OAK RIDGE NATIONAL LABORATORY

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PROBLEMS ENCOUNTERED DURING FOUR YEARS OF ORR OPERATION

W. H. Tabor
R. A. Costner, Jr.

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ABSTRACT

The over-all design and operation is reviewed in the light of four years of operating experience. Items discussed consist of the reactor components and instrumentation, reactor and pool cooling systems (including system cleanup), the emergency systems for electric power and reactor cooling, the waste-disposal systems (liquid, gaseous, and solid), and the building, itself.

No effort is made to describe the features of the ORR which make it the useful research tool that it is.

The ORR was the first of a class of reactors which combined the features of both the pool-reactor and tank-reactor types. Four years of operation have indicated areas where problems of various degrees have developed. These are discussed to enable reactor operators who are operating or anticipate operating reactors similar to the ORR to avoid some of these problems.

INTRODUCTION

The Oak Ridge Research Reactor[1] (ORR) is highly enriched, light-water moderated and cooled, and beryllium-reflected. It is enclosed in a tank which is submerged in a pool of light water. Design emphasized accessibility to the core region by placing the reactor control drives below the reactor and using water as a primary shield in order to provide quick and easy access to in-reactor experiments.

The core arrangement, a 7 x 9 rectangular configuration using 63 spaces, contains fuel elements, control or shim rods (for the ORR, these words are synonymous), beryllium-reflector pieces, and experiment core pieces. The ORR uses four fuel-cadmium shim rods and two beryllium-cadmium auxiliary shim rods for control. A normal fuel loading uses 25 fuel elements, with the remaining core positions occupied with beryllium-reflector pieces, special beryllium pieces adapted for experiment usage, and isotope production units. The core is housed near the bottom of an aluminum reactor vessel which is about 15 ft in over-all height and approximately 5 ft in diameter.

The reactor vessel is located near the end of one of the three pools of demineralized water; each pool is approximately 20 ft long and 10 ft wide. These pools are identified as reactor, center, and west. The reactor pool is about 29 ft deep, while the other two pools are about 26 ft deep. The pools may be made into a common pool by removing the gates which separate them.

Located above the end of the west pool is a hot cell which is arranged to permit the transfer of samples and experiments from the pool into the hot cells through doors in the bottom of the cell. The hot cell is divided into two sections, each of which has walls of dense concrete 3.5-ft thick designed to shield 10^6 curies of Co^{60} or the equivalent so that the radiation level outside the cell will be less than 5 mr/hr. This hot cell is intended for preliminary inspection of experiments and samples.

The ORR offers a variety of experiment facilities. These include six horizontal beam holes (6.5-in. diameter); two large test facilities, approximately 25 x 19 in., located on the north and south sides of the core; a flat poolside face which permits access to the core from the pool on the west side; and a variable number of in-reactor positions which may be used for experiments.

The ORR was completed early in 1958, and cost about $4.7 million. Criticality was attained on March 21, 1958; 20-Mw power operation was begun on April 29, 1958; and 30-Mw power operation was achieved on July 29, 1960. The reactor is illustrated in Figures 1 and 2.

Operating costs of the ORR increased ~27% with the increase in power from 20 to 30 Mw. This is attributed to extra fuel costs, a more comprehensive preventive maintenance program, and additional tests and development work related to basic studies for high-power operation. Table 1 indicates typical annual operating costs, contrasting 20- and 30-Mw operation.

An analysis of administrative procedures on ORNL research reactors is presented in detail elsewhere.[2]

Personnel requirements for the ORR operation are met by utilizing a manpower "pool" which supplies two other reactors, the Oak Ridge Graphite Reactor and the Low-Intensity Testing Reactor. Many of the people are shared efficiently among the reactors, although each reactor is directly supervised by its own reactor supervisor. Two supporting departments of the Operations Division, the Technical Assistance and Technical Development Departments, assist the Reactor Operations Department with the three operating reactors; an organization chart is given in Figure 3. Supporting help for engineering and maintenance and special services is supplied by other divisions at the Laboratory, and it is unnecessary for the Operations Division to expand its organization to obtain such services.

ROUTINE OPERATION

The ORR began a routine, power-operating cycle of 20 Mw on July 20, 1958. It consisted of three weeks of operating at power followed by a one-week shutdown for experiment insertions and/or removals, refueling, isotope removals and/or insertions, and miscellaneous routine maintenance work. During early cycles of operation, the three-week operating cycle was interrupted frequently because of component malfunctions. Occasionally, as a result of such interruptions, refueling was required due to xenon poisoning.

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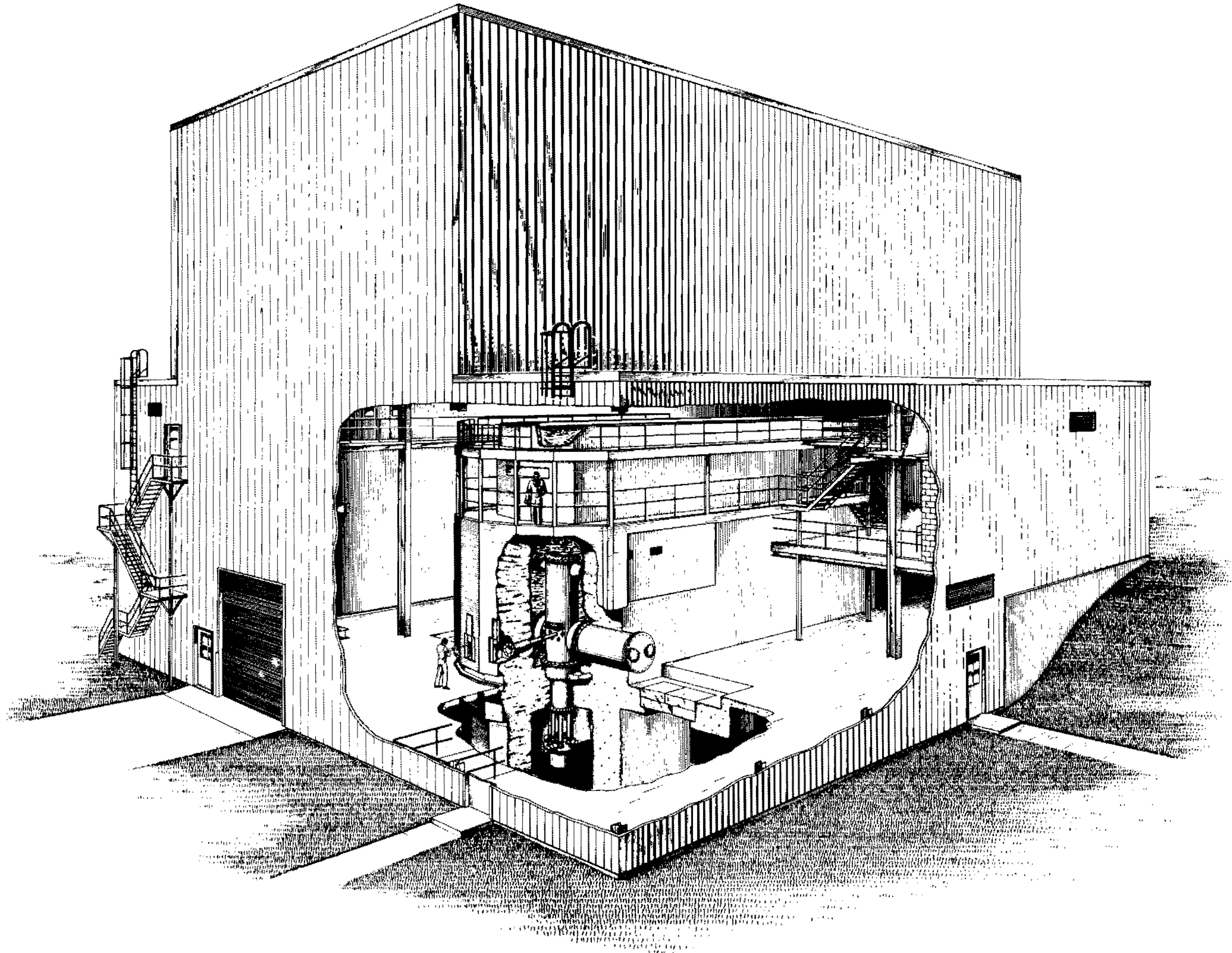

Figure 1. Cut-Away View of Reactor Building.

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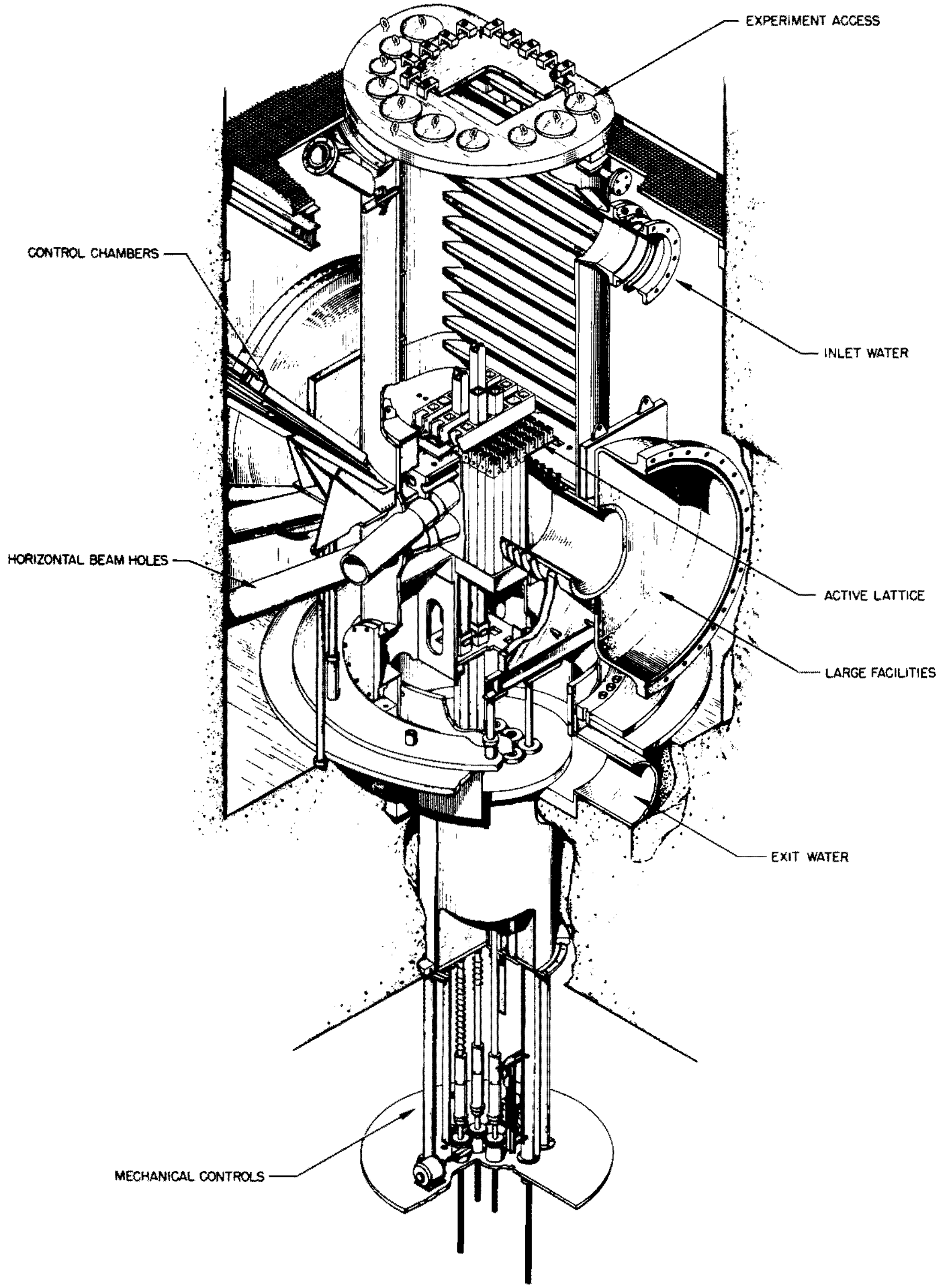

Figure 2. Cut-Away View of Reactor Tank.

Table 1. Annual Operating Costs of the ORR
20 Mw Versus 30 Mw

Item	20 Mw		30 Mw	
Labor				
Maintenance and mechanical shops		$ 54,000		$ 62,000
Research shops		14,000		32,000
Engineering		26,000		23,000
Electrical		8,000		11,000
Instrumentation and controls maintenance		27,000		44,000
Instrumentation and controls engineering		18,000		18,000
Operations		181,400		198,000
Miscellaneous		10,600		32,000
Expense allocation		232,000		286,000
Subtotal		$571,000		$ 706,000
Materials				
Operations Department		$ 47,000		$ 168,000[a]
Engineering and Maintenance and Instrumentation and Controls Divisions		53,000		80,000
Other				20,000
Subtotal		$100,000		$ 268,000
Special Services				
Health Physics		$ 27,000		23,000
Utilities		21,000		27,000
Worked Materials				
SS Material control	$5,000		$ 5,000	
Equipment decontamination	1,000		1,500	
Water demineralization	6,000		9,500	
Waste disposal	9,000	57,000[b]	45,000	61,000
Subtotal		$105,000		$ 111,000
Grand Total		$776,000		$1,085,000

[a]Includes ~$150,000 for fuel costs.

[b]Includes $36,000 for fuel elements in use.

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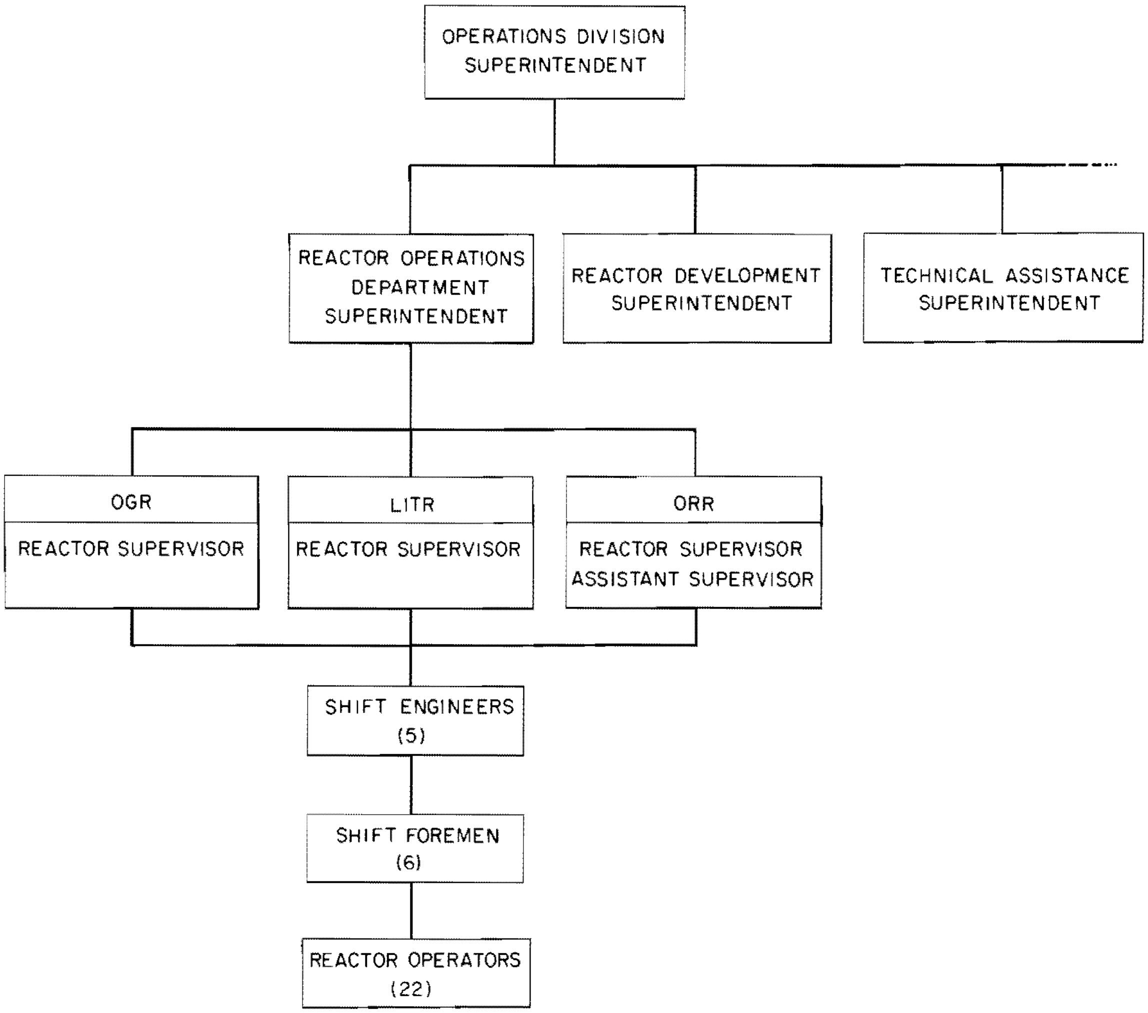

Figure 3. Organization Chart of Operations Division — Reactor Affiliated Departments.

The ORR was operated at 20 Mw during the cool season from about October to April of each year. During the remaining months, the reactor power was limited to 16 Mw due to inadequate heat-removal capacity. This inadequacy was in the water-to-air coolers which never performed at their rated capacity.

The experiment program at the Laboratory was being retarded by the lower operating level; and it was decided, after thorough technical investigations, to take the necessary steps to obtain 30-Mw operation. A detailed study resulted in the installation of shell-tube heat exchangers, using a spray tower in a secondary cooling loop for heat removal. This major modification was completed during the July 9-29, 1960, shutdown.

Operation at 30 Mw was begun on July 29, 1960. Concurrent with this higher power level, the operating cycle was altered to cover eight weeks--seven weeks of operation and one week of shutdown devoted to experiment insertions and/or removals and miscellaneous routine maintenance. Upon adopting the longer operating cycle and higher power level, it was necessary to interrupt the operating phase periodically for refueling and for isotope removals and insertions. Refuelings are necessary at a maximum of about every 18 days, with a specified date designated after four weeks of operation for isotope removals and insertions. Figure 4 indicates the percentage of operating time during each quarter of operation.

The scheduling of shutdown activities is a combined effort of staff members of Operations, Engineering and Mechanical, and Instrumentation and Controls Divisions. The large number of activities which require completion during each shutdown makes close coordination between the various jobs essential. Two formal meetings are held to organize the activities to be completed. During the first meeting, held about two weeks prior to the shutdown, the program engineers (i.e., those who are responsible for coordinating the design, fabrication, and installation of experiments) present detailed information on the job schedule. From this a preliminary schedule is derived. The second meeting is held one week before the shutdown. Plans for all jobs are finalized, and work to be completed during the shutdown must be indicated on drawings which are available for distribution to the crafts foremen of the Engineering and

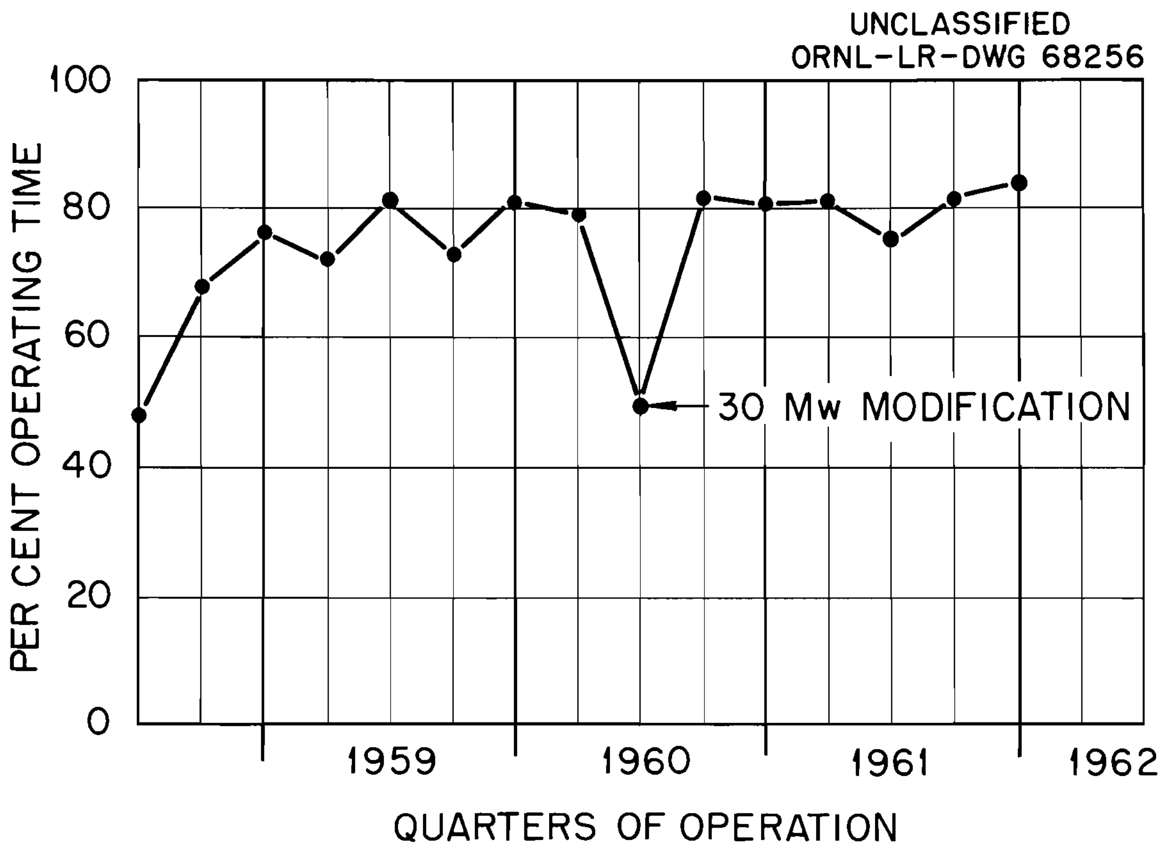

Figure 4. Percentage at Power.

Mechanical Division. This provides about a week for the foremen to become familiar with the jobs so that they can work efficiently during the shutdown week.

A formal shutdown schedule is prepared which includes pertinent information on all activities to be performed. This schedule is distributed to the persons interested about four days before the reactor is shut down. Alterations in the formal schedule may be made during the shutdown in order to expedite the over-all program; and this is quite often necessary due to unavoidable, last-minute cancellations of scheduled activities.

Following the shutdown, an evaluation study of the week's activities is made by a resident engineer; and recommendations are made to improve the job scheduling and handling in the future. This critique of the shutdown activities is a recent innovation which, it is hoped, will result in more efficient methods of handling them.

Many activities associated with operating a nuclear reactor depend upon administrative control. These activities are of varying degrees of complexity and affect the operating conditions of the reactor in many ways. In order to standardize operating techniques, formal procedures are written covering all aspects of operation.

Operating procedures for the ORR might be considered as falling into two categories--permanent and temporary. The permanent procedures are incorporated into the Operating Manual for Oak Ridge Research Reactor. Changes in operating conditions preclude the exclusive use of such a formal publication; therefore, revisions and additions to these permanent procedures, as well as temporary procedures, are provided in the form of "ORR Procedure Memoranda". These memoranda, which are submitted by the reactor supervisor and approved by the Department Superintendent, are circulated to operating and technical-support personnel. A complete set of these memoranda is maintained in the ORR control room and in division files.

Primary records maintained are the ORR Log Books and standard forms such as "ORR Hourly Readings" and "ORR Daily Water Checks". Secondary records such as daily, weekly, and quarterly reports are also maintained. The formality of presentation and the extent of distribution of these secondary records increases somewhat proportionally to the time period covered. A detailed description of records and maintenance of records is presented in the Operating Manual for the Oak Ridge Research Reactor.

REACTOR COMPONENTS

Fuel Elements

The ORR utilizes two types of fuel assemblies; a 14-plate assembly containing about 131 gm of U^{235} for shim rods and a 19-plate assembly containing about 200 gm of U^{235} for standard fuel elements (Figures 5 and 6, respectively). During initial operation, the fuel inventory consisted of a spectrum of fuel units as follows: eight 70-gm elements, twenty-eight 140-gm elements, twenty-eight 168-gm elements, twenty-three 200-gm elements, and eight 131-gm shim rods. This varied inventory was necessary to allow for possible discrepancy between calculated and actual conditions, to permit postneutron measurements for three core loadings, and to allow initial power operation with a core of "standard" geometry and without the presence of in-core experiments. Such an inventory would appear sufficient for the transition to a quasi-standard inventory consisting of elements originally containing 200 gm of U^{235} but with varying degrees of fuel depletion. It was found necessary, however, after a few months of operation, to procure several elements containing 150 gm of U^{235} in order to complete the transition.

Experience has taught us to warn the operators of a new research or testing reactor that early attention to this problem would be justified economically. An unusual core geometry, as illustrated in Figure 7, aggravated the problem at the ORR; but fabrication of fuel elements at the Laboratory (at that time) lessened the economic consequences. In particular, the shifting of neutron flux and the resulting changes in burnup per core position, the early insertion of standard-weight fuel elements, and the selection of proper initial positions for these standard elements are items to be considered. Fuel cycling and position selection, based upon calculations of routine operational conditions, can well lead to a necessity for expensive fuel procurement for interim operation.

Calculation of fuel loadings for the ORR is covered in another pres-

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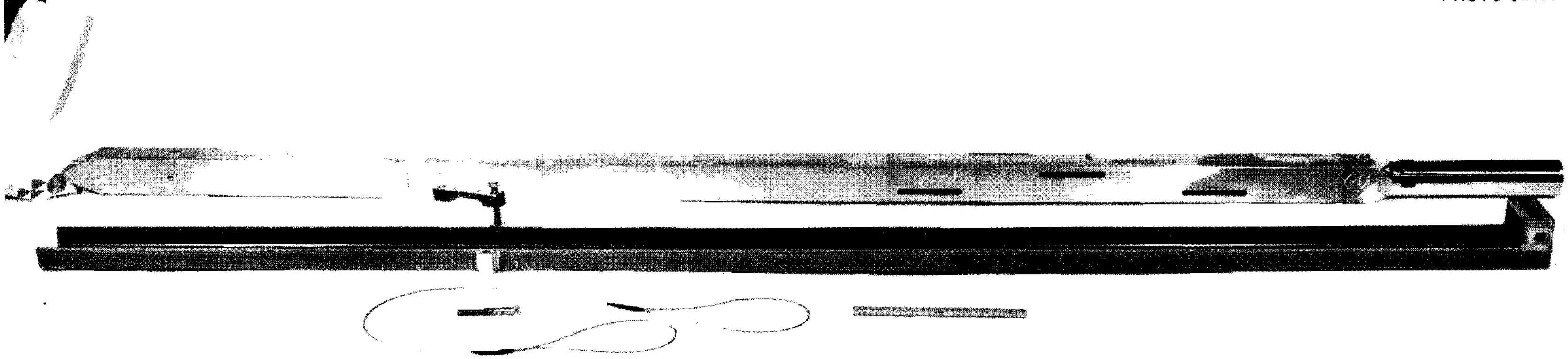

Figure 5. ORR Shim Rod and Carrier.

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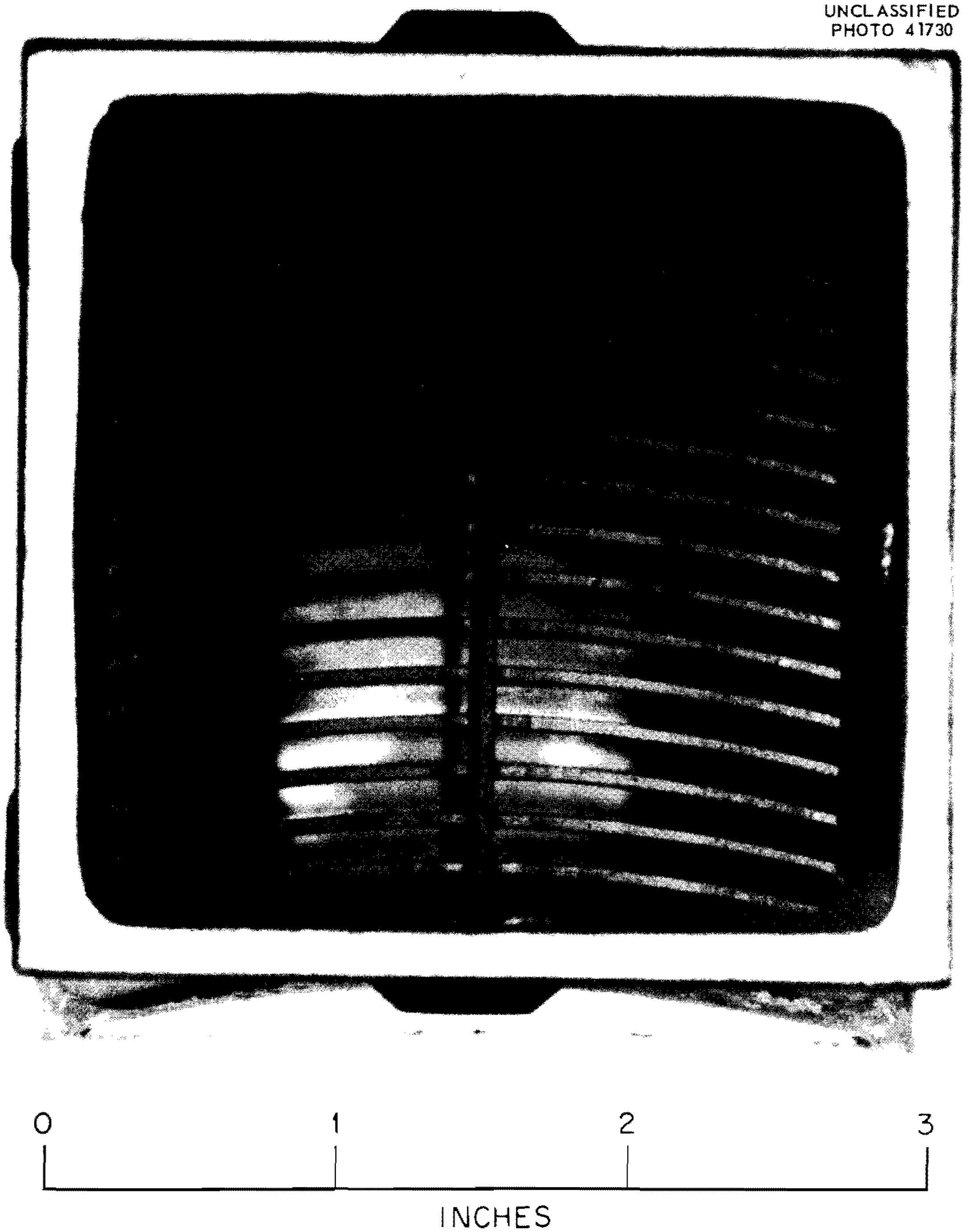

Figure 6. ORR Fuel Element.

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POOL

W

	1	2	3	4	5	6	7	8	9
A	A	Be	Be(S)	FUEL 168.25	FUEL 137.86	FUEL 167.31	R	Be	A
B	Be	Be	FUEL 135.33	SHIM 121.13	FUEL 129.08	SHIM 123.17	FUEL 129.08	Be	E
C	Be	Be	E 147.57	FUEL 126.09	FUEL 137.87	FUEL 126.46	FUEL 130.04	Be	Be
D	FUEL 167.96	FUEL 126.97	FUEL 131.83	SHIM 119.34	FUEL 137.25	SHIM 119.54	FUEL 130.23	FUEL 127.27	FUEL 168.44
E	FUEL 130.90	FUEL 127.32	FUEL 124.92	FUEL 60.73	FUEL 125.13	FUEL 60.84	FUEL 133.97	FUEL 127.74	FUEL 138.12
F	Be	Be	R	Be	R	Be	R	Be	Be
G	Be	Be	Be	Be	Be	Be	Be	Be	Be

S (left) — N (right)

E

Be ---- BERYLLIUM REFLECTOR PIECE

Be(S) ---- BERYLLIUM REFLECTOR PIECE CONTAINING NEUTRON SOURCE

E ----- EXPERIMENT

E 147.57 ---- PARTIAL FUEL ELEMENT CONTAINING EXPERIMENT

R ----- RADIOISOTOPE PRODUCTION FACILITY

A ----- ALUMINUM PIECE

TOTAL MASS --- 4038.67 g U^{235}

RODS AT CRITICAL --- 15.65 in. (53 %) WITHDRAWN

Figure 7. Core Configuration at Start-Up of Cycle 1.

entation;[3] therefore, only the problems of storage, handling, and disposal will be discussed here.

After transfer from ORNL storage vaults, initial storage of fuel elements in the ORR vault provides from four- to six-months' supply. Storage racks, located in the reactor and center pools, for partially depleted elements are illustrated in Figure 8. Although not shown in the figure, each rack is identified by Roman numerials (I through IV) and each rack position by Arabic numerials (1 through 30). An attempt is made to keep the major portion of the partially depleted elements in the reactor pool and all of the decaying, "fully" depleted elements in the center pool. Transfer of elements between the racks or from the racks to the core is simplified by the combination pool-type—tank-type design of the ORR.

A "typical" fuel element will, after about two weeks of operation in the ORR, be transferred to the racks for storage. Subsequently, it will be reinserted in the core four to eight times, progressing to more central positions. When an element containing about 135 gm of U^{235} is removed from the core, the element is considered fully depleted and is stored for shipment to the fuel recovery plant. The final fuel content, however, depends upon the content at the time of final insertion and the length of that particular operating period. Although elements with content as low as 109 gm of U^{235} (45% burnup) have been obtained, a 125-gm (37% burnup) content is typical.

A "typical" shim rod is transferred directly from the ORNL vaults to the ORR core where new shim rods are inserted in core positions D-4 and D-6 on a bimonthly basis (during the week-long shutdown ending an operating cycle). This provides a new rod in core position D-6 which contains maximum reactivity for use by the servo-control system. During the next succeeding end-of-cycle shutdown (after about seven weeks of operation), the shim-rod fuel content is about 80 to 100 gm of U^{235}. Transfer is made from core position D-4 to B-4 and from core position D-6 to B-6 for further depletion during a second operating cycle. After this, the fuel content is 60 to 70-gm U^{235}; and the shim rod is transferred to the shim-rod storage rack for decay. Additional burnup is

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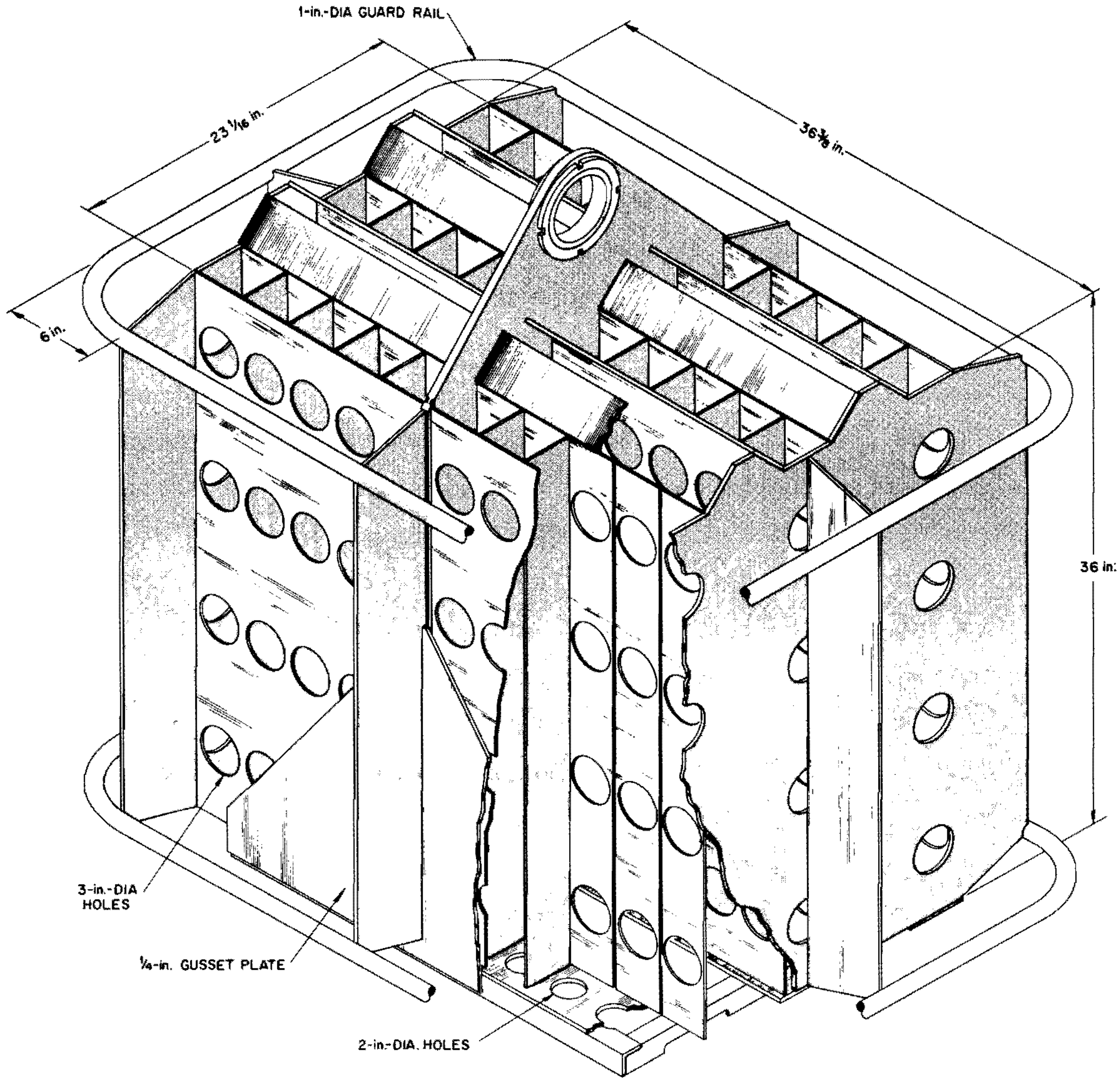

Figure 8. Fuel Storage Racks.

possible; however, initial tests indicated that shorter operating periods between refueling would result.

Fully depleted shim rods and fuel elements are allowed to decay for about 90 days. After this decay period, all portions extraneous to the fuel assemblies are removed by use of a remotely operated underwater saw. Two 7-place, shielded carriers are loaded with fuel assemblies and shipped to the fuel recovery plant on a monthly basis. Figure 9 shows a typical fuel carrier on the handling assembly.

The gamma-heat generation in an ORR fuel element after 90-days' decay is about 180 w. This value is calculated on the basis of data from Perkins and King.[4] Actual temperature measurements were made on a carrier about 24 hours after loading with seven depleted ORR elements. A thermocouple was attached to the external surface of the carrier, while a second thermocouple was placed inside the carrier via a drain hole. Results indicated no significant temperature difference. Temperatures were about 55°C.

In order to maintain criticality safety, fuel accountability records, and records for proper inventory control, a procedure has been evolved which is simple in operation and may appear redundant if cursorily examined. No transfer of a fuel unit is made without a written order from the reactor supervisor or his alternate. This order specifies both unit identity number and core or rack position; deviation from this order requires the permission of the reactor supervisor or his alternate. The engineer supervising any fuel transfer is required to identify and record each unit moved as well as the original and final locations of the unit, on a standard form. Day-shift personnel use this completed form, together with calculations of fuel depletion in the core, to maintain three separate records on each fuel unit (fuel elements and shim rods).

Fuel-accountability ledger books are maintained with individual, fuel-unit, ledger sheets filed according to unit location (i.e., core, vault, or pool); these sheets contain the past and current inventory of total uranium, U^{235}, and U^{236}. Each section of the ledger has a master control sheet showing the total inventory of uranium and U^{235} in that

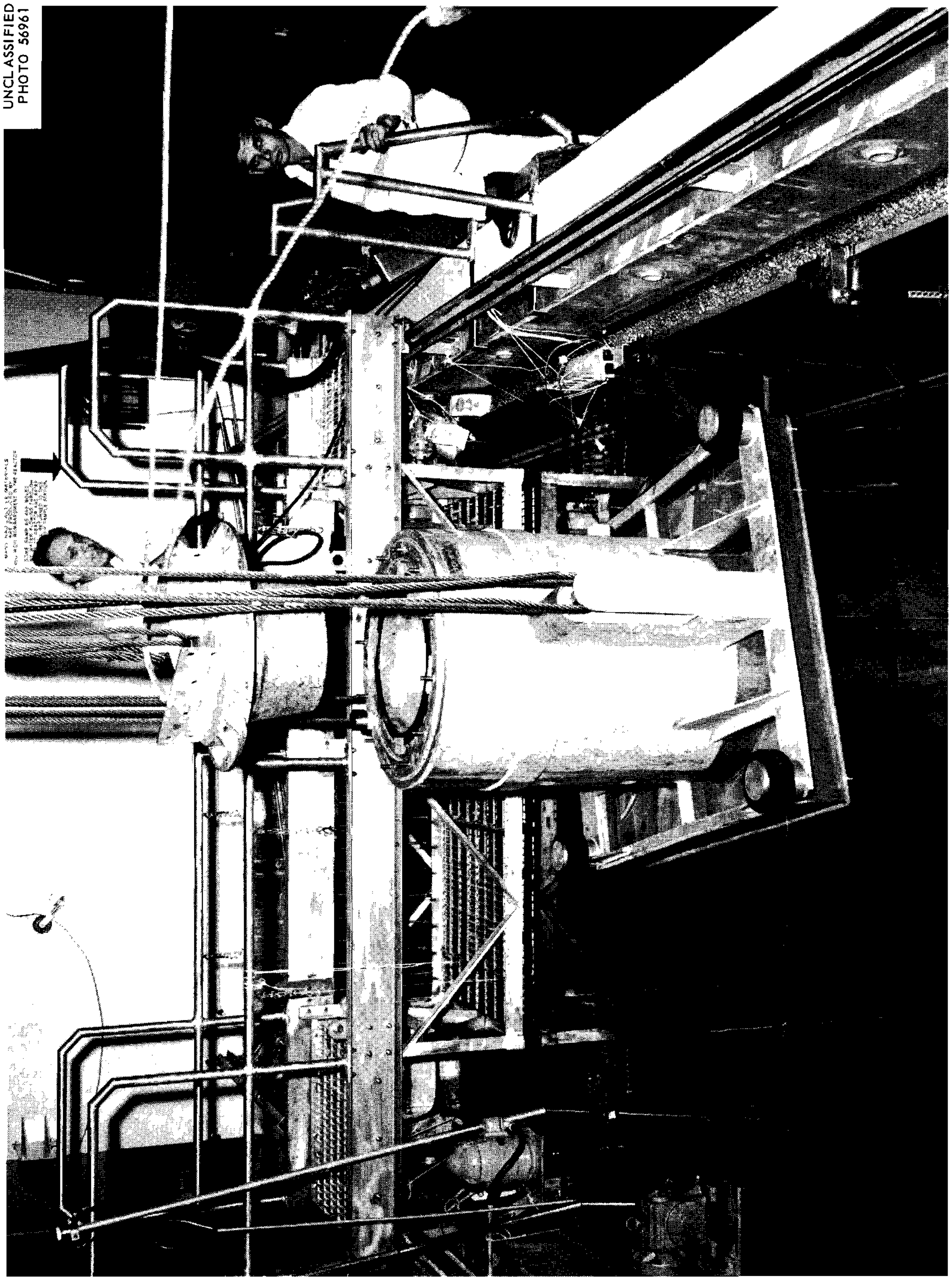

Figure 9. Fuel Carrier on Handling Assembly.

location. A fuel inventory card file is also maintained. A card for each element shows the current and past U^{235} inventory and is filed in sections according to location; i.e., pool and core. Two main sections are divided into subsections according to the U^{235} inventory; that is to say, all units containing from 180 to 190 gm of U^{235} would comprise one such subsection. Tags bearing individual unit-identity numbers are kept on location-indication boards which graphically display the core, pool storage racks, etc. This system of maintaining simple, although seemingly redundant, records tailored to three differing purposes has evolved over four years of ORR operation and works smoothly with a minimum of confusion.

Reactor Instrumentation and Controls System

The nuclear and process instrumentation, as initially designed and installed, was considered inadequate for routine operation above 20 Mw. Consequently, it was necessary to make several major modifications to the system to provide the reliability and coverage required for 30-Mw operation. Experience gained in operating the reactor at power indicated that several additional improvements were required. Only the major modifications and additions will be covered here, while the maintenance program of the instrumentation and reactor controls is presented in another paper.[5]

Nuclear Instrumentation

The initial design included only one magnet amplifier for each control rod. With that installation, a failure of one amplifier would cause a reactor shutdown. To eliminate this source of shutdowns, dual amplifiers were installed for each control rod with circuit modifications which would permit one of the amplifiers to assume the entire current load upon failure of the other amplifier..

During the first few cycles, repeated, unexplained dropping of one or more of the control rods was experienced. Investigation indicated that the hydraulic force acting on the rods exceeded that which had been expected. Normal operating conditions were 60 milliamperes of magnet current and 16,000 gpm of water flow. Initial tests showed that under these conditions the magnet release times were about 1 to 2 milliseconds instead of the 20 milliseconds for which the system was designed. The response time was increased by incorporating a resistor-capacitor network in the magnet-amplifier and sigma-amplifier circuits. This minimized the effect of voltage "spikes". In addition, the operating current was increased to 80 milliamperes. Operation continued after these modifications with very good results. New magnets were installed during July-September, 1959; and the resistor-capacitor network was removed.

The neutron-sensitive control chambers are, because of their location, greatly influenced by the contents of the beam holes which are located directly beneath them. Figure 10 indicates the relative locations of these components. Special tests revealed that the draining of a single beam-hole liner could increase the ion-chamber currents by as much as a factor of five. For this reason, safety precautions precluded the filling or draining of a beam-hole liner during operations. Initial design of the beam-hole plugs made the void of the plug common with the liner; and, since it was occasionally desirable to have this void filled with water for shielding in order to permit experimenters access to their equipment, a redesign of the beam-hole plug was made. This new design, shown in Figure 11, effectively made a "water can" of the plug which permits filling and draining the plug independently of the beam-hole liner. Special tests showed that no significant changes occur in chamber current when filling or draining the modified beam-hole plug. Operating history indicates that neither the research program nor reactor operation is retarded by using the modified beam-hole plug.

A special study of the possible use of gamma chambers at other locations which would be independent of beam-hole environment was begun. Chambers positioned outside the reactor tank at various locations (southeast, southwest, northeast, and northwest of the reactor tank) indicated they were less sensitive to beam-hole environment; however, in these locations, chamber currents increased ~1%/day due to fuel burnup in the reactor. Locating gamma chambers in the extreme north and south ion-chamber trays has given very stable results during normal operation and will supplement the neutron-sensitive control chambers.

Other disadvantages of the control chambers, as presently located

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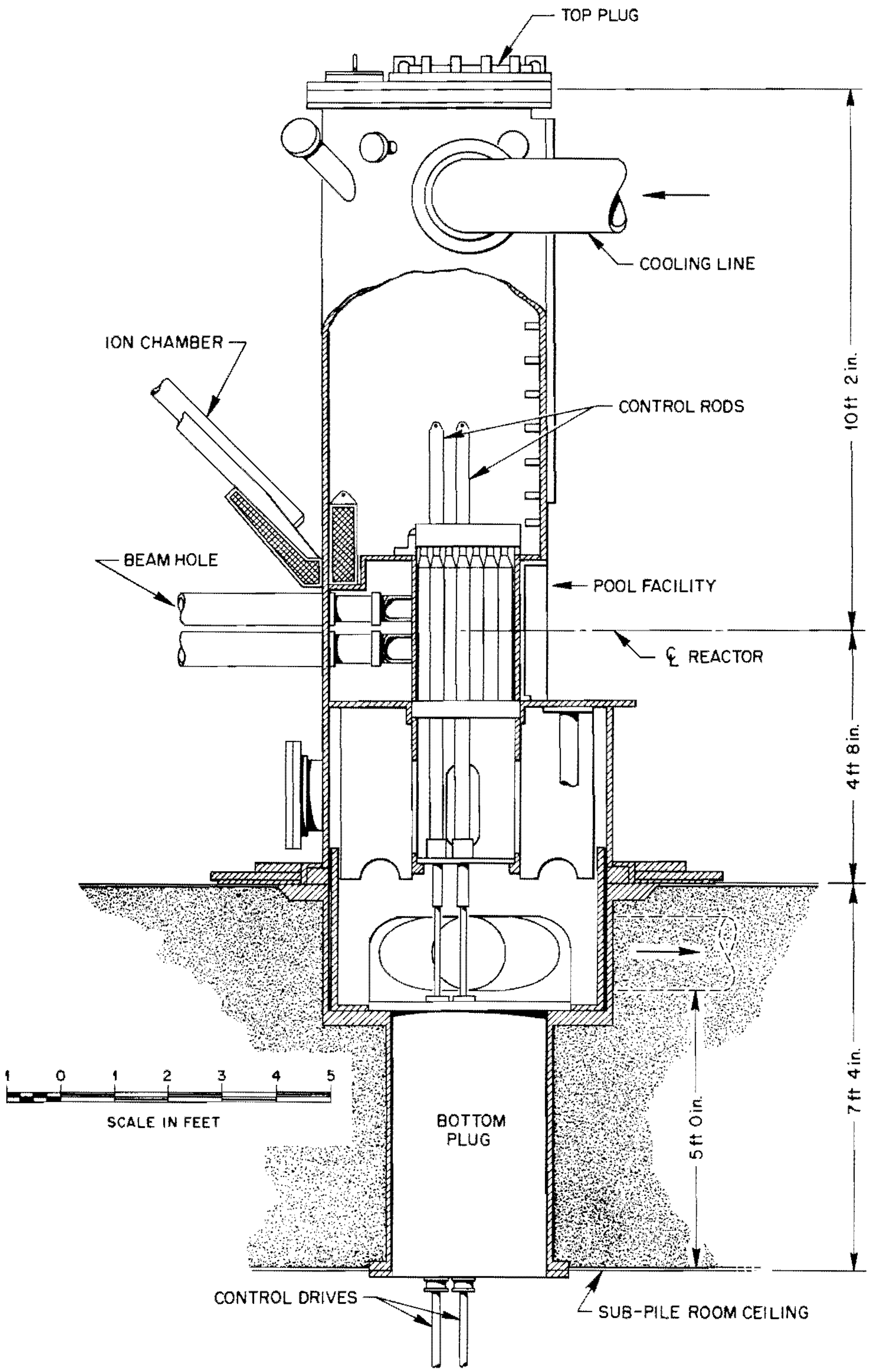

Figure 10. Cross Section Through ORR Showing Ion Chambers and Beam Holes.

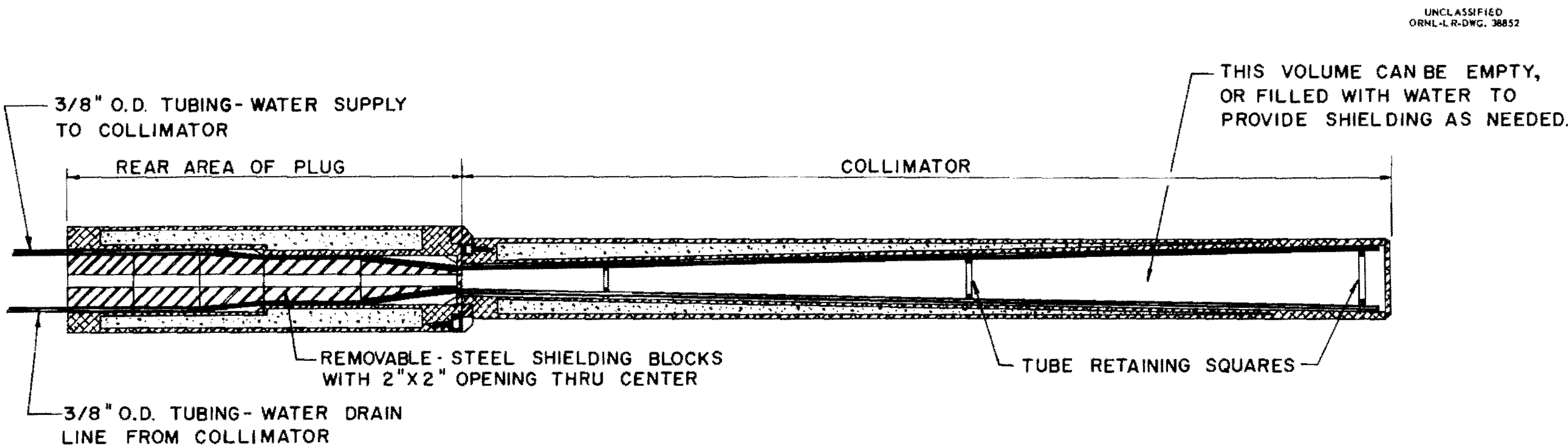

Figure 11. Modified Beam Hole Plug.

and suspended, are: (1) Occasionally difficulties are encountered in repositioning the chambers closer to the core. This is due primarily to oxide formation on the chamber and the trough on which it slides. (2) The relative location of the chambers to each other necessarily gives an interaction when the chambers are repositioned; that is, moving a chamber affects the neutron flux on the adjacent chambers. These have not been serious enough to require redesign or relocation.

Some peculiarities have been observed with the permanently mounted fission-chamber channel which is used as the startup channel. The fission chamber, as initially designed, used a Westinghouse WL6374 chamber which was installed from the bottom of the reactor tank and equipped with a remotely operated drive to give a movement of ~56 in. to within ~18 in. of the fuel. During startup, the fission chamber may indicate a decrease in counting rate by a factor of ten prior to indicating the neutron multiplication in the reactor. This action is attributed to moving the fuel section of a control rod containing a large amount of fission products away from the fission chamber. (Figure 12 illustrates their relative location.) This decreases the number of photoneutrons generated by the D_2O in the water in the vicinity of the fission chamber. The fission chamber channel "sees" the neutron multiplication of the reactor when the control rods are ~10 in. withdrawn (criticality is attained with the rods at ~15 in.).

Minor difficulties have been experienced with ground loops on the chamber circuitry which causes an extremely noisy channel. In all cases the difficulties were attributed to faulty insulation between the chamber and its housing or to radiation damage to the cable insulators. The polyethelene cable insulators were replaced with ceramic insulators which appear to be less susceptible to damage.

Mechanical troubles encountered in the drive unit in December, 1960, made it necessary to augment the reliability of the fission chamber channel. Consequently, an auxiliary chamber was located at the poolside facility to permit continuity of operation. After the permanent fission chamber was repaired, it was decided to maintain the poolside chamber as a readily available auxiliary chamber. The troubles

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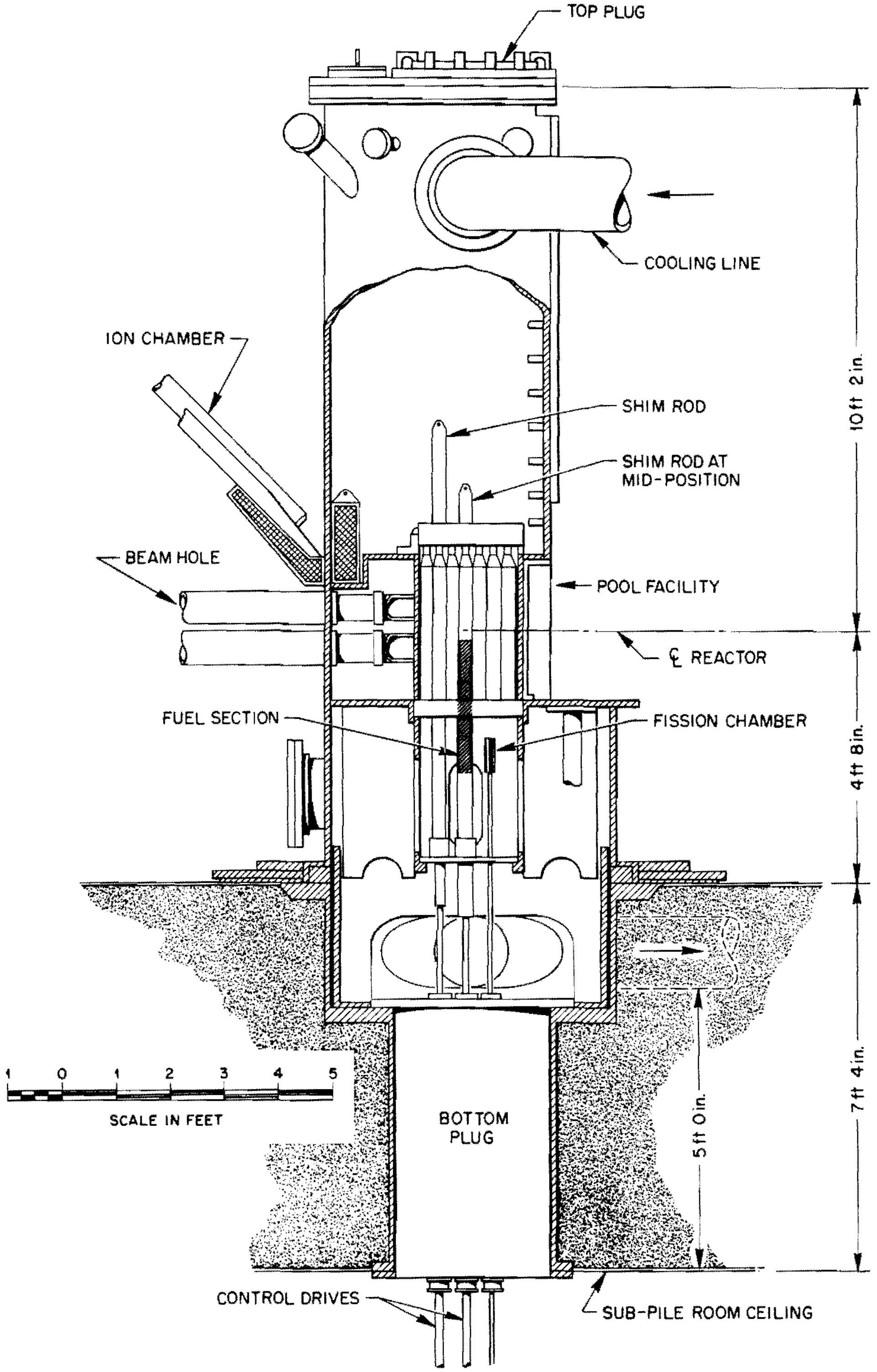

Figure 12. Cross Section Through ORR Showing Relative Location of Fission Chamber and Shim Rods.

encountered and the decrease in the counting rate with rod withdrawal further emphasized the need of a reliable chamber having proper response to shim rod movement.

Based on the results of a special experiment,[6] the development work on a dual fission-chamber unit to be located in the pool was given top priority. Presently, one of the two channels is undergoing tests to prove its reliability. It is anticipated that the dual fission chamber will be operating in about three months.

In an effort to minimize shutdown time due to a failure in the Log-N channel, an additional channel was installed; it is identical to, and independent of, the original channel up to the output of the period amplifier. A multistage SB-1 switch can be used to select one or the other channel, but not both simultaneously, as the operating channel. Only the channel thus selected will be connected to either the reactor control and safety system or the safety trouble monitor circuits associated with the period sigma amplifier. This is desirable to permit maintenance on one channel during normal operation.

The reactor safety system of the ORR has three independent safety-level channels which provide fast-scram protection if the power level increases to 150% of the normal value. The criterion for minimum instrumentation in safety-level protection is that at least two channels be operable. To provide electronic control action so that the reactor would never be operated on less than two reliable safety levels, modifications were made to the circuitry which provide a reverse of shim rods if minimum requirements are not met.

Process Instrumentation

The process instrumentation is an integral part of the reactor safety system. Continuous effort has been exerted to update it and provide reliability comparable to the nuclear instrumentation. With the increase in power to 30 Mw, the need was even more acute; and, during the modifications for the higher power operation, the following changes were completed:

(1) Initially, thermocouples were used as sensing elements for measuring the exit temperature of the reactor water. Resistance-bulb

thermometers, which are inherently more accurate and reliable, were installed in each leg of the exit water line. In addition to the increased reliability, this provides additional information relative to nonuniformity in the core loading; for example, with a core configuration using a nonuniform fuel loading, more heat may be generated on one side than on the other. The information transmitted is sufficiently important in relating core conditions that it is connected to the setback and slow-scram circuits of the reactor safety system. (A setback is defined as an automatic and controlled reduction in power via the servo control system. A scram is a complete shutdown by dropping the shim rods.)

(2) Initial installation included one differential-temperature channel using thermocouples installed in the reactor inlet and exit water lines. To increase reliability and to provide more accurate information, these thermocouples were replaced by resistance-bulb thermometers installed in both of the reactor exit water lines and in one of the inlet water lines. Due to possible nonuniformity in core loadings, the heat load through the two exit lines may be different, while the inlet sensing element measures an average due to proper mixing of the system water. The circuitry thus presents an average state of conditions. Serving as a back-up protector in providing temperature information about the reactor core, this differential-temperature channel was installed in duplicate and is connected to the reactor safety system to provide setback and slow-scram protection.

(3) Special tests[7] conducted during the initial approach to power to measure the surface temperatures inside the north facility, with the facility free of water and the reactor at 10 Mw, were invalid. However, similar tests under normal water-flow conditions through the facility gave results which compared favorably with design data. Instrumentation was installed to permit the routine readout of the flows through these facilities.

Major changes were made in the south facility during October, 1961, which affected the flow distribution in the facilities. Concurrent with these changes, instrumentation was installed to monitor the flows through the north and south facilities; and, since these are regarded as reactor operating parameters, the instrumentation is tied directly into the reactor safety system. Flow-monitoring instrumentation for an experiment test plug located in the south facility has an independent tie-in to the reactor safety system by way of an E-panel circuit since this is considered an experiment operating parameter. The E-panel is a method of tying an experiment into the reactor control circuit and consists of a multicontact switch which can be locked with a key.

(4) The cooling flow through the reactor core is measured by means of a venturi located in the reactor inlet water line. Instrumentation is provided by means of flow switches in order to produce a reactor setback or scram if minimum conditions are not met. This flow-measuring circuit is double tracked to provide a higher degree of reliability.

As additional protection for the flow-measuring channel and as an indicator of core condition, a channel to measure the pressure difference across the core has been installed. This provides a reduction in reactor power by way of a setback or scram if operating parameters are not maintained. This instrumentation will be activated by either a high differential pressure, which could be caused by either high flow or flow restriction through the core, or by a low differential pressure, which would indicate insufficient cooling flow.

Mechanical Controls

One or more of the control rods have dropped numerous times for "unexplained" reasons since the first few cycles of operation. Initially it was felt that the source of trouble was electronic; and, after modifications to the circuitry, the number of such rod drops decreased markedly. Figure 13 shows the distribution of unscheduled shutdowns through March, 1962. However, with the increase in water flow from 16,000 to 18,000 gpm, the number of spurious scrams increased. In addition, control rods failing to drop and sluggishness in the operation of the scram-latch mechanism of the control-rod drive have been experienced. These abnormalities necessitated a comprehensive investigation of the complete operation of the control-rod drive assembly. The control-rod drive assembly is shown in Figure 14. At the onset of drive

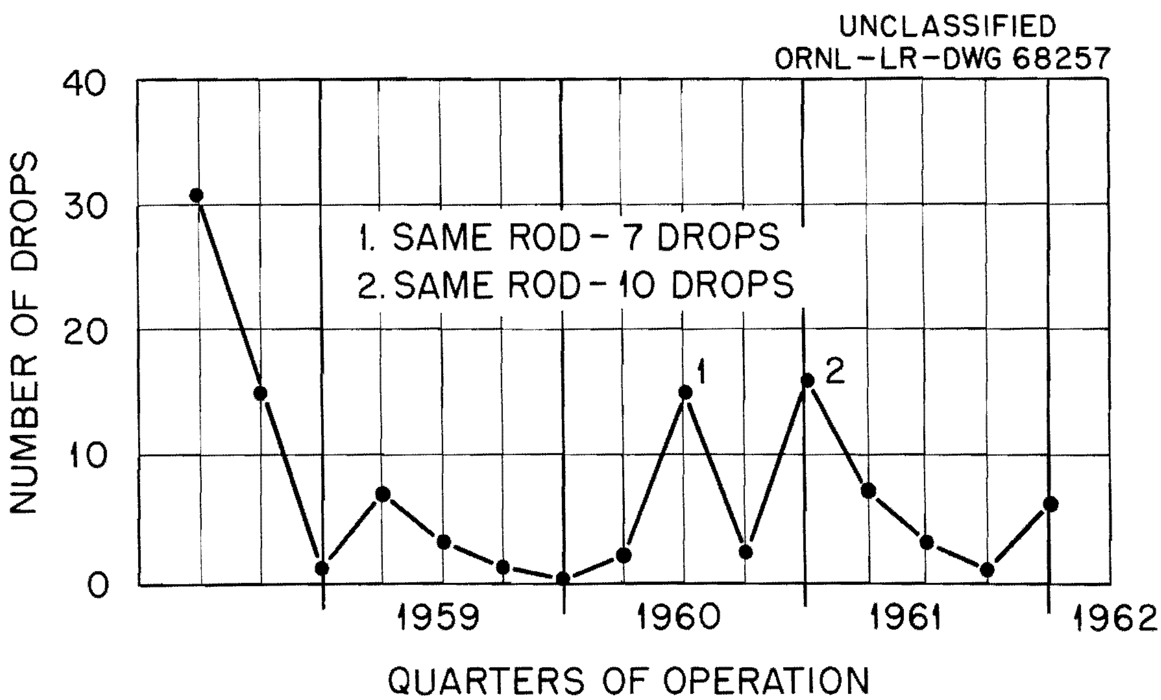

Figure. 13. Distribution of Unscheduled Rod Drops.

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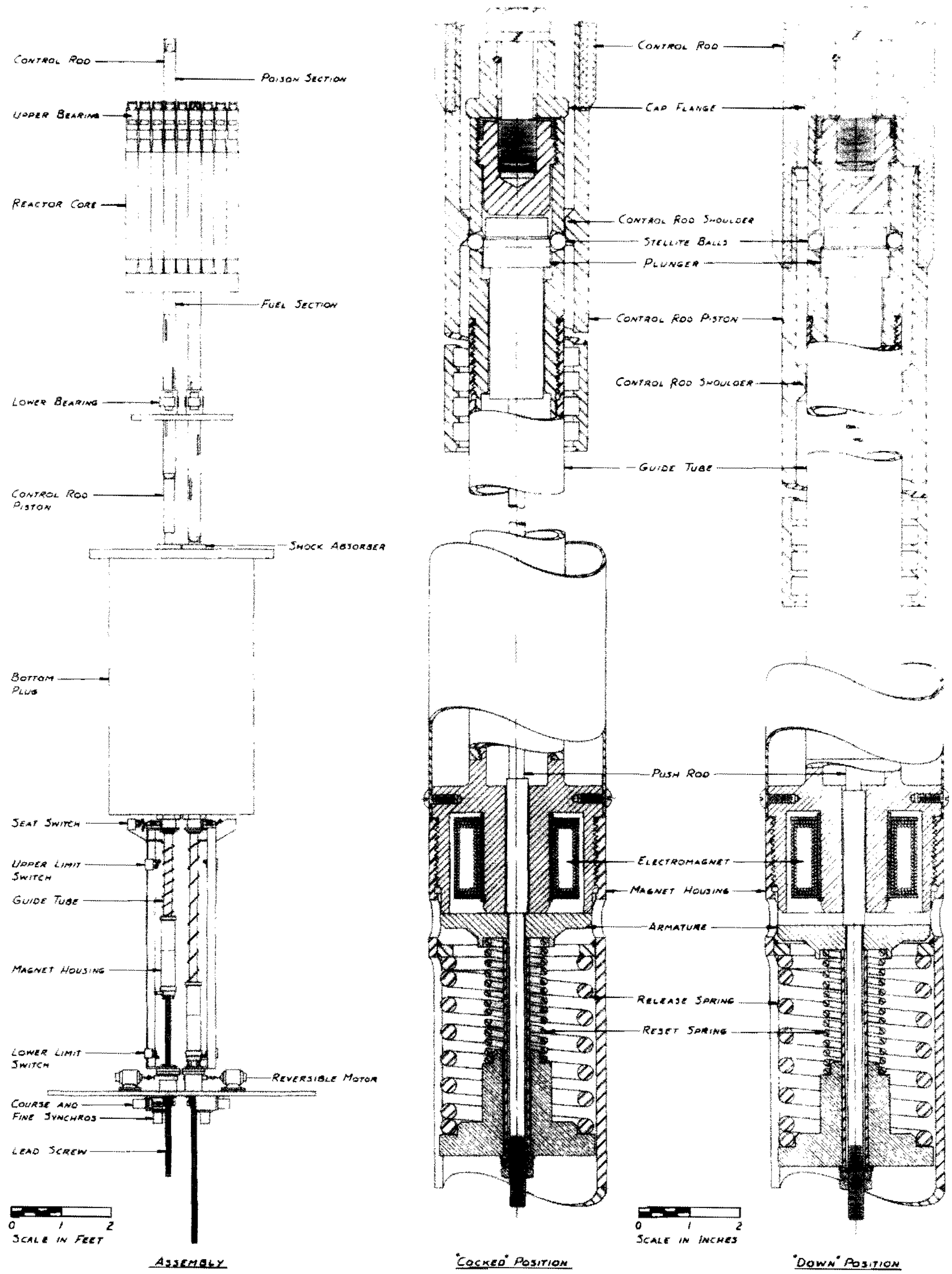

ORNL RESEARCH REACTOR MECHANICAL CONTROLS

Figure 14. Control Rod Drive Assembly.

troubles, a schedule of routine replacement of drive units was initiated, while a development program to determine the source of the trouble and how to alleviate it was started.

The problems encountered with components of the mechanical controls may be subdivided into three categories: (1) control-rod drive unit malfunctions; (2) locking of the hold-down arms; and (3) failure to seat of the beryllium-cadmium auxiliary shim rods which are located in core positions F-4 and F-6 and identified as rods No. 2 and 1, respectively. A "task force" has been assigned to study these problems. The scope of their work consists of: (1) investigating shim-rod drive unit failures; (2) providing technical assistance for proper maintenance and shop fabrication work on drive components; (3) providing technical inspections of all drive units during assembly and disassembly; (4) establishing a development program which will provide a trouble-free drive unit and test its components in a hydraulic test stand under simulated operating flow conditions; (5) investigating the problems associated with the beryllium-cadmium rods; and (6) providing a "positive-lock" mechanism for the hold-down arms.

Shim-Rod Drive Units

The troubles encountered with only the scram-latch mechanism can be categorically grouped as: (1) failure to release, (2) release for unknown reasons, and (3) failure to recock. However, the entire drive unit has contributed to the malfunctions. These, although they may or may not be related to those above, are: (1) water leakage around the bellows, (2) eccentricity of the magnet, (3) nonperpendicularity of magnet and push-rod extension, and (4) nonwaterproof coil and nondraining keeper.

A review of the abnormal functions experienced indicate the failure to release can be attributed to one or both of the following: (1) Indentation in the ball cage or the plunger and pockmarks on the balls. The contribution of this added frictional drag in the presently designed system can, with the added force due to high water flow, cause the push rod to fail in releasing. (2) In addition, foreign materials, such as aluminum shavings and sediment, have been discovered in this area. These foreign materials can also contribute to the malfunction. Figures 15a and 15b show, in exploded views, the plunger-ball relationship in the scram-latch area.

Quite a number of spurious rod drops have occurred. The exact cause of these incidents has not been determined, although several known things can contribute to this. Earlier, before technical supervision was present for the assembly and disassembly inspection, the units were assembled with no special effort made to identify component parts of the drive units. These components were used interchangeably, using an engineering drawing as an assembly procedure. Upon careful inspection of components, it was found that several components did not conform to dimensional tolerances as specified on the fabrication drawings. This, of course, has since been rectified; however, an accumulation of errors could have been a possible source of spurious scrams. Also when the shim-rod shoulder becomes worn, thermal expansion of the push rod can, in addition to the other contributors, exert sufficient force on the magnet to cause it to release. A third possible source of spurious scrams is improper contact between the magnet keeper and the magnet due to lack of perpendicularity on the shoulder of the push-rod extension. All these factors have been studied thoroughly, and steps are being taken to eliminate them as possible contributors.

The "failure to recock" action which has occurred several times can, in general, be attributed to increased friction in the scram-latch mechanism and/or the presence of foreign matter in this area. The inspection of a unit after it has failed to recock usually reveals one or both of these causes.

As has been mentioned previously, several actions are being taken to prevent these malfunctions. Continuous technical supervision for assembly and disassembly, as well as consultation on other abnormalities, are vital parts of the extended preventive maintenance program.

To combat the various troubles that have occurred in the drive tube, excluding the scram-latch area, several changes in procedure and slight modifications to components have been completed. For example, the O-ring seal at the expansion bellows is now tightened with a torque wrench. On several occasions water was detected leaking around the unit. This, of

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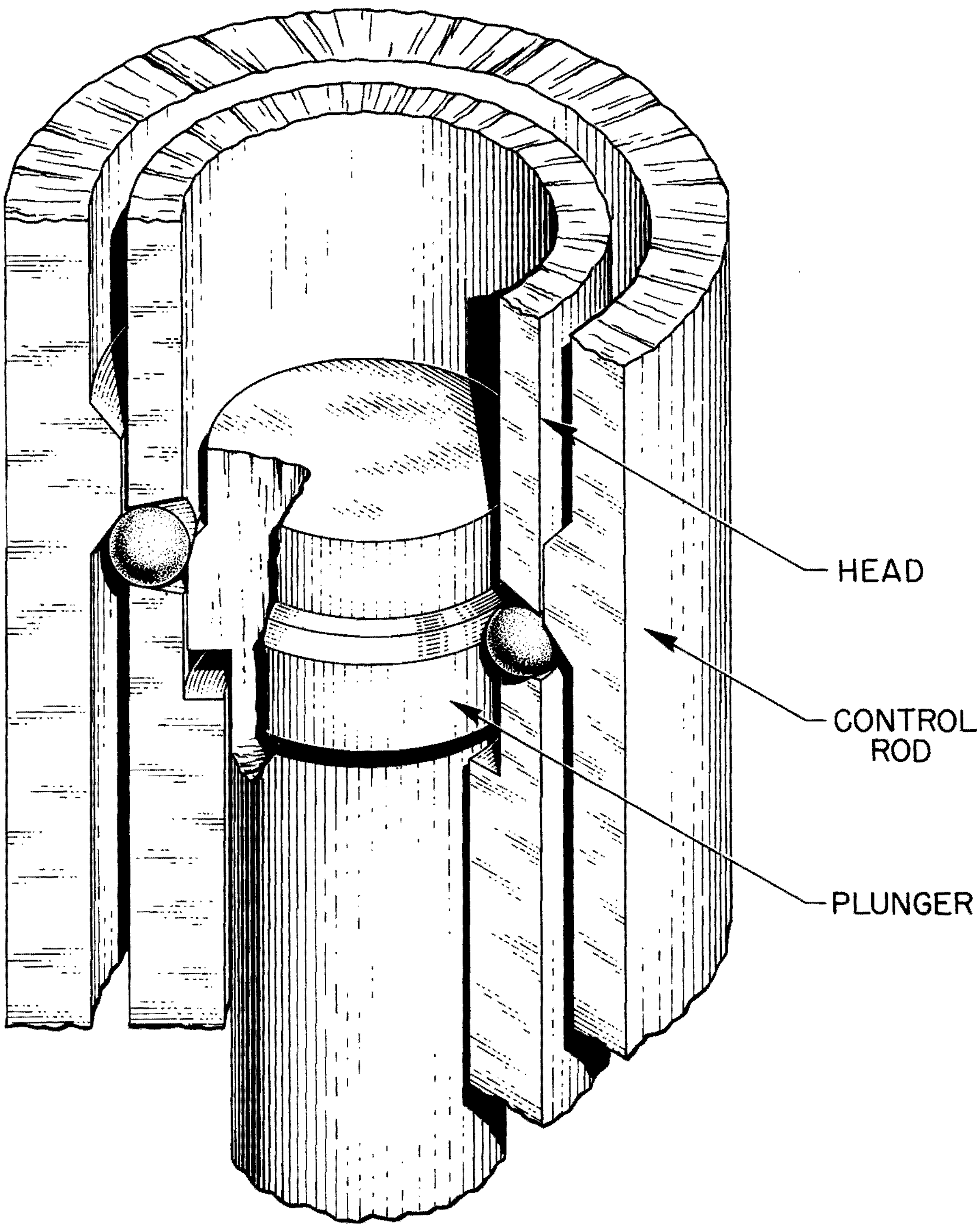

Figure 15a. Scram-Latch Area — ORR Shim Rod Drive.

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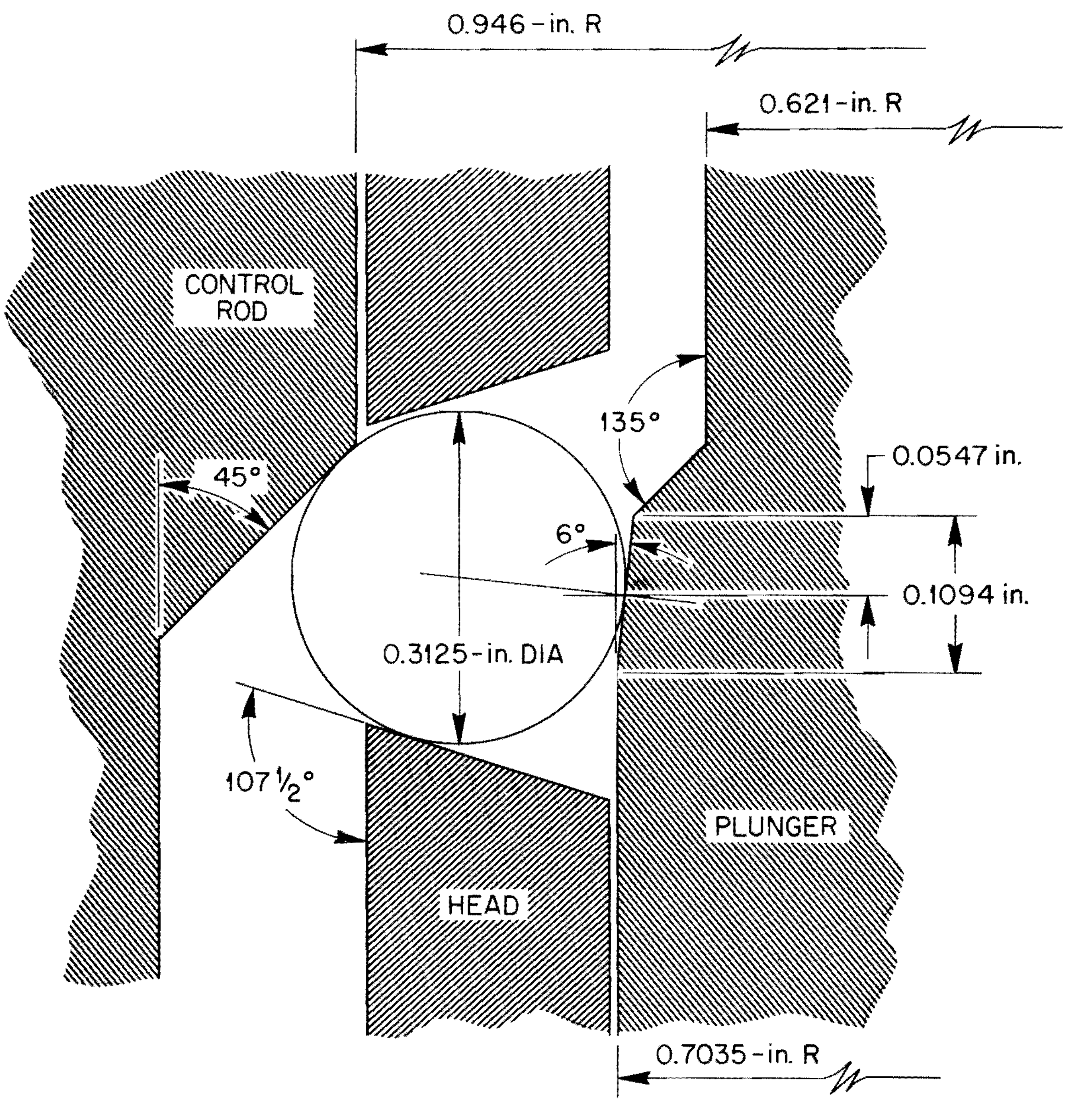

Figure 15b. Scram-Latch Area — ORR Shim Rod Drive.

course, could cause magnet trouble and did on several occasions prior to the installation of waterproof magnet coils. More rigid inspections are required on all components, and failure to meet the specified tolerance is the basis for rejection.

The task force has approached the shim-rod drive problem from two aspects--a modification of the present design to converge both magnetic and mechanical parameters to provide an acceptable unit[8] and that of using an altogether different type of force to recock the scram-latch unit. This new approach utilizes a gas at high pressure as the force to recock and hold the push-rod plunger in position, and a strong (preliminary tests indicate a force of 250 pounds) spring to accelerate the release. A prototype unit is undergoing tests in an out-of-reactor hydraulic system. Following the acceptance of a design, it will probably be installed in the ORR.

Until a new design has been proved acceptable, the interim corrective program has consisted of: (1) replacing all drive units with units containing plungers of known hardness (Rockwell C-56 or greater), waterproof magnet coils, and modified magnet keepers which prevent accumulation of water in this area in the event of leakage; (2) rigid inspections of all assembled drive units before installation; (3) replacing the initial push rod (actually a 1/4-in. tube) with a solid push rod; (4) modifying the lower end of the push rod by enlarging the lower section to about 5/8-in. diameter to minimize troubles encountered by elongation; and (5) using only magnets which have been checked to minimize the eccentricity and which have perpendicularity between the magnet face and center hole.

A rigid preventive maintenance program has been placed in effect along with the interim program mentioned above. This program consists of: (1) replacing a minimum of two drive units each major shutdown with acceptable rebuilt units which have been assembled according to a drawing prepared to serve as an assembly procedure and checking guide for the critical parts of the rod-drive system; (2) identifying each vital component of each drive unit to provide a chronological account of its behavior; (3) maintaining a complete record system relating the history of each component's service record; (4) performing critical adjustments only under the supervision of a member of the technical task force; and (5) maintaining a formal spare-parts record system.

Performance Evaluation of Shim-Rod Drives and Related Components

The shim-rod drive units and the many associated components must operate with a high degree of reliability to maintain safe operating conditions. Four cadmium-fuel shim rods were included in the initial control system; and, with the modifications for 30-Mw operation, two beryllium-cadmium shim rods were added.

The performance of the drive units under simulated and actual operating conditions is evaluated by checking the following action for each unit: magnet-release time, magnet-drop current, shim-rod drop time, and limit-switch operation. These tests are designed to reveal any significant trouble. Acceptable limits are specified in written procedures, and performance checks are completed prior to the beginning of an operating cycle or any time that a drive unit has been replaced or has had major maintenance.

Drive units have been replaced several times because of failure to perform within prescribed limits. The source of these difficulties has been described previously. Minor difficulties have been experienced with the two beryllium-cadmium shim rods. Although these troubles are not significant, credit for shutdown reactivity of these rods is not considered when loading the core. A study is under way to eliminate these conditions.

Hold-Down Arms

Two hold-down arms are in use in the ORR core area and are designed with a hinge-and-latch mechanism to permit access to the entire core area. These units function as: (1) a housing for the upper shim-rod bearings, and (2) a method of securing the fuel elements which are in adjacent rows to the shim rods. It is necessary to raise and lower these components to permit operations within the core region when movements of the core pieces are involved.

One major concerniin handling these units is that of ascertaining that they are positively locked in their lower position in order to prevent any interference with shim-rod motion. Some difficulty has been encountered in this respect since there is no visual method of inspection to check whether they are in the locked position. Because of this inadequacy, one shim rod stuck in the bearing while being raised. This produced no significant damage but is an indication of what might happen. Figure 16 illustrates this malfunction.

As a result of this concern, a new procedure was placed in effect to provide a physical means for checking a locked unit. It includes locking the unit, placing a special hook underneath the arm, and exerting an upward force in an attempt to move the unit. After the unit is secured, as indicated by this test, a manual test is performed on the shim rods. Each drive unit is driven up about 5 in., and each shim rod is manually lifted about 5 in. to insure freedom of movement through the bearings.

Periodically the shim rods are shifted within the core to provide uniform depletion and also to provide the maximum shutdown reactivity. After the completion of these relocations, it is mandatory that the control rods be completely inserted (i.e., actuating the seat switch) before lowering the hold-down arms. A similar situation to the one described above can easily be encountered if the hold-down arm is lowered on a shim rod that has not been fully seated. Such an experience was encountered when the shim rod was raised only about 1 in.; and, when the hold-down arm was lowered, binding ensued. Considerable trouble was encountered in freeing the shim rod; in fact, the shim rod was damaged during the removal. Detailed check sheets and proper administrative control has prevented recurrence.

It is important to note that a failure of a single hold-down arm can affect the operation of three control rods. Therefore, it is an absolute necessity that the operation of the hold-down arms be checked and declared locked and operable.

As an aid in providing positive assurance that the hold-down arm has locked, a prototype "positive-lock" attachment to the standard hold-down arm has been designed and fabricated. Further study of this design is being made by the development group assigned to control-rod drive study.

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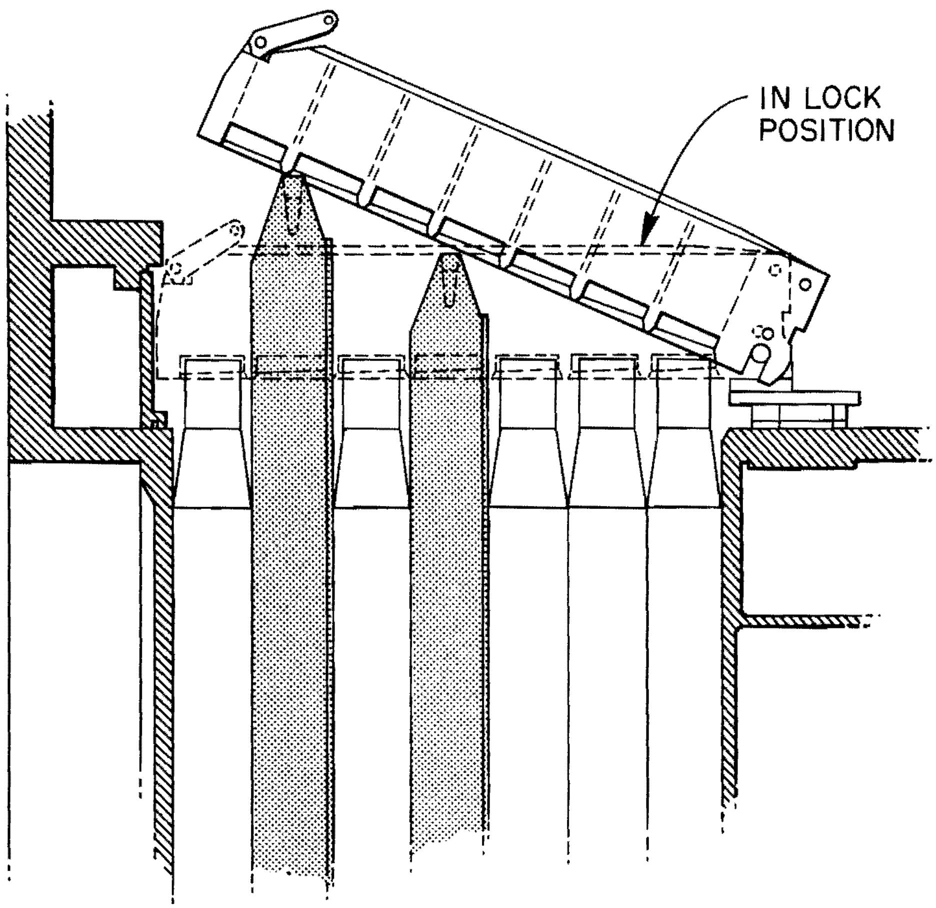

Figure 16. ORR Hold-Down Arm.

Shock Absorbers

The shock-absorber units, which decelerate the shim rods when they fall, are located in the bottom of the reactor vessel and are, because of location, a collection point for foreign matter which enters the reactor vessel. Since the operability of the reactor requires the shim rods to fully seat in these shock absorbers, it is of utmost importance that the rods move freely into them. On three occasions foreign matter has collected in a shock absorber and prevented the shim rod from seating properly. Neither event produced a serious condition since in each case removal of the rod from the core area was possible, and the replacement of the shock absorber was accomplished without incident. The foreign matter in each case was silt and materials which were unknowingly dropped into the reactor. For example, weld metal and several pieces of welding rod have been found. Once, a small screw which apparently became loosened from a tool was found wedged on the entrance of a shock absorber. This incident, involving a beryllium-cadmium auxiliary shim rod, would not permit the rod to enter the shock absorber. Because of this, the hold-down arm could not be raised in the normal manner; however, since the rod is worth only 1.98% $\Delta k/k$ for its entire travel, the rod was removed through the hold-down arm without unloading the fuel. Had this occurred with a fuel-cadmium rod, it would have been necessary to partially unload the core in order to permit removal of the rod.

Steps have been taken to minimize the dropping of anything into the reactor. Special emphasis has been directed toward all those who enter the pool; they are informed of the possible damage which can result. Also, the number of entry points to the reactor tank is minimized prior to starting work in the pool area.

Procedural Changes

As previously mentioned, it has been necessary in improving reliability and in adding the needed protection to make changes in the reactor control instrumentation and the reactor mechanical control assembly. To insure that these changes are not made hastily without undue thought and planning, a "check-and-balance" system has been initiated whereby a proposed change is reviewed by competent persons prior to incorporating these changes in the system. For example, a change in the reactor control instrumentation is reviewed by the ORR instrument engineer, the ORR reactor supervisor, the head of the Reactor Controls Department, and the Operations Division Superintendent; and, if acceptable, a formal document will be prepared and signed by these reviewers. The change is then incorporated in the control system. For a mechanical control change, a review is made by the group leader of the task force, the ORR reactor supervisor, and the Operations Division Superintendent. If acceptable, a formal change memorandum with the required signatures is prepared before incorporating the changes. The change memoranda become a part of the permanent record system of the ORR, and changes are reflected in appropriate drawings in order to maintain an adequate record.

To insure that all aspects of the reactor control instrumentation and mechanical controls assemblies receive the necessary checkouts consistent with good operating practices, check-out sheets have been prepared. During the shutdown period, between cycles of operation, a "hot" check of each recorder switch with its associated relays and circuits, a check of all electronic circuits, and a check of the limit switches of all drive units is completed by qualified instrument and operating personnel. Table 2 illustrates the major reactor component and instrument check-out areas. Any deviations from the criteria of operation must be resolved. It is the responsibility of ORR operations supervision to insure that all checkouts have been completed and are acceptable prior to power operation.

EXPERIMENT FACILITIES

The primary function of the ORR is to provide a research tool for the experimental program of the Laboratory and for AEC-sponsored programs. Due to the number, variety, and varying degrees of complexity of the experiments in the ORR, a separate presentation will be made on this subject.[9] A standardized review procedure is applied to each experiment during the design phase. This procedure, including the ORNL standards for acceptable materials, design features, and hazards review, is presented in another paper.[10]

Table 2. Reactor Component and Instrument Check

Items to be Checked	Frequency of Check	Purpose
Water flow conditions:	Bimonthly	Verification of the operability of circuit components
Reactor flow	Bimonthly	Verification of the operability of circuit components
Reactor ΔP	Bimonthly	Verification of the operability of circuit components
Pool flow	Bimonthly	Verification of the operability of circuit components
North and south facility flow	Bimonthly	Verification of the operability of circuit components
Annunciators--monitoring:	Bimonthly	Verification of the operability of circuit components
Nuclear and process instrumentation	Bimonthly	Verification of the operability of circuit components
Electronics:		Verification of the operability of circuit components
Log-N channels and associated period channels	Prior to reactor startup	Verification of the operability of circuit components
Safety-level channels	Bimonthly	Verification of the operability of circuit components
Count-rate channels and associated period channels	Bimonthly	Verification of the operability of circuit components
Experiments	Bimonthly (minimum) with a complete check prior to operation of any experiment	To insure that all instruments are working
Interlocks in reactor control circuitry	Bimonthly	To insure operability of circuit components
Shim-rod drive units:		
Routine replacement--two of six units	Bimonthly	Component inspection
Shim rods:		
Magnet drop current	Bimonthly	To verify operability and numerical values
Magnet release time	Bimonthly	To verify operability and numerical values
Time of flight	Bimonthly	To verify operability and numerical values
Limit switches	Bimonthly	To verify operability and numerical values

The ORR has four general types of experiment facilities. These include six horizontal beam holes which penetrate the east biological shield and terminate inside the reactor vessel at the core housing; two large engineering facilities, approximately 25 x 19 in., which penetrate to the core housing on the north and south sides; the flat poolisde face which permits access to the core region outside the reactor vessel on the west side; and a variable number of in reactor positions, access to ten of which may be gained through flanges in the reactor tank top. Figure 17 illustrates these facilities.

The number of experiments which are operating in the ORR totals 35. These occupy about 88% of the facilities. Figure 18 indicates the research assignments and fuel loading on March 31, 1962.

Operating history of experiments in the ORR indicates that the experiments are well planned, and the resulting inconveniences to Reactor Operations are minor. However, there have been a number of instrument difficulties which resulted in power reduction to the reactor. Figure 19 indicates the distribution of unscheduled shutdowns due to experiments. In addition, several minor "unusual occurrences" have been experienced which resulted in increases to the normal background level. Even though all experiments are reviewed intensively and the installation procedure is checked by competent personnel, component failures and human error are factors which have to be considered. Periodically, all experiments are reviewed again in light of operating experience in an effort to reduce all possible sources which may contribute to unusual occurrences.

A very brief description of experiments presently in operation or which will be put into operation in the immediate future are listed below.

(1) Horizontal Beam Holes: These experiments are classified as permanent and include experiments on time-of-flight measurements for neutron cross-section study, neutron-diffraction study, neutron spectroscopy, and magnetic analysis of fission fragments.

(2) North Engineering Test Facilities: An in-reactor thoria slurry loop to study production of U^{232} has recently been put into operation. An in-reactor, homogeneous, uranyl-sulfate loop operated successfully for

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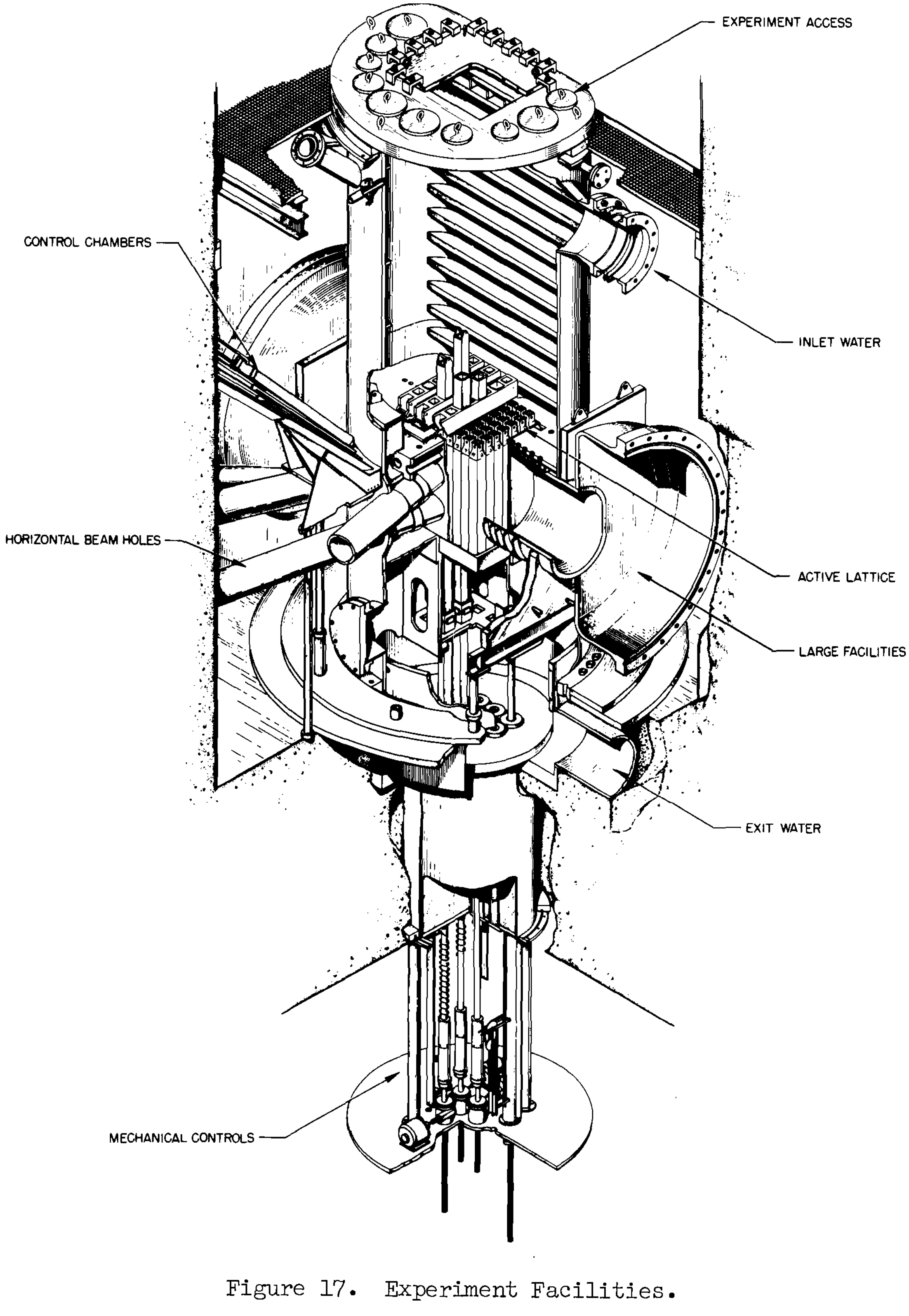

Figure 17. Experiment Facilities.

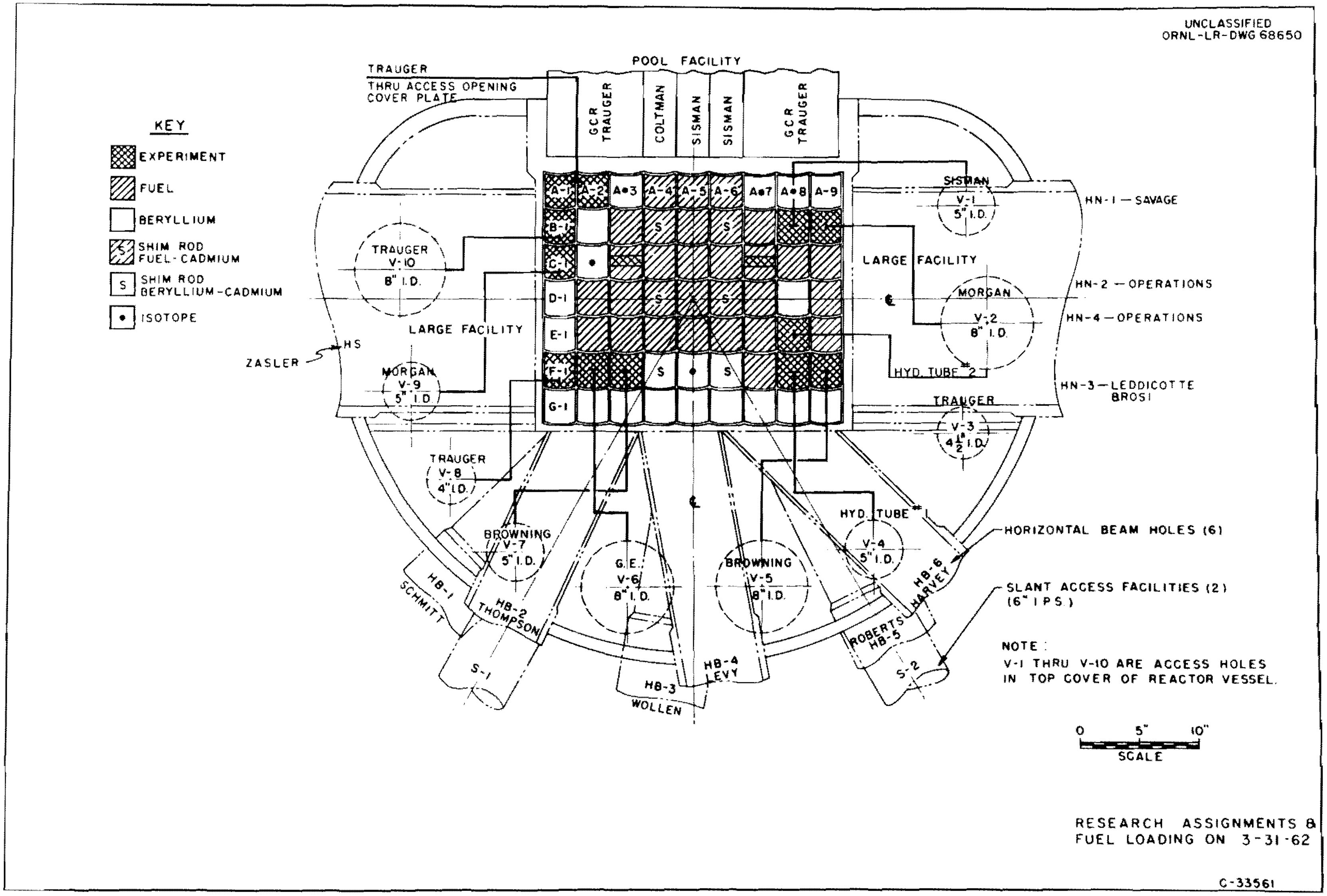

Figure 18. Core Configuration Showing Research Assignments and Fuel Loading 3-31-62.

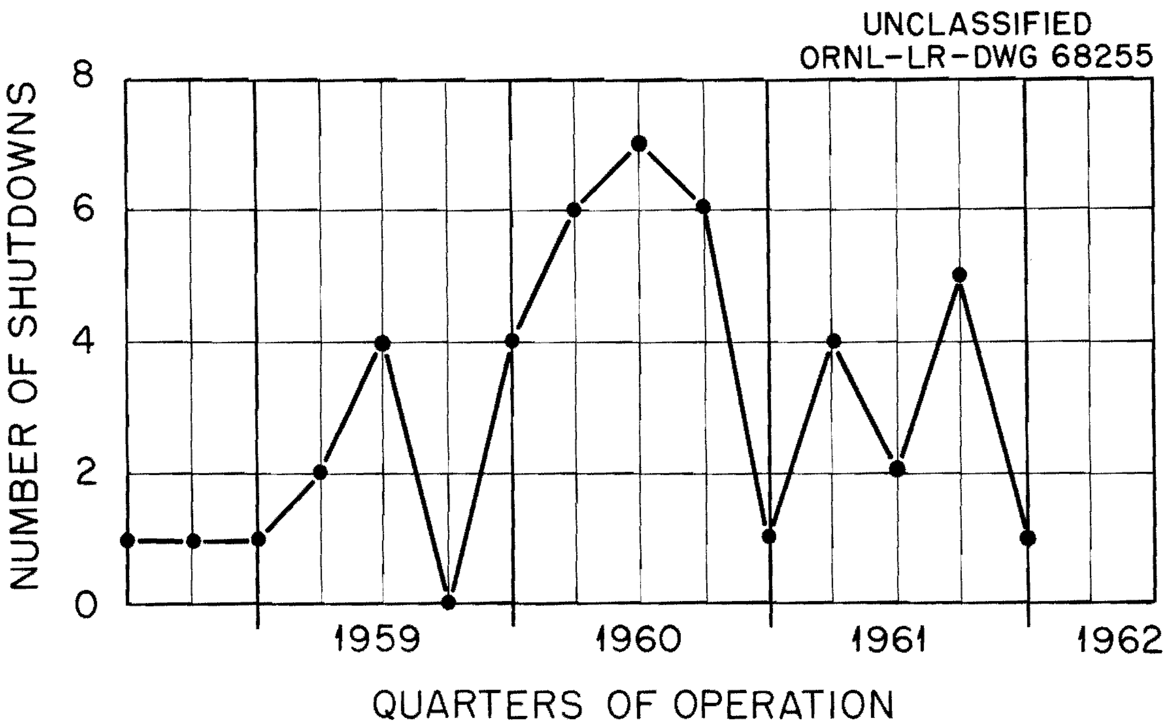

Figure 19. Distribution of Shutdowns Due to Experiments.

the expected duration of about six months. A pneumatic tube which enters the core region through this facility permits study of extremely short-lived materials.

(3) South Engineering Test Facility: Work is in progress for completing equipment installation associated with a gas-cooled fuel loop to be operated here. Scheduled operation of the experiment is about six months away.

(4) Poolside: The experiments located at this facility are of two major types--a gas-cooled capsule study program using stagnant gas and a materials-damage study program.

(5) In Reactor: Experiments in the core are of a varied type. However, they can be grouped as fuel studies, material-damage studies, radioisotope production, and He^6 recoil studies.

WATER SYSTEM

The ORR water system, as initially designed and constructed, consisted of three independent systems; a reactor primary, a pool primary, and a pool secondary system. Figures 20 and 21 illustrate them. Heat removal from the reactor system was accomplished by passing ~16,000 gpm of water through the core and using air-cooled heat exchangers to dissipate the heat. The pool system used a shell-tube heat exchanger with the primary system on the tube side and a secondary loop on the shell side with an induced-draft cooling tower for heat dissipation.

Shortly after full power operation (20 Mw) was attained, it became obvious that the air-cooled heat exchangers did not meet performance specifications, In addition, a serious wear problem, illustrated in Figure 22, developed in the heat exchangers due to vibrating turbulators in the tubes. A turbulator is a long, spiraled, metal plate and is used in this application to effect a larger heat-transfer area. An attempt, as illustrated by Figure 23, by the manufacturer to correct the performance deficiency proved unsuccessful; however, the wear problem was minimized by changing the method of securing the turbulators in the tubes. As a result of the cooling deficiency, a reduction in operating power to 16 Mw was required during the summer months, while cool weather permitted 20-Mw operation. The reactor was operated under these conditions until July, 1960.

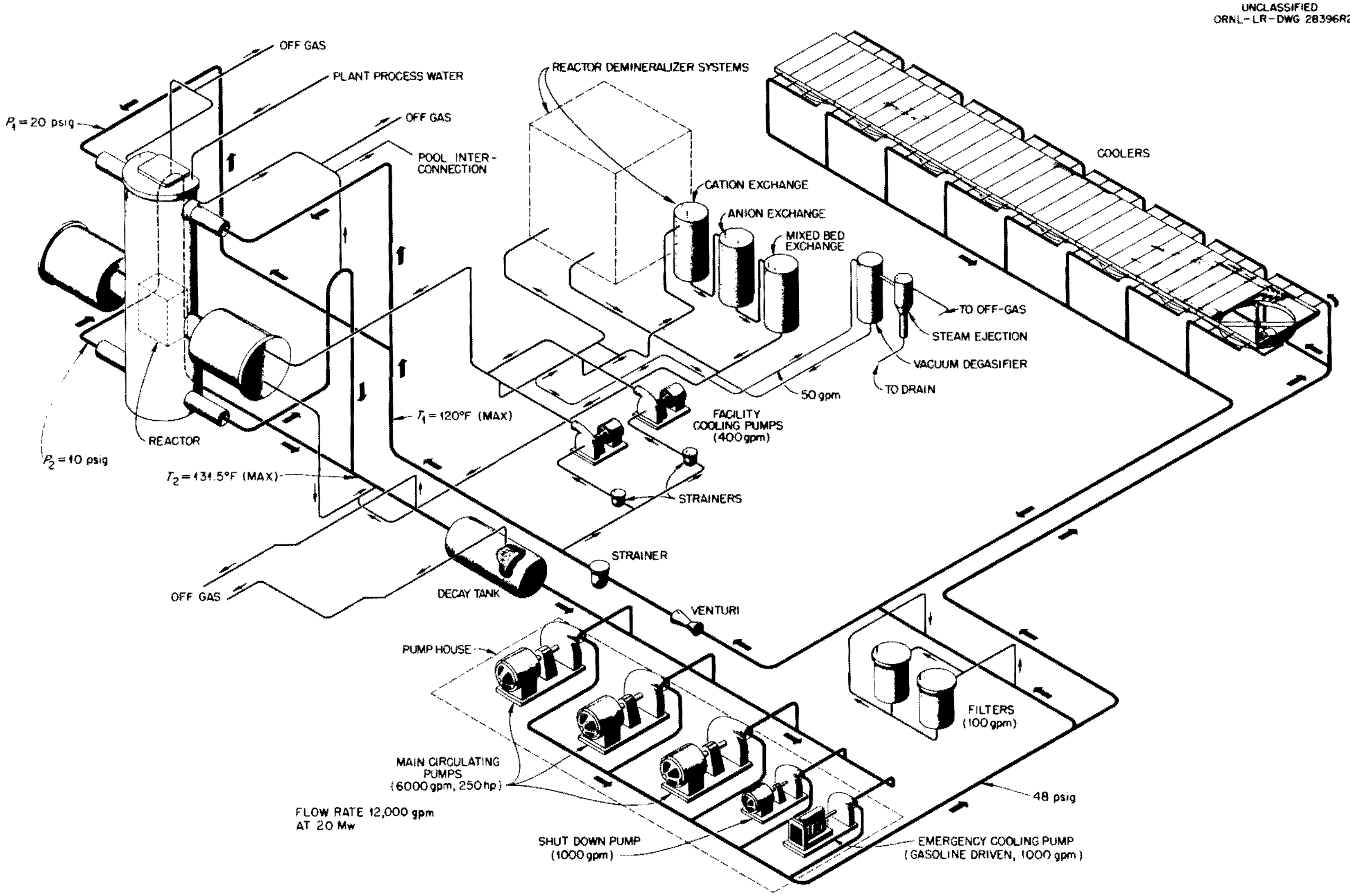

Figure 20. Reactor Cooling System at 20 Mw.

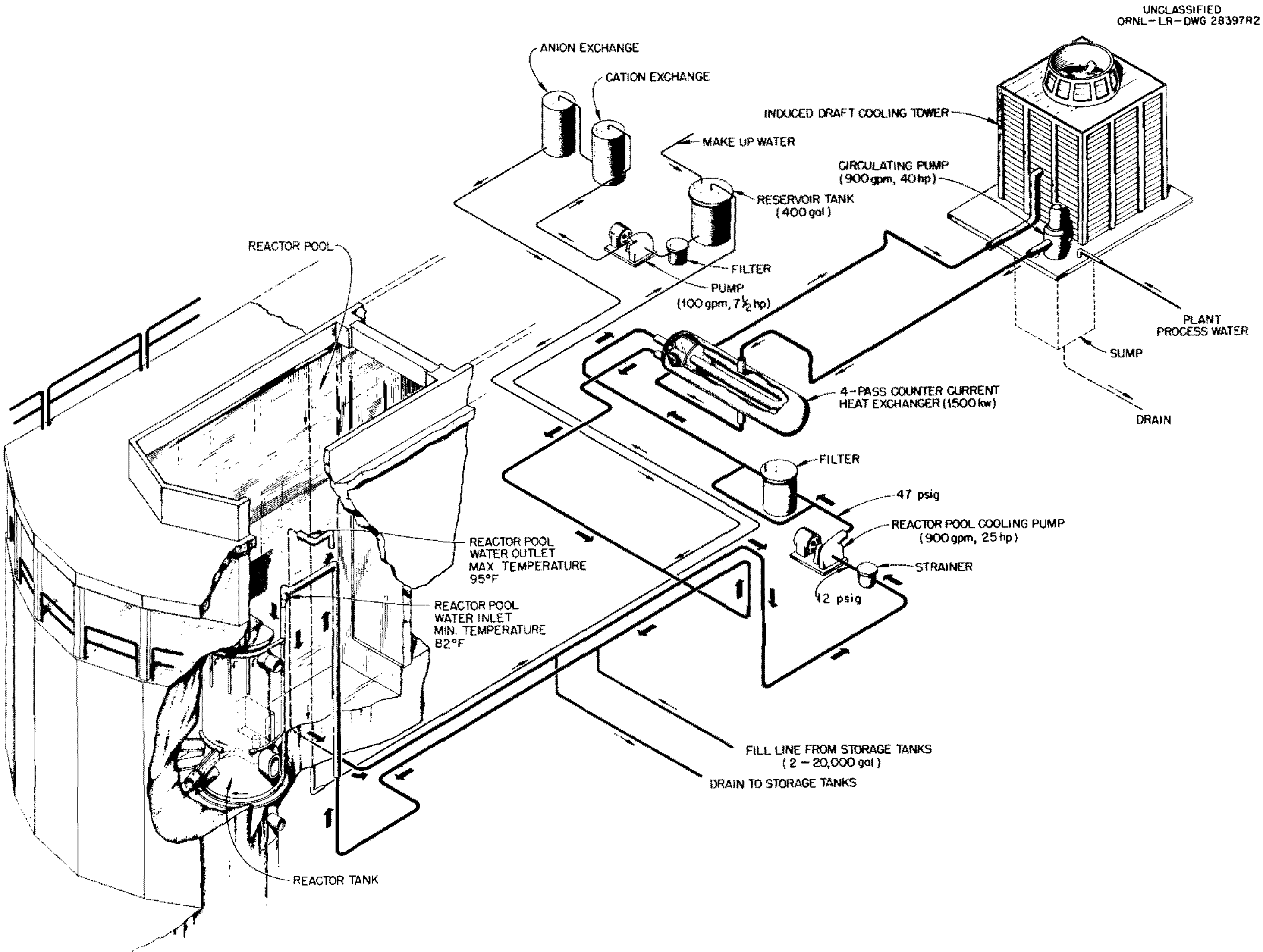

Figure 21. Reactor Pool Cooling System.

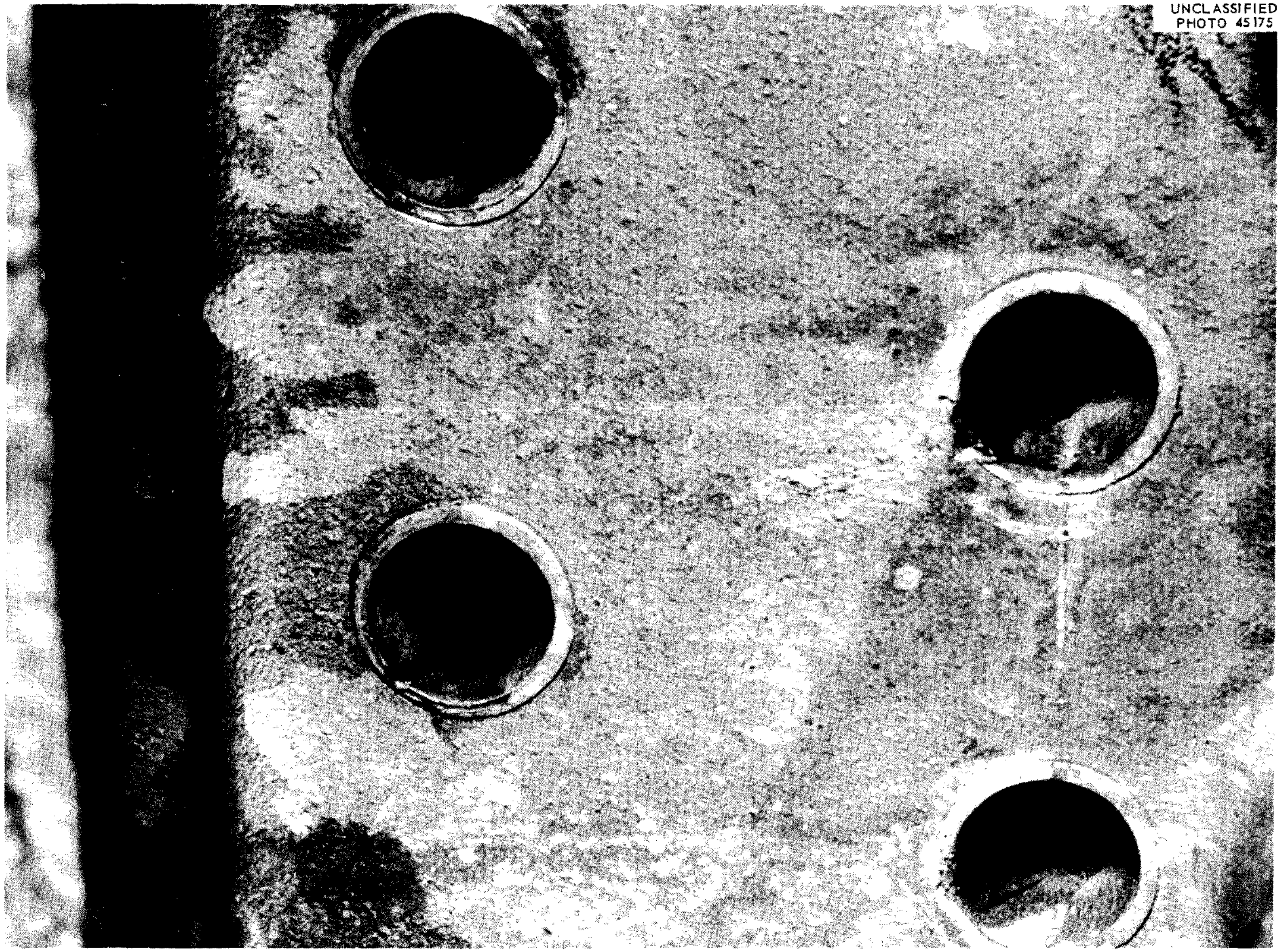

Figure 22. Tube Damage in Heat Exchangers.

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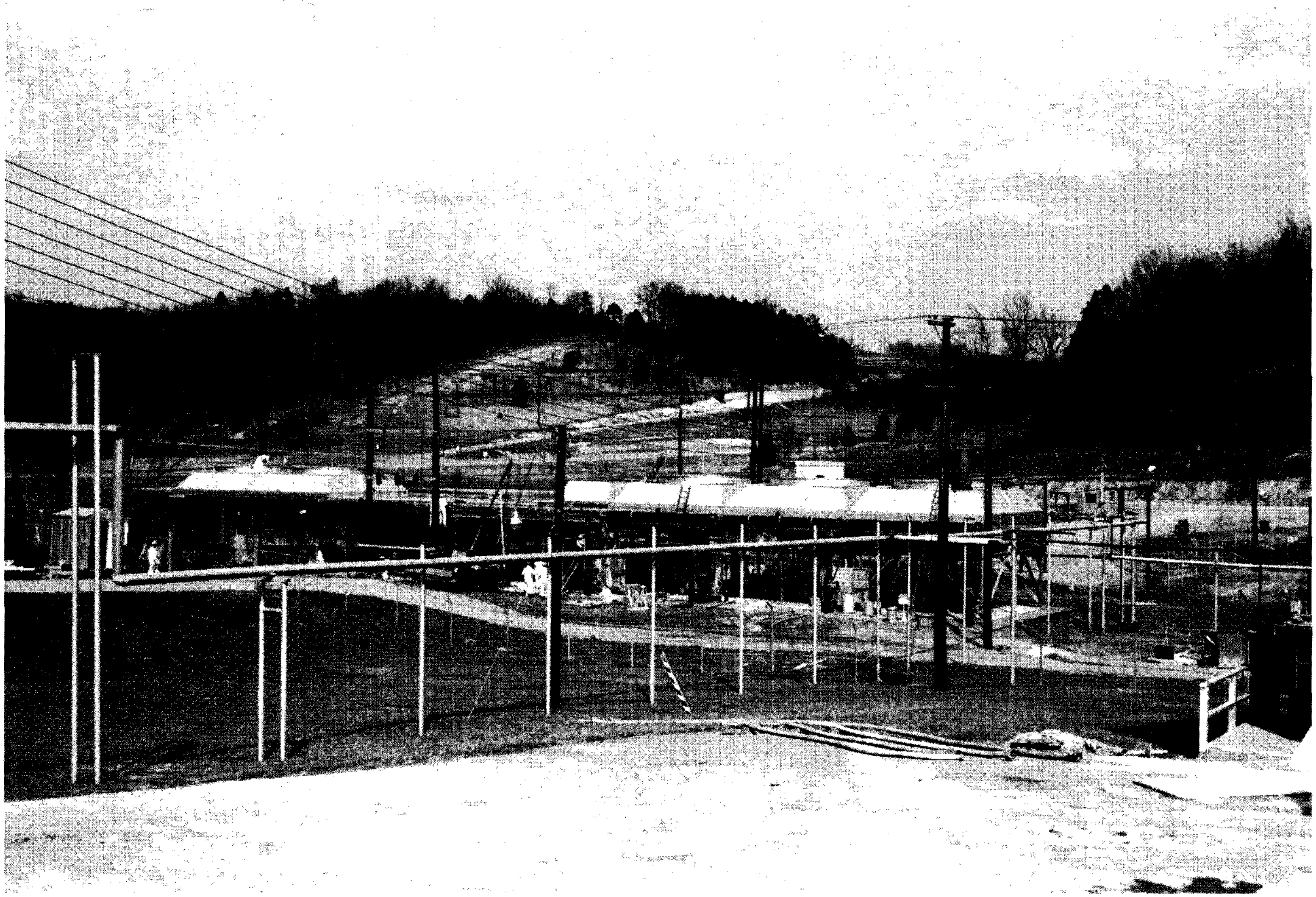

Figure 23. Air Cooled Heat Exchangers.

Minor changes in the controls of the secondary system have been necessary in order to provide better temperature control of the primary water. This is important because the pool water is used to provide cooling to the external side of the beam-hole tubes. Since the beam-hole tubes span a water volume from the pool structure to the reactor vessel, it is important to maintain a near-uniform temperature to minimize thermal stresses in the liners.

Modifications to Provide for 30-Mw Operation

To facilitate the research program at the Laboratory, it was decided to increase the operating level to 30 Mw. Therefore, it was necessary to perform major modifications in the primary cooling systems in order to provide the needed heat-removal capacity. The following major changes were made.

(1) Four stainless steel (type 304), shell-and-tube heat exchangers, connected in parallel, were added to the system in parallel with the existing air-cooled heat exchangers. Valving was included to permit the use of either or both types of exchangers However, for normal 30-Mw operation only the shell-tube-exchangers are used.

(2) A 24-inch, wafer-type, butterfly control valve using an air-motor positioner was installed in parallel with the four shell-and-tube heat exchangers. This control valve is used to regulate the flow through the shell-and-tube heat exchangers and provides stable temperature conditions in the reactor primary water.

(3) A crossflow, two-cell, cooling tower was added as a heat sink for the reactor secondary system. Circulation is provided by two pumps driven by 300-hp motors with a third pump driven by a 250-hp motor as a stand-by. A 12-in. butterfly control valve, similar to the one described in item 2, controls the amount of water bypassing the tower.

(4) An intricate control system combining the effectiveness of cooling-tower water temperature and the reactor primary water flow through the heat exchangers was installed. A detailed discussion is given in the ORR operating manual.

The 30-Mw cooling loop is shown in Figure 24.

Several minor difficulties have been encountered with components of

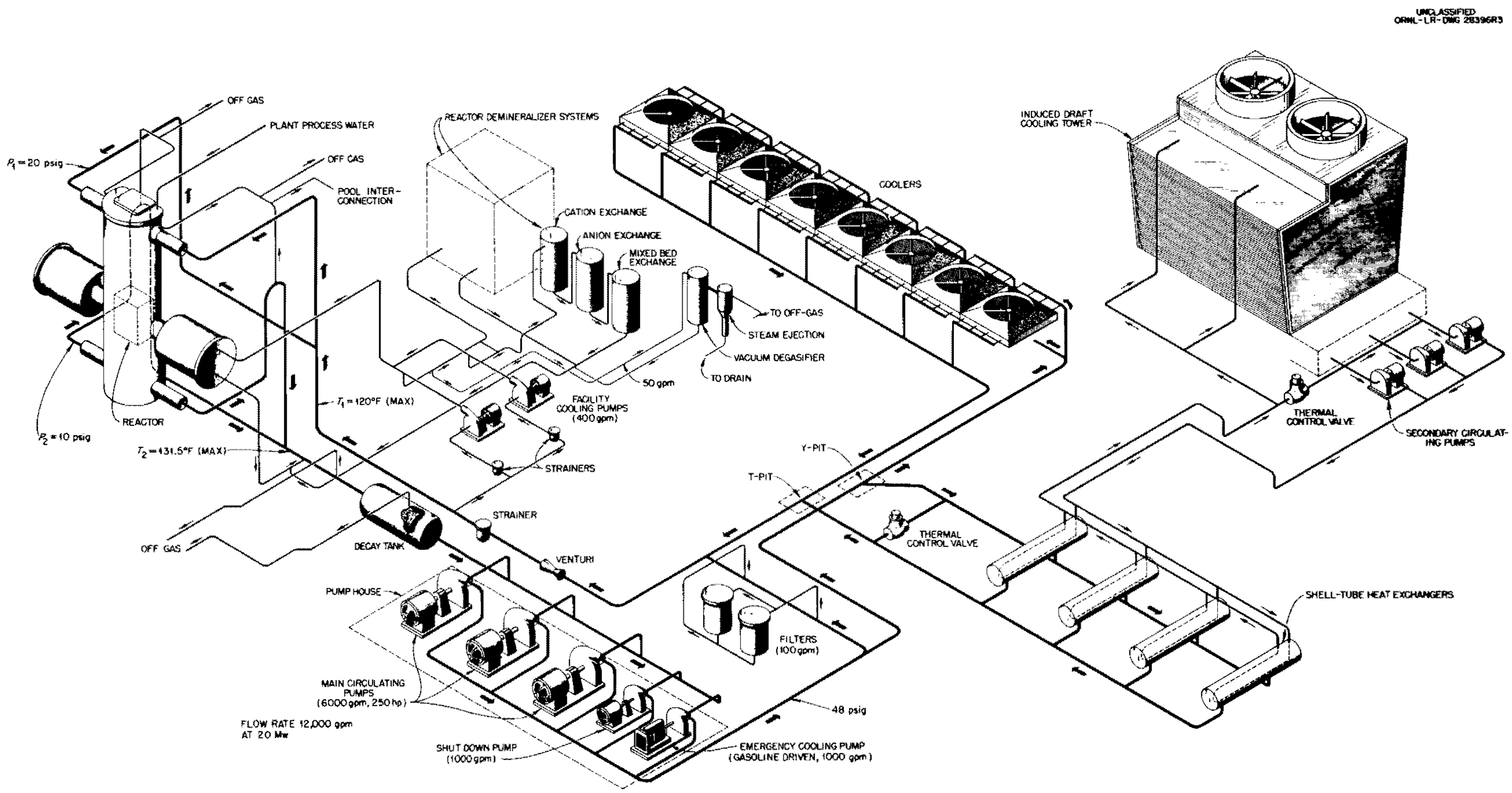

Figure 24. Reactor Cooling System for 30 Mw Operation.

the water system. The more significant of these problems, together with the methods used to overcome them, are discussed below.

Corrosion in the System

Since the primary systems of both the pool and reactor contain aluminum components, extremely close observance of the corrosion rate is necessary. Sample coupons of the different aluminum alloys of which the system is composed are continuously exposed and periodically inspected. The results so far indicate that the corrosion rate of the aluminum piping, liner, and core components is not severe. The corrosion rate is <1 mpy.[11]

In the pool secondary system, which uses chemically treated process water, the corrosion rates are also very low. Since the shell-and-tube heat exchanger of the pool system is made of aluminum, it is also a point of concern. Corrosion rates measured on specimens exposed to the secondary water showed maximum corrosion rates of approximately 1 mpy.[12]

Corrosion rates of aluminum plate that is in contact with concrete or where aluminum piping insulated with a fibrous material is encased in concrete are not quite so favorable. In July, 1958, a section of 6-in. aluminum piping (63ST-6AL) was replaced because it leaked water. Inspection revealed that the outer surface was badly pitted with some holes penetrating the pipe wall. The corroded section of this pipe is shown in Figure 25. The line was enclosed in one inch of glass-wool insulation surrounded by a waterproofed cardboard shell and then embedded in concrete. This failure is attributed to galvanic corrosion promoted by the water-soaked glass wool.

As a result of this failure, a major investigation was started to provide a dry environment for the principal water lines. Core holes were drilled through the concrete to the annular spaces, as shown in Figure 26. A vacuum system was provided to evacuate these regions. Condensate collections from all points indicated the environment to be acceptable until early in 1961 when the condensate collection rate on the south inlet reactor water line increased by a factor of ten. A helium leak check on this line made in May, 1961, gave positive indication that there is a leak; however, it was impossible to evaluate the

Figure 25. Corroded Section of Aluminum Pipe.

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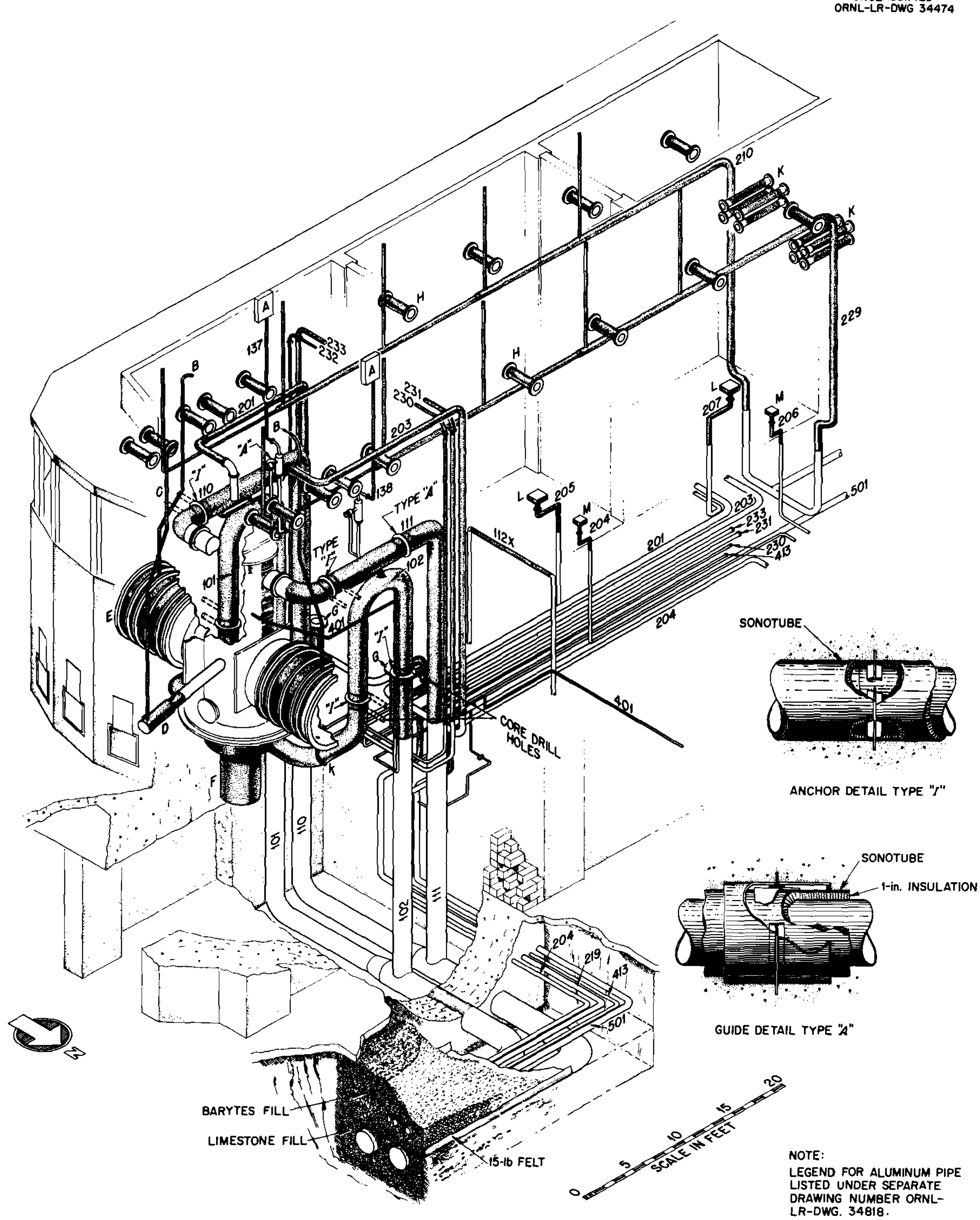

Figure 26. Major Water Lines.

exact size or location of this leak, based on this test. Present collection rates indicate that the leakage is now only about twice as much as the amount of normal condensation. Observation is being continued on a routine basis by cold-trap collections from this area.

Shortly after the failure of the 6-in. aluminum line, due to corrosion pitting, a number of test stands containing sections of aluminum pipe subjected to different environmental conditions were placed in operation. This was an attempt to gather information in order to enable predictions of line failure to be made since the tests duplicate conditions which exist in the ORR structure. Temperature-controlled water is recirculated through the aluminum piping while the outside of the aluminum is wetted. Periodic inspections have been made on the pipes. The first inspection was made about four months after the system was placed in operation and revealed traces of pitting. A second inspection, made about eight months later, indicated severe pitting on two units: one where the aluminum was exposed to wetted concrete and one where the aluminum was exposed to wetted fibrous glass. All other units appeared to be free of corrosion, although some were discolored. Subsequent inspections indicated no appreciable change in pitting.

During the shutdown of February 26, 1962, a leak in the pool liner was found. A detailed inspection revealed several small holes in the pool liner in the area where a 6-in. pool water line penetrated the liner. A sample of the liner was removed for inspection and testing. Preliminary inspection showed severe pitting on the side which was in contact with the concrete. This area of aluminum-concrete was also water soaked. A quick repair was made by welding an aluminum plate on the pool side to cover the affected area. A line was also attached utilizing a vacuum system to collect condensate. After a few hours of pumping, the rate of condensate collection subsided to a level which is about equivalent to air leakage. Pumping on this area is being continued. A complete inspection of the pool liner is being made, using ultrasonic means for detecting pitting, etc. Also, consideration is being given to installing lines at several locations to permit continuous pumping on the concrete-aluminum side of the pool liner.

Water Hammer: Cause and Prevention

The check valves located on the discharge side of the main cooling pump have been the source of several incidents of water hammer in the system. Only one incident was severe enough to create shock waves that damaged the system. This incident occurred during the performance of a series of tests to obtain data to be used in making an analysis of control problems. Upon subsequent failure of the primary by-pass valve and the immediate shutting down of the pumps, the check valves slammed closed, thereby generating a shock wave that ruptured the neoprene gasket between the reactor tank top and the access cover. Detailed inspections and measurements indicated no further damage to any components. As a result of this incident, three changes were made: (1) an oversized air operator was installed on the butterfly valve, (2) "nonslamming" check valves are being procured, and (3) a change in operational procedure for shutting down pumps has been placed in effect which requires the motorized valve on the pump discharge to be closed before stopping the pump.

Heat Exchangers

The air-cooled heat exchangers, as previously discussed, did not meet performance specifications; and the manufacturer was apparently unable to rectify the inadequacy. This feature and the fact that a large area would be subjected to a high-radiation field if a fuel element should rupture prompted the decision to install shell-and-tube heat exchangers in an earth-shielded pit for 30-Mw operation.

The operation of the shell-and-tube heat exchangers on the reactor system has not been without incident.

During January, 1962, radioactivity was detected in the reactor secondary water system. This, after evaluation, prompted a reactor shutdown to determine which heat exchanger was leaking. The procedure followed was: (1) all heat exchangers were isolated from the secondary system; (2) any pressure changes on the secondary side of the units while flow was maintained through the heat exchangers on the primary system were noted; and (3) the water on the secondary side of the units was sampled and analyzed for changes in radioactivity in the water. Both steps 2 and 3 aided in locating the leaking unit. A further test, which included removing the head section on the secondary side and pressurizing the primary side, located the exact source of the leak. Two tubes which had broken at the tube sheet were then plugged, since it was not feasible to replace the tubes at that time. Operation is continuing, using the repaired heat exchanger, while further investigations are being conducted to determine the cause of failure. Since the repaired unit was placed back in service, no radioactivity has been observed in the secondary system water.

Twice, the pool cooling water heat exchanger has caused concern. In November, 1958, on a routine inspection of the tube bundle, two small holes were found that penetrated the tube wall. They were apparently caused by the vibration of small rocks which were found in the shell of the heat exchanger. The holes were repaired by welding; also, some minor scratches, probably caused during the removal of the tube bundle, were repaired. Welds on the baffle-plate-to-tube sheet were cracked across their entire length. The welds were also repaired before reassembling the heat exchanger. A considerable amount of debris was found in the heat-exchanger shell and on the external tubes near the U-bend. The tube bundle and shell were cleaned before reassembly. In order to reduce the deposition in the shell and on the exterior tube bundle, a routine purge of the secondary section of the heat exchanger was established, and a routine inspection of the tube bundle was scheduled on a semiannual basis.

The performance of the heat exchanger decreased in April, 1961. During a routine inspection of the unit during May, 1961, the interior of the tubes (i.e., the primary side of the heat exchanger) was found to contain a foreign substance similar to filter media, and the exterior of the tube bundle appeared to contain a significant amount of foreign matter, as shown in Figure 27. Previous to the inspection it had been decided to clean the exterior of the tube bundle and the shell section with a special cleaning solution recommended by the Laboratory corrosion group. This cleaning was completed and was effective in removing the debris from both the exterior of the tube bundle and the interior shell

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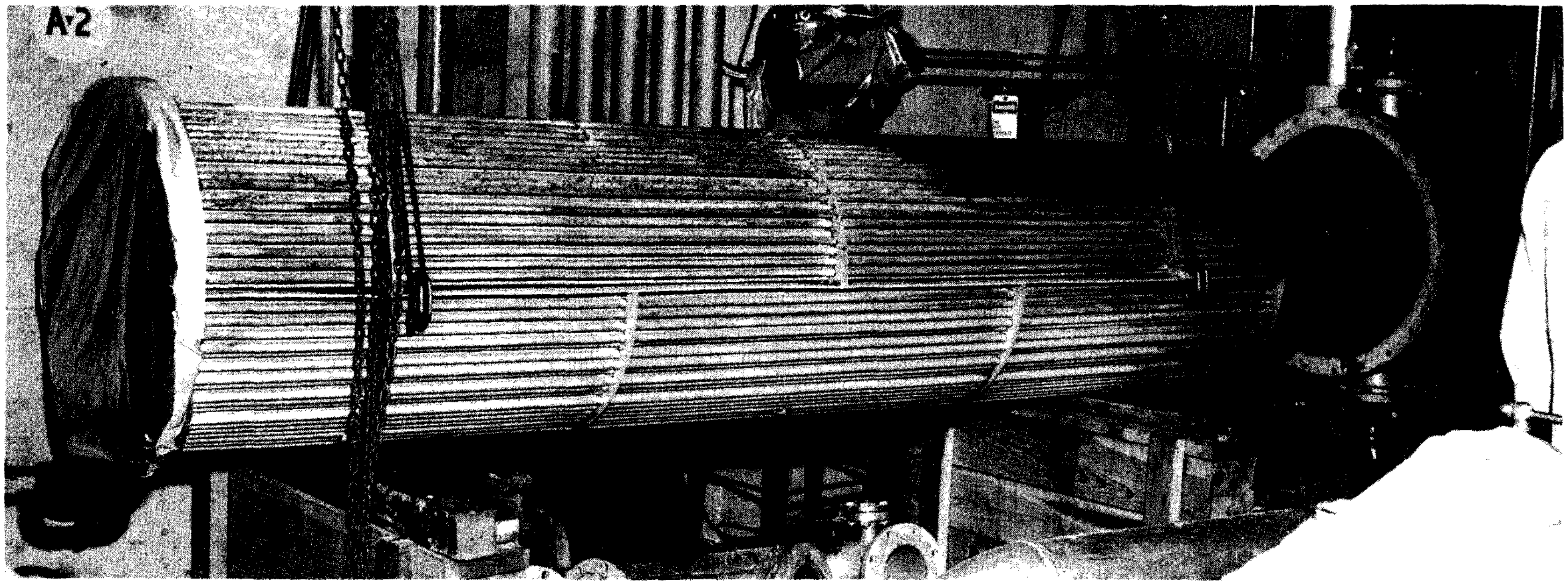


Figure 27. Pool Heat Exchanger.

section. The interior of the tubes was cleaned by flushing each tube individually, loosening the foreign matter with a test-tube brush, and then flushing it again with process water. The results of the cleaning operation were successful as indicated by an increase, to about normal, of the heat-transfer coefficient of the heat exchanger.

The foreign matter removed from the interior of the tubes was examined by members of the Biology Division; and they showed that it was bacterial and, after examining samples of anion resin on the bypass demineralizer, helped trace the trouble to the demineralizer column. Upon recommendation from the resin manufacturer, the anion resin was treated with a quaternary amine type of bactericide. These treatments, along with routine inspections of the heat exchanger, are being carried out on a semiannual basis. Subsequent inspections of the tube bundle show the treatment to be effective.

Even though demineralized water is used in both the reactor primary system and the pool primary system, and in each system a by-pass demineralizer is employed to maintain purity of the water, significant radiation levels are encountered. A comparison of the levels at 20 Mw and at 30 Mw is depicted in Tables 3 and 4. Typical radionuclides in the system are listed in Table 5. These tolerable levels of radioactivity are maintained through the use of bypass ion exchange columns. For the reactor system, two complete units with a capacity of 80 gpm each are provided. Normally only one unit is in service with the remaining unit on stand-by. For the pool system, one complete unit has been provided which has a flow capacity of 100 gpm. Sufficient time is available during reactor operation for the regeneration of this unit before appreciable change in water radioactivity is encountered. All columns are regenerated in place. Demineralizer performance is summarized in Table 6.

The demineralization systems at the ORR have performed satisfactorily. They have accomplished their primary goals of limiting corrosion and mineral deposition and holding the radioactivity of the cooling water at an acceptable level. This has been done with a minimum of attention. The separate-bed units have been easy to regenerate, even

Table 3. Radiation Readings

Power Level: 20 Mw
Flow Rate: 12,000 gpm
Date: 6-2-58

Location	Remarks	Radiation (mr/hr)
Top of pool	~2 in. above water	5
HB-1, 2, 5, and 6	Holes flooded with H_2O	1
HB-4	Instrumented plug with H_2O	50
HB-3	Instrumented plug with H_2O	30
North facility plug	Instrumented plug with H_2O	19
South facility plug	Instrumented plug with H_2O	20
South anion unit	Demineralizer in service	150
South mixed bed	Demineralizer in service	10
South cation unit	Demineralizer in service, through 2-in. lead shielding	200
Expansion pit	At grating level	20
No. 2 pump	Discharge line (in service)	65
No. 1 pump	Inlet line (not in service)	30
Air coolers	Background at 6-ft level	12

Table 4. Dose Rate Readings Taken at 30 Mw
Flow rate: ~18,000 gpm
Date: 3-23-62

Location	Qualifying Conditions	Dose Rate (mr/hr)
Reactor pool	~2 in. above water	15
Center pool	~2 in. above water (dam in gate)	4
HB-1	At external shield face, internal plug empty	1/4
HB-2	At plug in external shield face, internal plug filled	1/4
HB-3	At plug in external shield face, internal plug empty	3/4
HB-4	At plug in external shield face, internal plug empty	1 1/2
HB-5	At external shield plug with shutter closed	1/4
HB-6	Internal plug empty, ~1 ft from beam hole	1/4
HN-1	At small equipment chamber shield	< .2
HS-2	At edge of beam-hole plug on top side	7
Reactor north anion tank (in service)	At center of tank	200
Reactor north cation tank (in service)	At center of tank, 2 in. of lead	280
Reactor north mixed bed (in service)	At center of tank	4
Expansion pit (pump house area)	At grating	35
No. 1 pump	Inlet line	160
No. 1 pump	Discharge line	120
No. 2 pump	Inlet line	180
No. 2 pump	Discharge line	150
No. 3 pump	Inlet line	180
No. 3 pump	Discharge line	120
Shutdown pump	Discharge line	18
Shutdown pump	Inlet line	38
Emergency pump	Discharge line	14
Emergency pump	Inlet line	22
Decay tank (south of pump house)	On wood cover	20
North sump pit No. 3	On grating	13
By-pass valve pit	Top of west wall	15
Heat-exchanger pit	At south railing	15
Pool anion tank	At center	20
Pool cation tank	At center, 2 in. of lead	25

Table 5. Prinicpal Radionuclides in ORR Water (Typical)

Radioisotope	Radioactivity (d/m/ml)
Reactor Cooling Water[a]	
Na^{24}	5.0×10^4
I^{131}	23
I^{133}	16
Np^{239}	57
Cd^{115}[b]	1.2×10^4
Pool Water[c]	
Na^{24}	942
I^{131}	~1
I^{133}	~1
Np^{239}	46
Cd^{115}[b]	173

[a]Demineralizer flow rate, 75 gpm; reactor flow rate, ~18,000 gpm.

[b]The source of the Cd^{115} is the cadmium section of the shim rods which is exposed to the water.

[c]Demineralizer flow rate, 88 gpm.

Table 6. ORR Demineralizer Data

January-March, 1962

Column	Run No.	Initiation Date	Termination Date	Throughput (gal)	Specific Resistance ohm-cm Influent	Specific Resistance ohm-cm Effluent	pH In	pH Out	c/m/ml In	c/m/ml Out
Pool anion	31	12-12-61	1-9-62	2,540,196		981,900		5.84	180	64
Pool anion	32	1-9-62	2-8-62	4,379,310		940,250		5.9	151	50
Pool anion	33	2-8-62	3-12-62	3,537,324		919,133		5.9	3,440*	80
Pool anion	34	3-12-62	In service	2,572,542		1,185,400		5.9	130	40
Pool cation	9	10-12-61	1-9-62	10,723,518	573,060		5.65		965	159
Pool cation	10	1-9-62	In service	10,489,176	667,968		5.8		2,027*	1,351
South reactor cation	13	12-26-61	1-22-62	3,313,185	453,900		5.8		33,406	3,400
South reactor cation	14	2-19-62	3-9-62	2,235,570	464,422		5.8		26,925	2,783
South reactor anion	13	12-26-61	1-22-62	3,313,185		1,088,750		6.1	3,400	660
South reactor anion	14	2-19-62	3-9-62	2,235,570		987,205		6.1	2,783	582
South reactor mixed bed	16	12-26-61	1-22-62	3,313,185		921,325		6.2	660	532
South reactor mixed bed	17	2-19-62	3-9-62	2,235,570		1,000,891		6.2	582	576
North reactor cation	13	1-19-62	2-11-62	2,356,275	416,118		5.8		33,777	3,248
North reactor cation	14	3-9-62	In service	2,241,345	435,683		5.8		30,088	2,608
North reactor anion	13	1-19-62	2-11-62	2,356,275		1,089,870		6.0	3,248	622
North reactor anion	14	3-9-62	In service	2,244,345		1,305,950		6.2	2,608	381
North reactor mixed bed	16	1-19-62	2-11-62	2,356,275		858,217		6.0	622	479
North reactor mixed bed	17	3-9-62	In service	2,241,345		944,858		6.1	381	315

*High Due to Rhenium Sample.

though the reactor water systems are located beneath shielding walls which necessitates remote operation of all valves.

A few objectionable features of the demineralization systems have become apparent. Some of these are: (1) the mixed beds in the reactor water system are rather difficult to regenerate since the operation is completely manual, and (2) the closed drainage systems with a limited flow have hindered backwashing. This restricts the regeneration procedure since the theoretical values are not attained.

To minimize the escape of gaseous radioactivities into the ORR building due to release of gaseous activities from the open pool, a 50-gpm degasifier was placed in service in February, 1959, as shown in Figure 28. The effectiveness of the unit is indicated by the decrease in the equilibrium background activities. Analyses of gas samples taken from the reactor primary system reflecting the effectiveness of the degasifier system is shown in Table 7.

ORR EMERGENCY SYSTEMS

Electrical

Several emergency systems have been installed at the ORR to provide continued operation of certain components during loss of the normal electrical power. These units are designed to provide protection against melting of reactor fuel or experiments or to prevent the release of radioactivity through the building exhaust systems. Various degrees of trouble have been experienced with the systems, and the 350-kva diesel generator has been too unreliable to serve as an emergency supply. It is presently used for convenience power during a power failure and is not used as a first source of supply to critical components.

Based on our experience with emergency power, a system is now being considered in which a second set of components will operate continuously from a separate power source. The components would not have to be started or switched to a different power source in case of failure of normal power.

Where emergency power is absolutely required, two separate power systems (one of these would be normal power) would operate separate and independent components. If either system failed, the reactor would be

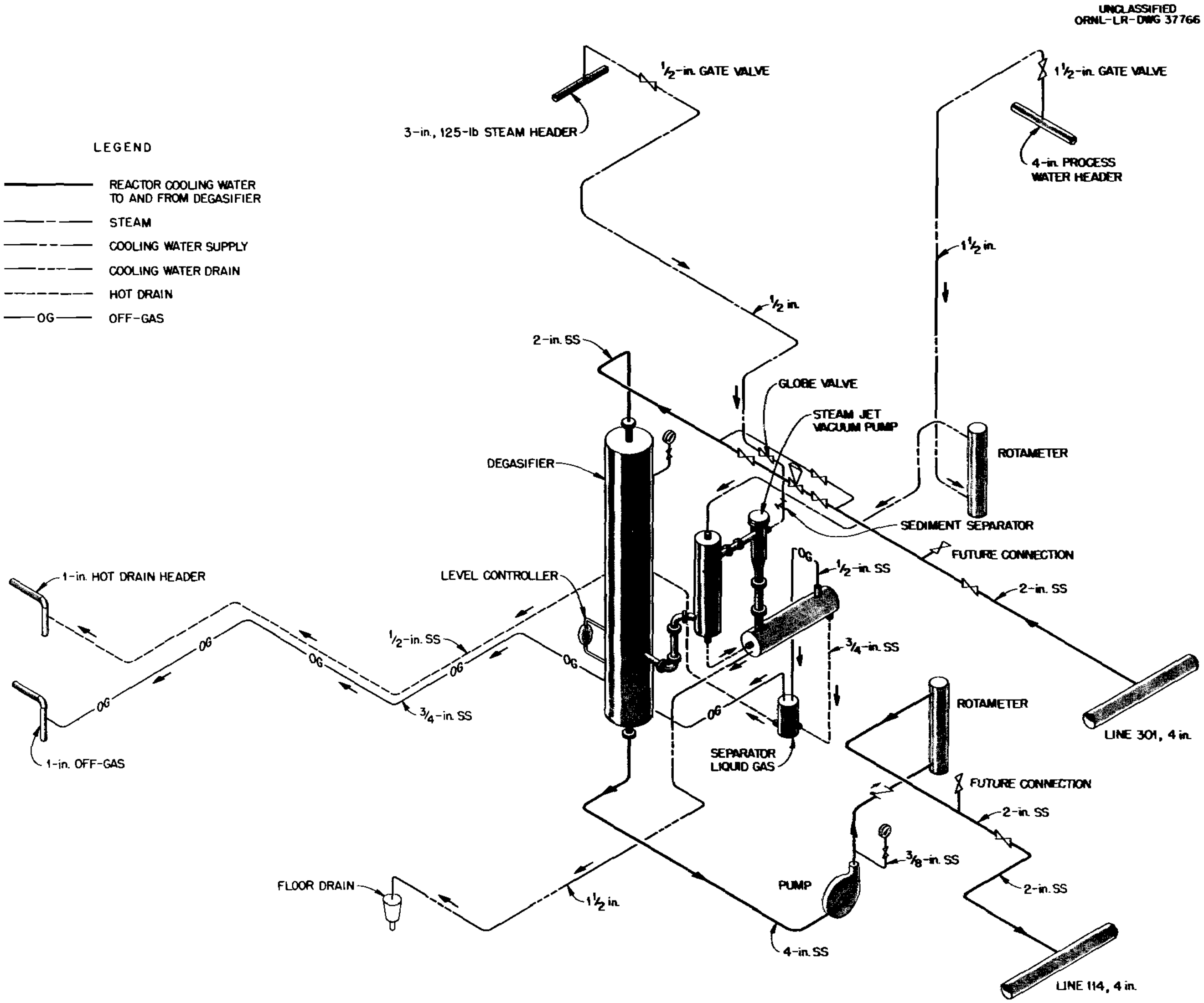


Figure 28. Degasifier System.

Table 7. ORR Degasifier Efficiency

Flow Rate: 50 gpm

Radionuclide	Decay Time From Sampling (Min)	Radioactivity Ratio* Exit Water / Inlet Water
A^{41}	3	0.014 ± 0.007
Xe^{135}	3	0.013 ± 0.003
A^{41}	14	0.010 ± 0.005
Xe^{135}	14	0.010 ± 0.002

*The factor limiting the accuracy of the determination of the ratio is the low count rate of the radionuclides in the exit water.

shut down until both were operating again. After loss of one system, the remaining operating system would provide for safe shutdown of the experiment or reactor. The proposed system and the normal system will have to be sufficiently independent so that simultaneous failure is almost impossible. With regard to experiments, a central, continuously operating, emergency-power system would eliminate or greatly reduce many of the existing problems. At present each experiment group must provide its own emergency power system, if needed. This leads to a diversification of systems with the consequent difficulties and expense of insuring maintenance and reliability as well as excessive first cost. Experimenters have encountered considerable difficulty in designing, constructing, and installing systems of sufficient reliability to be acceptable. Consequently, experiments are sometimes limited to operations such that complete loss of electrical power cannot lead to particular hazardous conditions.

The different emergency electrical systems are described below:

Diesel Generator

As original equipment, a 350-kva diesel generator was designed to supply power to the following:

(1) An electrically driven pump that provides shutdown cooling for the reactor. The power must be switched from the normal to the diesel system via an automatic transfer switch in the event of power failure.

(2) A pump in the building scrubber-exhaust system designed to remove radioactive gas from the exhaust air. This must also be switched, via an automatic transfer switch, from the normal to the diesel system.

(3) Various other building services of lesser importance.

(4) Experiments that require power to prevent melting or other damage if normal power is lost.

A review of operating history of this generator indicates that perfect reliability has not been achieved in using it as a start-on-demand component. During the early cycles of operation, it failed to start on several occasions. Mechanical difficulties were the major source of trouble, while on a few occasions electrical components failed.

The diesel system has been given a five-minute run, without load, each week; and a five-hour test run, under load, every two months. Most of the failures were detected during the testing periods. Increased attention to the testing and maintenance programs has improved reliability; however, usage is still restricted to that of convenience only. Additional systems have been provided in an attempt to achieve the absolute reliability required.

Battery-Powered System for ORR Experiments

Since one experiment could not tolerate the seven-second delay built into the diesel transfer system, a battery-powered system was installed to provide a ready source of electrical power. The present system consists of a battery bank using a rectifier system for maintaining the required charge rate, a dc motor, and an ac alternator. Under normal conditions, a rectifier system supplies current on a parallel branch to charge the batteries and to drive a dc motor. This motor drives an ac alternator that supplies power to the critical components of the experiment. Upon loss of normal power, the system continues to operate without the benefit of a charge to the batteries. The bank of batteries under this condition has adequate charge to supply power, thereby preventing destruction of the experiments by a fuel meltdown. The reserve energy in the battery bank is sufficient to provide for the following:

(1) Equipment operation for 47 minutes if no action by the experimenter is taken to reduce the load and if the diesel emergency power fails.

(2) Equipment operation for 83 minutes if the experimenter reduces the speed of the compressor to provide shutdown cooling and if the diesel emergency power fails.

(3) Equipment operation for 84 minutes if no corrective actions are taken by the experimenter and the diesel emergency-power system operates.

(4) Equipment operation for 118 minutes if corrective actions are taken to reduce the load and if the diesel functions properly.

Cooling

The ORR, operating at 30 Mw, has a built-in inventory of fission products which would supply afterheat in sufficient quantity to produce boiling should a loss of cooling water occur simultaneously with reactor shutdown. Original equipment to provide a means for afterheat removal consisted of a 1000-gpm electrically driven pump which had its power supplied by a diesel generator in the event of a power outage and a gasoline-engine-driven 1000-gpm pump. As previously reviewed, the diesel unit is not considered as a reliable source of power for critical components. The first line of defense for afterheat removal is dc motors directly coupled to the main circulating pump. The dc motors are supplied by a storage-battery bank.

Gasoline-Engine-Driven Pump

Use of a gasoline-engine-driven pump to provide emergency cooling presents similar problems to those associated with the present diesel system. The gasoline engine must start on demand and requires the action of several devices, any of which may fail. Testing under simulated emergency conditions is difficult and inadequate since the pump is incapable of developing an adequate head to open the in-line check valve when the main pumps are operating. Therefore, testing while the reactor is operating subjects the engine to no appreciable load, resulting in rapid deposition of carbon on the internal parts of the engine. This results in poor performance, excessive maintenance requirements, and reduced reliability.

Operating history shows that the engine has operated improperly about 6% of the times tested. It is undesirable to attempt revision of this unit to meet the requirements necessary to provide guaranteed emergency cooling. However, with the more intensive preventive maintenance program in force, it can be depended upon as a complement to the over-all emergency cooling system.

DC Electric Motors

Since a reliable afterheat removal source was a necessity for 30-Mw operation, battery-driven motors directly coupled to the main recirculating pumps were installed on two of the three units. It was felt that a continuously operating unit with minimum hardware and circuitry would provide the reliability required. The units were designed to provide a minimum of 500-gpm reactor water flow, and tests indicate that each will produce in excess of 1000 gpm for more than four hours after failure of the main pump power. The circuitry associated with these motors includes a bank of 18 battery cells, which are charged by an ac-supplied battery charger, and the initial monitoring circuitry, which was limited to indicate the positions of disconnects located in the battery-to-motor and charger-to-battery circuits.

These units failed to meet minimum specifications several times because of an inadequate battery charger. On each occasion, failures were detected during routine checking.

In an effort to provide more reliability, the following steps were taken:

(1) A monitoring system was provided for motor current, battery current, battery voltage, and for annunciating an alarm in the control room.

(2) A third unit was provided on the remaining pumping unit.

(3) The circuitry was revised to prevent overloading the battery chargers.

To maintain the reliability required for afterheat removal, at least two pumping units must be operating (i.e., actually running); and all components in the circuitry must be within prescribed limits of acceptability.

The installation of the third unit was completed in July, 1961. Since then, only once have the batteries of two dc units been concurrently undercharged--a condition which warrants continuous operation of the gasoline pump. Prior to the installation of the No. 3 dc motor, it was necessary to operate the gasoline pump continuously on at least six occasions. Concurrent with the installation of the No. 3 dc motor, a complete monitoring system for the three units was installed.

Others

Two additional sources to provide a water flow through the core are available should the previously described units fail. They consist of a manually operated dump valve and a manually controlled process water line.

The dump valve is located at a low point in the reactor system. It will, when opened, provide water flow from the pool into the reactor tank through the equalizer leg which produces an upflow through the core and out the dump valve. This coolant source is limited to about 60,000 gallons of pool water.

Plant process water is piped directly to a spray head located inside the reactor vessel through a two-inch line supplied at about 60 psig. This water flow is manually controlled by a hand valve located on the north side of the reactor building. This system would be used only in case of failures of the other sources of heat removal and is intended to keep the core wet.

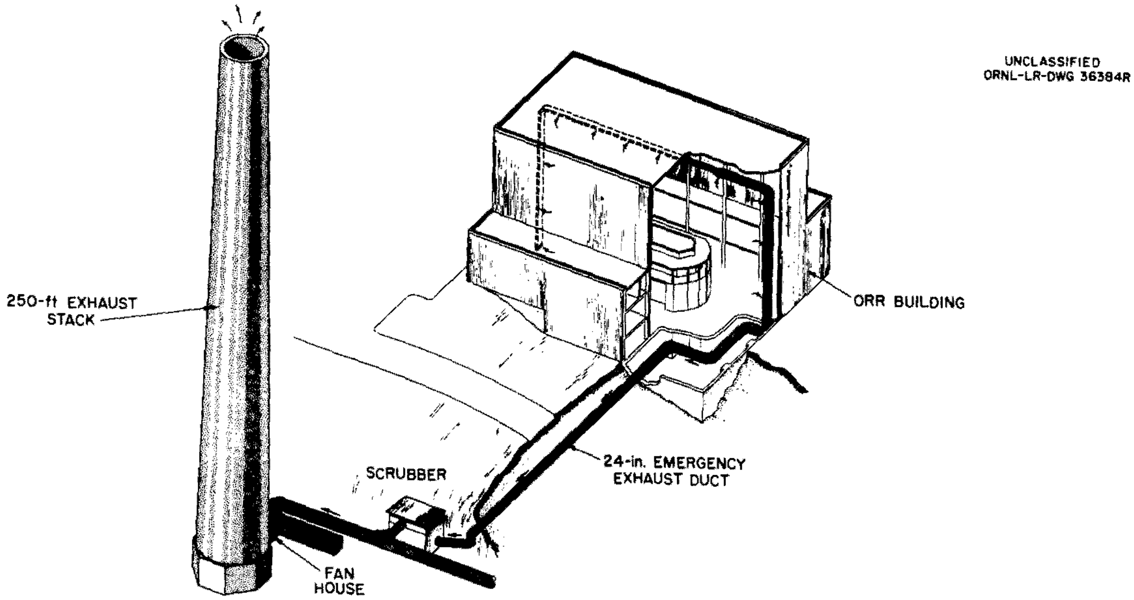
Clean-up Systems

Decontamination Scrubber in Ventilation System

Since the ORR building is not a pressure shell, it depends upon air inleakage to prevent the spread of radioactivity to surrounding areas should a catastrophic event occur. The inleakage is provided by: (1) a ventilation system consisting of duct work, inside the building, which connects to the 250-ft brick stack through a 24-in. duct; (2) a caustic scrubber; and (2) two blowers in parallel (one electrically driven and one steam driven). A diagram of the system is shown in Figure 29. Normally, the electrically driven unit is in service with the steam-driven unit on standby.

Under normal operating conditions, a continuous flow of air is swept out of the building through the described path with the caustic scrubber deactivated. This flow of air is maintained for two purposes: (1) to maintain ventilation for experiment cubicles inside the building, as illustrated in Figure 30; and (2) to improve system reliability by having continuous air flow.

Should there be an emergency in the building, operation of the system can be activated either manually or by a radiation detector. Upon activation, two important functions are completed: (1) All heating and ventilating units are automatically shut down and all dampers close, thereby sealing the building. In addition, the two large truck-access doors automatically close. (2) The caustic scrubber is placed in operation. It is vital that the ventilation system respond to provide the necessary inleakage and that the caustic scrubber operate to provide the



Schematic of ORR Emergency Exhaust System.

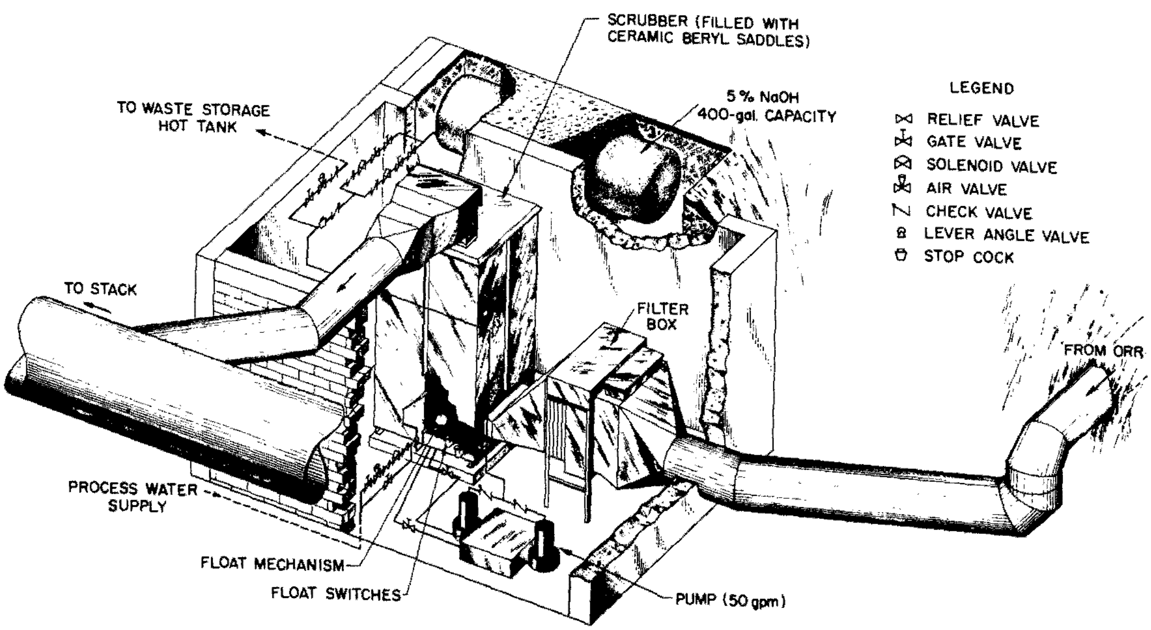


Figure 29. ORR Decontamination Scrubber.

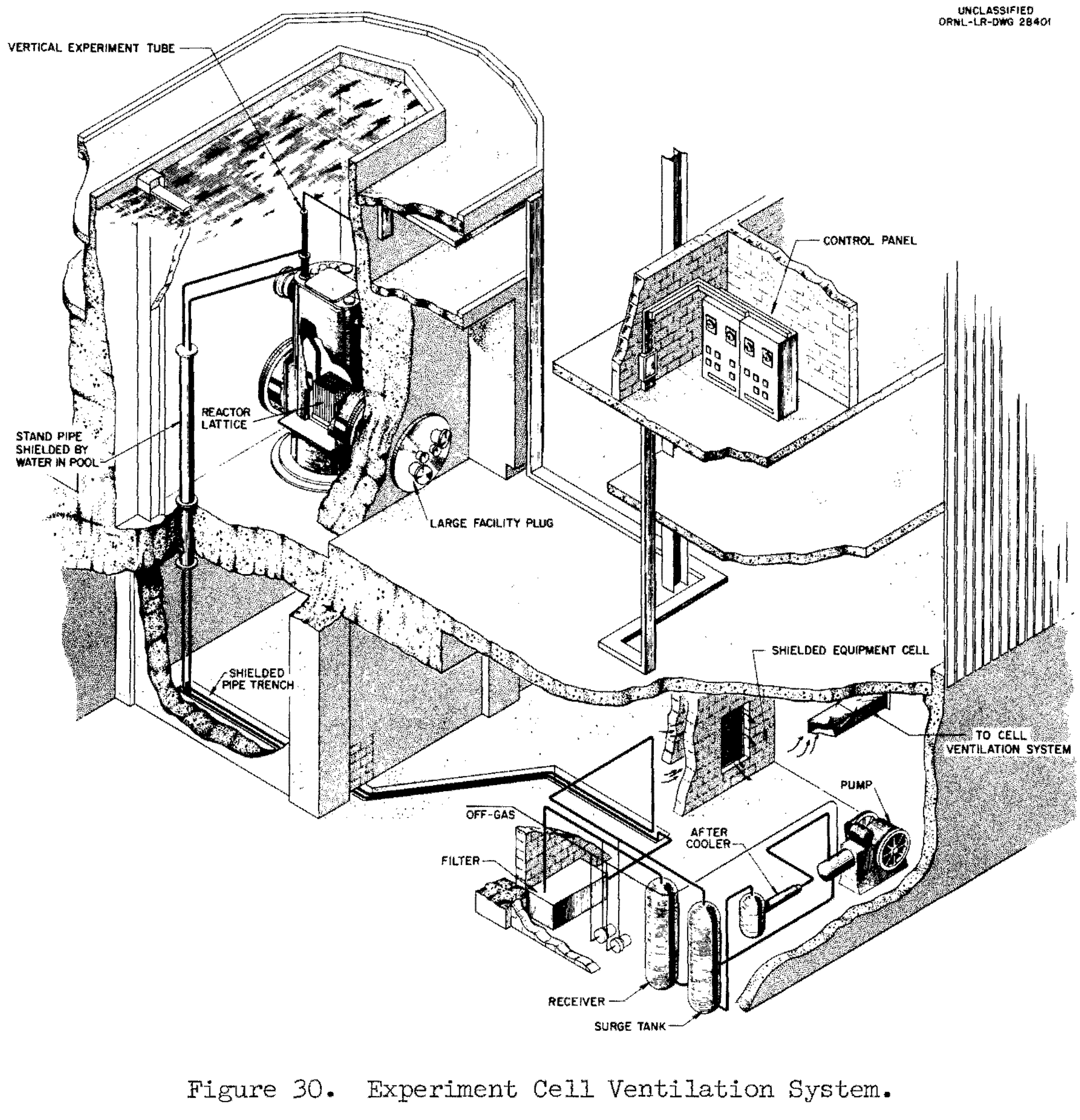


Figure 30. Experiment Cell Ventilation System.

necessary decontamination factor. An evaluation of the building containment system and the required decontamination factors is discussed separately.[13]

Operation of the system has not been of the highest reliability. While no failures have been experienced in sealing the building by shutting down the ventilation system, a number of components in the scrubber system have failed to respond normally. All failures have been discovered during the testing period made routinely during each major shutdown. A prerequisite to startup is that the scrubber satisfactorily perform a complete cycle of operation. A comprehensive preventive maintenance program has increased the reliability of the system. Therefore, a review of all components, with emphasis on reliability, is in progress with thought being given to the use of the scrubber as a continuously operating unit.

Preliminary design has been completed on a charcoal filter-type decontamination unit to replace the caustic scrubber in use on the ORR. This unit has two distinct advantages over the caustic scrubber now in service: (1) it has no mechanical components which "start on demand" and a minimum of electrical components thereby increasing the reliability of operation. (2) The pressure drop across the filter bank is sufficiently low to permit the major pressure drop to occur in the ORR building. This pressure drop will be distributed to provide a negative 0.30 in. wg (water gage) in the ORR building, and a negative 0.30 in wg in the experiment cell with respect to the building proper. With the operation of a decontamination unit of this type, it is felt that maximum reliability will be obtained.

WASTE REMOVAL SYSTEMS

Off-Gas System

To provide experiments with an air sweep for removal of possibly radioactive or contaminated gases, an off-gas system was installed. This system, with a negative pressure of 25 to 30 in. wg and a capacity of 500 cfm, was exhausted to a Laboratory 250-ft stack through a filter and Precipitron. Prior to initial nuclear operation, the possibility of the collection of liquids, particularly water, in the off-gas system was recognized. In order to prevent blocking of the system due to liquid accumulation at a low point in the 8-in. off-gas duct, a drain line to a 5-gal catch tank was provided. This tank could be emptied to the liquid hot-drain system by air pressure. It proved to be of insufficient capacity and was replaced by a 35-gal tank. After about 1 1/2 years of reactor operation, the increased use of the off-gas system for experiments and reactor auxiliary equipment had resulted in a liquid accumulation rate which made the operation of the catch tank troublesome. Late in 1959, an entrainment trap was installed in the 8-in. off-gas duct to remove moisture prior to the tie-in point for the original catch tank. The entrainment trap drains to a rectangular tank containing about 150 gal of liquid; the space in the tank above the liquid is provided with an air sweep to the cell-ventilation system in order to remove any gases that may be released. A water-trap leg allows discharge from the tank to the process drain system at a rate equal to the collection rate.

The entrainment trap and its associated tank has been very satisfactory in spite of such changes as the replacement, in the Laboratory off-gas system, of the Precipitron with a continuously operating scrubber. The scrubber resulted in increasing the off-gas vacuum at the ORR from the previous 25 to 30 in. wg to 35 to 40 in. wg.

Certain experiments in the ORR require off-gas service to maintain sample cooling; and other experiments require off-gas service to operate auxiliary, high-pressure systems. Long-term use of the present off-gas system to satisfy these requirements has raised two objections. The first is that dependence is placed on positive-displacement units to maintain the off-gas capacity normally required. These units are: (1) an electrical motor-driven unit; and (2) a back-up, start-on-demand, steam-turbine driven unit. The second objection is that some experiments are capable of accidentally releasing sufficient quantities of high-pressure gas to exceed the capacity of the present off-gas system.

In the event of failure of the mechanically driven units or of accidental overpressurization, a possible reversal of flow in local areas could occur. This is of concern since those experiments which depend on the system could be disabled and release highly radioactive or contaminated gases into building working areas.

In order to remedy this situation a "pressurizable" off-gas system was designed and is being installed. This system will operate, normally, at a negative pressure of ~ 40 in. wg with a capacity of 500 cfm (design conditions of the ORR building). This capacity is supplied by an electrical-motor-driven centrifugal fan. Since all sources discharging gas at greater than atmospheric pressure will be tied into this system, failure of the centrifugal fans would not result in complete flow blockage and the ensuing consequences. The basic difference between the operation of dual off-gas systems and the standard off-gas system alone will be a complete separation of air-sweep functions and of pressurized gas discharge functions and the availability of a method for contained dissipation of pressurized gases in case of failure of any air-handling unit.

Intermediate-Level Waste System

Although a later paper will describe the ORNL waste-disposal system in detail,[14] description of the ORR intermediate-level waste system would be incomplete without stating the local criterion regulating the use of this system. It is this: all liquids known to contain (as well as liquids which could accidentally contain) greater than about 10^{-4} curies per gallon of unknown emitters are discharged into this system. An example of this class of liquids is the condensate from the ORR degasifier. As originally designed a 2-in. stainless steel line from the basement of the ORR building carried this liquid to an ORNL waste-disposal-system collection tank with a capacity of 2,000 gal.

The intermediate-level waste system depends on gravity feed to the collection tank which is only about 6 ft lower than the basement floor. If the only access to this system were through valves kept normally closed by administrative control, liquids could be pressure-fed into the system and reasonable discharge rates obtained. Although such restricted access is maintained for all reactor and hot-cell operations (with the exception of the degasifier), there is another type of access in use. Various experiments require access to the hot-drain system on a continuous or unscheduled basis; therefore, there are a number of normally open access points. Since the ORR building is a multilevel structure, discharge into the system is presently restricted to about 10 to 12 gpm in order to prevent backflow at normally open access points.

This restricted flow handicaps a number of operations. For example, the efficiency of backwashing the ion exchange columns prior to regeneration is limited and in particular the removal of "fines" from the cation columns during the backwashing operation. Another example is the rinsing operation that follows regeneration. A rinse rate of 50 gpm is recommended for one of the ORR columns, and this is not possible with the present low discharge rate to the hot-drain system. An additional problem has resulted from the lack of a high off-gas vacuum in the intermediate-level waste system at the access points in that the present system allows only about -4 in. wg, and very close administrative control must be maintained over operations involved with installation of new access points and with proper closure following the dismantling of old experiments.

The system that is in the final stages of evolution at the ORR will include two separate lines to the collection tank. One line will provide access through normally open valves for semicontinuous, low-flow-rate requirements (primarily those associated with experiments). An integral part of this line will be a mechanism for efficient off-gas vacuum to sweep out the gas released from liquids under unusual conditions. A second line will provide access through normally closed valves for occasional high-flow-rate requirements (primarily those associated with reactor and hot-cell operations).

Process-Waste System

All liquid waste from the ORR building which is not discharged to the Intermediate-Level Waste System is discharged to the Process-Waste System. The reactor operating staff has not experienced any major difficulties with this system. The difficulties associated with controlling the monthly discharge rate and with the necessity for pumping that portion of the waste collected in the basement up about 17 ft above the basement have been minor.

Solid-Waste Removal

From the standpoint of reactor operating personnel, all solids permanently removed from the reactor could be considered waste. This would include not only such items as the nonfuel-bearing sections of fuel elements and shim rods but also experiments. The three methods for disposing of such waste are: by use of the ORR hot cells, by shielded transfer from the ORR pool, and by unshielded transfer from the ORR pool.

The ORR hot cells have been used primarily for separating experiment samples from associated tubing and instrument leads. The sample is then removed from the cell in a carrier and shipped to other cells for analysis. The extraneous matter left in the cell is loaded into larger carriers for shipment to the ORNL Burial Ground. The amount of material thus disposed of is, in general, relatively small compared with the amount left in the ORR pool for decay. The latter may consist of pipes 25 to 30 ft long and up to 4 in. in diameter. Since the ORR has operated for about four years, it has been possible to move a few of these large pipes to the Burial Ground unshielded; however, long-term storage is becoming impractical due to the increased experimental program. Therefore, it is planned to equip one of the hot cells with a hydraulically operated shear capable of crimping and cutting 4-in. diameter pipe. Then, storage of material in the ORR pool will be greatly reduced.

Small items such as fuel-element end boxes are removed from the ORR pools in a general-purpose carrier that has a cavity about 18 in. in diameter and 18 in. deep. Larger items such as the nonfuel-bearing sections of shim rods cannot be removed in this manner. The lower sections of shim rods are shipped, unshielded, to the Burial Ground after about nine months' decay; radiation levels of about 500 mr/hr, at contact, are encountered. Removal of the upper sections, which have been exposed to higher neutron fluxes, is more difficult. They are removed from the pools with long tools and placed in a waste container that has about one inch of lead shielding. After about nine months' decay, the radiation levels encountered are: unshielded, about 10 r/hr at contact and, through the bottom of the container, about 600 mr/hr. This last operation is performed on "off" shifts or on week ends and will be unnecessary when the shear is ready for use in the hot cells.

INADEQUACIES OF BUILDING AND STRUCTURE

Building

Four years of experience has been gained in operation of the ORR as related to the ORR building. For this experience to be useful to other reactor operators, consideration must be given to the conditions at ORNL which resulted in the necessity for, and design of, a general-purpose building to house the ORR. Since it was desirable to locate the building within the existing Laboratory complex and in the vicinity of the two similar-purpose reactors (i.e., OGR and LITR), the size of the available site dictated that space be provided in the building for some activities not directly related to ORR operation. Some examples of such additional space allocation are: office space for experimenters, for Instrumentation and Controls Division maintenance engineers (and foremen), and for Engineering and Mechanical Division maintenance foremen; clothing change-room facilities for those working in the building; an instrument shop; and, originally, a small shop for mechanical maintenance.

It can be seen that such experience would be of more use to those reactor operators having or constructing a general-purpose building than to those who plan to provide space in a separate structure for activities such as those outlined above. In this light, the inadequacies of the ORR building may be considered in three catagories: space limitations, lack of provision for isolation of different areas, and the difficulties resulting from the undesirable traffic patterns between certain working areas.

Space limitations in the ORR building have adversely affected experimenters and operating personnel primarily; however, maintenance and support workers have been affected to a lesser degree. Probably the most handicapped group due to limited space is composed of those involved in experimentation at the horizontal beam holes. The available working space between the reactor shielding face and the building was originally limited to 28 ft. The nature of the experiments necessitated the addition of large external shields which further limited the working space to 21 ft. From a practical standpoint, individual beam holes are more stringently limited due to such obstructions as columns, floor hatches, and the east truck entrance. These limitations have resulted in such expediencies as an open gallery for the instrumentation of one beam-hole experiment and an enclosure of temporary construction for another. At present a design for a two-story, 20-ft extension of this end of the reactor bay is being considered.

Another area of limited space of concern to both experimenters and reactor operators is the reactor pool. The original idea had been to locate bulky items such as heaters, compressors, large charcoal traps, etc., in shielded cubicles in the basement. As experiment installation progressed, it was realized that not only was access to the basement limited (one experiment required half of it)/ but the basement itself was soon almost fully occupied. In addition, some experiments required the location of bulky items, of the type described, much nearer to the reactor than the basement. Therefore, a large fraction of the relatively limited second-level balcony is occupied by shielded enclosures and some rather large items have been located in the reactor pool, making mechanical installation and modification of experiments more difficult. In retrospect, provision of an "experiment cubicle level" at, or slightly above, the level of the reactor tank top would be more desirable. Such a working level should be as extensive as the reactor bay itself and should include suitable, shielded pipe-chases to allow construction of shielded cubicles in any portion of the "level". Many of these cubicles could be of concrete-block-type construction to provide for alteration or removal for subsequent experiments. In general, the individual cubicles would be maintained under negative pressure with respect to the remainder of the "cubicle level", which in turn should be maintained at negative pressure with respect to the remainder of the building.

The space provided for the reactor supervisory staff is quite limited and consists primarily of three 10- x 13-ft and two 9- x 13-ft offices. Since the average occupancy exceeds 1 1/2 persons and since frequent meetings with experimenters and/or with maintenance-support personnel are required, one serious lack is that of suitable space for such meetings. Such space should be adjacent to the supervisory staff offices where files and blueprints are maintained. Further, since a major portion of each staff member's work involves brief consultations with one or two nonstaff members, a reduction of the average occupancy would also be desirable. The prior discussion does not include that of the shift engineers who supervise reactor operation on off-shifts. No suitable office space is available for these four men. One desk and one filing cabinet is provided adjacent to the control room in a space originally designated for equipment and instrument repair, but over half the space is occupied by an air-conditioning unit for the control and staff offices. It has recently been necessary to utilize a large portion of the remaining space for expansion of the reactor controls.

Problems confronting maintenance and support personnel are less immediate; however, when involved with a research reactor and experiment installation of the size and complexity of the ORR, such problems are not to be ignored. Mechanical maintenance requirements for the reactor and experiments soon exceeded the capacity of the small shop originally provided, and at one time this work could be found in progress in any unassigned space in the building. Predominantly, such work had, by necessity, to be preformed near the reactor building but could not, practically, be performed in the then existing Laboratory field shops. Therefore, a building was built adjacent to the ORR, and a field shop was relocated to this building. At present, the amount of such maintenance activities in the reactor building is being reduced and the original ORR mechanical shop being vacated; however, a small area for maintenance on shim-rod-drive units has been established in the basement.

The space required for the group that supports and maintains the instrument and control systems has gradually increased. The goal of this group has been to install and maintain instrumentation for a gradually increasing experiment program, to upgrade the reactor control system, and at the same time to continue to effect a high degree of reliability and operational continuity. For such a goal to be met successfully, not only the total effort but also the intensity of effort must be gradually increased. (A minor portion of the work of this group has involved support of the operation of the LITR, OGR, and associated experiments.) The original mechanical shop is now used as an instrument shop, and two offices are required for engineers and foremen. Although these offices are fairly large, the average occupancy is four.

There are two areas in the ORR building which, because of limited space, adversely affect the effort of a number of groups working in the building. These are the clothing change rooms and the truck entrances. The two change rooms are each about 19 x 37 ft and contain lockers, toilets, shower stalls, and storage space for work clothing. The capacity has been exceeded due to the number of personnel working in the building, especially during an end-of-cycle shutdown, and to the need for providing space for Laboratory personnel working in several other nearby buildings.

The two truck entrances are provided with 12-ft-wide doorways. The west entrance on the second floor has an associated area about 36 ft long and 15 ft wide to enable trucks to be unloaded with the doors closed. Since this is the entrance normally used for movement of transfer casks into the building, it has been necessary to provide a storage area for these casks which occupies a portion (about 10 ft long and 8 ft wide) of the unloading area. The east truck entrance on the first floor is similar, but the unloading area is limited to a length of about 19 ft and a width of 14 ft due to the proximity of the beam-hole area. Since these entrances must be capable of automatic closure in the event of an accident, there has been some difficulty in moving large items into the building with the reactor operating due to the limited size of the truck which can be accommodated. It appears that a generously sized truck lock or annex with sealed doors at each end would be useful, in particular for the west entrance. Such an annex could be external to the ORR building. Since this latter truck entrance also serves the hot cells, considerable time could have been saved had a supplementary bridge crane been provided.

One feature of the ORR building which has been quite unsatisfactory is the lack of isolation between various areas in the building. Although there have been no major releases of radioactive material into the building, the experience gained as a result of some minor releases from experiments indicates that such lack of isolation or compartmentalization results in wide-spread problems generating from what was originally a local release. In the event of a major release, costly decontamination of the entire building would unnecessarily result. The three levels of the reactor bay and the basement should be individual compartments separated from each other and from the laboratory and office space on the second and third floor. An additional advantage which would be realized from compartmentalization is the reduction of noise and vibration in individual experiment areas. Such modification of the ORR was recently investigated, but the resulting additional structural loading precluded such compartmentalization.

Another feature of the building, which is incidental to the question of space isolation but related to that of decontamination, is that of the abundance of internal surfaces. In the ORR building a majority of the wiring conduits and plant-services piping are exposed. This is also true of major structural members in the reactor bay. Experience such as that gained at the OGR following the plutonium release of 1959 showed that exposed surfaces greatly increase the cost and time required for decontamination.

During the design of a research reactor building, careful consideration should be given the purpose of various areas and the traffic patterns between them. In the ORR building several key areas have unfortunately become general thoroughfares. This could have been prevented in some instances by providing alternative passageways and in other instances by relocating the work or function performed to other areas. One example is the limited access on the third floor between the laboratory area on the south side and the operating staff office area on the north side. This access is limited to two routes: around the third-level, poolside balcony or west of the hot cells. Portions of the poolside balcony are often necessarily occupied by equipment; during end-of-cycle shutdown much of this area is designated a contamination zone. The available area west of the hot cells is required. The use of such areas as thoroughfares is undesirable, and on occasion both routes are blocked by contamination zones. The only remaining access is via the second floor.

A second example of an area which developed into a thoroughfare consists of the third-floor change room and adjacent stairwell on one end and the ORR control room on the other. Connecting these extremes is a hallway which provides access not only to the offices of the operating staff but also to the poolside balcony. Of primary concern was the traffic through the control room to stairs leading to the reactor-cooling-system area. Since this route was considerably shorter than any other available from the third floor, the control room itself became a thoroughfare. In addition to such traffic, the fact that no convenient space external to the control room was available for observers often resulted in the presence of groups of trainees and visitors in the control room. A gallery was constructed which, by serving as an alternate traffic route and observation area, has markedly reduced such undesirable use of the control room.

Although heaviest during the end-of-cycle shutdown, the traffic from the third-floor change room or the adjacent stairwell through the partially enclosed hallway to the poolside balcony has gradually increased. At present this hallway, which also provides access to the offices of the operating staff and to the control room, is the most heavily traveled area in the building. While the degree to which the working day of reactor supervisory personnel is subject to interruptions and distractions is probably unexceeded even in a research laboratory, it is apparently true that interruptions and distractions are inherent in such work and can be reduced in degree only. Had the hallway been fully enclosed and an alternative passage provided this situation would not exist.

Structure

There are some miscellaneous examples of inadequacies which have become apparent during four years of operation and which do not readily fit into any of the categories previously discussed. Since these examples primarily concern mechanical and physical properties of the reactor and pool structure, the term "structure" can serve as a heading for a brief listing of these examples.

The use of aluminum as a pool liner has, in addition to causing corrosion problems, complicated numerous operations due to concern about possible mechanical damage. Similar complication has resulted due to the absence of pool-floor areas capable of supporting large carriers. A difference in elevation between the top of the pool wall and the adjacent floor, which results in a parapet (as at the ORR), appears unnecessary (a removable guard rail would serve as well) and in many cases is a hindrance. Finally, the distance from the reactor building to the primary cooling pumps and to the present heat exchangers, which resulted from the original use of air-cooled heat exchangers in the particular area available for ORR construction, is excessive.

SUMMARY

Since this material was primarily prepared for reactor operations personnel, the emphasis was placed on problems and inadequacies which have been encountered during four years of ORR operation. No effort was made to describe those features which make the ORR the very useful research tool that it is.

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