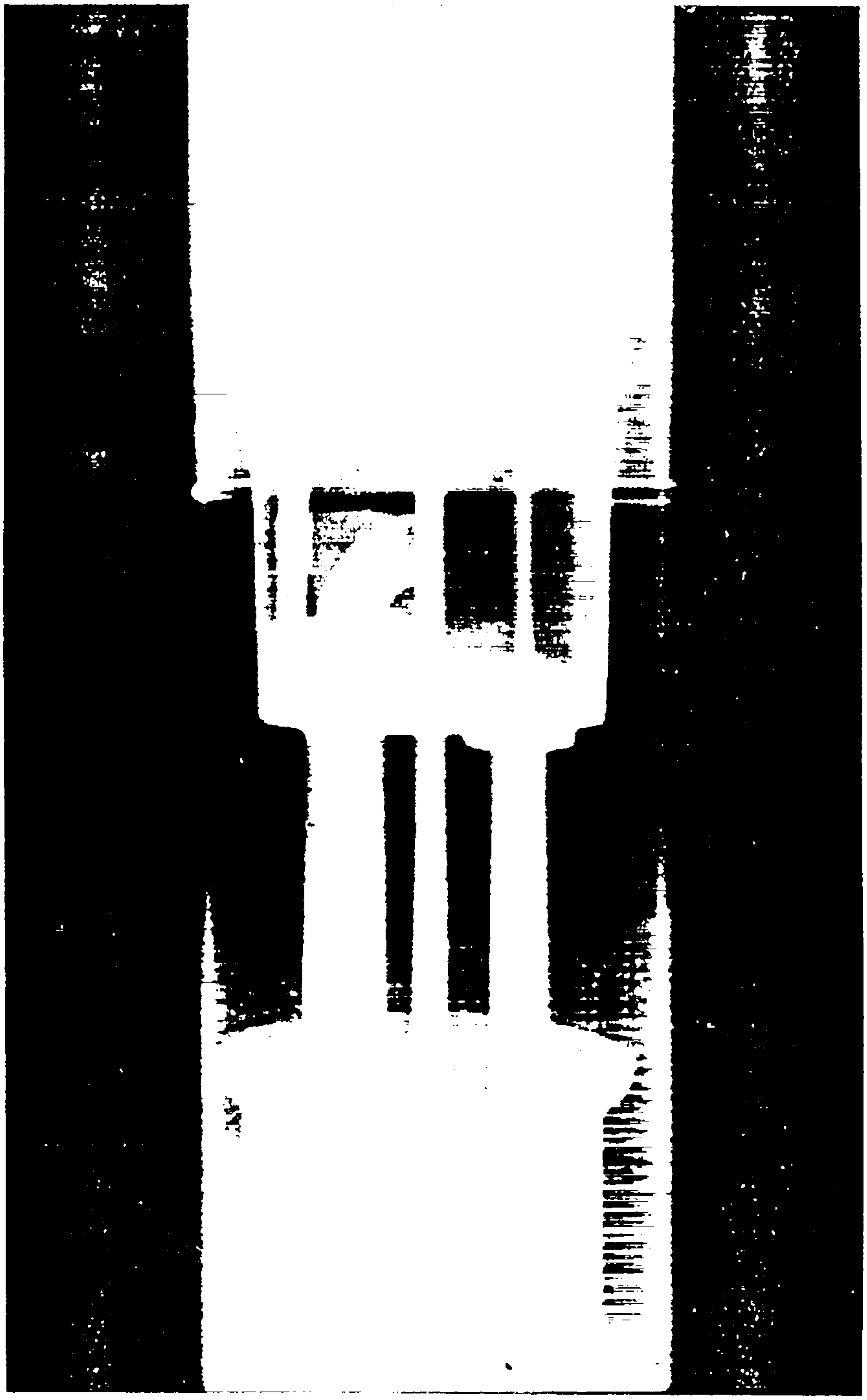


Fig. 29 Radiograph of Core Fuel in Core - Sodium Flow 0.2 gpm

Up to this point, attempts to observe the pumping and fuel transfer with the gamma ray TV, using the iridium source, were unsuccessful. This source was only 10 curies and not intense enough to produce a sufficient signal to noise ratio for observing any detail. The Co-60 source was then tried and, though the energy was higher than the optimum energy for the intensifier screen, fuel motion in the core could be observed. This was apparently due to the greater intensity of the source. Motion pictures were taken of the monitor screen while varying the fuel flow from zero to maximum several times. Rapid starting of pump action was quite visible as the fuel surged out the pump elbow. When these movies were completed, a radiograph was taken and it appeared that the level in the upper pot was not as high as it had been in the previous films (see Fig. 30). At the same time, the fuel flowmeter indicated that the level was changing. It was suspected that fuel had been lost either by carry-over caused by surging the pump or a leak in the core assembly so the system was shut down for examination. This was done by transferring the fuel to the reservoir and then shutting off the sodium flow and bottom tank heater so that the fuel would freeze from the bottom up. A radiograph was taken at the reservoir level to see if the float was indicating the fuel level. As shown in Fig. 31, the float was functioning properly and indicating the correct level.

After the fuel had been frozen, the loop heaters were shut off and the sodium frozen. When the system reached room temperature, a radiographic scan of the entire system was made to determine if any fuel had been carried out into the sodium loop or leaked out of the core assembly. No evidence of leaks or carry-over was found and a fuel inventory, by measurement of the radiographs, showed that all the fuel was contained within the core assembly and reservoir. On this basis it was decided to make a second run.

4.2 Run No. 2

Before starting the second run, an operational procedure was outlined to be sure that all of the test objectives would be covered. The motion picture films were developed and studied and it was found that the blanking bar of the TV

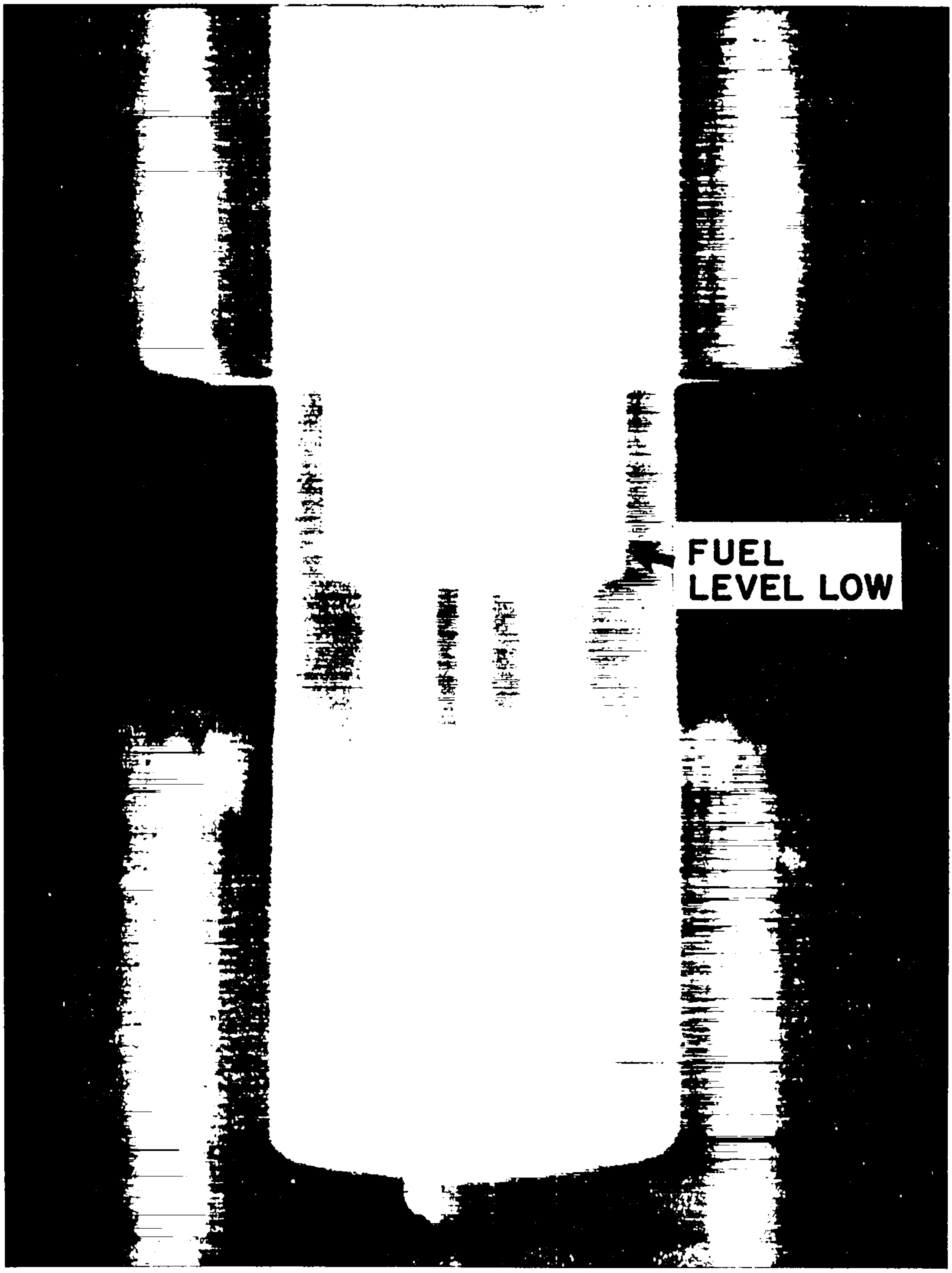


Fig. 30 Radiograph of Core-Level in Upper Pot Appears Low

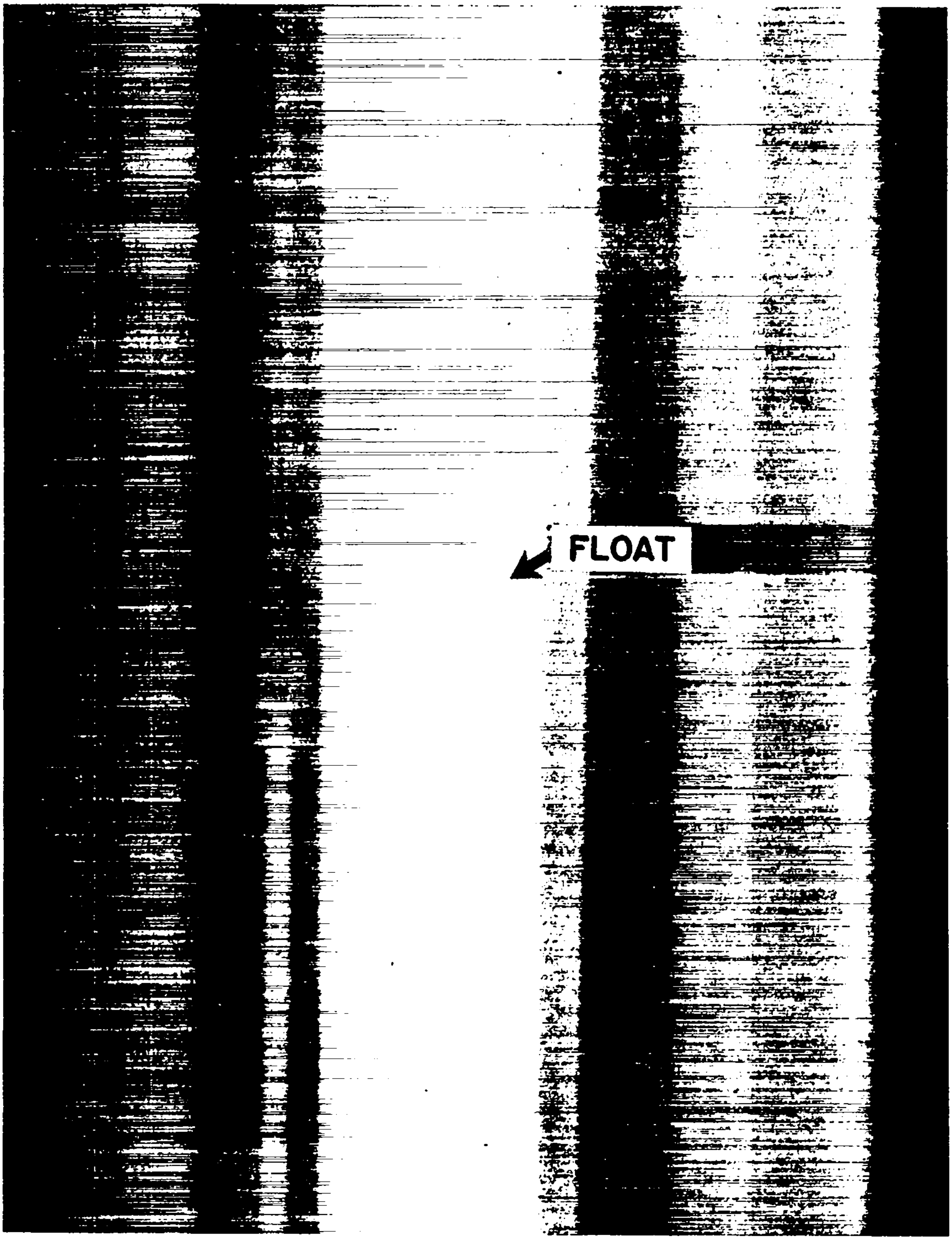


Fig. 31 Radiograph of Float at Upper Reservoir Level

camera caused flashing bands on the movie film. The frequency of these bands was a function of film speed and was particularly bad when the film speed was just slightly out of synchronization with the TV camera. A test film was then made at different film speeds to determine the speed at which the blanking bar effect was minimum. This speed was determined to be 16 frames/sec.

A new iridium source was obtained which was 35 curies. This source was a lower energy and higher intensity than the Co-60 and produced a very good image on the intensifier screen. With this source,it was possible to see details of the core assembly such as the tantalum bobs on the fuel flowmeter rod. A photograph of the monitor screen, with the source at the upper pot level, is shown in Fig. 32.

It was decided to take radiographs at two source levels in the core area and at the reservoir level during the second run . So that the exact source levels could always be repeated, the iridium source was used at the core area either directly on the lower platform table or on an aluminum block. For a core level radiograph, the source was placed on the platform;and for radiographs of the upper pot level, the block was put on the platform with the source on top of it. The Co-60 source was used at one position on the upper platform table for checking fuel level in the reservoir. The beams of the sources were collimated sufficiently to allow both of them to be used at once without the beam of one exposing the film of the other. The iridium source was also used for the gamma ray TV so a compromise was made on source distance to serve both functions without having to move the source table.

When all preparations were completed, the heaters were turned on to remelt the sodium. This was done carefully so that the sodium would melt from the top down to prevent damaging any of the loop sections, particularly the bellows. After all the sodium was melted, the E. M. pump was turned on and the sodium circulated around the loop.

During the first run, numerous fuel transfers were made and each time the fuel was pulled into the reservoir a small amount of sodium was also drawn in when the core fuel level dropped below the reservoir inlet. This increased the volume of sodium in the bellows and moved the working travel of the bellows down

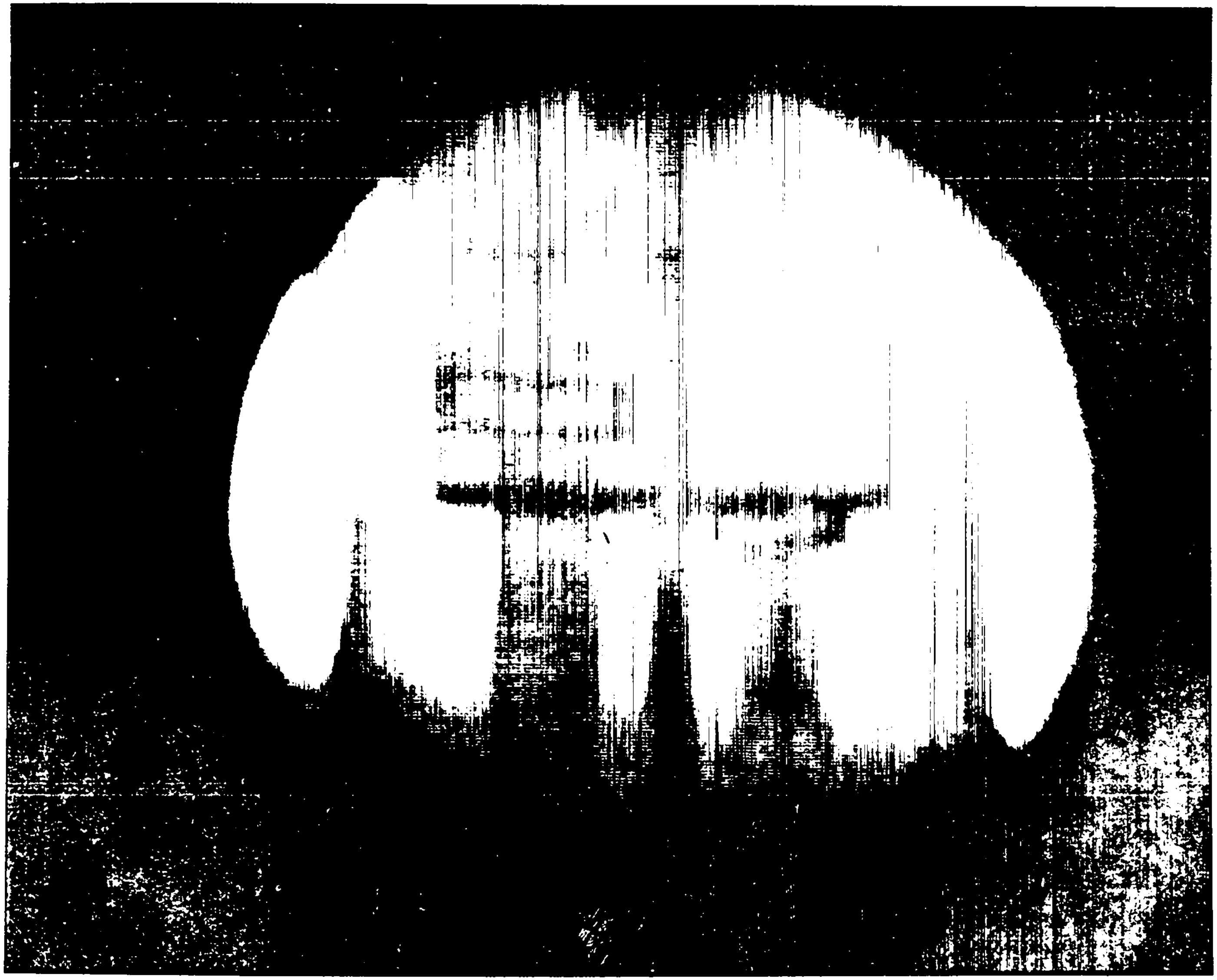


Fig. 32 Photograph of TV Monitor Screen

toward the lower limit. To shift the working travel back to its original position, the excess sodium was pushed back into the tank through the bypass before the fuel was remelted.

The method for taking periodic inventories of the fuel during the second run was based on this entrance of sodium into the reservoir when the core level dropped below the reservoir inlet. The procedure for taking inventory was to draw the fuel into the reservoir while watching the bellows sodium pressure. As the fuel was pulled up into the reservoir,the pressure would continually drop until the fuel level in the core dropped below the reservoir inlet. At this point, sodium would be drawn in and tend to break the vacuum as indicated by the pressure gage. The bellows drive was then stopped and the float height determined by the scanner. A radiograph was taken at the float area to be sure that the float was positioned properly with respect to the fuel level. As long as the float returned to the same position each time an inventory check was made in this manner, it was assumed that all the fuel was still in the core assembly.

To remelt the fuel without damaging the reservoir or core assembly, the heater at the top of the container tank was turned on first in order to melt from the top down. Sodium flow was reduced to a minimum to eliminate any appreciable heat exchange from the upper tank section to the lower section. The heating was done as rapidly as possible to maintain a steep thermal gradient down the tank. The complete melting of the fuel was indicated by the sudden drop in bellows sodium pressure. In the liquid state, the fuel would drop into the core until balanced by a vacuum in the sodium pusher line equal to the fuel head. As previously described, the bellows drive was then operated to draw all the fuel possible into the reservoir to establish the reference level of the float for subsequent inventory checks.

Fuel was transferred into the core by the bellows pusher with sodium flowing at 0.2 gpm. During this transfer, the iridium source was set at the core level position for TV viewing and motion pictures taken of the operation. The source was then moved to the upper pot level position and motion pictures taken of the lift pump action. Sodium flow was then increased to 0.4 gpm and more motion pictures taken. Complete data sheets were taken for each of these flow rates.

At this point, an effort was made to determine the sodium flow and pressure at the slip point of the lift pump. This is the point where sodium flowed up the mixed pump leg through the fuel but did not circulate the fuel. The point was determined by gradually increasing the sodium flow and watching the fuel flowmeter and TV monitor for the first sign of fuel flow. The sodium flow rate and pressure were noted when fuel flow started.

At the end of these operations, the fuel was transferred back into the reservoir for an inventory check. .The float level obtained, as indicated by the scanner, agreed with the reference level so it appeared that no fuel had been lost from the core assembly.

The purpose of the bypass line around the bellows pusher system was to have the capability of transferring fuel from the reservoir to the core even if the bellows system failed to operate. It could also be used to be certain that all available fuel was transferred to the core without depending on any bellows drive reference or radiographs. A fuel transfer was made using this method and motion pictures were taken of the TV monitor during the operation. It was found that good control of the transfer rate was obtained with the equalizer valve and that the pressure transducer could be used to indicate the rate of transfer and completion of the operation. With all available fuel transferred to the core assembly, the level in the upper pot was slightly below the bottom of the pump plenum chamber. Transferring fuel by this method involved nothing more than breaking the vacuum in the sodium above the fuel in the reservoir and equalizing reservoir and container tank pressures. After the fuel had been transferred to the core and pressures equalized, the bellows was compressed, with the bypass still open, to push into the container tank the amount of sodium normally displaced during a transfer with the bellows system. This was done in order to keep the bellows drive within its normal working travel when pulling the fuel back into the reservoir.

With the fuel in the core, and reservoir and container tank pressures equalized, the sodium flow was raised to 0.6 gpm and motion pictures taken of the pump action as shown on the TV monitor. To make certain that there was no excessive fuel carry-over at this flow rate, this flow was maintained for only a short time and at the end of the run the fuel was pulled back into the reservoir for an inventory check. The float returned to its reference position which indicated that there had been no loss of fuel from the core assembly.

The next step was to run three different flow rates with the equalized pool of fuel in the core. Fuel was transferred to the core using the bellows pusher system and then the bypass valve was opened to equalize pressures. Sodium flow rates of 0.2, 0.4, and 0.6 gpm were set, in sequence, with complete data sheets and a radiograph taken at each flow rate. Figure 33 was taken at 0.2 gpm and it can be seen that fuel was being circulated and that there was evidence of sodium carry-back in the fuel return leg. The fuel level in the upper pot was just below the pump plenum and no fuel was visible in the reservoir outlet tube.

Flow was then increased to 0.4 gpm as shown in Fig. 34 and the increased fuel flow is apparent. This film indicates that there had been a loss of fuel from the core assembly as the level in the upper pot is considerably below the pump plenum. This was even more apparent at the 0.6 gpm flow as shown in Fig. 35 where the fuel level dropped down into the well at the top of the fuel return leg. It appears that there was very little fuel being circulated as the density in the pump leg was relatively low.

At the end of these runs, the fuel was again pulled back into the reservoir for an inventory check and it was found that the float was 2 cm below the reference level. As this indicated that ~ 150 g of fuel had either leaked or been carried over out of the core assembly, the heaters were shut off and the system allowed to freeze. A radiograph taken at catch pan level after the system had reached room temperature showed that there was fuel in the catch pan, on top of the core, and out in the container tank (see Fig. 36). All planned operations had been completed and sufficient data obtained so no additional runs were attempted.

In order to study the core area in more detail, the insulation and heaters were removed from the container tank and radiographs taken in three different planes. Reduction of the object-to-film distance and elimination of heater windings resulted in more definition and less magnification of the core assembly. Figure 37, taken with the source in normal position in front of the test assembly, shows fuel in the catch pan and on the bottom of the tank. It also shows fuel around the connection between the core and fuel return tube and carry-over on

Fig. 33 Radiograph of Core - Sodium Flow 0.2 gpm

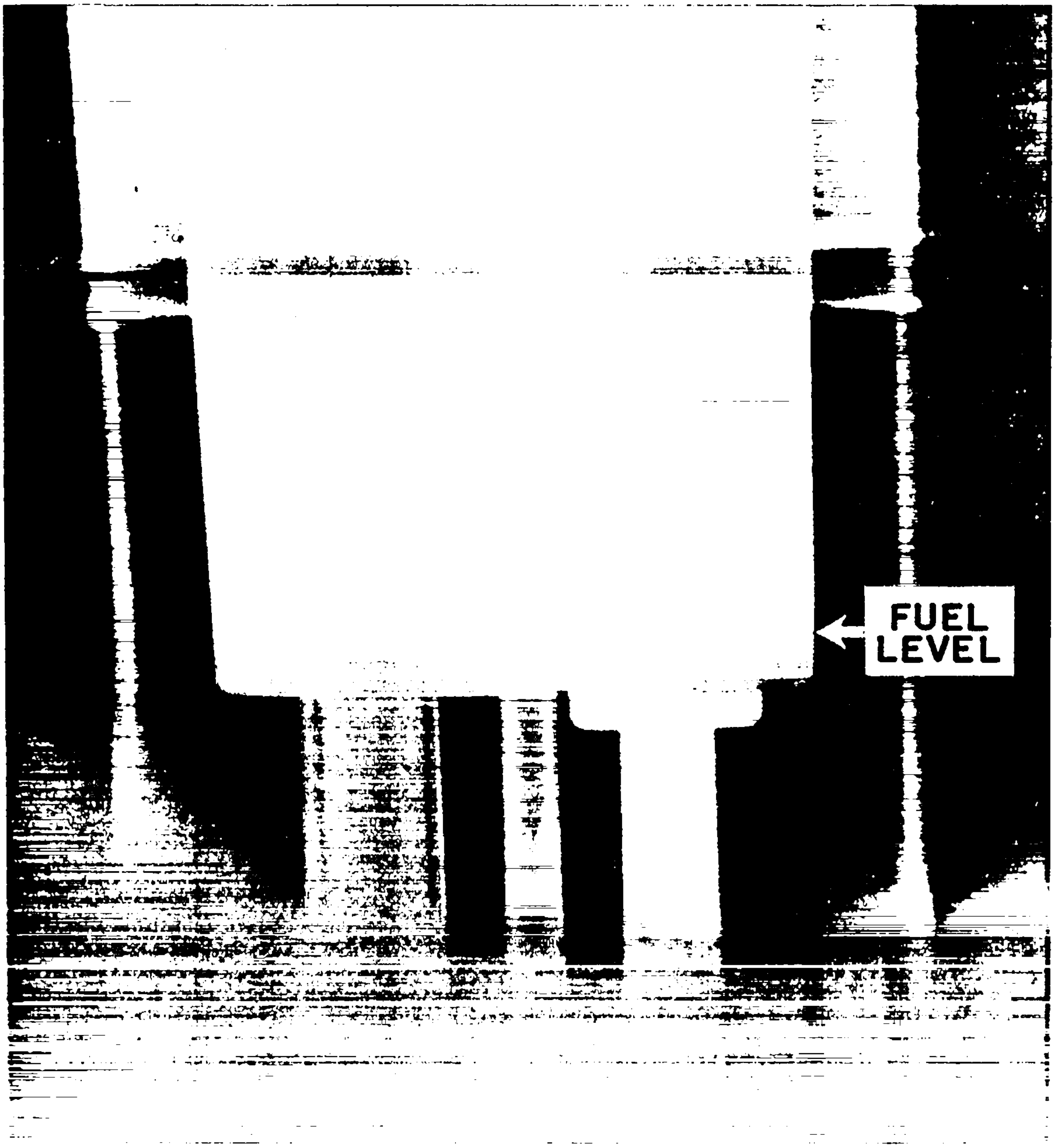


Fig. 34 Radiograph of Core - Sodium Flow 0.4 gpm

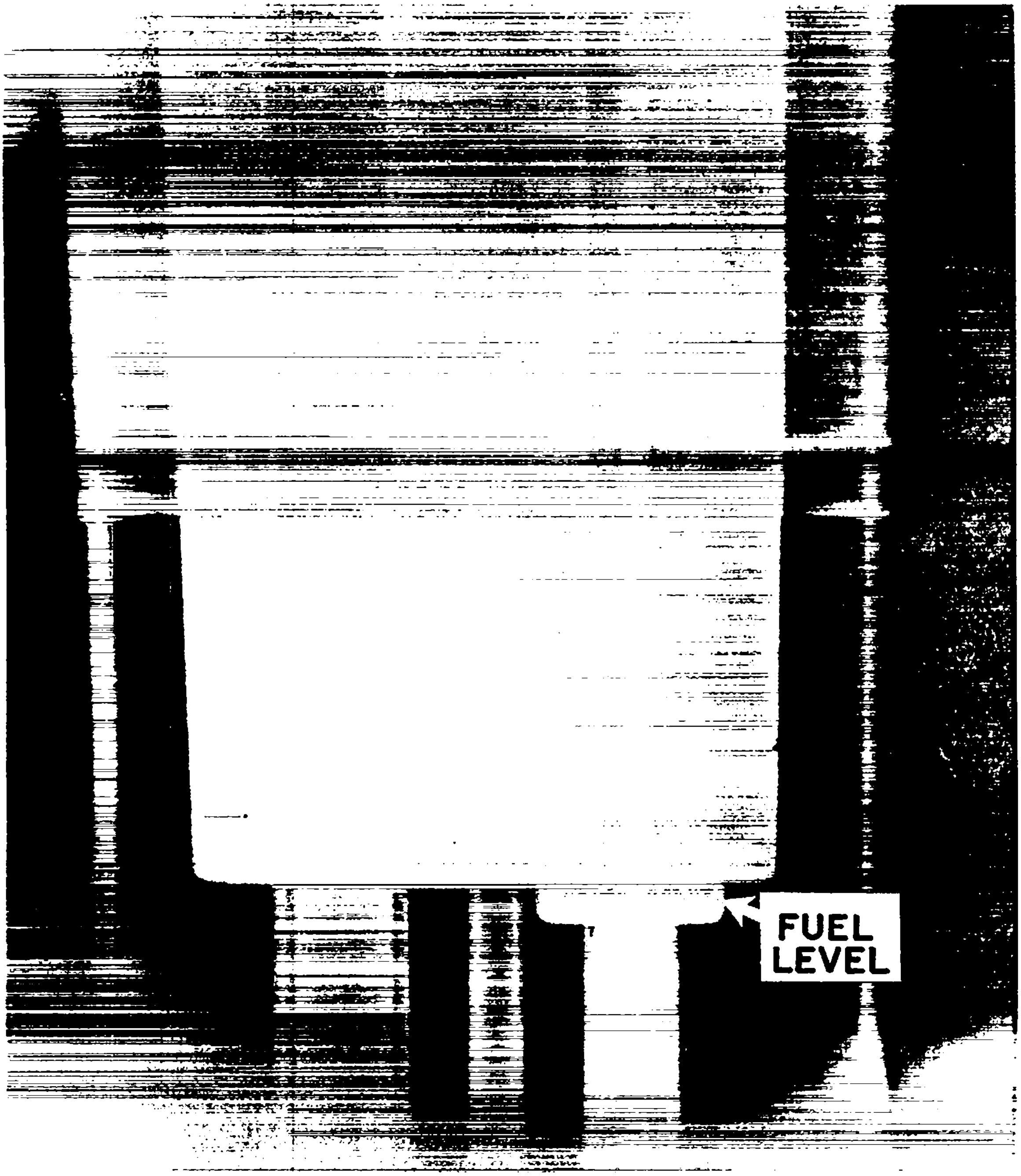


Fig. 35 Radiograph of Core - Sodium Flow 0.6 gpm

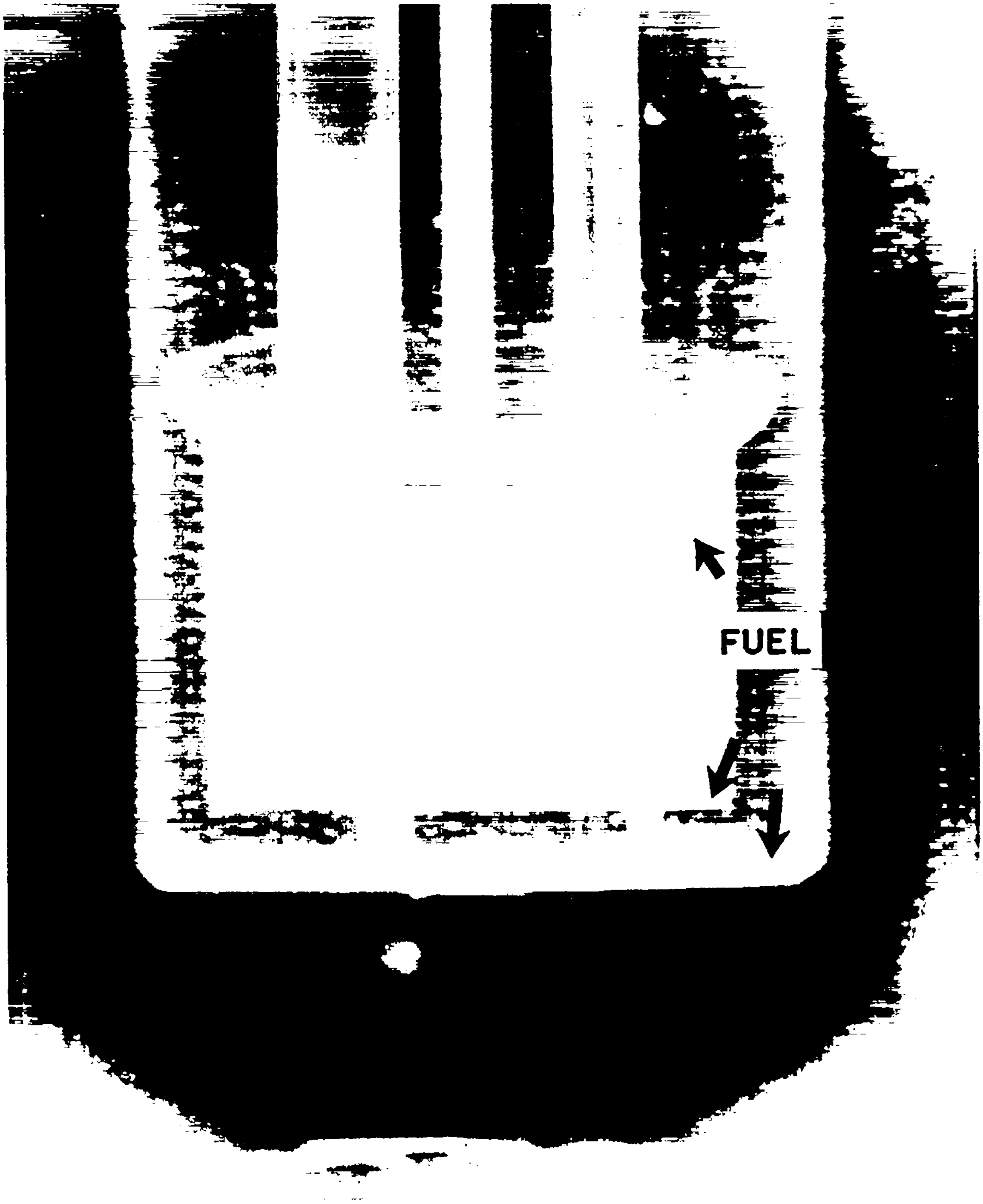


Fig. 36 - Radiograph at Catch Pan Level - Fuel Frozen

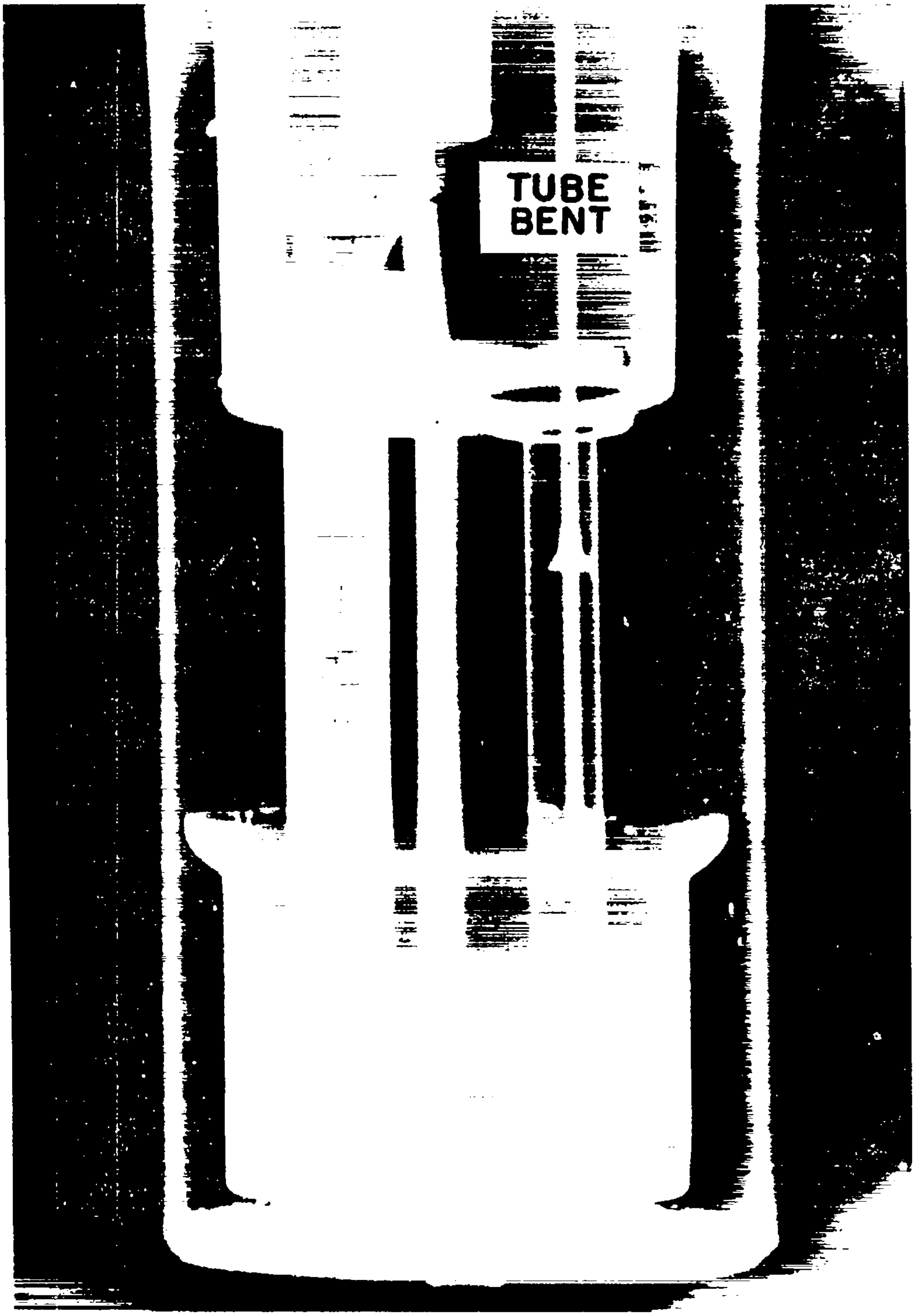


Fig. 37 - Radiograph of Core with Insulation and Heater Removed

the edge of the catch pot. Other particles of fuel can be seen clinging to the tank wall. Distortion of the core assembly is apparent, particularly of the reservoir outlet tube in the upper pot area. The source was moved 60° to the left and a second radiograph taken as shown in Fig. 38. Core distortion is more apparent from this position as the core pot is tipped at an angle and touching the catch pan wall (see arrow). The third radiograph taken, with the source 90° to the right, shows that the core pot had swung forward bending the pump and fuel return tubes from the vertical. See Fig. 39. To better ascertain the amount of fuel which had collected at the bottom of the container tank, a radiograph was taken with the source located at this level. See Fig. 40. This film indicates that the amount of fuel carried out of the tantalum assembly was not appreciable and the bulk of fuel lost from the core section was still contained in the catch pot. It was also of interest to determine how high fuel had been carried above the upper tantalum pot. A radiograph taken in this area showed some fuel particles scattered around the tank wall; however, there were none more than 2 in. above the top of the pot. See Fig. 41.

The insulation and heaters were also removed from the sodium loop and a radiographic survey was made to determine if any fuel had been carried out of the tank. No evidence of fuel was found in any section of the loop.

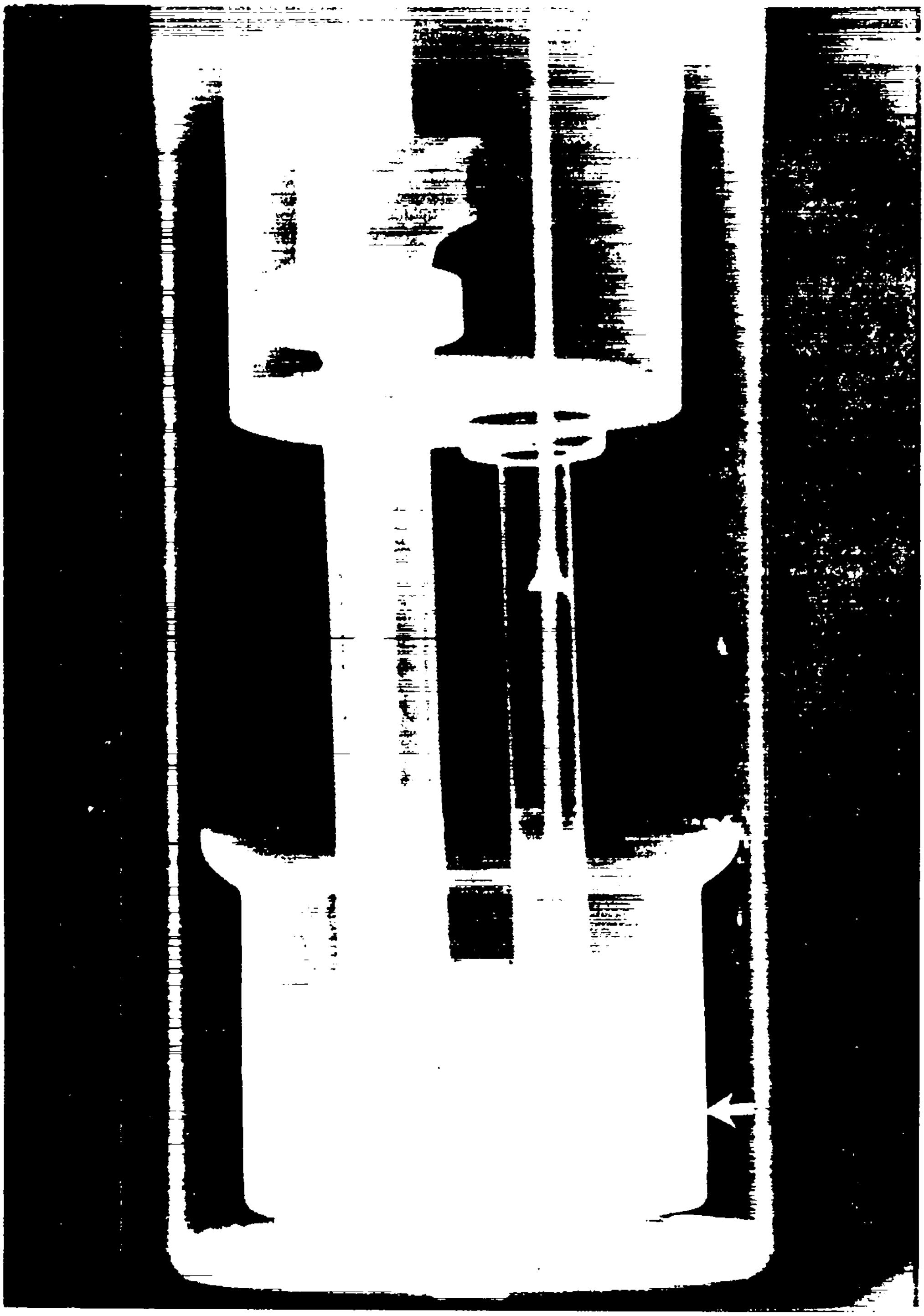


Fig. 38 Radiograph of Core - Source Moved 60° Left

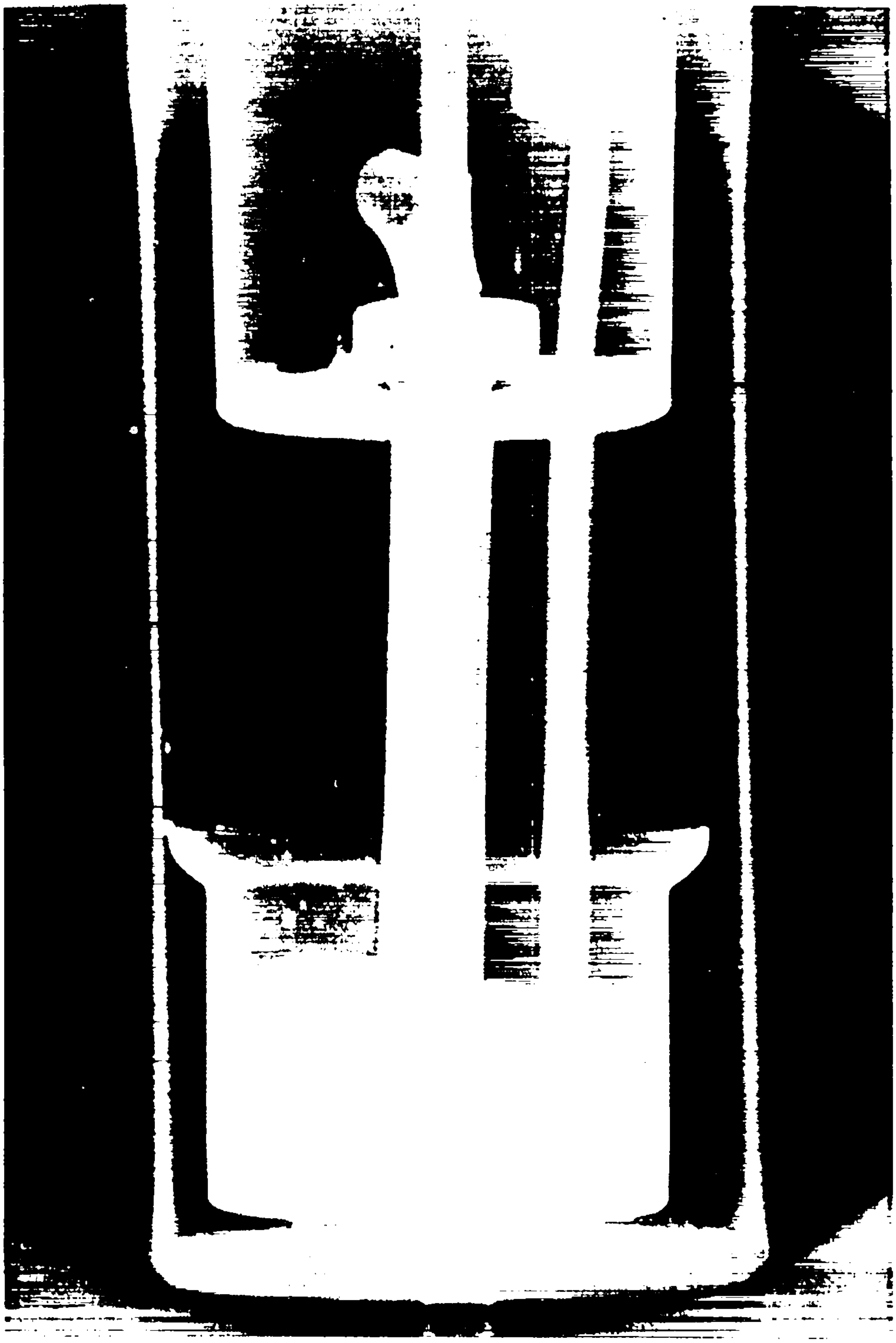


Fig. 39 Radiograph of Core - Source Moved 90° Right

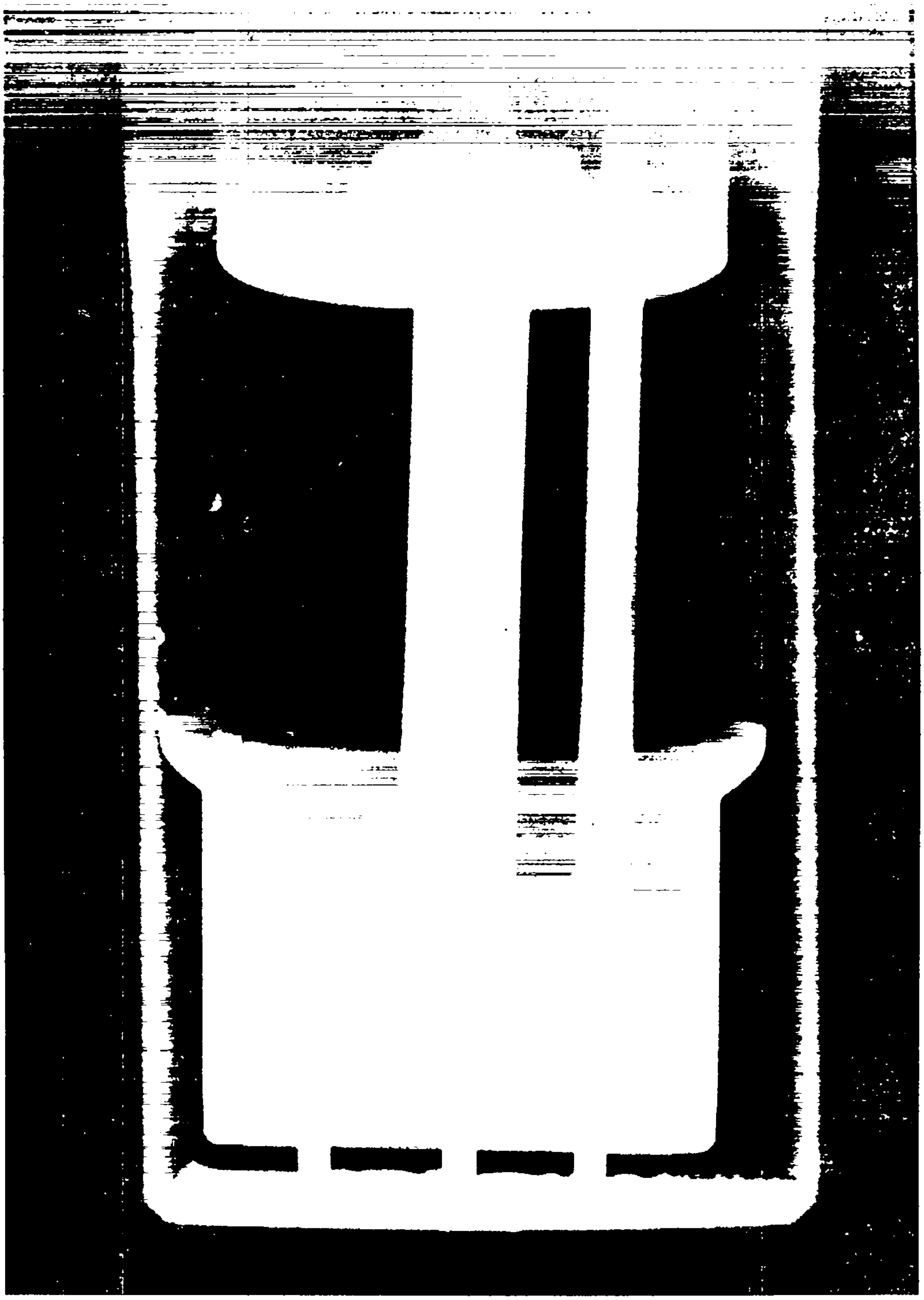


Fig. 40 Radiograph at Catch Pan Level

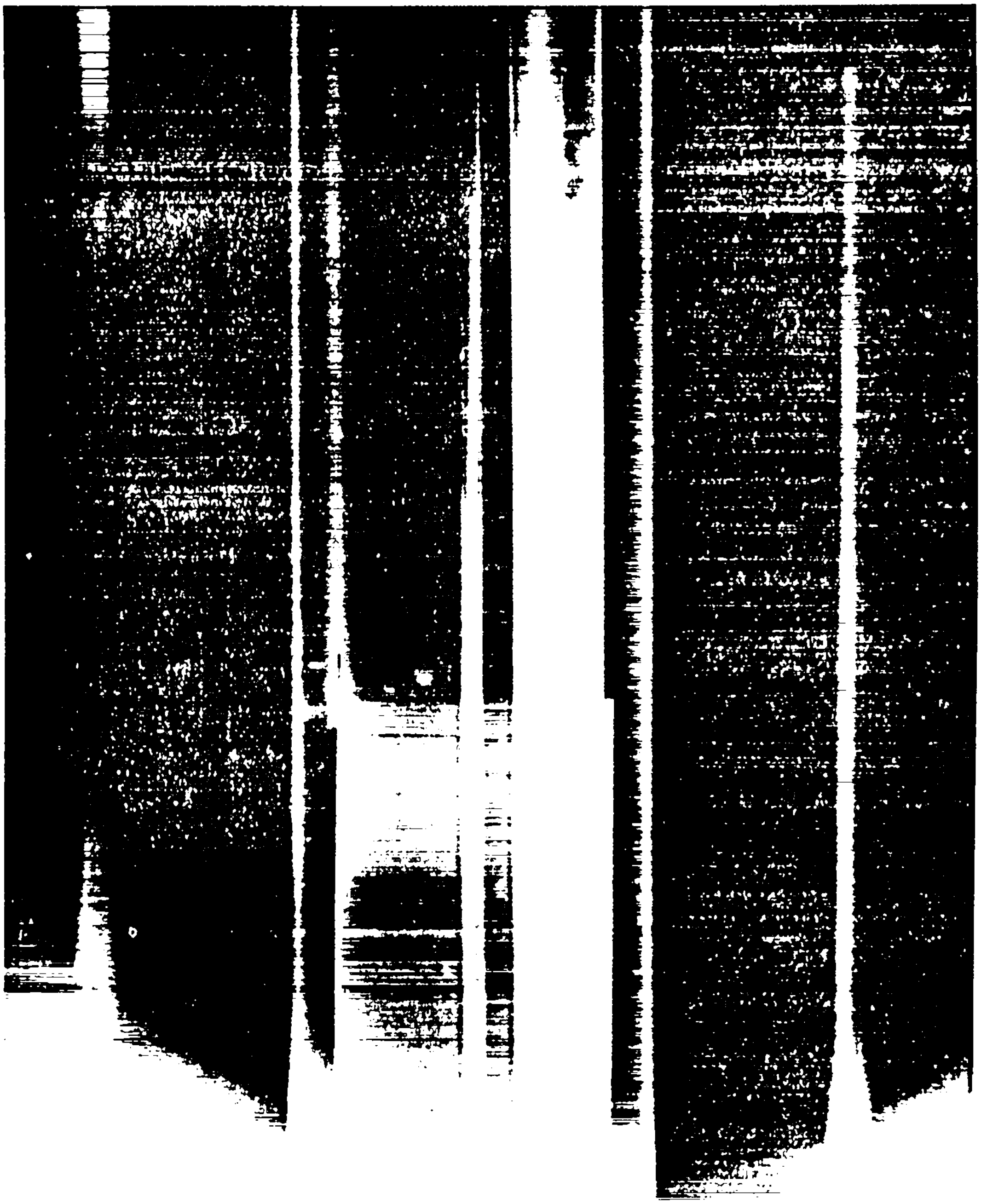


Fig. 41 Radiograph of Upper Tantalum Pot and Reservoir

5. RESULTS

5.1 Fuel Transfer System

No difficulties were encountered in the operation of the fuel transfer system. It provided a very positive action in the transfer of fuel which indicated that the sodium under the operating conditions was essentially incompressible. A plot of reservoir float height vs bellows position, as shown in Fig. 42, displays the linear characteristic of the system. The horizontal portion of the curve occurs when the float bottomed out in the reservoir. This plot was readily reproducible and indicates that the float was moving freely in the reservoir with the fuel surface. A plot of bellows pressure vs bellows position was also reasonably linear and shows the changes in section of the core assembly. See Fig. 43. The first portion of the curve is the pressure change during the filling of the core. The sudden change in slope occurred when the fuel started to fill the pump and fuel return tube, as the reduced cross-sectional area produced a greater change in head for a given bellows displacement. The slope again flattens out during the filling of the upper pot where the cross-sectional area is larger. Bellows pressure vs float position was also plotted as shown in Fig. 44. The nonlinearity of this curve results from the reduction in gas volume in the top section of the container tank. As fuel was transferred from the reservoir and replaced by sodium from the bellows pusher, the sodium level in the tank rose and increased the gas overpressure. As this pressure increase was an inverse function of the gas volume, the nonlinearity is more apparent at the higher bellows pressure. This curve also indicates the bottom float position where float position no longer changed with increasing pressure.

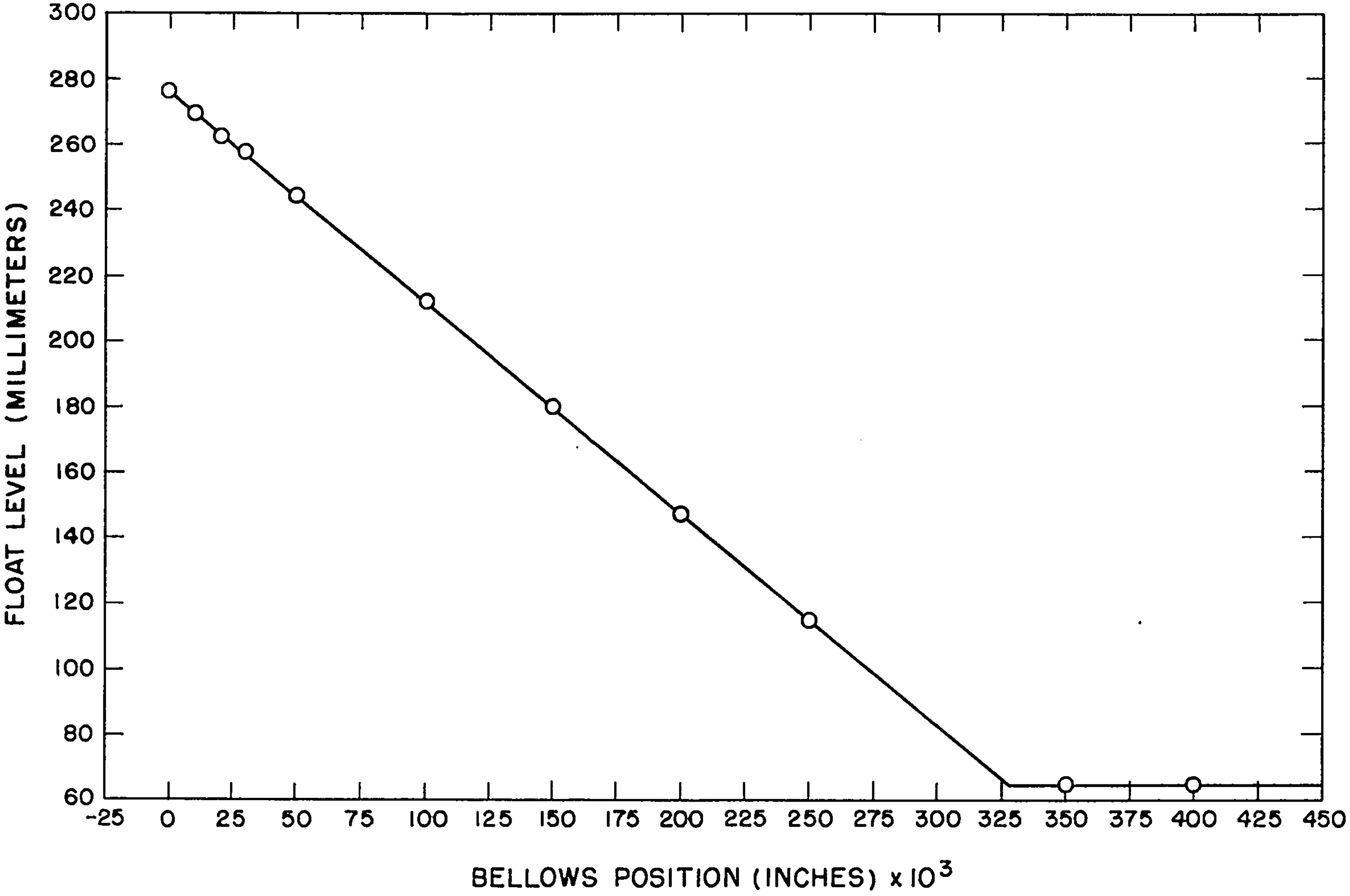


Fig. 42 Plot of Float Level vs Bellows Position

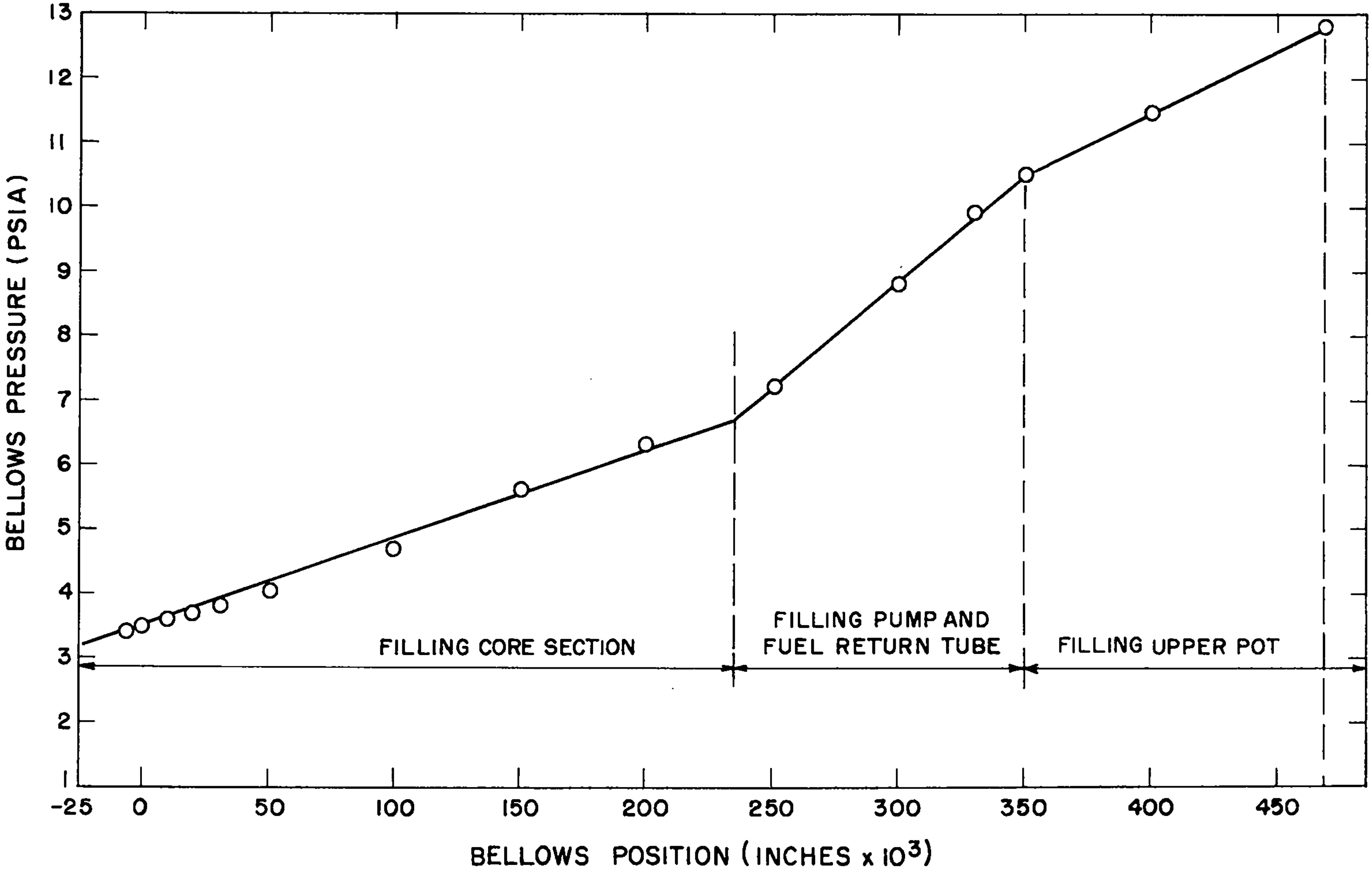


Fig. 43 Plot of Bellows Pressure vs Bellows Position

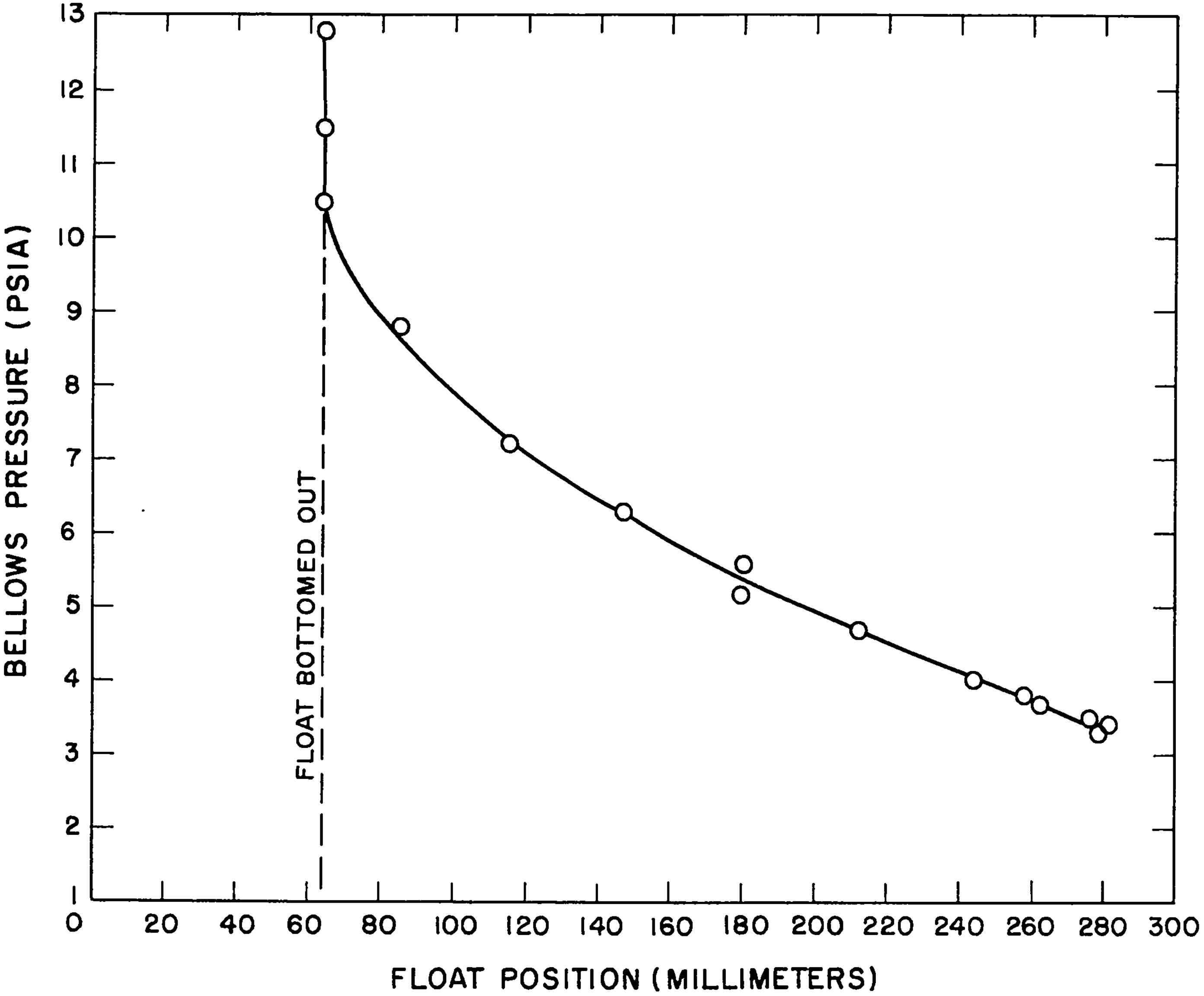


Fig. 44 Plot of Bellows Pressure vs Float Position

The bellows temperature was never allowed to go above 180°C and the pressure limited to 5 psig because of its fragile nature. Although this temperature was well below the operating temperature of the loop, the transfer rate was slow enough to allow ample time for the sodium to reach equilibrium temperature without any noticeable effect on the isothermal conditions of the loop.

5.2 Lift Pump

The lift pump operated satisfactorily and appeared to have characteristics similar to the copper pump in the water-mercury model. For flow characteristics of the copper pump see Fig. 45. No absolute flow rates were obtained for the fuel flow as it was not possible to calibrate the fuel flowmeter. An attempt was made to determine fuel flow by estimating the density of the mixed stream in the pump from the radiographs. Knowing the sodium flow rate and mixed stream density, the fuel flow could be determined using the value of sodium slip flow established in the second run. It was found, however, that the density of a given film varied considerably because of emulsion heating during exposure. This made it impossible to make any useful density measurements, particularly where it was necessary to compare one film with another.

A comparison of the motion pictures taken of the water-mercury system with those taken of the TV monitor indicated that the general flow characteristics of the two pumps were quite similar. It was also noted that the pumping action of the mercury-water model, when viewed on gamma ray TV, was almost identical to that of the plutonium-sodium system. Based on the results of this experiment, it appears that mercury and water are good substitutes for the plutonium-iron alloy and sodium in the preliminary development of pump systems.

The slip point of this pump was determined to be 0.15 gpm based on three trials. This was reproducible, as the same value of slip flow was obtained for each trial. When the slip flow was exceeded and fuel circulation started, the sodium flow rate increased to 0.22 gpm with the same E. M. pump power setting, indicating a drop in resistance to sodium flow with fuel circulating.

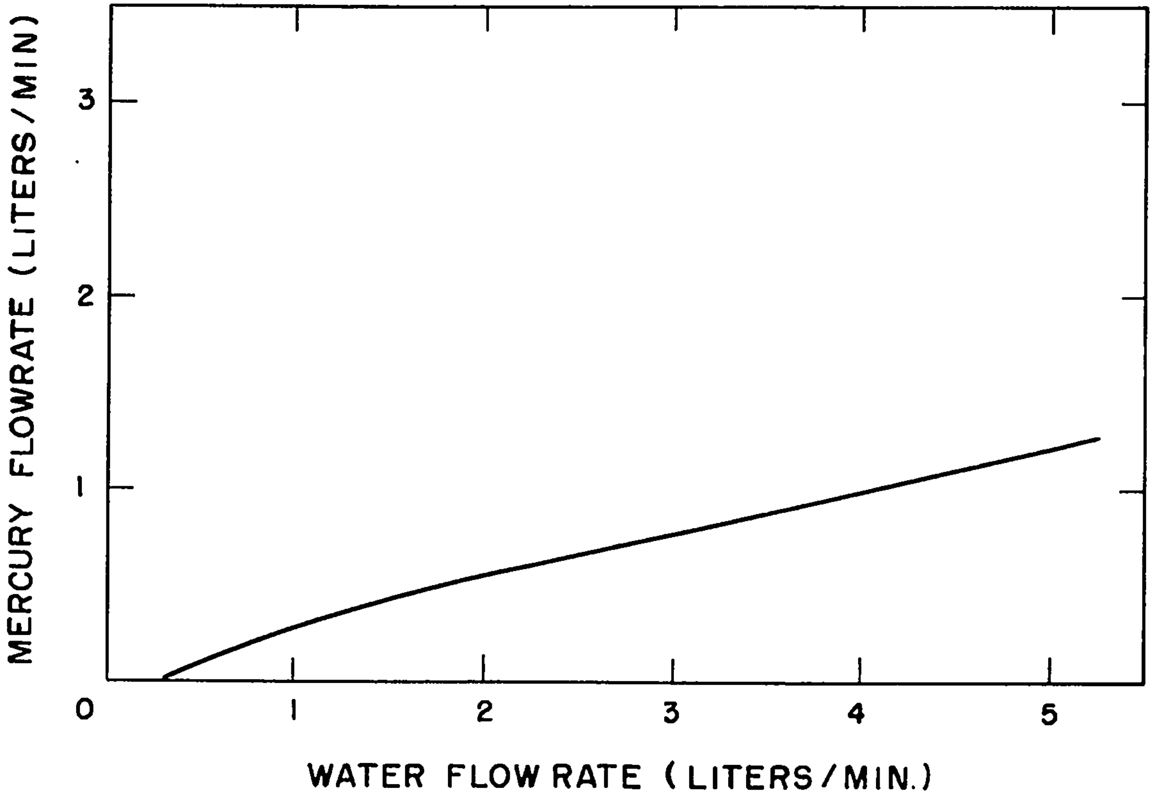


Fig. 45 Plot of Mercury Flow vs Water Flow for Copper Pump Model

There was no evidence of any fuel being carried out of the tantalum assembly by the sodium, except at the end of the experiment after the core level had dropped due to a leak. At the conclusion of the first run, there were no fuel particles in the bottom of the container tank or in the external sections of the loop. There was still no evidence of fuel carry-over during the second run, even at the highest sodium flow, until the apparatus had been shut down due to loss of inventory and radiographs taken of the core assembly and container tank bottom. It appears that, with the normal operating level in the upper pot, the fuel separated readily from the sodium and returned to the core. This was also the case for the mercury-water pump which shows the similarity of the two systems. Radiographs taken at higher flow rates showed low density areas below the two fuel flowmeter bobs indicating trapped sodium in these areas. Apparently sodium was carried down the fuel return tube to at least these points and possibly into the core. If sodium did enter the core, however, it could not be seen in the radiographs as the gamma rays could not penetrate such a large mass of fuel and show any contrast. This carry-back effect was also noticed in the mercury-water model where water was carried part way down the return tube by the mercury, but it did not appear that it was carried down far enough to enter the core.

5.3 E.M. Pumps

No difficulty was encountered in obtaining sufficient sodium flow and head using one pump. Both pumps operated equally well except that the lower pump caused the temperature recorder to go off scale on one of the thermocouples due to some unexplained coupling effect. Because of this, the upper pump was used exclusively except when the lower pump power was used to heat its section during the melting of the sodium.

During the hot trapping of the sodium, data were taken for sodium flow rate vs pressure and pump current. A plot of the curves obtained is shown in Fig. 46.

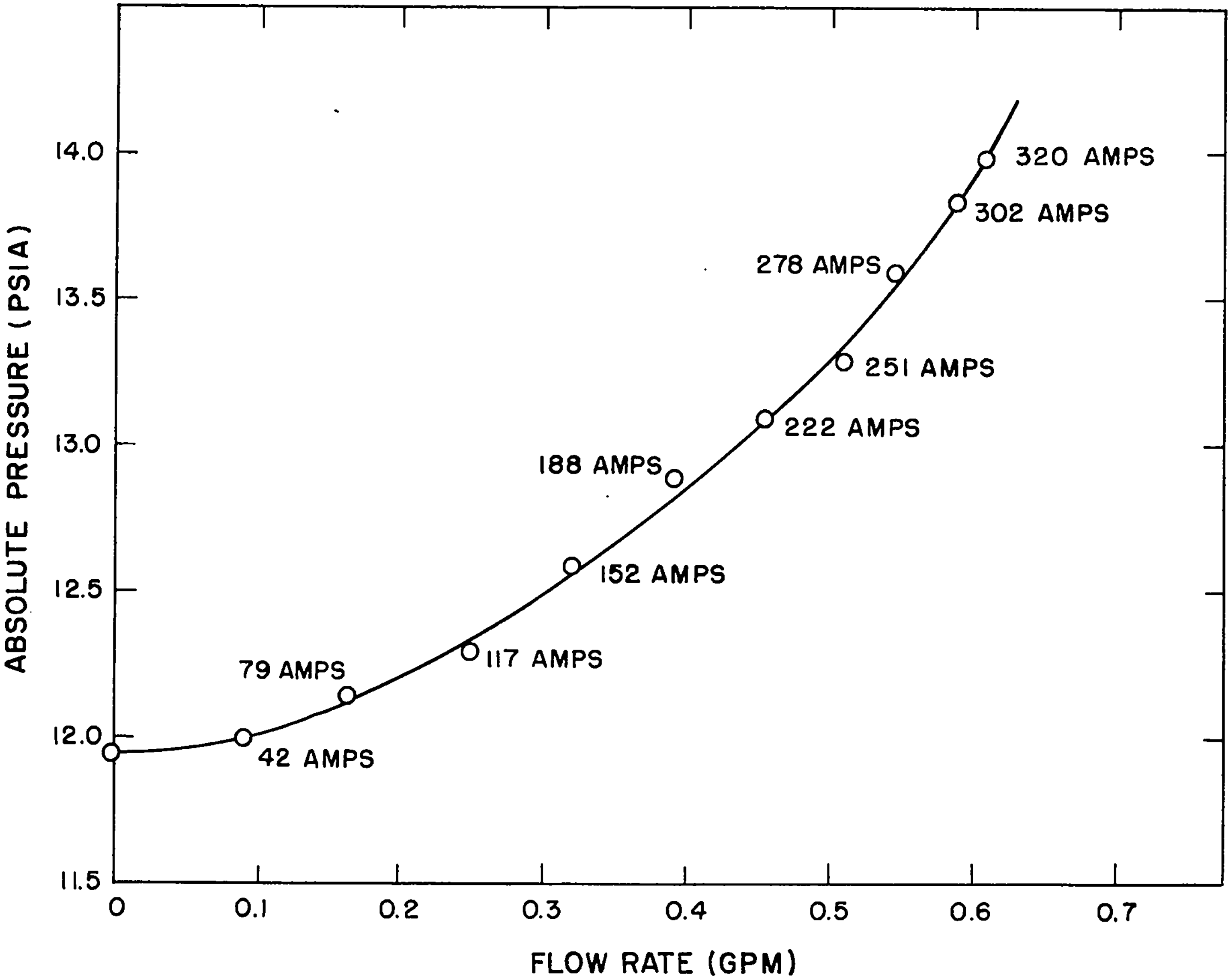


Fig. 46 Plot of E.M. Pump Pressure vs Sodium Flow Rate

5.4 Instrumentation

5.4.1 Pressure Transducer

The sodium pressure transducer proved quite adequate for determining E.M. pump and bellows pusher pressures. It was particularly useful during fuel transfer operations as it indicated the approximate rate of transfer and the completion of the operation. When transferring to the reservoir, a decreasing pressure in the bellows was indicated until the fuel level in the core reached the reservoir inlet, at which point sodium was drawn in causing a sudden increase in pressure. This indicated that all the fuel was drawn into the reservoir that was possible. When transferring fuel into the core, an increasing bellows pressure was indicated as the fuel head was decreased. Compression of the bellows was continued until the pressure difference between the reservoir sodium, as indicated by the transducer, and the tank sodium, as indicated by the bourdon gage, was zero. Equalization of these pressures signified approximate equalization of core and reservoir levels and completion of the operation. The only difficulty encountered with the transducer system was caused by freezing the sodium after the first run. The freezing and remelting of the sodium in the transducer apparently caused some permanent distortion of the bellows and resulted in a 10-psi error in pressure reading. A recalibration of the system corrected this error, however, and no further difficulties were encountered.

5.4.2 Fuel Flow and Level Indicator

This instrument, used as a level indicator, was quite useful when transferring fuel from the reservoir to the core with sodium flow off. As fuel rose up into the fuel return tube and contacted the lower bob, a sudden change in output of the indicating meter could be seen. Addition of more fuel from the reservoir was then shown as steady increase in output until the level reached the upper bob. This produced another sudden change in output followed by a steady increase in output until transfer was complete.

When a transfer of fuel was made with sodium flowing, there was erratic action of the level indicator when the fuel level became high enough in the pump tube to start fuel circulation. This was caused by the combination of upward buoyant forces and downward flow forces.

The operation of the instrument as a fuel flowmeter was also impaired by its sensitivity to level changes. When fuel was being circulated, the liquid surface in the upper pot would oscillate as the fuel tended to pile up on the side opposite the outlet elbow. This caused a continuous change in level which was reflected as noise in the indicating meter. Although the instrument gave a definite indication of fuel flow, no quantitative values were obtained because of lack of a calibration method.

5.5 Gamma Ray TV

When a source with sufficient intensity was obtained, excellent images of the core system were produced on the monitor screen. The sensitivity of the intensifier screen was sufficient to show rapid motion of the fuel. Motion pictures of the monitor provided an excellent permanent record. Some noise effect was produced by heating of the end of the intensifier tube when it was positioned close to the container tank heaters for an extended period. This effect was minimized by placing a reflector on the end of the tube and moving the tube away from the tank when it was not in actual use.

Although the source table was adequate, difficulty was encountered in setting desired source levels. The combined jack and screw thread adjustment was inconvenient to operate and provided no reference points for resetting required levels. It was also necessary to unstack the lead shielding each time the upper platform level was changed.

5.6 Flow Calorimeter

The sodium flow rates obtained with the flow calorimeter were inconsistent and did not agree with values obtained with the E. M. flowmeter.

Temperature difference measurements varied considerably for the same flow settings and appear to be the major source of error. This is believed to have been caused by insufficient turbulence of the sodium at the inlet and outlet resulting in incorrect bulk sodium temperatures. Flow measurement by this method appears to be feasible; however, mixing chambers at the inlet and outlet should be used in order to establish a uniform sodium temperature at the points where the temperature difference is measured. Further development of such a flowmeter could best be done in a sodium instrument loop without the complication of alpha-contaminated sodium.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Fuel Transfer System

It is recommended that further development work be done on this type of transfer system for operation in a radiation field. Neither radiographs nor radioactive floats could be used for determining fuel levels under such conditions; however, this may be accomplished by pressure measurements. The pressure curves plotted from the data obtained during this test indicate the possibility of level determination by measurement of the fuel head. A differential pressure measurement could be made to indicate this head. The sudden changes in the slopes of the bellows pressure curve, with abrupt changes in cross-sectional core areas, might also be useful to establish reference levels.

Preliminary feasibility studies of such a system should incorporate lucite models using mercury and water as the working fluids. In more advanced stages, involving sodium and plutonium alloys, the gamma ray TV, radiographs, and radioactive floats would provide sufficient information to calibrate any of the pressure devices used for this purpose.

Although the float moved freely after all the fuel was melted and thoroughly mixed, floats used in future experiments should be designed to prevent sticking when tipped at an angle. Free float motion is essential when the float is used as a fuel leak indicator. This could be done by making the bottom section more spherical instead of a cylindrical shape. The activity of the radioactive foil was sufficient for obtaining adequate count-rate yet low enough to permit personnel to work in its vicinity.

It was noted after melting the fuel that a skin-like formation developed at the fuel surface in the reservoir. This caused the tipping of the float and prevented its motion at the start of the first run. Such a condition might be prevented if the fuel could be melted in an upper section of the reservoir and filtered into a lower working section. Any impurities filtered out would remain in the upper section of the reservoir and could not enter the core assembly. In the initial loading, the fuel would be placed above the filter and the float below.

The positive displacement characteristics of the bellows pusher system indicate that it has potential as a fuel metering device. If it were calibrated at temperature, the linear displacement of the bellows could indicate the amount of fuel transferred into or out of a core.

6.2 Lift Pump

The lift pumping of plutonium alloys using sodium as the pumping fluid appears to be feasible. One of the major factors in the design of such a system is the separation of the sodium and fuel at the pump outlet. This involves two separate and distinct problems: carry-over of the fuel by the sodium and carry-back of the sodium by the fuel. Excessive carry-over would preclude the use of stainless steel for all external loop sections likely to contact the fuel. This would seriously complicate the design and construction of the sodium loop. Any carry-back of sodium into the core would reflect as nuclear instability of the core and make control difficult. Both of these conditions are functions of pump and separation chamber design, mixed stream velocity, plutonium alloy-sodium density ratio, fuel return leg velocity, wetting of the tantalum by the fuel, and separation pool depth. In this particular core assembly, there was no evidence of fuel carry-over during normal operation. There was, however, evidence that sodium was being carried downward by the fuel, at least as far as the lower flowmeter bob. This occurred at the higher sodium flow rates as indicated in the radiographs taken at 0.4 and 0.6 gpm.

As neither carry-over nor carry-back could be tolerated in a circulating core, it is recommended that an extensive study be made of the separation problem. Here again, much of the preliminary development work could be done with lucite models using mercury-water to mock-up the plutonium-iron and sodium system. Wood's metal type eutectics and hot water could be used to simulate lower density plutonium alloys.

6.3 Instrumentation

6.3.1 Pressure Transducer

This was the first attempt to use this particular pressure transducer in a sodium system and it was quite satisfactory. Only one unit was installed on a trial basis so the flow pressure and bellows pusher pressure were measured by valving from one to the other in turn. Any future loop systems should have one transducer for each required pressure measurement. In cases where remote operation of a system is desirable, all pressure measurements, including cover gas and gas manifold pressures, could be measured with these transducers as they are readily adaptable to remote readout.

These pressure transducers could also be used as differential pressure gages. This would be very useful for measuring the fuel head in a fuel transfer system where it is possible that head would indicate level.

6.3.2 Fuel Flow and Level Indicator

This instrument was quite satisfactory as a fuel level indicator. It could also be used as a sodium level indicator with a lower density bob. In both cases, it could be adapted for use as a leak indicator in conjunction with the proper relays and alarms.

When used as a fuel flowmeter, difficulty was encountered obtaining a satisfactory signal to noise ratio. As the instrument is sensitive to vertical forces in either direction, the oscillation of the fuel surface reflected as level change and affected the downward force exerted by fuel flow. This caused unstable output readings and uncertainty in the interpretation of flow data. Further development, mostly of the core assembly design, is needed to produce a satisfactory flowmeter of this type.

6.4 Gamma Ray TV

The gamma ray TV used in this experiment was shown to be a valuable tool in the study of dynamic systems. By selecting sources of sufficient strength and optimum energies, this system would be useful in many different applications where the study of motion within opaque containers is required. The high sensitivity of the intensifier screen, as compared to radiographic film, makes it possible to view rapid motion yet produces sufficient definition for identification of details. Motion pictures of the monitor screen proved to be a good method for obtaining a permanent record of the action viewed. The TV monitor system is well suited to remote operation of loop systems.

A new system is now being constructed incorporating a more sensitive intensifier tube, a new TV camera, and a new monitor. A kinescope recorder could be added to provide a more convenient method for obtaining the permanent film record. A motor-driven source mount is also being constructed which will have a synchro readout to indicate height. With the capability to move both the intensifier tube and source, a rapid vertical scan of a system will be possible.

6.5 Radiographs

The quality of the radiographs taken during this experiment was excellent. The only difficulty encountered was in determining changes in fuel level by comparing various radiographs. This was due to the fact that the source levels were often different which made the exact fuel level difficult to determine. It is recommended that in future tests the source height be recorded for each radiograph. This can be obtained from the synchro readout of the new source mount.

6.6 Core Failure

From a study of the radiographs, it appears that the loss of fuel from the core assembly during the second run was the result of a leak at the joint between the fuel return tube and the core. This leak occurred during the last series of flow tests between the 0.2-gpm and the 0.4-gpm settings as shown by the definite level change in the upper pot. The radiograph of the 0.6-gpm setting indicates that the level had dropped even further and that the pump action was that of a jet pump more than a lift pump due to the low level. This caused carry-over of the fuel out of the upper tantalum pot into the container tank. The reduced sodium velocity in the container tank apparently resulted in a rapid settling of the dense fuel to the bottom of the tank as no evidence of fuel particles could be observed in the radiographs of the upper tank section. The bulk of the fuel in the catch pan appears to be the result of the leak while the fuel on the bottom of the container tank and the particles on the edge of the catch pan resulted from carry-over.

It is believed that the leak was caused by excessive stressing of the joint during the freeze-up at the end of the first run. When the layer of fuel, which could not be drawn out of the bottom of the core, was frozen, it completed a continuous column of tantalum from the bottom of the core to the fitting at the top of the reservoir. The equivalent length in the core suspension assembly was partially made up of stainless steel. The large difference in thermal expansion of tantalum and stainless steel resulted in a contraction of the suspension which was much larger than that of the tantalum reservoir column. With the core held relatively fixed by the tantalum column and the upper pot being moved upward by the contraction of the stainless hanger rods, large forces could have been transmitted to the joints at the top of the core. It is believed that these forces strained these joints causing the leak during the second run.

The distortion of the core assembly, noted after the second freeze-up, was probably the result of a similar condition. In this case, however, the frozen fuel in the catch pan eliminated the free suspension of the core assembly with respect to the container tank. With the catch pan resting on the bottom of the tank and the core attached to the catch pan by the fuel, a continuous column of tantalum was created from the bottom of the tank to the fitting at the top of the reservoir. As the stainless steel tank contracted much more than this tantalum column during cooling, large compressive forces were applied to the core assembly. This caused the distortion of the core assembly and the bending of the reservoir outlet tube.

6.7 Future Development

Excluding nuclear aspects, the two major problems in developing a mobile fuel reactor core are instrumentation and separation of the fuel and pumping fluid.

Although the core behavior in this experiment could easily be studied, the major tools for observation - gamma ray TV, radiographs, and radioactive float - could not be used under radiation conditions. This leaves only the pressure transducer and the fuel flow and level indicator to provide all the information with regard to lift pump action, fuel transfer operations, and location of fuel levels. As shown in preceding discussions, these would not be adequate to successfully operate a critical core assembly. Considerable development work must be done to create more and better instrumentation for this purpose.

There is also more information required concerning materials compatibility such as container corrosion, mass transfer of container material by the fuel, and solution transfer of fuel components by the sodium. These factors are integral parts of the feasibility studies as they affect the design, choice of materials, and type of plutonium alloy for a mobile fuel core. It may be possible to obtain some of this information from loop tests designed primarily for pump and fuel transfer development. In some cases, however, it may be more practical to design special mass transfer experiments for specific information.

The major accomplishment of this experiment was to show that the technology and equipment are now available for the undertaking of the studies of dynamic liquid metal systems, essential in the development of mobile fuel reactor cores.