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PLANS FOR POST-OPERATION EXAMINATION OF THE MOLTEN-SALT REACTOR EXPERIMENT

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ABSTRACT

In December 1969, after more than 4 succ ful years, the nuclear operation of the MSRE was concluded and the plant was placed in standby. Work planned for early in FY-1971 includes removal of some core graphite; viewing inside the reactor vessel and inside the fuel-pump bowl; inspection of portions of the salt piping, the offgas charcoal bed, the coolant salt pump, and the control rods; and testing the coolant salt flowmeter. Each study is justified by its benefit to the Molten-Salt Reactor Program. Procedures and tools are available for some jobs; for others, they are currently being developed.

Keywords: reactors, fused salts, MSRE, operation, inspection, maintenance, remote handling, leaks.

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INTRODUCTION

The primary purpose of the Molten-Salt Reactor Experiment was to demonstrate the practicality of the molten-salt reactor concept. To this end its design[1] incorporated essentially the same materials and many of the design features of proposed molten-salt power reactors. Its primary purpose was accomplished as it was operated for more than 4 years at Oak Ridge National Laboratory. Experience[2] with the MSRE was quite encouraging and a great deal of new information (particularly with regard to fission product behavior) was obtained. In December 1969, the reactor was shut down because its original goals had been met and continued operation, although offering additional information, could not be justified in the very stringent budget situation. Except for removal of an experimental array from the core, all post-operation examination was deferred until the next fiscal year. In the interim the reactor was placed in a standby condition.[3]

GOALS OF POST-OPERATION EXAMINATIONS

The broad goal of the post-operation examinations is to complete the gathering of information from the MSRE by in-place inspection, removal of specimens and some pieces of equipment, and detailed examination of these in hot cells. Specific objectives include determination of the condition of materials with the greatest exposure to the reactor environment, the condition of key equipment (pumps, heaters, insulation), the location and nature of deposits in selected parts of the fuel salt and offgas systems,

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[1]R. C. Robertson, MSRE Design and Operations Report, Part I — Description of Reactor Design, ORNL-TM-728 (January 1965).

[2]P. N. Haubenreich and J. R. Engel, "Experience with the MSRE," Nucl. Appl. Tech. 8, 118 (1970).

[3]P. N. Haubenreich and R. H. Guymon, Plans for the MSRE Between End of Nuclear Operation and Beginning of Post-Operation Examinations, internal memorandum MSR-69-121 (December 1969).

and the exact location and nature of a leak in a salt freeze valve. This information will influence materials development and the design of equipment and systems for future molten-salt reactors.

CRITERIA

The scope of the post-operation studies will be limited to those whose costs are justified by the benefits to the Molten-Salt Reactor Program.

Tentative plans call for holding the radioactive fuel salt (about 360,000 curies of fission products as of July 1970) frozen in the MSRE tanks until such time as salt mine disposal is feasible. The post-operation examinations shall not prevent the ultimate removal of the salt nor leave the system in an unsafe condition in the interim. In addition, to preserve the option of fluorinating the salt for uranium recovery, the operability of the processing facility shall be preserved.

Exposure of personnel to radiation during the post-operation examination shall not exceed normal occupational limits prescribed by ORNL and the USAEC.

STEPS IN DEFINING THE CAMPAIGN

Planning for the post-operation examination, to some extent, began with the design of the reactor, when provisions were made for removing the 5 central bars of core graphite. Final selection of post-operation studies, of course, had to await operating experience and evaluation to point out areas of most interest and other program developments (such as the budget) to determine what could be justified.

In February 1969, the head of the MSRE Operations Department sent a request for suggestions for final operations and shutdown of the MSRE to group leaders in the MSRP. Responses were consolidated to eliminate duplications and in October 1969, a tentative list of post-operation tasks was distributed with a request for comments. This list was discussed with ORNL and AEC-ORO reactor safety review committees and with AEC-DRDT representatives. After discussion and review of the tentative list with MSRP staff members in which benefits were weighed against costs, the program described in the next section was arrived at in March 1970.

STUDIES AND TASKS TO BE UNDERTAKEN

The studies that we propose to make are listed in Table 1. Under each study are listed the separate jobs, some to be done on-site, some in X-10 hot cells, involved in that study. Not shown in the table are the tasks of removing some items for use in development facilities, decontaminating areas outside the containment cells, securing the plant, and disposing of the fuel salt. The justification for and objectives of each study (in the order listed in Table 1) and each task are discussed in the text of this section. Job descriptions, including purposes and general procedures, are presented in the next section.

Table 1

List of Studies to be Made and the Jobs that will be Involved

Investigation of leak near freeze valve FV-105

- View vicinity of FV-105
- Excise FV-105
- Inspect FV-105

Examination of fuel-pump bowl internals

- Excise sampler cage and baffle
- View inside of pump bowl
- Inspect sampler cage and baffle

Examination of reactor vessel internals

- Prepare for core work
- Remove access plug and rod thimbles
- Remove some core graphite
- View core and inside of reactor vessel heads
- Close reactor access
- Cut off piece of rod thimble
- Inspect core graphite bar
- Inspect rod thimble piece

Table 1 (continued)

Examination of fuel piping

- Excise sections of piping at heat exchanger inlet and outlet
- Inspect sections of piping

Inspection of fuel drain line

- Remove heater H-103
- View drain line inside reactor furnace

Examination of charcoal bed inlet

- Excise inlet section of a main charcoal bed
- Inspect inlet section

Examination of radiator tubing

- Excise tubing near inlet and near outlet
- Inspect for deposits and corrosion

Examination of thermocouple wells in coolant salt piping

- Excise wells at radiator inlet and outlet
- Inspect for deposits and integrity

Test of differential pressure system on coolant salt flowmeter

- Cut coolant piping
- Test pressure measuring system

Inspection of coolant pump rotary element

- Remove rotary element
- Inspect

Inspection of control rods

- Examine
- Remove elements
- Inspect elements

Verification of remote maintainability

- Remove and inspect heater units
- Remove fuel pump motor
- Disconnect fuel sampler line

Investigation of Leak Near Freeze Valve FV-105

A leak appeared in the primary system on December 12, 1969 shortly after the scheduled end of nuclear operation. Correlation of changes in cell air activities with certain operations indicated that a small leak had developed in or near freeze valve FV-105 (leading to fuel drain tank FD-2) about two hours after the fuel was drained for the last time. Amounts of xenon and iodine indicated that a few ft^3 of gas and perhaps some salt (1 cc or less) escaped into the cell before the leak was effectively stopped by freezing salt in the line.

This is the only leak that ever occurred in the primary system and the explanation is not known. Examination of radiographs and other construction records showed nothing suspicious. We believe corrosion could not have been a significant factor in the origin of the leak, and radiation damage at this location should be virtually nil. The most likely hypothesis is that thermal stresses in the valve caused a crack to originate at the welded juncture of the cooling-air shroud and the pipe and to propagate through the pipe wall.

We should determine the exact location and description of the leak and, if possible, derive an explanation.

Examination of Surfaces Inside the Fuel-Pump Bowl

During operation of the MSRE, effects related to the salt-gas interface in the fuel-pump bowl were of considerable importance. Bubbler level elements indicated that considerable amounts of gas were carried under the salt surface by the xenon stripper jets. The density profile above the bubblers could not be measured, but the fluid surface was certainly higher because of the gas. There is reason to think that the surface was not quite uniform (being lower inside the sampler baffle, for example). Certain fission products tended to concentrate at salt surfaces, with perhaps some going into the gas space as a "smoke." Oil leaked into the pump bowl from the shaft bearing region at a few cc per day. Some oil decomposition products probably deposited on the pump bowl surfaces and some on the salt where they may have influenced fission product separation and bubble behavior. Thermocouple readings indicated that fission product heating of the pump bowl above the salt level was moderate but changed from time to time for unknown reasons.

A sample capsule was dropped into the pump bowl in August 1967 and another in March 1968. The steel cap of the first capsule was retrieved in May 1968. There was some evidence that the second capsule was jammed between the cage and baffle during recovery attempts.

We should observe surfaces inside the pump bowl for evidence of deposition and the patterns displayed. It appears now that it will probably be practical to cut out a section of the pump bowl top with the sample cage and baffle attached. This would make it possible to determine much more about the deposits and also to inspect for evidence of corrosion. (Conditions in the vicinity of the dissimilar metal junctions in the sample capsule are particularly interesting.) The information will aid in understanding the MSRE behavior and will be useful in evaluating design of off-gas systems for future molten-salt reactors.

Examination of Reactor Vessel Internals

The effect of reactor operation on core materials was monitored by exposure at the center of the core of experimental arrays containing specimens of graphite and Hastelloy-N like those used in the construction of the MSRE. Arrays were removed after 1087, 4510, 9005, 11,555, and 13,172 equivalent full-power hours. Usually the replacement array included some subassemblies with previous exposure, so very long total exposures were accumulated on some specimens before detailed examination and testing. The conditions of the specimens, which were assumed to be typical of the core, never gave any cause for concern over the condition of the core. Although this surveillance program was presumably quite adequate, its validity can be supported by examination of portions of the core graphite and Hastelloy-N exposed from start to end of the MSRE operation.

The condition of Hastelloy-N can be determined by inspection of the removable core access assembly, which includes the control rod thimbles and a plug exposed to the fuel stream in the core exit. After the assembly has been visually inspected in the reactor cell, a portion of a rod thimble can be cut off and examined closely in a hot cell. Metallographic examination of interior surfaces will reveal any effect of the exposure to the cell atmosphere used for cooling. The exterior surface will show effects of very long exposure to the fuel salt. (It will not be practical to shape specimens for physical property testing from the thimbles, but this is unnecessary since irradiation effects were well described by the specimens from the experimental arrays.)

Removal of one of the five central stringers will make available graphite exposed to fuel flowing through channels with a cross section typical of the bulk of the core. Surface appearance and penetration of salt constituents and fission products in regions free of flaws should be compared with results from the experimental arrays.

There was no detectable evidence of any physical damage to the core during operation, nor did thermocouple readings on the lower head and near the core support flange indicate any substantial accumulation of sediment. Nevertheless, a look will be worthwhile. An optical device and light can be used to view and photograph the top of the core and the upper head of the reactor vessel, the lower grid structure, the bottom head, and the drain line inlet. If loose fragments, broken graphite, sediment or other deposits are discovered, they should be examined as closely as is practical.

Examination of Fuel Piping

The MSRE operated for 13,172 equivalent full-power hours with a temperature difference of 40°F between the fuel entering and leaving the heat exchanger. Close examination and comparison of Hastelloy-N surfaces exposed to fuel at the extremes of the temperature range will provide information on corrosion and mass transport under the reactor conditions. Short sections of the 5-inch pipe near the heat exchanger inlet and between the heat exchanger and the reactor vessel should be cut out and examined metallographically for this purpose.

Inspection of Fuel Drain Line

The juncture of the fuel drain line with the reactor vessel was subjected to a combination of stress and irradiation about as severe as any in the reactor. Removal of this section is not practical, but it can be viewed from a distance by removal of heater H-103 and insertion of viewing devices in its place inside the reactor furnace. The juncture, the drain line, and the exterior of the insulation box around the drain valve should be scrutinized for any evidence of incipient trouble.

Examination of Charcoal Bed Inlet

During the initial escalation of the MSRE power in 1966, plugging occurred at several points in the fuel offgas system, including the inlets of the charcoal beds. Even after the installation of an efficient filter (the "particle trap"), plugging recurred at the charcoal bed inlets. This was believed to be due to polymerization of oil vapors downstream of the filter and accumulation of the polymers on the steel wool in the entrances of the beds. This could not be verified directly, but the restrictions could be cleared temporarily by lowering the cooling water level around the beds and applying heat to the inlet section. There was concern over possible reduction of the adsorptive capacity of the charcoal by the oil residues but no change was detectable from the few thermocouples spaced at 80-ft intervals in the bed. A short section of the inlet to one section of the beds should be cut out and the explanation for the recurrent plugging verified. A sample of charcoal from the inlet should be tested and if its adsorptive capacity is seriously reduced, samples should be obtained from further along the bed to determine the extent of the effect.

Examination of Radiator Tubing

The chromium concentration of the coolant salt remained very low through the entire operation, indicating that corrosion was extremely low or that corrosion-product chromium was being deposited. There were no corrosion surveillance specimens in the coolant system. Sections of the 3/4-inch tubing should be cut from the radiator near the inlet and outlet ends and examined for information on corrosion in the coolant system.

Examination of Thermocouple Wells in Coolant Piping

Because of the desire to eliminate, insofar as possible, conceivable sources of trouble, the MSRE design included only 2 thermocouple wells in salt piping: one each at the inlet and outlet of the radiator. The pipe with these wells should be cut out and sectioned and a careful inspection made to see if the wells suffered any unusual corrosion. The possibility of deposition on what were to some extent "cold fingers" should also be investigated.

Test of d/p System on Coolant Salt Flowmeter

There is a significant discrepancy between the reactor power that was indicated by the system heat balance and the power indicated by observed changes in isotopic ratios of uranium and plutonium in the fuel. The latter indicated up to 10 percent lower power than the heat balance. The possible reasons for the discrepancy have been checked one by one until now only the coolant salt flow rate has not been verified as thoroughly as possible. This must be done. The ultimate test will consist of cutting the salt lines near the venturi flowmeter and applying signals to test the entire transmitting and modifying system.

Inspection of Coolant-Pump Rotary Element

The salt pumps are key components in a molten-salt reactor. Except for the small amount of oil leakage (about 2 - 5 cc/day) into the pump bowls, there was no problem with either the coolant-salt or fuel-salt pump in the MSRE. The problems due to oil leakage were not serious enough to warrant replacing the original units with seal-welded replacement rotary elements that would have had no oil leakage into the bowl. As a result, the original units served for the entire duration of the operation. An inspection should be made to determine the condition of the pumps and to permit some judgement as to remaining service life. The fuel and coolant rotary elements are essentially the same, but the coolant pump operated considerably longer, pumping salt for 26,076 hr compared to 21,788 hr for the fuel pump. Since the coolant pump rotary element is also nonradioactive and more accessible, it should be removed and thoroughly inspected.

Inspection of Control Rods

The control rods in the MSRE, of a unique, flexible design, on the whole performed well. There were gradual changes in drop times, however, that were attributed in part to changes in the flexibility of the rods with long exposure and use. On occasion, rods were pulled out of the thimbles and viewed from a distance in the reactor cell for evidence of unusual scratches or dragging. (None was found.) It was not possible to inspect the internals of the rod or to ascribe a reason for changes in flexibility.

The rods must be pulled to gain access to the core and at that time the active section of one should be removed for examination in a hot cell. The Inconel-canned Al_2O_3-GdO_3 ceramic poison elements should be checked for dimensional changes and the flexible metal hose and rod should be closely inspected.

Verification of Remote Maintainability

An important goal of the MSRE was to demonstrate that maintenance of the molten-salt reactor, with its highly radioactive fuel circulation system, was in fact practical. To this end, the radioactive portions, including virtually everything in the reactor cell, were designed to be replaceable. Replacement of core specimens, work on the offgas system, replacement of air-line disconnects, and repair of the fuel sampler-enricher and in-cell heater units demonstrated the feasibility of the general approach. Some features were not tested, however, because most of the equipment required no maintenance. It would be worthwhile to try certain of these features. The difficulty of replacing the fuel-pump motor should be determined by removing the old motor or at least loosening several of the flange bolts. The flanged section of the sampler tube, which was designed to be swung out of the way for pump bowl replacement should be removed as intended. (This needs to be done in preparation for cutting into the pump bowl.)

Removal of Coolant Salt Pump Bowl and Piping

It has been proposed that a fluoroborate technology test loop be constructed, using the MSRE coolant pump and other portions of the coolant salt system. Since portions outside the reactor cell are not radioactive, removal would be a straightforward task that can be done when needed. The only consideration is that lines leading into the reactor cell be sealed, since they are penetrations of the containment envelope.

Recovery of MSRE Coolant Salt

Salt for a proposed loop to test gas injection and stripping technology can be prepared most economically by adding ThF_4 and LiF to the MSRE coolant salt. The coolant salt, 2610 kg of LiF-BeF_2 (66 - 34 mole percent), should be melted and removed when required for this purpose. This operation will also test some aspects of techniques that may be used eventually in disposal of the fuel salt.

Decontamination

The spread of radioactivity during the work described above will be controlled by proper ventilation, temporary containment enclosures, the establishment of contamination zones, and other techniques that have been proved in use at the MSRE and elsewhere in ORNL. When necessary during the campaign and at its conclusion, some of the contaminated tools and material will be disposed of and the rest will be decontaminated. Before the task is finished, everything outside the containment will be decontaminated to safe levels.

Securing the Plant

There is currently no demand for the fissile material in the MSRE fuel salt (37 kg U, 84% ^{233}U). Because of the extremely high ^{232}U content (220 ppm) and consequent radiation problems, it is doubtful that the uranium will ever be worth the cost of recovery from the salt. We propose to keep the fuel salt frozen in the MSRE drain tanks, safely contained until developments make it possible to decide on the optimum method of disposal. Meanwhile the option of stripping the uranium by the fluoride volatility process will be retained by preserving the MSRE processing plant.

The MSRE reactor cell and drain tank cell will be resealed after the examination work is completed. Service lines into the cells which were left connected to the ancillary systems during the interim period will be capped to minimize chances of accidental openings. The reactor equipment that is heavily contaminated with fission products will be retained within the cells and the offgas containment system. (As of July 1970, the total fission product activity in the salt and elsewhere in the reactor will amount to about 360,000 curies.) Some radioactive items with little or no transferable activity may be placed in other shielded cells in the reactor building. Radiation zones will be defined, marked and secured as required by ORNL procedures. The conditions in the reactor, cells, and building will continue to be monitored remotely by the Central Waste Monitoring Group at ORNL. Access to the reactor building and grounds will be strictly controlled by the existing system of fences, gates, and guard service.

Disposal

Items that are not required for the containment of the radioactivity nor for the possible future operation of the processing facility will be identified and advertised. Those items whose removal can be justified by program needs will be removed. Such removal will be planned and supervised to guard against inadvertent compromise of the continuing needs of the MSRE.

The safety of the plant will be reviewed periodically by appropriate groups in ORNL.

We expect that eventually it may become desirable to transfer the fuel salt, containing the fissile material and the bulk of the fission products, to a more permanent waste storage situation. The best way to get the salt out would now appear to be to cut the line from the salt fluorination tank to the experimental salt still and transfer batches of molten salt into transport containers connected at that point. It would also be feasible to pull salt into containers through a dip tube installed through the drain tank access port. After the bulk of the activity is removed this way, if there is no foreseeable need for equipment in the reactor and drain cells, the cells can be filled in and closed to provide permanent containment for the remaining activity.

JOB DESCRIPTIONS

This section gives some additional detail on the jobs that will be involved in the studies described in the previous section. The letters in each job identification refer to the principal location of the work (RC = reactor cell; DC = drain cell; CC = coolant cell; HC = hot cell at X-10; O = at reactor site outside of cells; L = laboratory). The numbers in the job identification refer to the sequence in which the work will probably be done (see Table 2). The order in which the jobs are discussed, however, is that in which they are listed in Table 1. The "purpose" is the specific contribution toward the broader objective of the study of which the job is part. A preliminary description of the procedure is given to indicate the scope of the job and the present plan of attack. The detailed procedures have yet to be developed and proved in most cases.

View Vicinity of Freeze Valve FV-105 (Job DC-1)

Purpose — To look for evidence of the leak and its cause. If any is found, to decide more precisely the probable location of the leak. If any salt is observed, to determine the amount and its condition. To obtain measurements and photographs to be used in detailed plans for excision of section with the leak.

General Procedure — Remove drain cell top blocks, cut membrane, set up maintenance shield, remove lower blocks, insert lights and viewing devices, take photographs, remove heater units in vicinity of FV-105, view and photograph, remove tools, reinstall blocks, remove maintenance shield.

Excise FV-105 (Job DC-2)

Purpose — To remove the section of drain line where the leak has been found (or is believed to be) so that detailed inspection can be made.

General Procedure — Set up maintenance shield, remove lower block, install lights and viewing devices. Clear away interfering wiring, insulation and supports. Use pipe cutter to sever lines. Lift sections to be inspected into shielded carrier and transport to hot cell. Thread ends of line in cell, close with pipe caps, test. Remove tools, etc., replace block, remove maintenance shield, seal membrane, install top blocks.

Inspect FV-105 (Job HC-6)

Purpose — To ascertain the location, nature and probable cause of the leak.

General Procedure — (In hot cell) — If leak is in FV-105, remove cooling-air shroud. Inspect exterior visually and by dye-penetrant technique. Section and examine metallographically.

Excise Fuel Pump Sampler Cage and Baffle (Job RC-13)

Purpose — To remove this assembly to a hot cell for detailed examination. To provide an opening through which the interior of the fuel-pump bowl can be viewed.

General Procedure — Set up maintenance shield, install lights and viewing device. Remove FP heaters and leads. Use plasma torch to cut away interfering portion of support plate and ring. Remove flanged section of sampler tube, then cut tube just above bowl cooling shroud. Cut out ring of shroud around tube. Use plasma torch to cut through upper head of FP bowl in circle close around sampler baffle. Lift short section of sample line with attached latch stop, capsule cage and baffle into shielded carrier and deliver to hot cell.

Inspect Sampler Cage and Baffle (Job HC-4)

Purpose — To determine the nature of any deposits on the metal surfaces inside and outside of the baffle and how the deposition varied at and above the salt-gas interface. To see if the 10-g capsule that was dropped in March 1968 is still wedged outside the cage as it seemed to be. To examine specimens from selected spots for evidence of corrosion.

General Procedure — (In hot cell) — Remove assembly from carrier, view and photograph. Section vertically and horizontally. Remove deposits from some sections mechanically, from others chemically. Prepare specimens for metallographic examination.

View Inside Pump Bowl (Job RC-14)

Purpose — To make observations and photographs that can be used with the results of Job HC-4 to describe the deposition of salt mist, oil residues (and perhaps fission products) on the various surfaces exposed to salt and gas in the pump bowl.

General Procedure — After removal of the sampler cage and baffle (Job RC-13) look down at bottom head below hole and photograph it. Insert viewing device with light through the hole (about 3-in. diameter). Look at and photograph top head, top and bottom of "shed roof," overflow line, volute support cylinder, and volute. Look for remains of capsules and latch key in bottom head. Remove viewing equipment.

Close Fuel Pump Bowl (Job RC-15)

Purpose — To prevent free communication between the inside of the fuel system and the cell atmosphere under credible future conditions. (There would seem to be no way for the pressure differential to exceed 5 psi or the temperature to exceed 200°F.)

General Procedure — Prepare a patch to fit over the hole and seal against the pump tank. Apply the patch, remove tools.

Prepare for Core Work (Job RC-2)

Purpose — To clear the way for opening the core access flange. To make the control rods available for inspection.

General Procedure — Set up maintenance shield. (The upper blocks and part of the reactor cell membrane will have been removed in Job RC-1.) Disconnect control rod drives and move to spare cell. Remove control rods and hang in reactor cell. Remove the graphite sampling standpipe. Clear away control rod drive shielding, bracing and any other obstruction from the reactor access flange area.

Remove Core Access Plug and Rod Thimbles (Job RC-7)

Purpose — To give access to the interior of the reactor vessel. To permit inspection of Hastelloy-N that has received long exposure in the core. To permit examination of plug surfaces for evidence of unusual deposition around the salt-gas interface.

General Procedure — Unbolt, lift out, and hang in the reactor cell.

Remove Some Core Graphite (Job RC-8)

Purpose — To provide a bar of graphite from the core for examination in a hot cell.

General Procedure — Lift one of corner bars into a carrier and deliver to hot cell. (A second bar, perhaps the center, may also be removed.)

View Core and Inside of Reactor Vessel Heads (Job RC-9)

Purpose — To look for evidence of unusual deposits in low-velocity regions, any fragments of graphite or other loose objects, and any broken graphite stringers.

General Procedure — Lower viewing device and light into upper head. View and photograph inside of core access nozzle and fuel outlet on the way down. View and photograph in upper head with particular attention to top of graphite and retaining wires. Lower device through core, scanning for anything unusual. View and photograph horizontal graphite, support grid, flow directors and surface of lower head. Remove viewing devices.

Close Reactor Access (Job RC-10)

Purpose — To prevent free communication between the inside of the fuel system and the cell atmosphere under credible future conditions.

General Procedure — Install a blank flange on core access nozzle.

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Cut Off Piece of Rod Thimble (Job RC-11)

Purpose — To obtain a piece of thimble for close examination in hot cell.

General Procedure — With access nozzle and attached rod thimbles in the reactor cell, sever No. 3 thimble just below the pipe-to-tube transition. Deliver the lower end of thimble, including the guide assembly and throat, to hot cell.

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Inspect Core Graphite Bar (Job HC-2)

Purpose — To see if there is any perceptible difference between condition of this graphite and that of the graphite in the specimen arrays. To look for evidence of unusual flow situations.

General Procedure — (In hot cell) — Examine surfaces, observe patterns related to flow in channels, look for any evidence of salt intrusion between bars. Section bar and determine distribution of salt constituents and fission products in graphite.

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Inspect Control Rod Thimble (Job HC-3)

Purpose — To attempt to determine why a rod hung on withdrawal and the replacement rod (with beveled shoulders on the end fitting) did not. To see if moisture or foreign matter (such as fragments of blower drive belts) in the cooling air had significant deleterious effects. To determine if surfaces exposed to salt were corroded or otherwise affected.

General Procedure — (In hot cell) — Cut open to reveal lower ends of guide bars. See if bars are loose or warped. Examine surfaces for evidence of corrosion.

Excise Sections of Fuel Piping (Job RC-17)

Purpose — To remove surfaces from hot and cold sides of fuel circulation loop for close examination, closing up the openings after the removal.

General Procedure — Set up maintenance shield. Use an 18-in.-dia cutting wheel on a mast-mounted tool to cut out 12-in. sections of 5-in. pipe. One section will be from Line 101 between the pump discharge and freeze flange 101; the other from the horizontal run of line 102 between the heat exchanger exit and freeze flange 102. Transfer sections in shielded carriers to hot cells. Close severed ends of pipe in cell with caps suitable for anticipated conditions.

Inspect Sections of Fuel Piping (Job HC-5)

Purpose — To determine effects of corrosion and fission product deposition for comparisons between "hot" and "cold" sections and with other indications (core specimens, rod thimbles, remote gamma-ray spectrometry).

General Procedure — (In hot cell) — Examine surfaces metallographically and for elemental composition of deposits.

Remove Heater H-103 from Fuel Drain Line (Job RC-3)

Purpose — To provide an opening through which equipment can be inserted to view beneath reactor vessel. To test maintainability.

General Procedure — Set up maintenance shield. Pull H-103 and store in reactor cell.

View Drain Line Inside Reactor Furnace (Job RC-4)

Purpose — To look for effects of operation and evidence of incipient trouble.

General Procedure — Insert viewing device with light through H-103 port and guide sleeve in thermal shield. View and photograph outside of

FV-103 enclosure, with attention to condition of sheet metal, insulation and thermocouples. Scrutinize and photograph drain line and visible portion of reactor vessel, with emphasis on drain line near vessel juncture. Remove viewing device.

Excise Inlet Section of Main Charcoal Bed (Job O-5)

Purpose — To get short section at inlet of one main charcoal bed to hot cell for examination.

General Procedure — Set up work shield. Lower water in charcoal bed pit. Sever 1/2-inch inlet line near 1-1/2-inch cap at bed entrance. Cut bed about 6 inches below cap, taking care not to spill charcoal. Remove in shielded carrier to hot cell. Cap 1/2-inch line and bed (1-1/2-inch pipe).

Inspect Inlet Section of Main Charcoal Bed (Job HC-7)

Purpose — To determine reason for recurrent plugging. To determine if adsorptive capacity of charcoal is significantly reduced. If so, to determine the reason.

General Procedure — Cut open, look at, and photograph steel-wool-packed inlet section. Remove charcoal. Test adsorptive capacity for xenon or krypton. Compare with result of same test on unused charcoal of same type.

Excise Sections of Radiator Tubing (Job O-2)

Purpose — To provide specimens from "hot" and "cold" ends of tube bundle.

General Procedure — Cut out a 6-inch section of 3/4-inch tube near inlet end of tube bundle and one near outlet end. Deliver to Metals and Ceramics Division laboratory. (These specimens will not be radioactive, but precautions with regard to beryllium must be observed.) Close cut ends of tubes in radiator.

Inspect Sections of Radiator Tubing (Job L-1)

Purpose — To look for effects of corrosion and mass transport.

General Procedure — Examine metallographically. Determine composition of any deposits.

Excise TC Wells at Radiator (Job O-3)

Purpose — To remove these wells for inspection.

General Procedure — Observing beryllium precautions, cut out a 6-in. section of 5-inch coolant piping containing radiator inlet thermocouple well. Cut out a similar section with the outlet well. Deliver to M & C laboratory. Cap severed ends of pipe in coolant system.

Inspect Coolant TC Wells (Job L-2)

Purpose — To look for evidence of any unusual corrosion or incipient trouble. (Pipe surfaces can also be compared with surfaces in radiator tubes.)

General Procedure — Examine metallographically. Determine composition of any deposits.

Test d/p System on Coolant Salt Flowmeter (Job O-1)

Purpose — To determine the output from flow transmitters FT-201A and FT-201B as a function of the differential pressure applied to the cells. The calibration is to be done in place to avoid any movement of the salt-NaK diaphragm seals or the NaK-filled lines leading to the d/p cells which conceivably could cause a shift in the readings.

General Procedure — Cut out a section of line-201 just ahead of upstream d/p connections. Install plug in venturi between the upstream and throat d/p connections. Cap the line and apply argon pressure to section with upstream d/p connections. Record output for both flow transmitters as a function of applied d/p over full range of transmitters.

Remove Coolant Pump Rotary Element (Job O-4)

Purpose — To permit detailed inspection of the rotary element and interior of the pump.

General Procedure — Disconnect, remove and deliver to Reactor Division pump facility in Y-12. After inspection of interior of pump, install cover plate to close the opening.

Inspect Coolant Pump Rotary Element (Job L-3)

Purpose — To determine effects of operation. To obtain information on which to base judgement of serviceability and remaining life.

General Procedure — Observe evidence of oil leakage and decomposition. Look for unusual rubbing. Check key dimensions against originals.

Examine Control Rods (Job RC-5)

Purpose — To see if there is any evidence of unusual rubbing or damage on the outside of the rod.

General Procedure — With the rod hanging in the reactor cell, examine carefully through periscope.

Remove Section of Control Rod (Job RC-6)

Purpose — To get active section of control rod to hot cell for inspection.

General Procedure — Cut Control Rod No. 3 just above poison elements. Deliver lower end of rod, with elements, to hot cell.

Inspect Control Rod and Elements (Job HC-1)

Purpose — To look for possible explanation of changes in stiffness of rod. To inspect elements for effects of exposure.

General Procedure — Remove poison elements. Examine hose for degree of oxidation and roughening of surfaces that slide when hose is flexed. Measure canned elements. If any can is swelled, cut open and determine condition of ceramic.

Remove and Inspect Heater Units (Job RC-16)

Purpose — To determine condition of units. To judge difficulty of repair and replacement. To make way for excision of sections of fuel pipe.

General Procedure — Set up maintenance shield. Disconnect heater H-101-1. Lift and set back in place, noting difficulties. Remove to equipment storage cell. View. Repeat for heater H-102-3.

Test Fuel Pump Motor Removal (Job RC-1)

Purpose — To determine if unbolting system is still operable after over 4 years' exposure.

General Procedure — Unbolt and remove all top blocks. Cut and remove sections of membrane as required for this and later jobs. Set up maintenance shield. Disconnect power and instrument leads to pump motor. Unbolt oil and water lines. Loosen several extension bolts on motor flange. If motor must be off for Job RC-13, proceed to remove motor to equipment storage cell.

Disconnect Fuel Sampler Line (Job RC-12)

Purpose — To determine if disconnect system is still operable after long exposure to cell environment. To prepare for excision of sampler cage and baffle.

General Procedure — Set up maintenance shield. Remove clamps from flanges on spoolpiece. Use installed jack to compress bellows and clear flanges. Swing aside. Note any difficulties, judge practicality of provisions for remote removal of pump bowl.

SCHEDULE

Some of the non-radioactive work, such as that on the coolant system, may begin before July 1, 1970 if funds are available. Before the work in the reactor cell and drain tank cell can commence, tools must be procured and tested, detailed procedures must be developed, and the plans must be reviewed and approved by program and safety groups. A target date of July 6 has been set for the beginning of the in-cell work.

Table 2 shows the sequence of in-cell work that now appears most logical, progressing generally from jobs involving less chance of contamination to those likely to involve the most contamination of the cell, tools, and shielding. The estimated dates tend to be optimistic since they include no allowance for "unusual" delays. Although critical-path scheduling was used in planning maintenance and modification work throughout the operation of the MSRE, this type of diagram is not shown here because the in-cell work requiring the portable maintenance shield falls on a single path and most of the other work can be done as "fill-in" jobs whenever it is most convenient.

A goal will be to have virtually all the work of securing the plant finished by October 2, 1970. Hot-cell work and analyses should be completed by December 4, 1970. These dates may be extended if, for example, it is more economical to do so than to work overtime.

STATUS

As of April 10, the general strategy has been decided for each job and plans have been sketched in enough detail to establish confidence in the feasibility (by one means or another) of all the important jobs. A shear and plasma torch have been selected for procurement, other tools and the maintenance shield are being readied, and the prototype fuel pump is on hand to be set up in the maintenance practice cell as a mock-up for developing the procedure for cutting into the pump bowl.

Table 2

Sequence[a] and Estimated Dates[b] of Work
In MSRE Reactor and Drain Tank Cells and X-10 Hot Cells

		Reactor and Drain Tank Cells	Available to Hot Cells
July 6			
10	DC-1	View FV-105 vicinity	
	RC-1	Test FP motor removal	
15	RC-2	Prepare for core work	
	RC-3	Remove heater H-103	
	RC-4	View beneath reactor	
28	RC-5	Examine control rods	
	RC-6	Remove section or rod	Control rod and elements
	RC-7	Remove core access plug	
	RC-8	Remove some graphite	Core graphite
	RC-9	View core	
	RC-10	Close core access	
	RC-11	Cut rod thimble	Rod thimble
Aug. 7	RC-12	Open sampler tube	
	RC-13	Excise cage and baffle	Cage and baffle
	RC-14	View in FP bowl	
	RC-15	Close FP bowl	
21	RC-16	Remove and check heaters	
	RC-17	Cut 5-in. fuel pipe	5-inch pipe
Sep. 4	DC-2	Excise FV-105	FV-105
18		Seal cells	
		Decontaminate	

[a]The jobs listed for the MSRE cells cannot be done in parallel because all require the portable maintenance shield. The sequence was determined mainly by contamination considerations. Items will be available for hot-cell work in the sequence listed.

[b]These dates are based on preliminary procedures and make no allowance for unusual delays.

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