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OPERATION OF THE PLUTONIUM-FUELED FAST REACTOR LAMPRE*

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SUMMARY

LAMPRE, a 1 MW experimental fast reactor, fueled with plutonium and cooled by sodium, operated successfully for two and a half years.** In this simple system, the use of plutonium fuel and liquid metal coolant proved to be straightforward. Some of the experience gained with this system should be applicable to larger, more complex fast reactors.

Adequate coolant purity was maintained in the LAMPRE system so that a refractory metal container for the fuel could be satisfactorily used. Nitrogen from the atmosphere was observed to diffuse into the coolant loop through the pipe walls, which operated at temperatures in the range 450°C to 650°C; the nitrogen concentration in the gas space above the sodium was controlled by periodic flushing, and no ill effects attributable to the nitrogen were observed.

During the course of the experiment, fission products and plutonium were released into the coolant loop. This had only a minor effect on the established procedures for reactor operation, fuel handling, etc. Additional conservatism was applied to maintenance tasks, but it appears in retrospect that more than necessary caution was used.

The distribution of fission products in the system was not examined in detail, because not all of the loop was accessible to gamma scanning equipment. Where measurements could be made, the results -- particularly with respect to cesium -- are consistent with fission product transport and distribution observed in laboratory experiments.

A major part of the core structure, and some of the coolant loop, was disassembled after the conclusion of the reactor experiment. This was accomplished without particular difficulty. The level of dispersable plutonium contamination was lower than had been expected. In the hot trap system, plutonium contamination was firmly fixed on the pipe walls; sections of these components were removed from the loop without any special techniques to prevent the spread of radioactive materials. The larger sections of gas piping attached to the top of the reactor vessel contained detectable levels of plutonium, but conventional bagging techniques were adequate to permit uneventful disassembly of the system. Smaller gas lines connected to the fuel charging machine were safely removed without bagging.

INTRODUCTION

Other papers in this session have described the operation of fast reactors which resemble the breeders that may be a part of the nuclear power complex during the next decade. The experience which will be discussed here was obtained with a somewhat different reactor: it was physically very small, and it generated no electrical power. Its only similarities to a fast breeder were that it was fueled with plutonium, cooled by sodium, and operated at temperatures about equal to those proposed for the central station reactor. It may seem unlikely that much information relevant to operations of large systems was obtained with this 1 MW reactor which dumped its power to an air radiator. However, some of the operating experiences selected for discussion here will perhaps be of general interest.

Though LAMPRE (as well as some aspects of its operation) has been described previously (1-7), a brief review of the reactor's design and purpose is appropriate before operating experiences are discussed.

The short-term objective of the LAMPRE project was quite limited. In 1957, when serious work on the liquid plutonium fuel program began, there was (even as in 1967) no flexible reactor facility for testing fast reactor fuels in a hard spectrum at high temperatures.

LAMPRE was constructed to provide such a facility at the Los Alamos Scientific Laboratory. The primary purpose of this low cost, fast neutron system was to permit investigation of some of the most obvious questions about the suitability of liquid plutonium alloys for use as fast breeder fuels. It appeared that the operational stability of such a system, and the extent to which gaseous fission products escaped from the fuel, could be assessed in a preliminary way by tests made in such a facility. Clearly the modest power rating of the reactor would limit its useful-

*Work performed under the auspices of the U. S. Atomic Energy Commission.
**The coolant loop was in service for approximately three and one-half years.

DISCLAIMER

ness for establishing definitively the potential burnup capability of the fuel. However, it was hoped that (a) this experimental reactor would run reliably at a high plant factor and thereby offset to some extent its low power rating, and (b) that more conclusive data on burnup capability would be obtained in a larger, follow-on reactor experiment. (This last goal was not achieved because the liquid plutonium fuel program was cancelled by the AEC in 1965.)

The general design of the system for implementing the program objectives is best described by reference to several illustrations. Figure 1 shows a fuel element (an 8-in. long, 7/16 in. diameter tantalum capsule which contained a 6 in. height of liquid plutonium alloy) and its extension, or handle, by means of which the fuel element could be inserted into and removed from the reactor. About 140 of these fuel element assemblies constituted the core, which was located in the 10-in. diameter reactor vessel shown in Figure 2.

A fuel transfer machine (Figure 3) was attached to the top of the reactor vessel; it was used to lift fuel assemblies out of the reactor, to remove the fuel capsules from the handles, and to install new fuel capsules.

Reactor control was provided by movable sections of a neutron reflector outside the vessel; the reflector assembly is shown in Figure 4. These control elements were actuated by hydraulic cylinders located beneath the reactor, as shown in Figure 5.

The coolant system, which contained about 8 ft^3 of sodium, is shown in Figures 6 and 7.

The obvious simplicity of the LAMPRE system illustrates the basic philosophy applied to its design. This was to provide the capabilities necessary for normal operation in the most straightforward manner, and to omit special or infrequently needed capabilities which might be required to deal with a great variety of hypothetical (or even barely conceivable) misfortunes. It was felt that most non-normal circumstances could be dealt with adequately by brute force, if they occurred. This point of view probably seems more naive now than it did in 1959, but it still has some merit. In the case of a reactor which must run on a fixed schedule, it may however be difficult to achieve the required balance between the initial cost of providing for varying eventualities and the penalties associated with having the reactor off the line while its staff invents "fixes" and accumulates "operating experience."

The chronology of the LAMPRE program is indicated in Table I. The "operating experience" which is discussed here was selected from events that occurred during the five year interval from late 1960 to late 1965. This period covers the disassembly of the reactor as well as its actual operation.

The specific areas of operating experience which are described include (a) maintaining purity of the coolant, (b) the appearance of nitrogen in the cover gas system, (c) fission products and fuel in the coolant, (d) mechanical design features; some good, some to be avoided in the future, and (e) the handling of plutonium contaminated fuel elements and components in relation to normal operation of

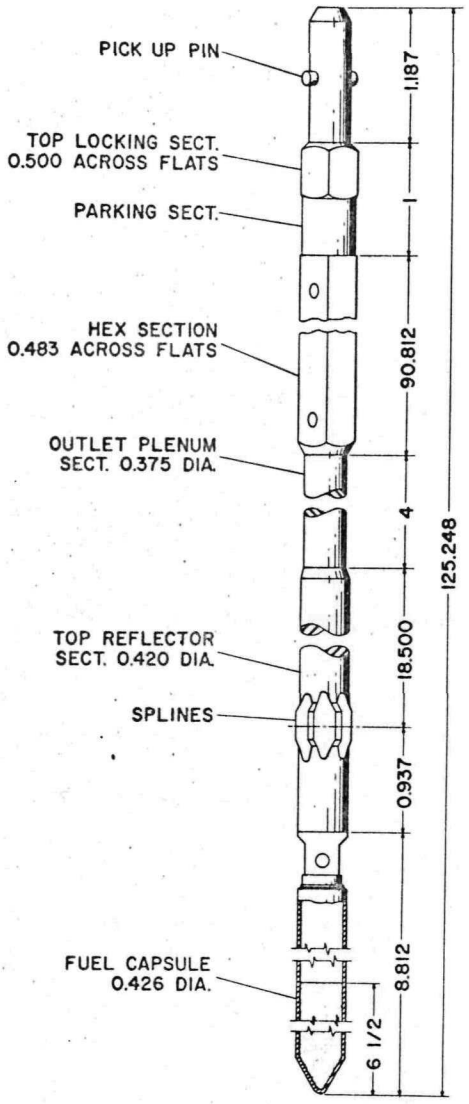

Fig. 1. LAMPRE Fuel Capsule and Handle.

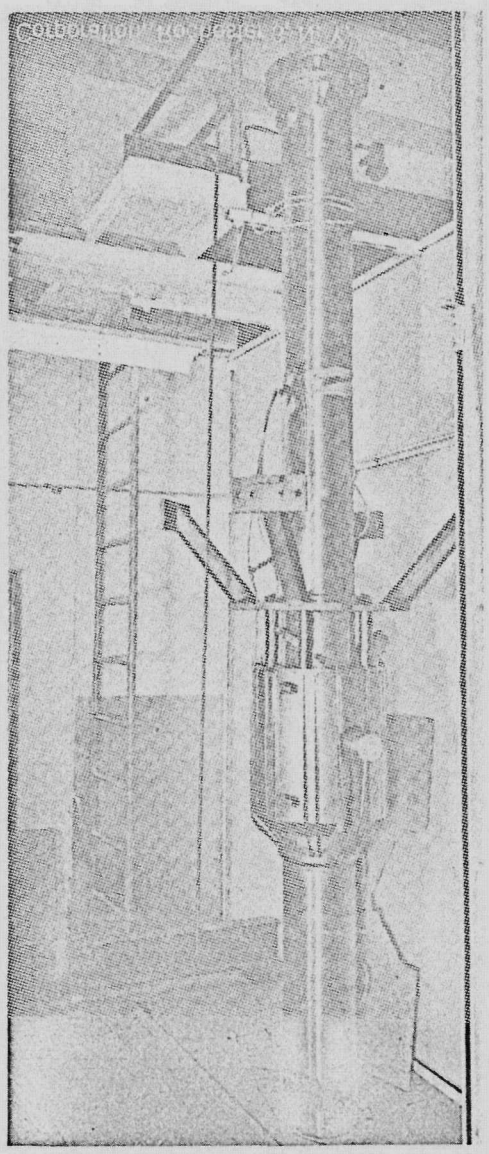

Fig. 2. LAMPRE Reactor Vessel.

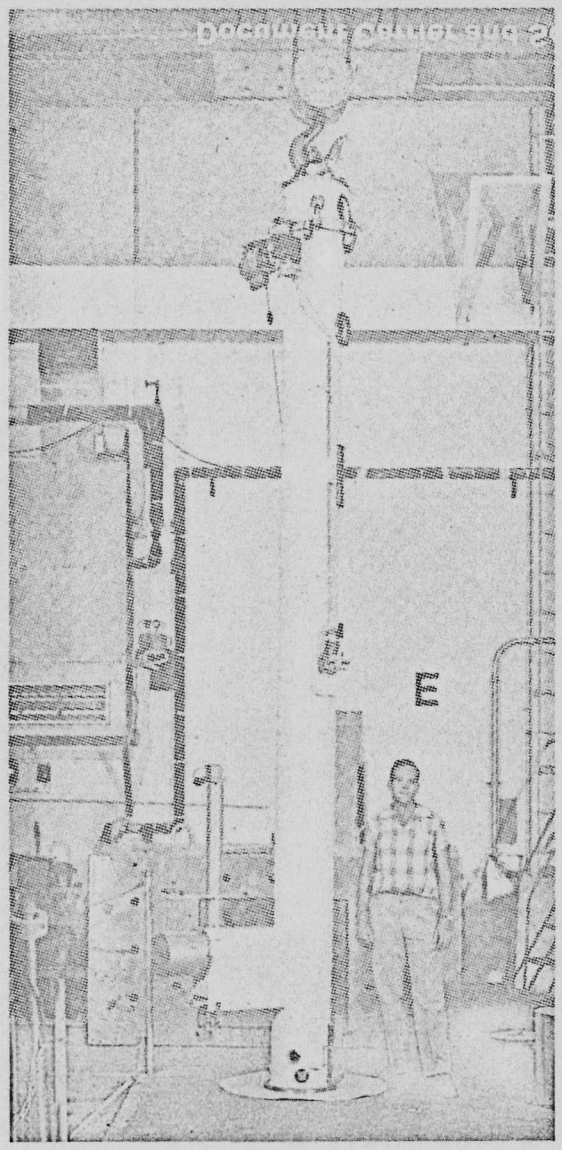

Fig. 3. LAMPRE Fuel Transfer Machine. (A helium atmosphere was maintained at all times in the machine.)

the reactor and to final disassembly of the system.

COOLANT PURITY

It was known that the tantalum fuel container in the LAMPRE core would not be tolerant of large concentrations of oxygen in the sodium coolant. When the reactor was being designed, it had not been established what the threshold level of unacceptable oxide content was, but there was evidence that cold-trapped sodium would not be satisfactory for use with tantalum. On the other hand, laboratory experiments showed that circulating the sodium through a hot trap filled with zirconium foil and operated at 650°C to 700°C provided adequate coolant purity so that corrosion of the tantalum by the sodium was no problem. The LAMPRE system was therefore equipped with three such hot traps installed on a bypass section of the sodium loop. Each trap contained 5.5 lb of zirconium metal in the form of 0.007 in. thick foil. (The coolant loop contained about 350 lb of sodium; the ratio of the foil area to sodium volume was 10 ft^{-1}.) Circulation of sodium through the hot traps was originally produced by a small auxiliary electromagnetic pump; this failed early in the game because of unsuitable construction, but the main loop Δp produced approximately 1% bypass flow through the hot traps.

Reactor grade sodium was initially

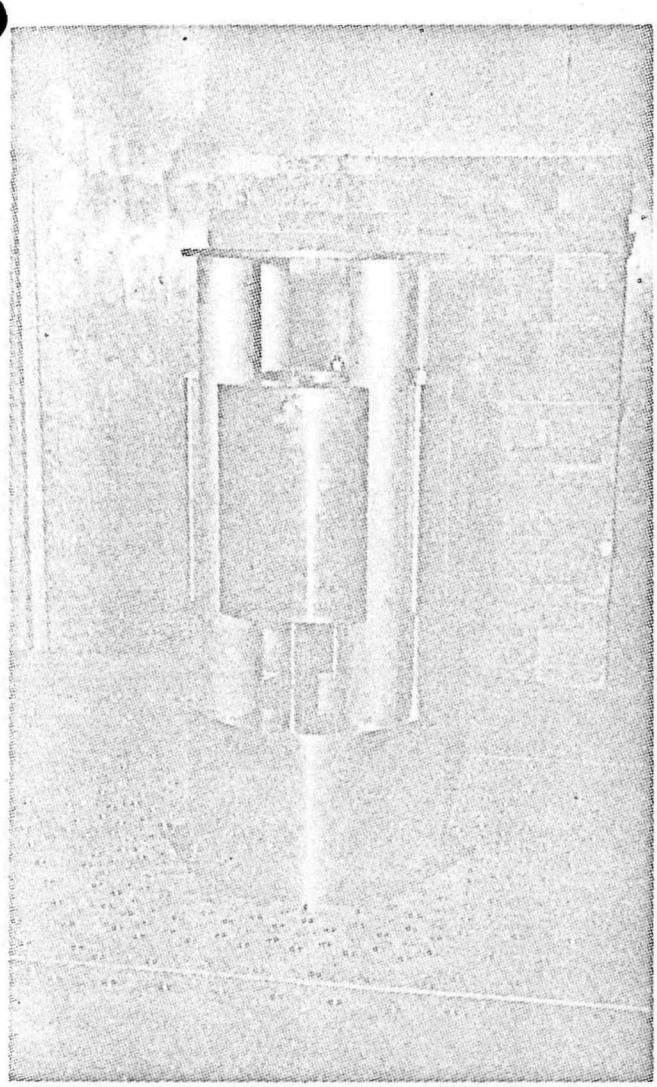

Fig. 4. LAMPRE Reflector Assembly. (Reactivity control for LAMPRE was provided by movable neutron reflector segments, outside of the reactor vessel. The vessel had not been installed when this photo was made.)

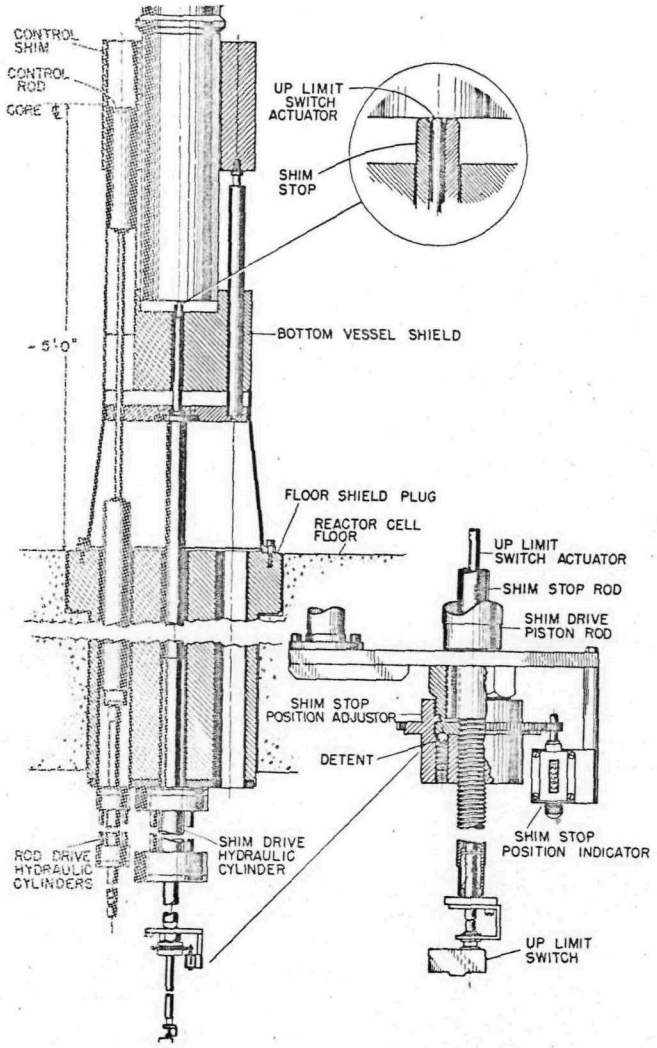

Fig. 5. LAMPRE Control Elements and Associated Hydraulic Cylinders for Actuation.

charged to the system dump tank, which had both a cold trap and plugging indicator. Plugging temperature in the dump tank circuit was 110°C when the sodium was admitted to the main loop. (The main loop had been evacuated and baked at 350°C for 8 days.) After 5 days' circulation in the main loop, the sodium was returned to the dump tank for additional cleanup; the plugging temperature at this time was ~115°C. When this cycle had been completed, the sodium was returned to the loop in preparation for loading the Core I into the reactor. No further cold trapping was performed on the main sodium charge, but the dump tank circuit was continuously cold trapped during the 3-1/2 years that the coolant loop operated. There were small interchanges of sodium between the tank and the main loop during this time because of leakage across a defective valve seat.

Prior to loading Core I, one of the three hot traps was cut off the line and the zirconium foil was examined. Only the foil at the inlet end of the trap (about 10% of the total) showed evidence of oxidation. The remaining hot traps were removed when the reactor was disassembled. Analysis of the foil from these has not yet been completed.

It appears that sodium purity was adequate for compatibility with the tantalum capsules throughout the experiment. The evidence for this is that:

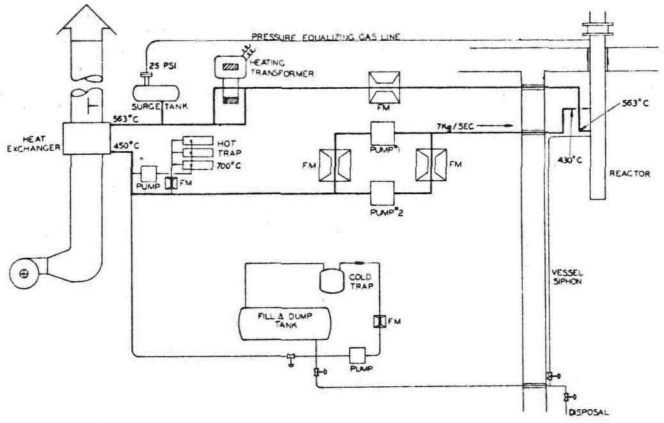

Fig. 6. Schematic Diagram of the Single-loop LAMPRE Coolant System.

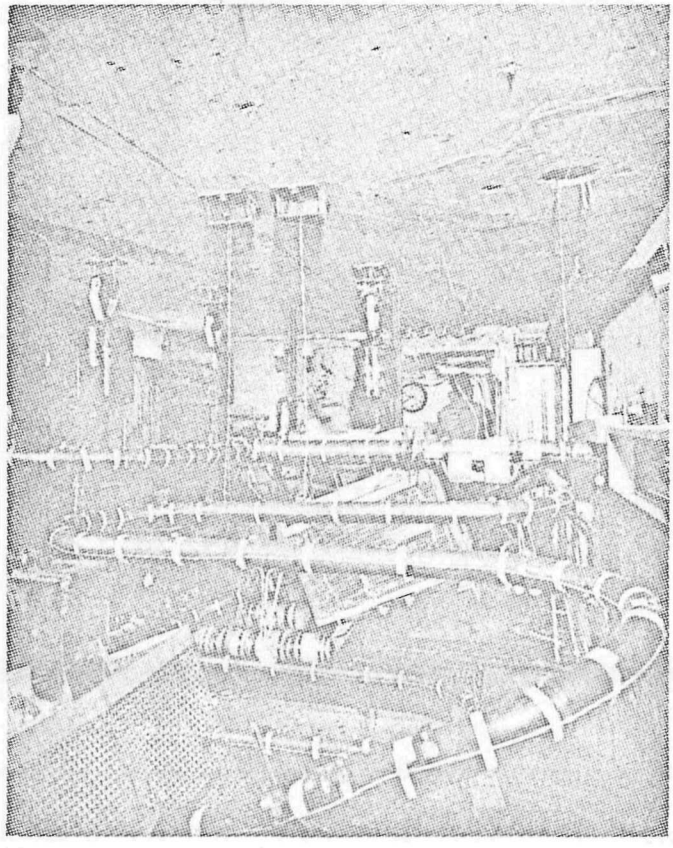

Fig. 7. Part of the LAMPRE Cooling System During Installation.

1. There appeared to be no chemical attack of the tantalum.

2. The observed increase in hardness of the tantalum fuel containers seems to be only that attributable to neutron irradiation, and not to oxygen pickup.

3. Metallurgical examination of irradiated fuel capsules did not show the presence of "oxide platelets" (except for those occasionally found in weld areas; these were assumed to have been introduced during capsule fabrication).

On the basis of this experience, it seems that maintaining adequate sodium purity to permit the use of refractory metal fuel cladding is feasible even in systems much larger than LAMPRE. A more conclusive statement could be made if there had been regular monitoring of the oxide content in the LAMPRE coolant. Techniques for on-stream oxygen analysis at the 0.1 ppm level were not available during the LAMPRE program, nor are they at the present time. But now, at least, there is additional information on the parameters which determine the effectiveness of hot traps; and it appears that a hot trap with a specified life, capable of maintaining a given sodium purity in a particular coolant loop, can be designed according to established rules. This technology may be applicable to special problems (as in the closed loops planned for FFTF) though it does not appear to be needed for the presently proposed fast breeder designs.

NITROGEN IN THE HELIUM COVER GAS

A gradual buildup of nitrogen in the reactor cover gas system was observed soon after the coolant loop had been filled with sodium. This was disturbing for two reasons. First, it might indicate that air was coming into the system through a previously undetected leak: this would eventually exhaust the hot traps' capability to maintain a low oxygen concentration in the sodium. Second, there was concern that nitrogen might be transferred to tantalum components in the core and cause them to become brittle.

Extensive testing failed to reveal any air leak in the system. Chemical analysis of potting compounds and insulation used on thermocouple wire inside the vessel indicated that they contained no significant source of nitrogen. The possibility that N_2 was diffusing through the walls of the hot traps (whose nominal temperature was 675°C) was initially discounted when it was found that nitrogen entered the system at the same rate after the hot traps were cooled to 475°C.

TABLE I

CHRONOLOGY OF LAMPRE PROGRAM

R & D	Fuel & Container Studies (Laboratory Loops)	1957 - 1964
	Mockup Critical Experiments	1957 - 1959
Core I Operations (0 - 400 kW)	Warm, Wet Critical	Feb. 1961
	Hot, Wet Critical	March 1961
	Core Unloaded	Jan. 1962
Core II Operations (0 - 1000 kW)	Hot, Wet Critical	April 1962
	Operations Terminated	July 1963
	Core Unloaded	April 1964
Disassembly	Core, Coolant Loop & Auxiliary Systems	1964, 1965

After a more careful analysis of the data on the buildup of the nitrogen concentration as a function of time and temperature, a plausible explanation for the observations was found: Nitrogen was, despite the initial conclusions to the contrary, entering the system by diffusion through all parts of the coolant loop. The relative areas, thicknesses, and temperature of all the coolant loop components were such that several of them contributed substantially to the total N_2 inflow to the loop. A major change in the total rate of N_2 buildup had therefore not been produced by varying the temperature of the hot traps alone. In subsequent experiments it was determined that the permeation rates of N_2 were approximately 20 ± 10 and 7 ± 4 ppm N_2/h at nominal system temperatures of 475°C and 380°C, respectively. Calculated rates, using permeability coefficients for N_2 through iron, (because no data for stainless steel were found) were in reasonable agreement with the measured values.

An average N_2 concentration of ~300 ppm was maintained throughout the life of the reactor by purging the helium-filled cover gas system when the N_2 level had built up to ~600 ppm. Whether this was a useful or an unnecessary precaution has not been determined.

It appears, at least on the basis of the LAMPRE experience, that nitrogen will be a normal component of the cover gas in similar high temperature systems. In any specific case, however, the possibility that it is entering as air probably cannot be ruled out definitely unless on-line equipment for oxygen analysis is available on the sodium system.

RELEASE OF FISSION PRODUCTS AND FUEL INTO THE REACTOR COOLANT

Fission products and about 160 g of fuel were released into the reactor coolant during the course of LAMPRE operations. This leakage resulted from the penetration (on three occasions) of the fuel capsules by the liquid plutonium fuel.

The initial contamination of the coolant loop occurred after physics measurements and plant shakedown had been completed, and operation at design power with a high plant factor was becoming a reality. After replacing the defective fuel capsule (and those adjacent to it in the core) operation of the reactor was resumed. The emphasis continued to be on achieving as much burnup as possible; consequently, diagnostic measurements which might have provided definitive quantitative information on the fate of fission products in sodium-cooled reactor systems took second priority to keeping the reactor on line. Nevertheless, certain observations were made on the behavior of the system. Some of these are described below.

The reactor system was equipped with radiation detection equipment which monitored a portion of the cover gas volume for the presence of fission products. This equipment

(shown schematically in Figure 8) was located at about the mid-point of a 30 ft long, 3 in. diameter pipe which interconnected the gas volume in the reactor vessel with that in the surge tank. Except when substantial changes were being made in the sodium flow rate, there was no pressure differential available to force gas through this line. The detector, therefore, probably did not give a quantitative measure of the amount of fission products actually released to the cover gas, nor could it indicate the time dependence of the release with precision.

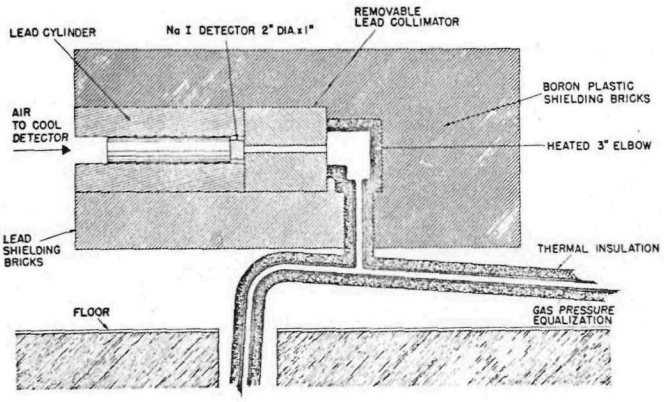

Fig. 8. Fission Product Detector on the LAMPRE Cover Gas System.

At the time of the first release of fuel and fission products, it was calculated that the pressure of fission gases in the fuel capsule was about 145 psi. About 90 g of fuel jetted from the capsule in a few seconds (as indicated by the reactor power record), but the cover gas monitor gave no indication above background until approximately a half hour after the fuel release.

Some months after this first release of fuel, a second and third such event occurred; pressures in the fuel capsules in these cases were estimated to be 370 psi. Figure 9 shows the response of the cover gas monitor to the second release of fission products. The signal was readily detected even in the presence of the background produced by the unencapsulated fuel present in the core region as a result of the first fuel release several months earlier.

Attempts to identify the fission products in the cover gas were not extensive. ^{133}Xe was found in one sample of gas obtained some time after the first release of fission

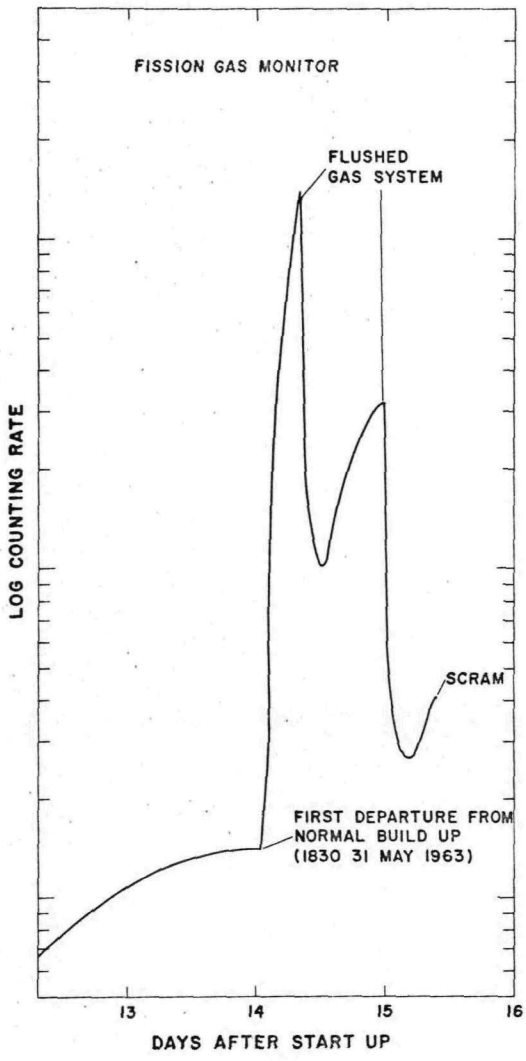

Fig. 9. Response of the LAMPRE Fission Product Monitor to Release of Fission Products in the Reactor Core.

products from the core; it appears to have producted an initial activity of approximately 5×10^6 dpm/cc in the cover gas. Both ^{133}Xe and ^{135}Xe had previously been identified by gamma-ray scanning of exposed portions of the cover gas plumbing.*

*Also, ^{41}A was observed in the high purity helium cover gas. The concentration was several times that which could be accounted for by neutron capture in the ^{40}A present in the cover gas. Calculation indicates that in the high energy neutron spectrum, an (n,p) reaction with the 200 ppm of ^{40}K present in the coolant would produce radioactive argon in an amount approximately equal to that found.

The configuration and location of the coolant loop made it impractical to examine the spatial distribution of fission products in the loop as a function of time after the release of fission products and fuel from the core. However, it was possible to obtain specimens of coolant using the fuel transfer machine to insert and remove small sampling devices. The sodium so obtained was analyzed for fission products by a combination of gamma-ray scanning and radiochemical techniques. The amounts of plutonium and tantalum present were also determined by use of an arc spectrograph or by counting methods.

Initially, when sodium was obtained by lowering a sampler through the stagnant top surface of the coolant in the reactor vessel, no consistent analyses were obtained. Subsequently, a sampler that extracted a sample of flowing sodium from the core was devised. Specimens obtained in this fashion did yield consistent analytical results.

Table II lists the radionuclides and elements which were identified as present in sodium samples taken from the reactor core during the post-fuel release period of reactor operations.

Prior to disassembly of LAMPRE, a limited investigation was made of the spatial distribution of fission products in the system. In this study, the surge tank and a few fuel capsule handles were scanned with a

TABLE II

FISSION PRODUCTS, OTHER RADIONUCLIDES, AND ELEMENTS IDENTIFIED IN LAMPRE SODIUM SAMPLES

Species	Origin	Approximate Concentration or Activity
$^{239,240}Pu$	Released fuel	<1 ppm
^{24}Na	$^{23}Na(n,\gamma)^{24}Na$	--
^{22}Na	$^{23}Na(n,2n)^{22}Na$*	≃ ½ μc/cc Na
^{51}Cr	$^{50}Cr(n,\gamma)^{51}Cr$	--
^{58}Co	$^{58}Ni(n,p)^{58}Co$	--
^{54}Mn	$^{54}Fe(n,p)^{54}Mn$	--
^{182}Ta	$^{181}Ta(n,\gamma)^{182}Ta$	**
^{136}Cs	Fission product	0.01 - 10 μc/cc Na
^{137}Cs	" "	
^{140}La	" "	
^{127m}Te	" "	
^{129m}Te	" "	
^{131}Te	" "	
^{132}Te	" "	
Fe	From coolant loop material	5 - 20 ppm
Ni	" "	<5
Cr	" "	<1

*On the basis of the observed ^{22}Na activity, it was estimated that the cross section for this reaction in the LAMPRE neutron spectrum was 6×10^{-6} times the effective fission cross section for plutonium fission in the core, or approximately 10^{-5} barns.

**The observed ^{182}Ta activity in the sodium samples corresponds to a concentration of approximately 0.8 ppm tantalum by weight.

gamma-ray spectrometer. ^{136}Cs was found on the walls of the surge tank above the sodium level. A qualitative estimate of its concentration could not be made on the basis of the scanning data, but a general radiation survey of the loop indicated that the fission product activity in the surge tank was 30 to 50 times the general level in other parts of the loop. The results obtained from a scan of fuel capsule handles is shown in Figure 10. The peak of the ^{137}Cs distribution occurred at the approximate level of the surface of stagnant sodium in the reactor vessel; normal temperature at this point was about 200°C.

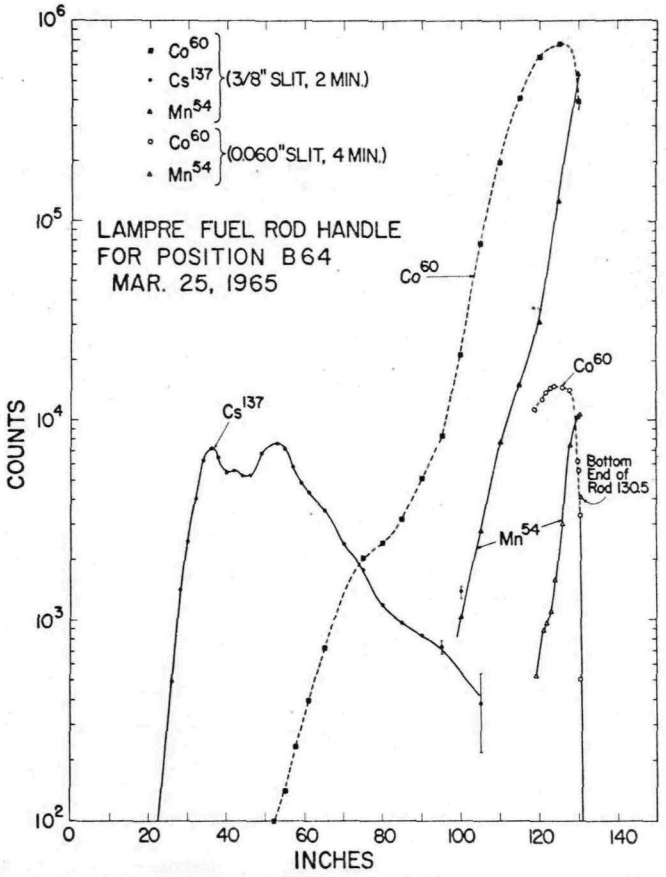

Fig. 10. Fission Product (and neutron induced) Radioactivity on a Typical Fuel Capsule Handle from LAMPRE. (The top of the handle is at the zero inch position; normal level of the sodium coolant was at approximately the 25 in. position.)

The observed pattern of cesium concentration is consistent with that seen more recently in laboratory loops containing irradiated liquid plutonium alloys in direct contact with circulating sodium. The role of the xenon precursor in the transport of ^{137}Cs was not established in LAMPRE, since it was not possible to measure ^{137}Cs and ^{136}Cs ratios. But the experience in the laboratory, plus the identification of ^{136}Cs in the reactor surge tank, shows that there is direct transport of this fission product by sodium.

Some additional information on fission product distribution was obtained during the disassembly of LAMPRE. At that time, a suitably processed sample of sodium from one of the hot traps was beta-counted. The total activity was approximately 2.5×10^5 dpm/g of sodium; the beta radiations were tentatively identified as those of ^{90}Sr and ^{106}Ru. No alpha particles were detected in this sample.

Later, a 3 cm x 3 cm specimen was cut from the stainless steel wall of a hot trap. It was cleaned of sodium and examined for alpha, beta, and gamma activity. The gamma spectrum showed peaks corresponding to those from ^{106}Ru and also from ^{54}Mn and ^{182}Ta. A measurement of the beta particle end point energy supported the identification of ^{106}Ru. There was no ^{90}Sr reported. The observed counting rate from alpha-particles on this specimen was about 10^3 dpm/cm^2 of surface, but the activity was not swipeable.

Though the plutonium contamination which was transported to parts of the coolant loop appeared to be low level, substantial amounts of fuel were deposited on components in the reactor vessel. Readily visible quantities of fuel alloy were observed on fuel capsules adjacent to those from which fuel was released, as well as on some capsule handles. The presence of this contamination did not affect routine operations (such as fuel handling) in any major way, however, because all fueling equipment had been designed to provide complete containment of irradiated fuel capsules at all handling stages. The equipment was such that it not only minimized the possibility of releasing plutonium in the operating area, but more important, it would accommodate the accumulated gaseous fission products (stored at high pressure in the upper section of the fuel capsules) in the event of a fracture of the capsules during fuel transfer manipulations. Occasionally small amounts of plutonium contamination were found on accessible interfaces between fuel transfer components, but these were readily decontaminated by techniques accepted as routine in any facility which handles plutonium. No release of gaseous fission products to the reactor operating area was ever observed.

Fission products (from sodium which

dripped off fuel capsules during transfer operations) accumulated on some parts of the fuel handling equipment. Some fuel alloy was also deposited on the fuel transfer gear from the contaminated surfaces of the fuel capsules and their handles. No operational problems resulted, however; in the few cases where repairs to the fuel transfer machine were required, straightforward techniques, using temporarily installed plastic "glove bags," provided satisfactory containment of all contamination.

A simple extrapolation of the LAMPRE experience with fission products and metallic plutonium in the coolant loop to large systems and other fuels may not be justified. But to some extent, the observations and conclusions summarized below may be valid for many cases:

1. Detection of fission products in the cover gas can be a reliable indication of fuel element failure, but to be quantitative and to establish time of failure with precision, circulation of the cover gas may be required. The detection equipment should be capable of identifying specific fission products; a 400 to 4000 channel pulse height analyzer in conjunction with a suitable detector would seem to be the ideal arrangement. There should be provisions for recording the gamma-ray spectrum of radioactive components in the cover gas as a function of time, since relative abundances of the fission products observed may be useful in diagnosing the kind or sequence of failures.

2. If fission products are released, there will probably be localized deposition of ^{137}Cs on the loop walls in the coolant cover gas region. Whether this selective concentration is a help or a hindrance as far as loop maintenance is concerned will depend on the details of the reactor system. Laboratory experiments (8-9) have shown that such deposits can be (a) removed by flushing with sodium, and (b) redeposited in cold traps elsewhere in the loop.

3. The presence of plutonium in the coolant loop does not necessarily require any special techniques for fuel handling and system maintenance; those which would be accepted as good practice in the case of systems contaminated with fission products are probably adequate. Furthermore, in systems which contain liquid sodium, or solidified deposits of sodium vapor, the bagging techniques which would be appropriate to prevent sodium oxidation during maintenance work will be little different than those required for plutonium containment.

EXPERIENCE WITH SYSTEM COMPONENTS

Fuel Transfer Equipment and Operation

Fuel transfer equipment, though it is in a sense only auxiliary equipment for a reactor, has often been a source of unpleasant operating experience. This is probably because such equipment is generally complicated, and is expected to perform mechanically precise operations in a hostile environment whose components may be dry inert gas, sodium (either liquid or vapor), high temperatures, and intense radiation fields. The requirements on the LAMPRE fuel transfer equipment (Figure 11) were not as stringent as those typical of larger systems; perhaps for this reason, it operated in a generally successful manner throughout the experiment. Some features of its design and comments on fuel handling experiences are discussed below.

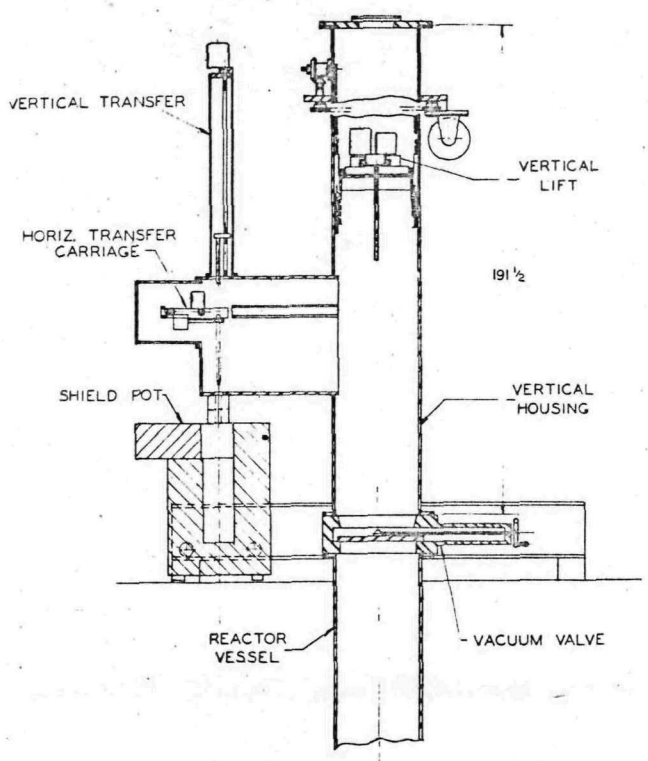

Fig. 11. LAMPRE Fuel Transfer Machine.

Because the fuel capsule handles extended above the sodium level in the reactor vessel, visual monitoring (with periscopes) of much of the fuel transfer operation was

possible. The need for precise, reproducible positioning of units such as the capsule handle grabber was therefore avoided to some extent. Position readout was provided for most moving parts of the fuel transfer mechanism, but verification that the proper coordinates had been selected, and that full engagement of parts had occurred was made in most cases by visual inspection. For some of the motions, the combined use of position readout and fixed mechanical stops to limit travel was deemed adequate. For a third class of operation, where neither position readout nor viewing was feasible, manually operated devices which allowed the operators some "feel," were used.

The main component of the fuel transfer machine was the vertical lift ("r,θ carriage") which moved along the length of the transfer machine housing. This device carried the capsule handle grabber; it was equipped with suitable gears and motors so that the grabber could be positioned at r,θ coordinates corresponding to the location of a specific fuel capsule handle. Engagement of the grabber to the capsule handle was done with a simple spring-loaded bayonet-type coupling. The vertical lift was supported by three loops of roller chain which ran on sprockets located at the top and bottom of the transfer machine housing. Sprocket shafts extended through the housing in O-ring seals. This permitted the shaft bearings, and the power source for the vertical lift, to be located outside of the housing; they were therefore accessible for maintenance, and their lubricants could not contaminate the reactor cover gas. The shaft seals were lubricated with a proprietary vacuum grease; they functioned satisfactorily without maintenance during the four-years in which the transfer mechanism was used.

Roller chains were degreased before installation. They gave no trouble, even in the dry helium atmosphere, probably because they operated at light loadings (<25 lb/chain)* and slow speeds (15 to 30 ft/min). The small ball screws in the transfer unit also operated satisfactorily without lubrication; they too were loaded very lightly.

Power for driving the vertical lift was supplied by an electrically driven hydraulic transmission consisting of an axial piston, positive displacement, variable delivery pump, and a hydraulic motor. This arrangement provided stepless speed control in either direction and also made it possible to preset (by means of a pressure regulator) the maximum force which could be applied by the vertical lift. The equipment operated satisfactorily for four years and required no maintenance during that period.

The r,θ motions in the vertical lift unit were powered by small motors of the type used for pen drives in self-balancing potentiometric recorders. Prior to installation, the motors were disassembled, degreased, and sparingly relubricated with vacuum pump oil. These low-priced motors were quite satisfactory, even when used intermittently at voltages substantially above their normal rating. One motor failed during the four year life of the transfer mechanism; this was apparently because of excessive use of high voltage to increase its torque.

Minor electrical troubles caused by arcing occurred in the transfer mechanism when circuits were energized while the mechanism housing was evacuated. Potting of the terminal strips (with proprietary silicone-base sealant) eliminated the problem.

Electrical power to motors on the vertical lift was provided via wires spooled on a proprietary cable reel in which the use of slip rings was avoided by a double-wrapped cable configuration. This device functioned satisfactorily until conductors failed because of fatigue from flexing. The cable unit was repaired once, and then replaced, during the life of the reactor.

LAMPRE fuel capsules were attached to their handles by a threaded connection. This method was selected because it seemed that its simplicity might more than offset the possibility of thread galling and subsequent seizure. In practice, it was reasonably successful. The mating components were 304 stainless steel; thread dimensions were carefully specified.* The threads of each fuel capsule were inspected just prior to installation in the reactor. Precise torque control at assembly was not possible, because there was no capability for torque measurement in the fuel transfer mechanism. As an alternative, the operator judged, by observation of the operation, when the shoulders on the threaded pieces made contact. During the removal of Core I and Core II, about 1% of the fuel capsules could not be removed with the back-off torque (nominally 110 to 120 lb/in.) produced by the transfer mechanism. Auxiliary, manually operated mechanisms, which permitted the application of

*The strength at the lift was adequate to provide a fuel assembly withdrawal force of 1000 lbs.

*The handle had a class 3B 5/16-18 thread. The major diameter of the male thread on the capsule was set at 0.300 ± 0.001 in. Pitch diameter was held to the range 0.2712 - 0.2734 in. Assembly clearance of the two parts was therefore 0.004 - 0.009 in.

larger torque, were used in the case of these few capsules. They were removed by back-off torque only 5-10% greater than that normally available.

The fuel transfer equipment was, except while actually in use, isolated from the reactor by a large valve. Because of this, and also because the temperature of the small amounts of sodium near the top of the reactor vessel was <125°C, only minor amounts of sodium vapor were deposited on the fuel transfer mechanisms. This did not interfere with their operation.

Control Elements

The only significant mechanical malfunction in the LAMPRE system was the binding of the large annular control element, or "shim" (Figures 4 and 5). This element, which had a reactivity worth of approximately $26, was initially the only one of the five control devices which could be scrammed. Near the end of Core I operations, it was observed that the scram time had increased substantially above its normal value of 0.9 sec. After considerable investigation, the general nature of the trouble was determined, and ways of eliminating it were devised. Though the details of this problem were unique to the LAMPRE system, reference to them may lead to observations of general applicability.

It was discovered that the binding of the shim was a function of reactor power, which established the average temperature and the temperature gradients in the control element assembly and also in the air-cooled graphite shielding surrounding the control shim. But it was not possible to establish in detail what component(s) of the control element structure was actually making contact with other stationary parts of the reactor system. Several unfortunate circumstances contributed to this inability to make a detailed diagnosis:

1. Neither the temperature of the control element, nor the ambient temperature in the control element channel, could be measured directly; the conditions under which binding occurred therefore could not be precisely defined.

2. As-built dimensions of the complete set of control element components had never been determined, though it was known that, except for noted deviations, all pieces were "within tolerance." A similar situation existed with respect to the reactor vessel, and to the diameter of the air flow channel surrounding the control element.

3. No parts of the control system (except the drive units, which clearly were not the source of the trouble) were observable by any direct means.

4. The shim could not be removed for inspection without first dismantling the reactor vessel.

An obvious solution to the problem was to somehow regulate the temperature of the shim unit so that binding would not occur regardless of the reactor power and temperature. It also seemed best to move the scram function from this part of the control system to the four control rods, and to operate the shim in a powered "rundown" mode so that continuing malfunctions might be detected by more sensitive means than by measuring scram time.

A capability to regulate the shim temperature was achieved by installing, in the cooling air plenum directly below the reactor vessel, an adjustable baffle which could be used to vary the portion of the shield cooling air which passed through the control shim channel. This was a tedious task because the only available personnel access to this space was through a small air duct. Also, the radiation field under the reactor vessel was intense enough to require that the work be split among several people in order to keep individual radiation doses at a reasonable level.

A deacceleration, or snubbing, capability already existed in all five hydraulic circuits of the control system; the addition of the scram function to the rod drives therefore required only simple changes in the piping and control wiring which were accomplished without difficulty.

Control Element Drives

LAMPRE control element drives have been described in detail previously (6). These simple hydraulic units were completely satisfactory in operation. The only maintenance required during a four year period was the replacement of a few elastomer valve seats, and bleeding the oil circuit to eliminate air apparently entrained in the oil reservoir.

Heating System for the Sodium Loop

The LAMPRE coolant loop was equipped with two systems for keeping the sodium hot when the reactor was not producing power. One was a conventional arrangement of resistance heaters on the sodium piping. A second source of heat was supplied by a transformer unit in

which a portion of the loop served as the single-turn secondary winding of the transformer (Figure 6). Currents of up to 8500 amperes were produced in the sodium loop; more than 85% of the power (35 Kva) was developed in the flowing sodium. This method was effective and reliable. It is most likely not applicable to the large diameter piping system anticipated in big LMFBRs; but where space is limited, and power input must be high, this method of loop heating seems to be an excellent one. It might therefore be useful for auxiliary sodium circuits on large systems, or for cases such as in-pile sodium test loops. The only obvious disadvantage is that electrical noise may be developed in thermocouple circuits attached to the piping.

DISASSEMBLY OF THE REACTOR

About a year after the end of the LAMPRE operation, some parts of the reactor were dismantled. The general level of beta and gamma radioactivity in the system was by then quite low (observed gamma-ray dose rates were 10-100 mr/hr) and the disassembly required no complicated procedures.

The coolant loop and reactor vessel were first drained of sodium and then filled with helium. Sections of piping were cut using hack saws or power operated cut-off saws. Initially, these cuts were made with the equipment inside special flexible plastic "glove bags" installed around the piping at the site of the cut (Figure 12). It was found however, that neither the tools nor the inside of the bag became contaminated to a detectable level, so the use of bagging techniques were discontinued, even in the case of pipes which could not be drained of sodium.

Permanent closures were applied to cut piping by driving tapered aluminum plugs into the pipe bore and welding steel caps over the ends of the pipes. This technique was applicable even for pipes which contained frozen sodium, providing of course that sufficient sodium was removed to permit fitting the plugs.

After all fuel capsules had been removed from the reactor, the fuel transfer machine was uncoupled from the reactor. This operation did require the use of glove bags, (Figure 13) because there was considerable plutonium contamination present on the inner surface of the transfer machine. A cask to contain the fuel capsule handles was subsequently installed on the reactor vessel, and the handles were pulled out of the reactor, and racked in the cask.

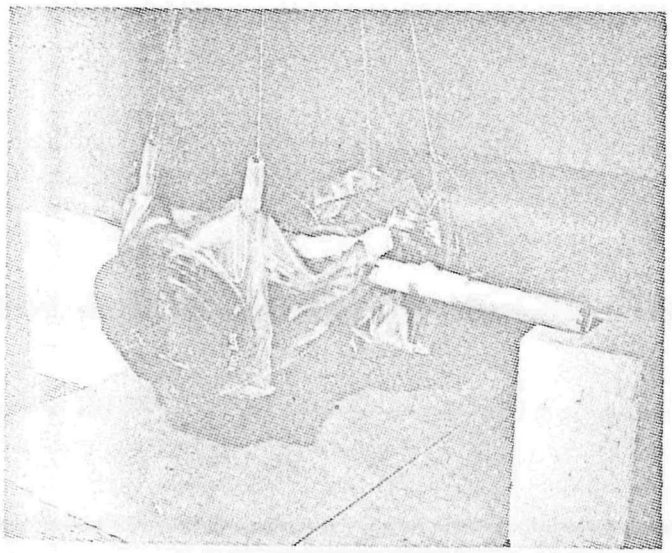

Fig. 12. Typical "Glove Bag" used for Severing Coolant Loop Piping.

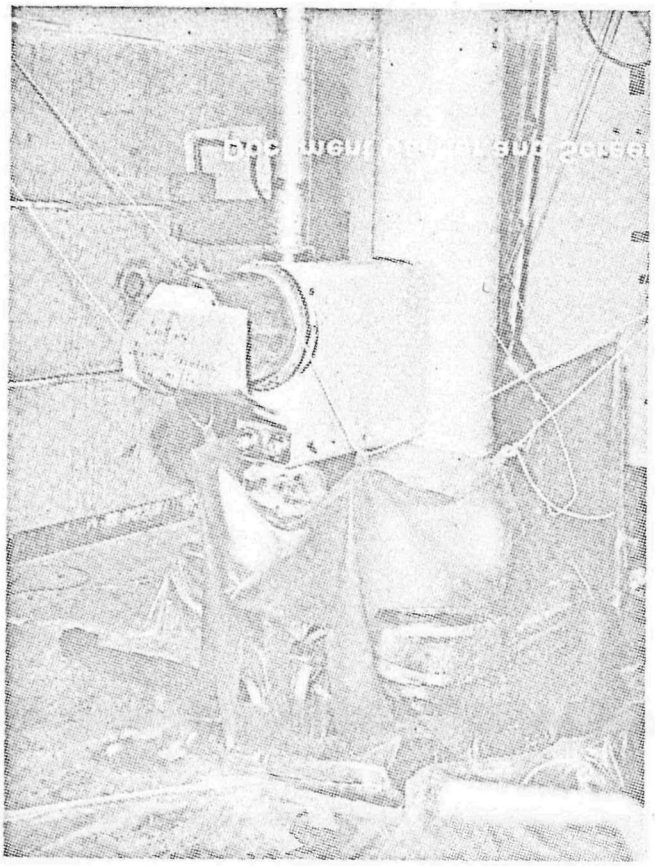

Fig. 13. Bagging Technique Used for Uncoupling the Plutonium and Fission Product Contaminated Fuel Transfer Machine from the Reactor Vessel.
(Glove ports are visible at the lower right.)

When all components of the reactor core had been removed, it was observed that some of the fuel which had been released from the core had been retained on the fuel assembly support plate. No quantitative estimate could be made of the mass of fuel retained on the plate since neither it nor the catch pot below the coolant inlet plenum were removed from the reactor.

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