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ORNL-TM-279

THE OAK RIDGE RESEARCH REACTOR (ORR), THE LOW-INTENSITY TESTING REACTOR (LITR) AND THE OAK RIDGE GRAPHITE REACTOR (OGR) AS EXPERIMENT FACILITIES

Kenneth D. George

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ABSTRACT

Those characteristics of the ORR, LITR, and OGR that experimenters have found to be important are listed. The results of a survey conducted among experimenters on the utility of the reactors for various types of experiments are discussed, and some changes which might be made to improve the utilization are listed. A brief outline, with references, of most of the experiments currently being performed is given in an Appendix.

*On loan from U. S. Army Ordnance Corps, Picatinny Arsenal, Dover, N.J.

INTRODUCTION

At the Oak Ridge National Laboratory (ORNL) three general-purpose research reactors are currently being operated, by the Operations Division, on a continuous 24-hours-per-day basis in order to provide irradiation services for experimenters. These reactors are the Oak Ridge Research Reactor (ORR), the Low Intensity Testing Reactor (LITR), and the Oak Ridge Graphite Reactor (OGR). The ORR has been in operation for the past four years, the LITR for eleven years, and the OGR for about nineteen years.

It was felt that, in view of this unique situation, a survey of experiments might reveal the factors that led to the choice of the reactor most favorable for each experiment. It is realized that factors other than purely technical ones may be overriding in the choice of the reactor for some experiments. For example, relocation of expensive built-in equipment may be uneconomical, space in one of the newer reactors may not be available for allocation to a particular experiment, and budget limitations for particular experiments may not permit the use of more costly irradiation facilities. This paper presents the results of a survey of experimenters using the reactors and gives brief descriptions of most of the experiments currently being performed. Information on a few experiments that are no longer being performed is also included. References to publications giving detailed descriptions and the results of the experiments are included where available. It should be pointed out that for many of the experiments now in the ORR, initial exploratory work was performed in the OGR and/or the LITR.

DESCRIPTIONS OF THE REACTORS

Oak Ridge Research Reactor

This reactor uses MTR-type, enriched-uranium fuel elements and beryllium reflector pieces in a 7-element x 9-element rectangular lattice with moderation and cooling provided by forced circulation of demineralized water.[1] The reactor tank is submerged in a water-filled pool having walls and bottom of barytes concrete which serves as a biological shield as well as the pool container. Control-rod drives are operated from below the reactor (Fig. 1). The reactor is housed in a building about 100 ft x 108 ft in area with four floors, including a basement. A reactor balcony 6 ft wide extends around the outside of the pool structure at an elevation roughly midway between the first- and second-floor elevations (Fig. 2).

The main reactor characteristics of importance to experimenters are as follows:

1. Operating power: 30 Mw
2. Thermal-neutron flux: 1.6×10^{14} n/cm^2-sec (average); 5×10^{14} n/cm^2-sec (maximum).
3. Neutron flux distribution: see Ref. 2.
4. Gamma heating: 3-10 watt/gm depending on material and lattice position.
5. Coolant temperature: reactor cooling-water inlet temperature--120°F.
6. Coolant pressures: about 11 psig below core; 36 psig above core (full flow).
7. Operating cycle: 8 weeks, comprising 7 weeks at full power and 1 week of shutdown for maintenance, experiment changes, and refueling.

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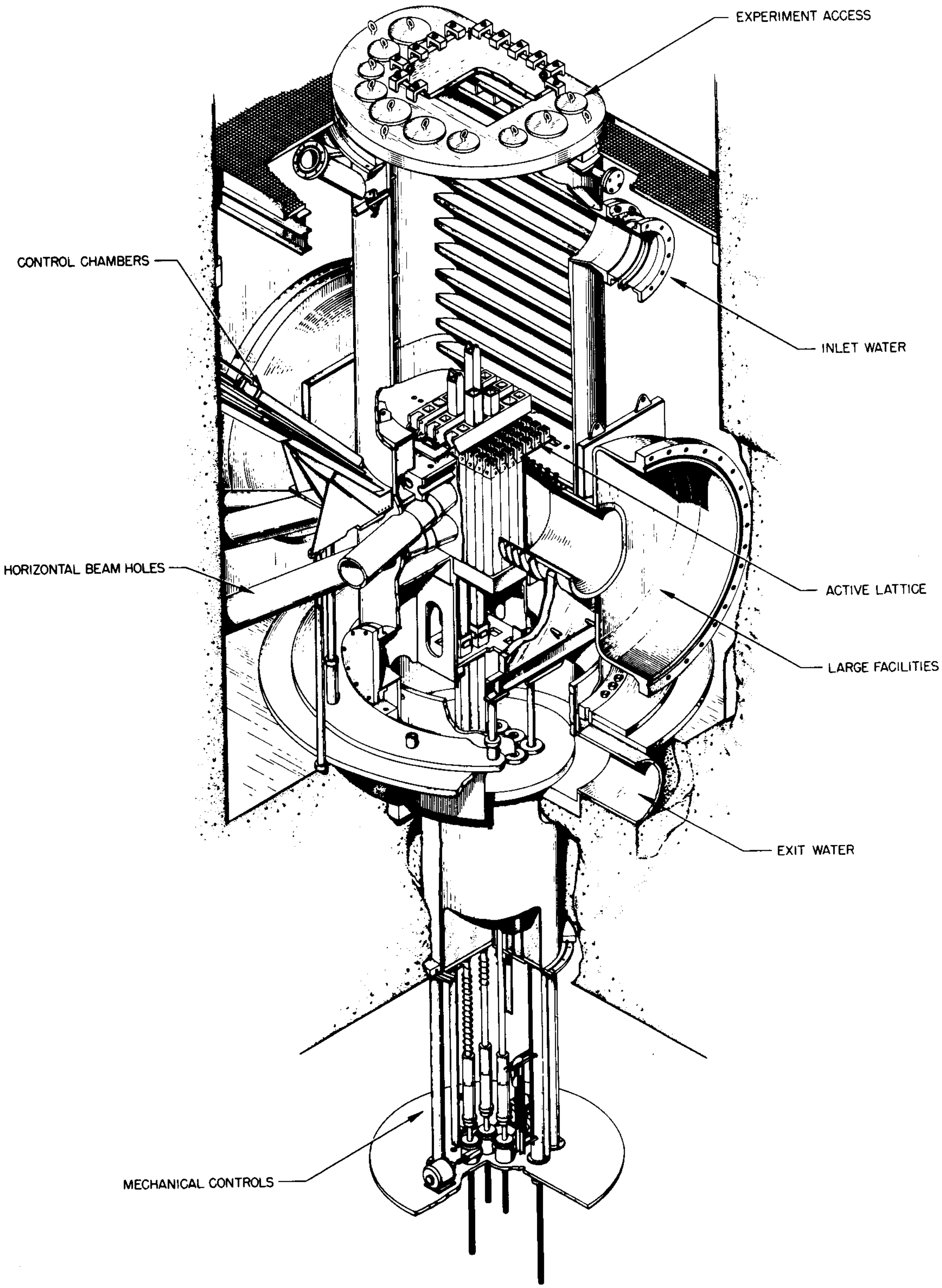

Fig. 1. View of the ORR Core and Tank.

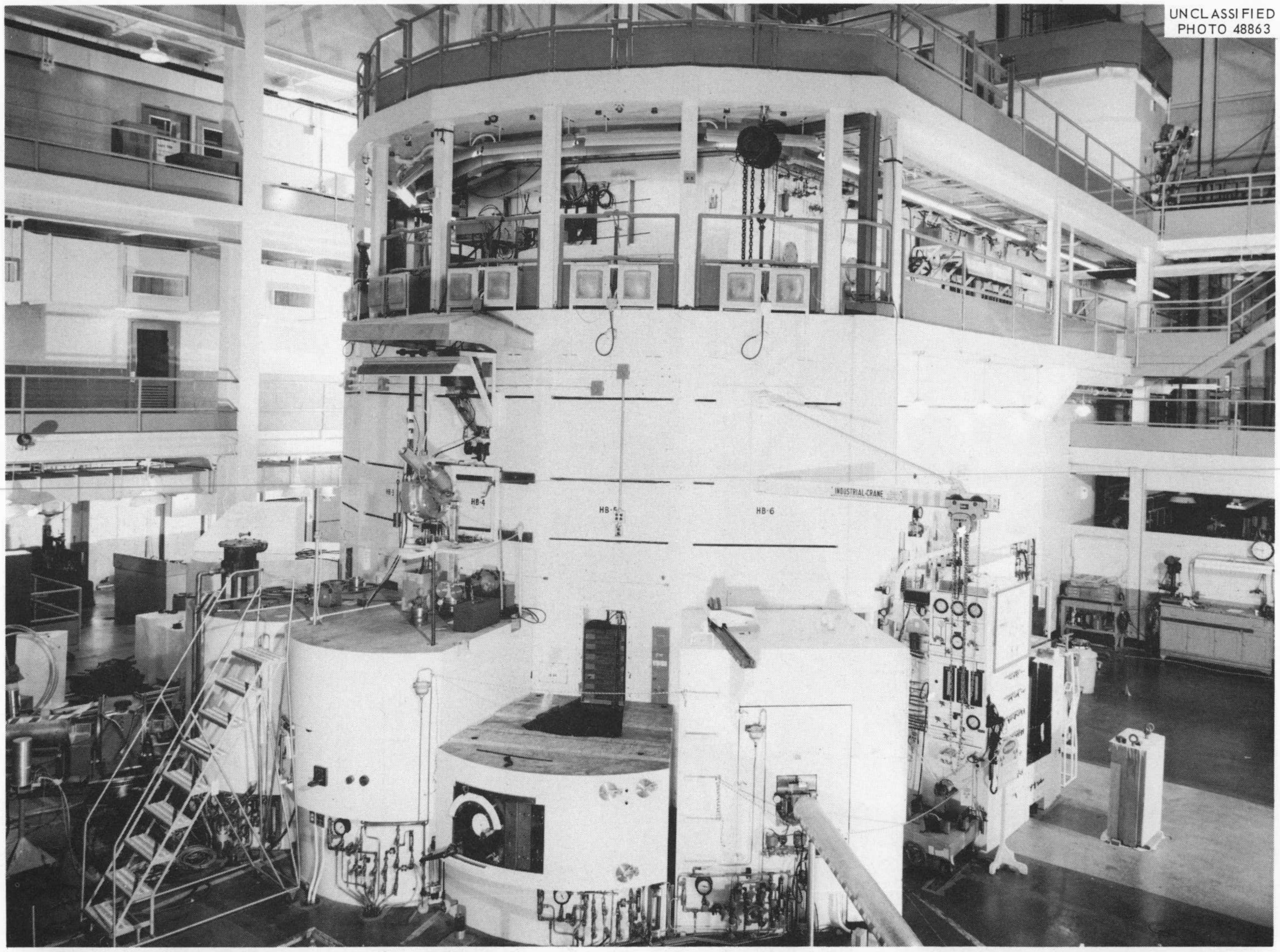

Fig. 2. East End of ORR Showing Beam-Hole Shields and Reactor Balcony.

8. Refueling cycle: about 12 days; within each operating cycle there are three short ($\sim \frac{1}{2}$ day) shutdowns for refueling.
9. Operating time: about 80%.
10. Unscheduled shutdown frequency: average of about four per month.
11. Operating costs: $80,000 per month (includes labor, overhead, materials, fuel fabrication cost; but no U^{235} cost, reprocessing cost, nor depreciation).

The irradiation facilities[3] available at the reactor for the performance of experiments are:

Lattice Positions

These provide the highest neutron fluxes (up to 5×10^{14} n/cm^2-sec) available in the reactor. Access is through flanges in the reactor tank top, but the reactor can be refueled without disturbing experiments (Fig.3). A typical, but not current, allocation of lattice positions and access flanges to experiments is shown in Fig. 4. Lattice positions are identified by a combination of a letter (A through G) and a numeral (1 through 9).

Horizontal Beam Holes

Six beam holes, each 6 in. in diameter, are provided. The beam can be shut off by flooding the 6.4-ft-long collimator section of the hole with water and rotating a 2-ft-thick steel shutter (Fig. 30).

Engineering-Test Facilities

These two large facilities (Fig. 5), located on the north and the south sides of the reactor, each have 19 x 25 in. obround access holes to the side of the lattice and are closed with $5\frac{1}{2}$-ft-diam. shielding plugs. These plugs may be penetrated with several smaller holes for

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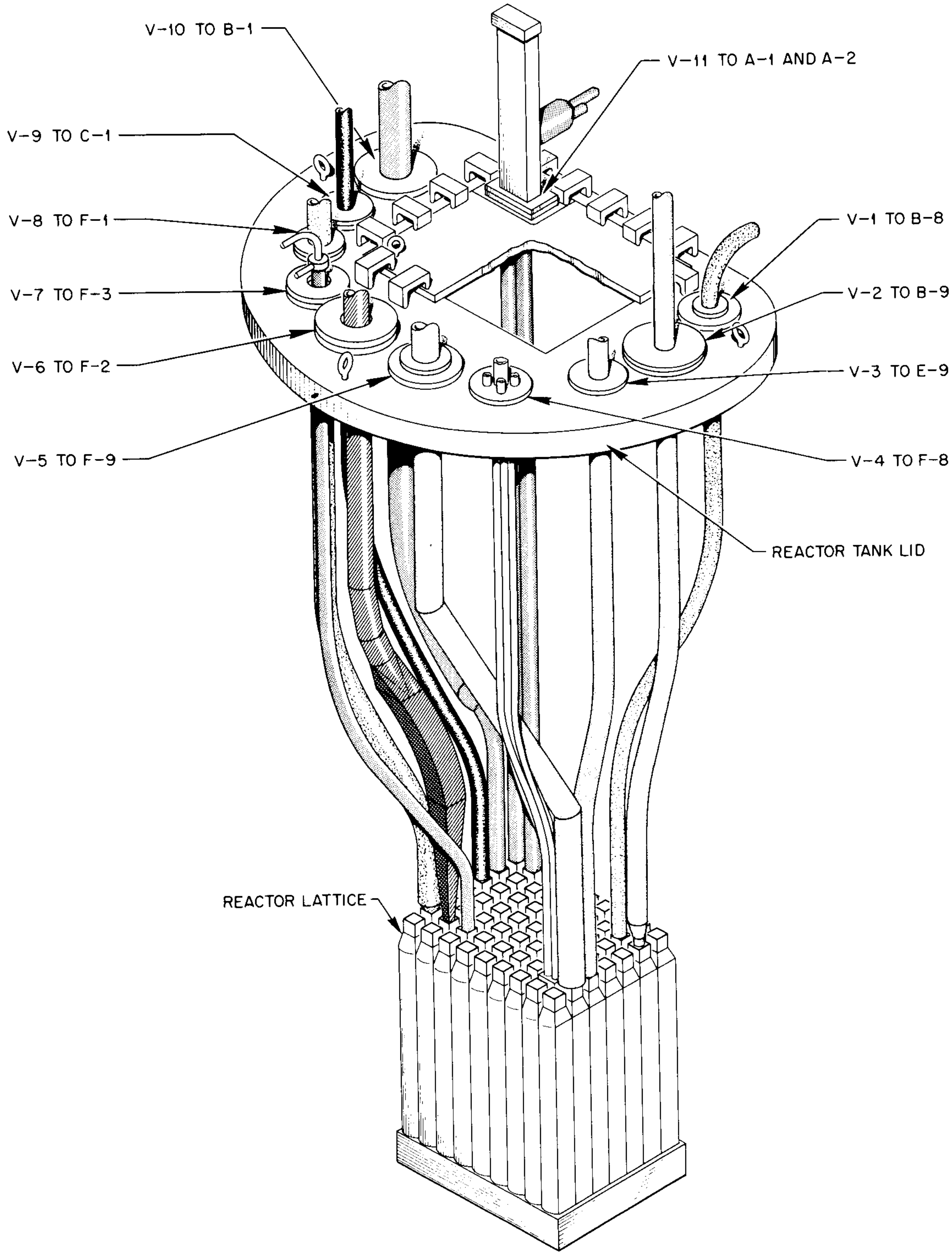

Fig. 3. ORR Vertical Experiments.

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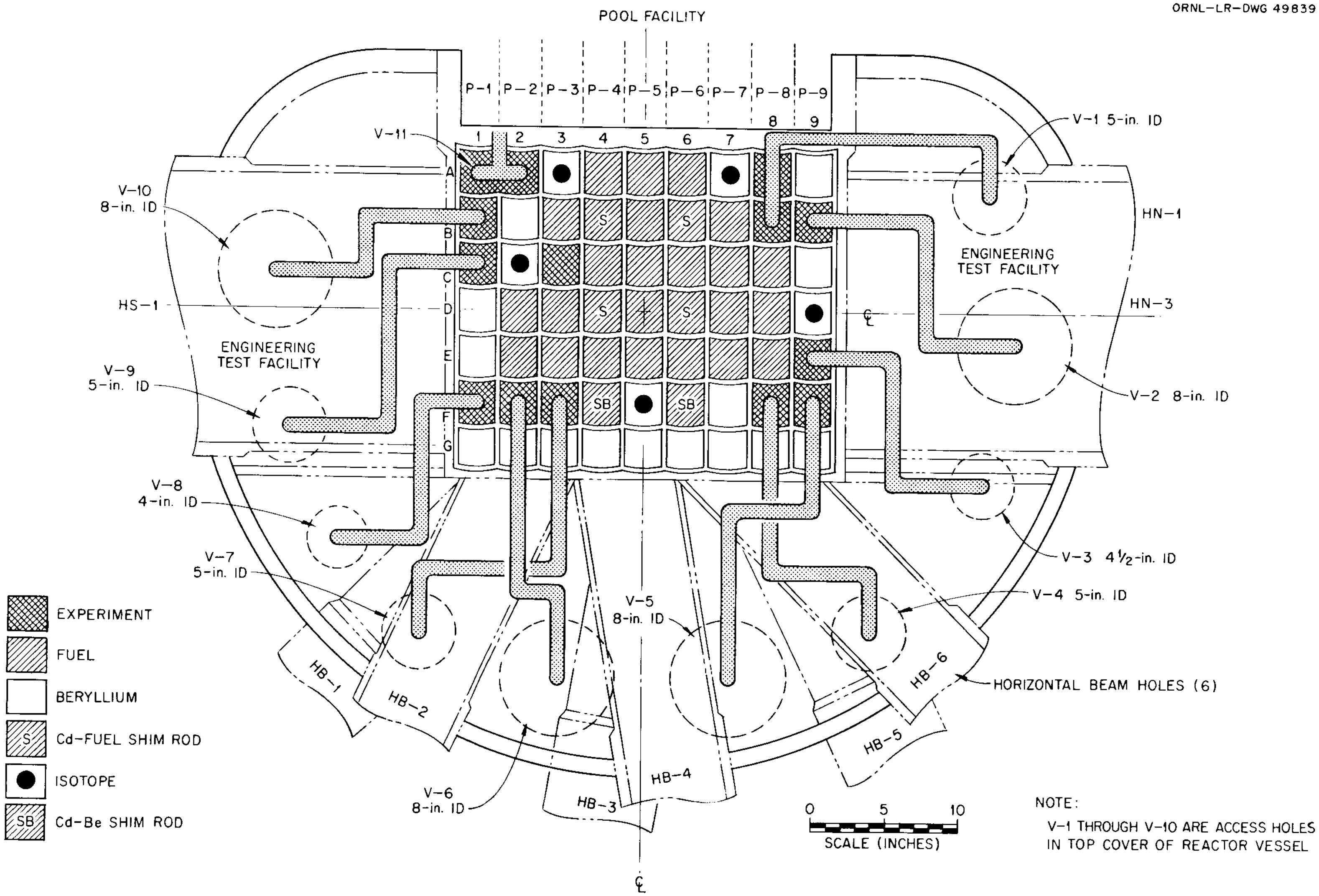

Fig. 4. ORNL Research Reactor Lattice Pattern and Experiment Locations.

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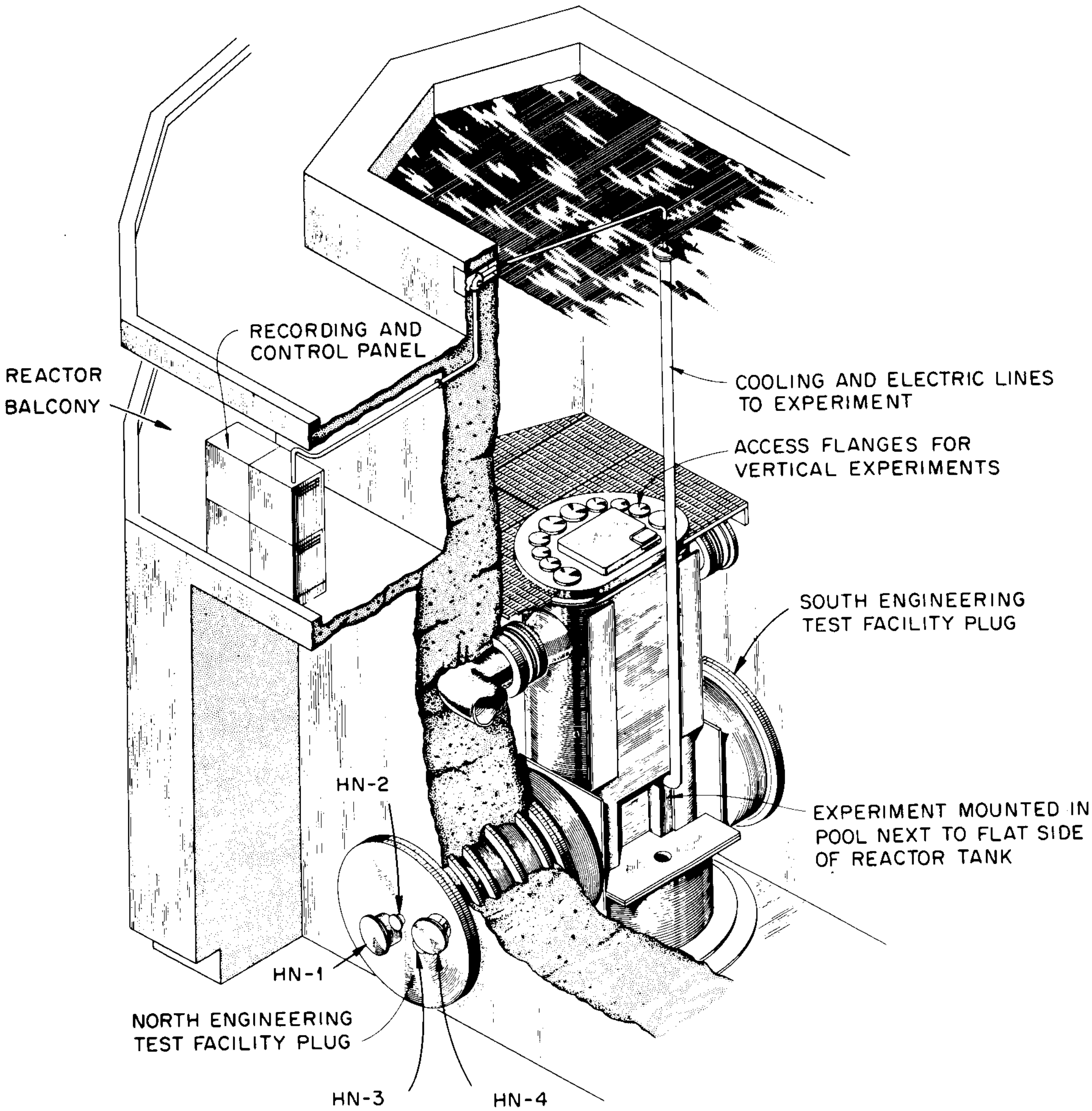

Fig. 5. ORR Engineering Test and Poolside Irradiation Facilities.

experiments that individually do not require the use of the entire hole. Such penetrations are designated HN-1, HN-2, etc. (for the north facility). The maximum thermal neutron flux in these facilities is about 7×10^{13} n/cm^2-sec.

Poolside Irradiation Facility

In this, the most accessible facility in the reactor (Fig. 5), experiments may be placed on the flat, west side of the reactor tank close to the lattice. The maximum thermal and fast (> 0.4 Mev) neutron fluxes available at this facility are each approximately 4×10^{13} n/cm^2-sec.

Hydraulic-Tube Facility

Four sample tubes are provided for transporting 5/8-in.-OD (3 tubes) and 1 1/8-in.-OD (1 tube) aluminum sample containers (or "rabbits") from a loading station in the pool to lattice position F-8 (Fig.6). Up to two rabbits may be loaded in each tube. Samples may be sealed either in an unperforated rabbit or in smaller containers which are then placed inside a perforated rabbit (Fig. 7). While in the reactor core, the rabbits are continuously cooled by water flowing through the hydraulic tubes. Irradiated rabbits can be unloaded in an adjacent hot cell, if desired. The thermal neutron flux in lattice position F-8 is $1 - 2 \times 10^{14}$ n/cm^2-sec.

Pneumatic Tube Facility

This facility allows small (5/8-in.-OD by 1 1/8-in.-long) sample containers, or "rabbits", of high-density polyethylene plastic (Fig. 7) to be transferred to or from the reactor with a transit time of 2-3 seconds. The sample space within each rabbit is about 1.3 ml. The reactor terminus of the facility is at the reactor end of a small penetration (HN-3) in the north engineering test facility. The maximum

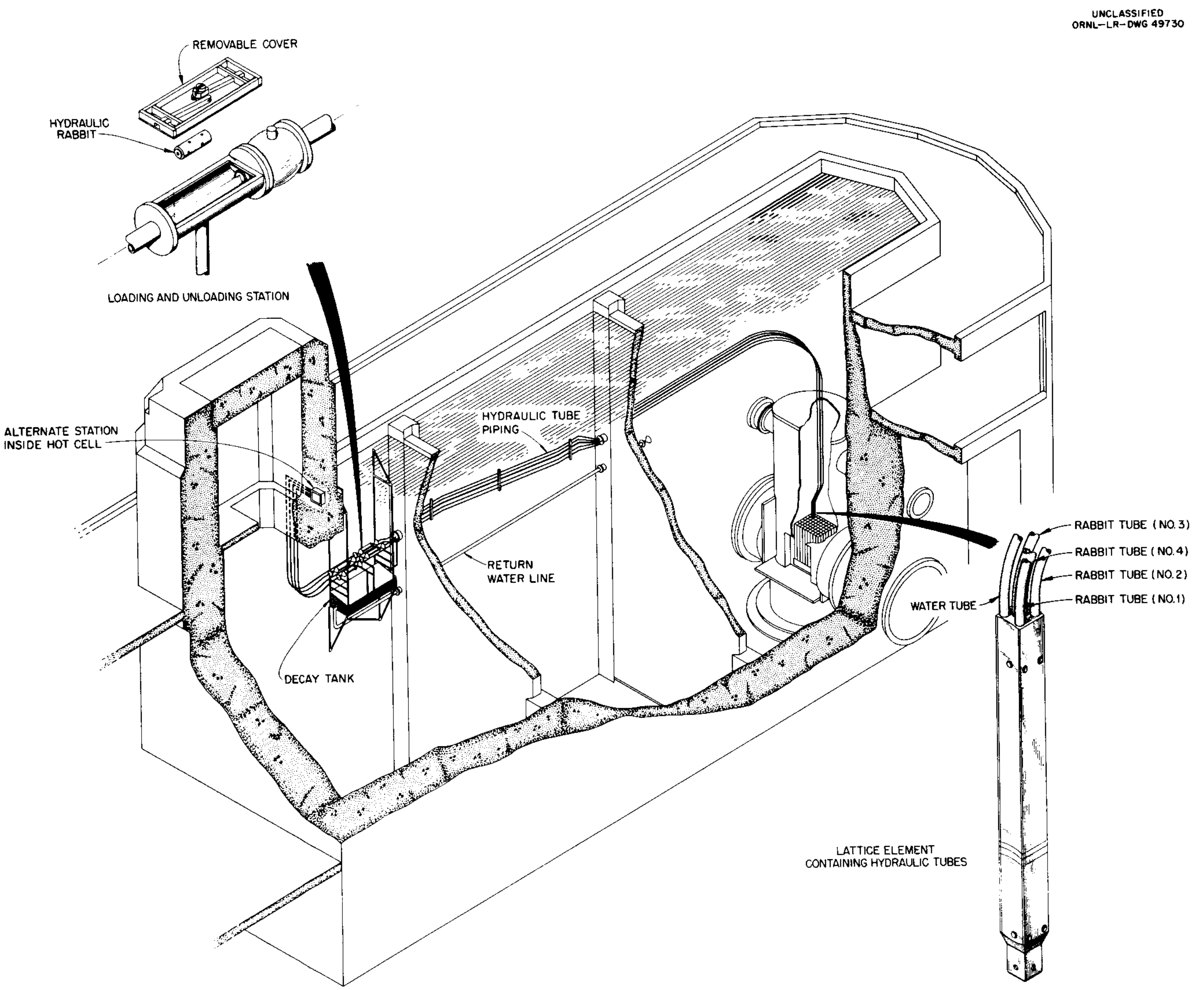

Fig. 6. ORR Hydraulic Rabbit System.

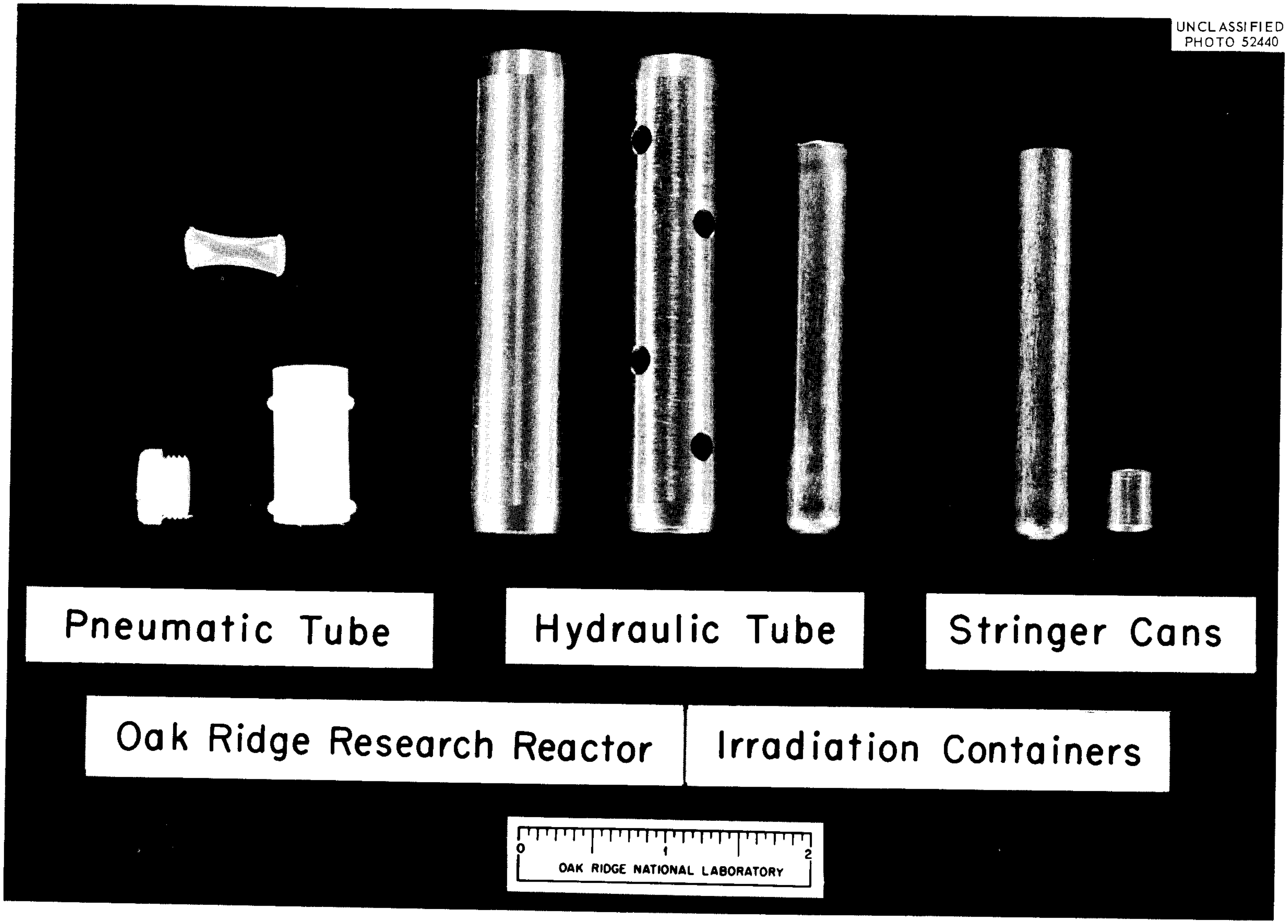
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PHOTO 52440
Pneumatic Tube
Hydraulic Tube
Stringer Cans
Oak Ridge Research Reactor
Irradiation Containers
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Fig. 7.

thermal neutron flux in HN-3 is 6.5×10^{13} n/cm^2-sec. While under irradiation, the rabbits are cooled by forced air flow. Irradiation time is limited to about 40 min. because of the possibility of rabbit failure due to radiation damage. The rabbit loading station is within a hood in a chemistry laboratory located in the reactor-building basement.

Low-Intensity Testing Reactor

The LITR was the original hydraulic-test mock-up of the MTR. It was converted to a training reactor for the operating staff of the MTR in 1951 and subsequently has been used as a testing reactor.[4]

This reactor (Fig. 8) uses MTR-type, enriched-uranium fuel elements and beryllium-reflector pieces in a 5-element x 9-element lattice with moderation and cooling provided by forced circulation of demineralized water. The reactor tank is surrounded with concrete block shielding. Control-rod drives are mounted on the top of the reactor tank. The reactor is flanked on two sides with two large rooms for housing experiment equipment (Fig. 9). The beam holes open into these rooms. Two higher levels around the tank, called the "midriff" and the "top level", are enclosed for the shelter of experiments and of operating personnel.

The main reactor characteristics of importance for experiments are as follows:

1. Operating power: 3 Mw
2. Thermal-neutron flux: 1.7×10^{13} n/cm^2-sec (average); 5×10^{13} n/cm^2-sec (maximum).
3. Gamma heating: 0.8 - 1.6 watt/gm, depending on material and lattice position.
4. Coolant temperature: water inlet temperature--approximately 95°F.

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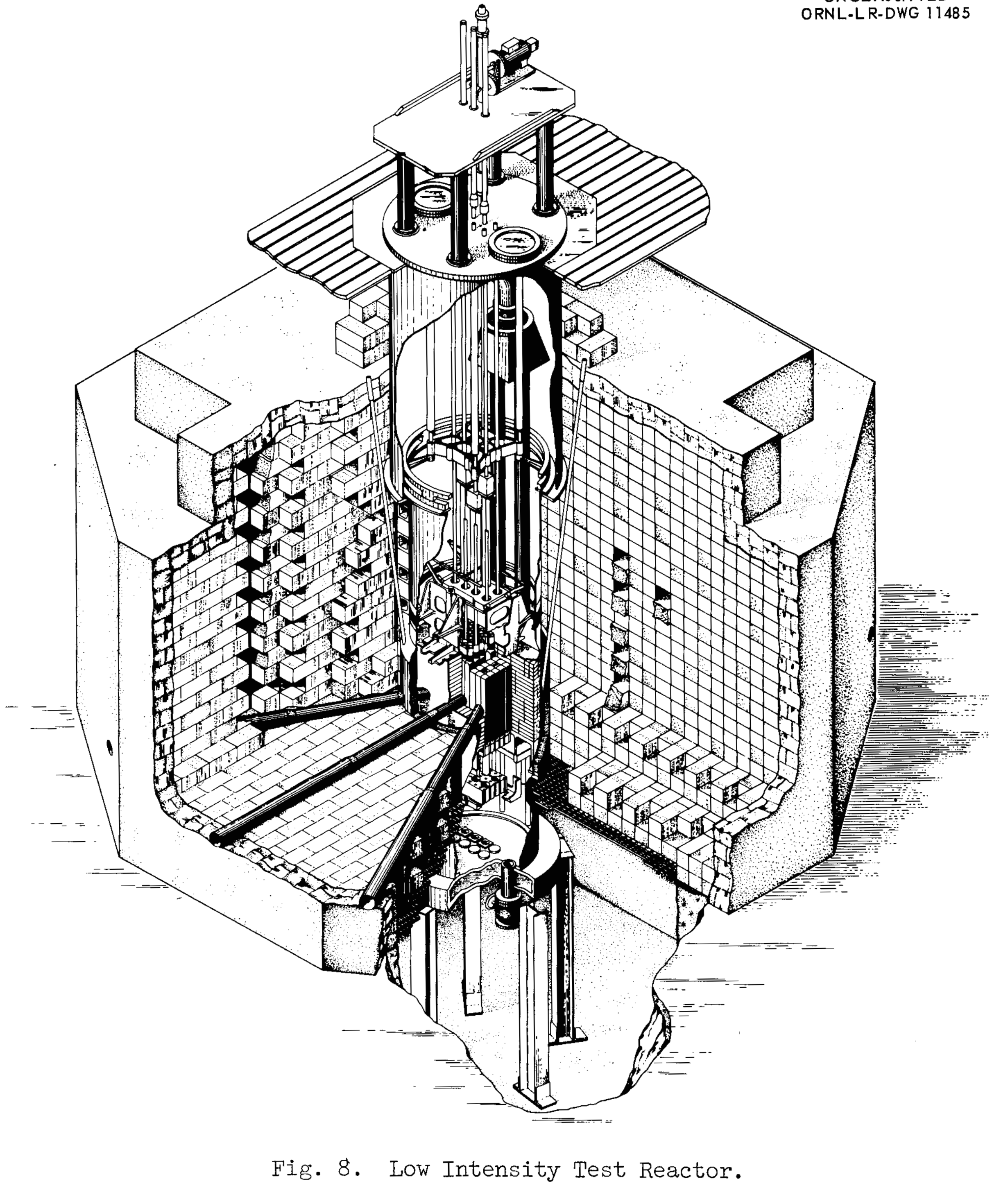

Fig. 8. Low Intensity Test Reactor.

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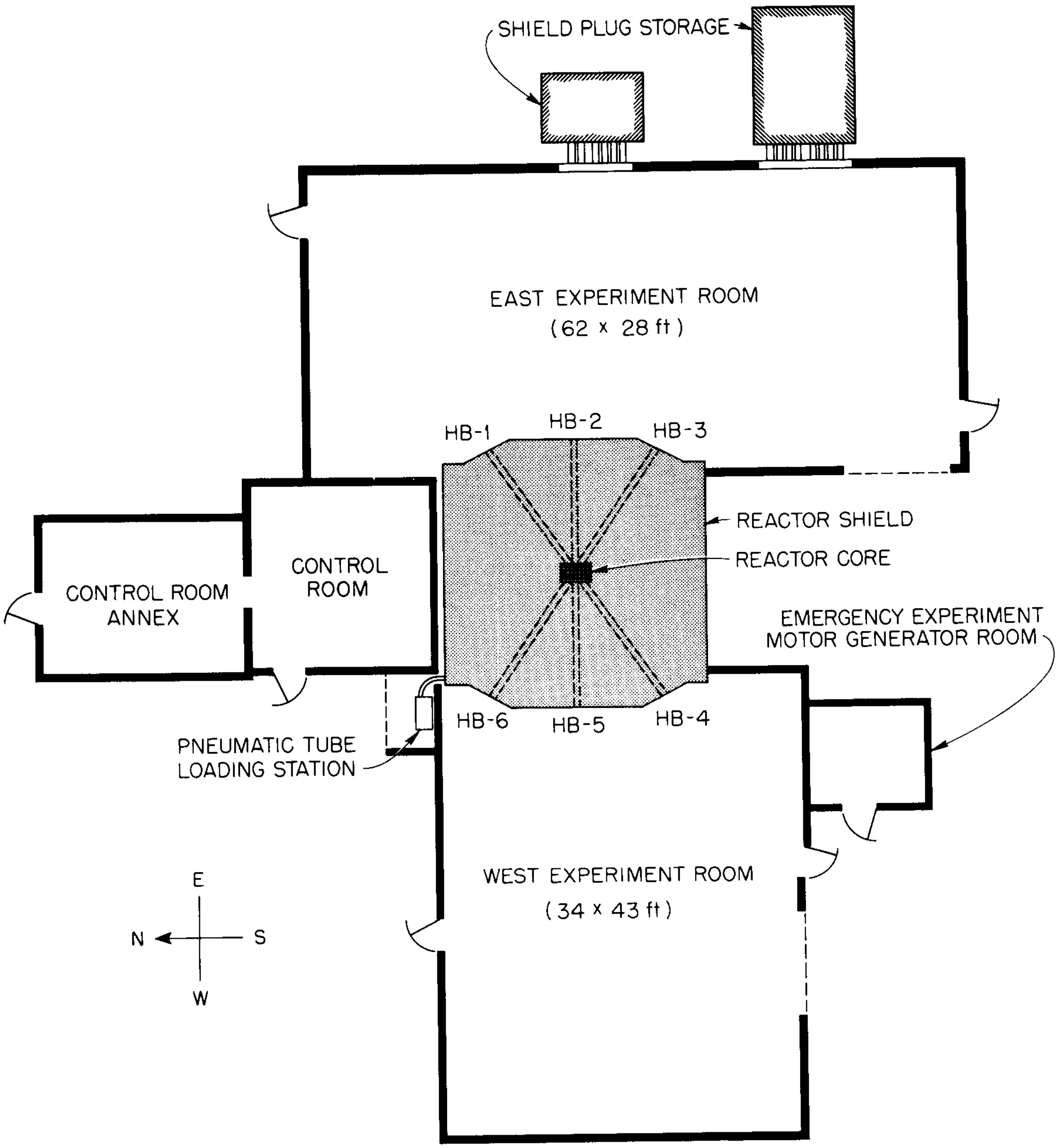

Fig. 9. LITR Experiment Area — Ground Floor.

5. Coolant pressures: about 10 psig at the lattice (The pressure drop across lattice at full flow is less than 1/2 psi.)
6. Operating cycle: shutdown for ~2 1/2 days every 4 weeks; additional short (several hours) shutdowns each week if needed by experimenters.
7. Refueling cycle: 4 weeks
8. Operating time: about 88%
9. Unscheduled shutdown frequency: about 5 per month
10. Operating costs: about $18,000 per month (Same basis as ORR, q.v.)

The irradiation facilities available for experiments are:

Lattice Positions

These provide the highest available neutron fluxes and are accessible through flanges in the side and the top of the tank. In the latter case, experiments have to be disconnected each time the tank top is removed. Lattice positions are designated by the letter "C" followed by two digits representing the numbers of two intersecting rows.

Beam Holes

Six horizontal beam tubes, each 6 in. in diameter are provided. Three tubes terminate in each experiment room. The maximum thermal neutron fluxes at the lattice ends of these beam tubes range from 8×10^{12} to 3×10^{13} n/cm^2-sec.

Pneumatic Tubes

Two pneumatic tubes are available to take samples, up to 3/8-in. diameter by 1 7/8-in. long, to a region in the reflector where the neutron flux is 10^{13} n/cm^2-sec.

Oak Ridge Graphite Reactor

This reactor (Fig. 10) differs markedly from the ORR and LITR. The OGR is a graphite-moderated, air-cooled, natural-uranium-fueled reactor[4]. The core and reflector is a 24-ft cube of graphite blocks containing horizontal fuel channels arranged in a rectangular grid with 8-in. spacing. The graphite cube is surrounded with a 7-ft-thick concrete biological shield. The over-all reactor, including the shielding, is about a 40-ft cube. The reactor is housed in a building roughly 140 x 180 x 80 ft high. The large amount of space available in the building and at the reactor experiment faces has allowed separate rooms to be built in convenient locations for housing experiment equipment.

The main reactor characteristics of importance for experiments are as follows:

1. Operating power: 3.5 Mw
2. Thermal-neutron flux: 1.1×10^{12} n/cm^2-sec (maximum)
3. Gamma heating: $\approx 10^{-3}$ watt/gm (in carbon)
4. Temperature in experiment holes: 25° - 160°C
5. Pressure inside reactor: about 29 in. water gage below atmospheric
6. Operating cycle: shutdown every seven days for about 10 hrs.; other shutdowns at experiment convenience
7. Refueling cycle: none required (Conversion of U-238 to Pu-239, and the occasional replacement of fuel in those channels containing a burst slug, is sufficient.)
8. Operating time: about 90%
9. Unscheduled shutdown frequency: about 1 per month
10. Operating costs: about $27,000 per month (Same basis as ORR, q.v.)

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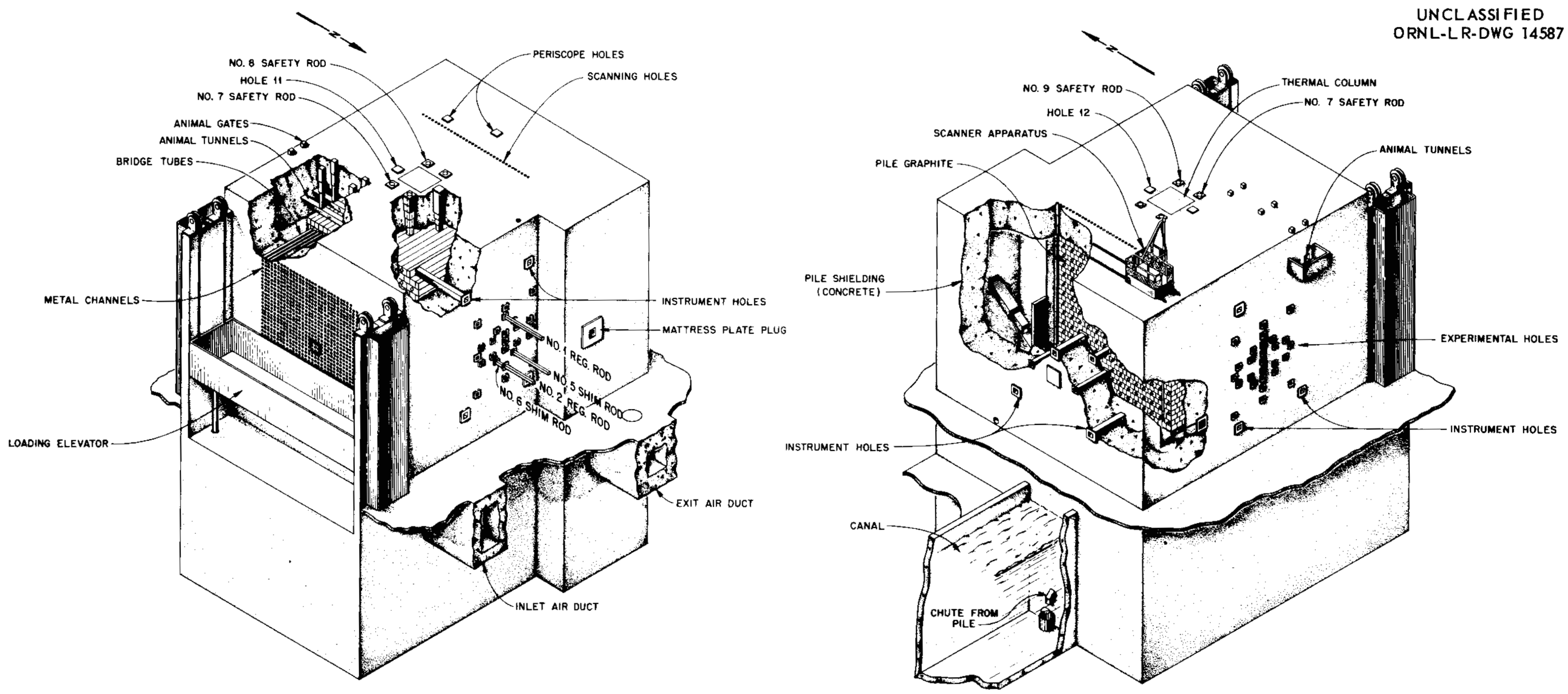

MAXIMUM FLUX: 1.1×10^{12} NEUTRONS/CM^2/SEC

MAXIMUM OPERATING TEMPERATURES:
METAL: ~250° C
GRAPHITE: 170° C

NUMBER OF LOADING HOLES: 1248

COOLING AIR FLOW: 120,000 CU. FT. PER MINUTE

GRAPHITE CUBE: 24 X 24 X 24 FT. 4 IN. HIGH

OVERALL DIMENSIONS: – HEIGHT: ~35 FT.
LENGTH: 47 FT.
WIDTH: 38 FT. 2 IN.

FUEL: ALUMINUM-CLAD NORMAL URANIUM SLUGS,
1.1-IN. DIAMETER, 4 IN. LONG,
WEIGHING 2½ POUNDS PER SLUG.

NUMBER OF SLUGS PER FUEL CHANNEL: UP TO 54

CURRENT USAGE: RESEARCH AND RADIOISOTOPE PRODUCTION

POWER LEVEL: 3500 KW

CONTROL AND/OR SHIM RODS (NEUTRON ABSORBERS):
5 SHUTDOWN RODS AND
2 REGULATING RODS

Fig. 10. Oak Ridge National Laboratory Graphite Reactor.

The number of irradiation facilities available for experiments is very large. The main facilities are 4-in.-square horizontal holes that run through the graphite cube at right angles to, and midway between, the fuel channels. Unused fuel channels in the core and reflector are also available. Table 1 on the following page summarizes the facilities available.

DISCUSSION OF SURVEY RESULTS

In this discussion some of the advantages and the short-comings of the three reactors are pointed out. Not all these points are intrinsic to the particular type of reactor; in some cases they arise from the design of the enclosing building. The comments which follow apply specifically to the three reactors as they are presently built and housed at the Oak Ridge National Laboratory.

It is well recognized that no one reactor design can be optimum for experiments in a wide variety of research and of engineering disciplines. If the design is optimized in favor of a particular type of investigation, it is inevitable that its utility for some other types of work will suffer. The design of a general-purpose reactor, therefore, has to be a compromise. The same can be said for the operating cycle of the reactor. Operating cycles which are best for one experiment will be unsuitable for others. Local changes in neutron flux can be made in order to favor a particular experiment, but this in general will result in disturbances to the flux at other experiment locations that may be undesirable. In an existing reactor, flexibility in operating schedule or in fuel distribution to favor the maintenance or the operation of a particular experiment may

Table 1. Research Openings Into Graphite Reactor

Kind of Facility	Number of Facilities	Maximum Thermal Neutron Flux (n/cm^2-sec)	Approximate Gamma (r/hr)	Approximate Temperature °C
4-in.-square horizontal	42	3.6×10^{11} to 1×10^{12}	3×10^5 to 8×10^5	35 to 160
4-in.-square vertical	3	8×10^{11}	6.7×10^5 (measured)	135 to 140
1.68-in.-diam. horizontal	4	1×10^{12}	9×10^5	35
2 3/4 x 3/8 in. foil slot	1	1.1×10^{12}	9×10^5	160
Unused fuel channels in core region	5	5.5×10^{11} to 1×10^{12}	4.5×10^5 to 9×10^5	35
Unused fuel channels in reflector region	418	10^{10} to 3×10^{11}	10^4 to 3×10^5	30 to 40
14-in.-square biological tunnel, bare	1	5×10^8	3.4×10^3 (measured)	25 to 35
14-in.-square biological tunnel, lead-lined	1	1.3×10^9	200 (measured)	25 to 35
5-ft-square vertical thermal column	1	about 1×10^8	135 at top of column (measured)	Room Temp
2½-ft-square horizontal (core hole)	1	5×10^9	1.2×10^4 (measured)	Room Temp

be a great convenience to that experiment. If, however, similar privileges were extended to all experiments in a complex facility like the ORR, the resulting reactor cycle or flux distribution would in all likelihood be unfavorable to all; and the reactor would be less efficient as a research facility.

Not all experiments require the highest attainable neutron flux. In some experiments a relatively low flux is required for producing a low reaction rate in the samples; in others it is necessary to avoid the high gamma heating which usually accompanies a high neutron flux. The three reactors under discussion each differ in average neutron flux by roughly an order of magnitude. The ratio of gamma heating rate to neutron flux in the graphite-moderated OGR is, however, an order of magnitude lower than in the water-moderated ORR and LITR.

Types of Experiments

While there is no very clear-cut distinction between the types of experiments being done at the three reactors, many of the same experiments having been done at each reactor as it became available, it can be seen from those experiments described in the Appendix that some rough generalizations can be made. These are as follows:

1. The outstanding characteristic of the ORR is its high neutron flux ($\sim 10^{14}$ n/cm^2-sec average). Its use is thus favorable for most investigations requiring the highest available neutron flux when the effects of nuclear heating can either be tolerated or eliminated. Some of these investigations are:

a. Physics investigations in which several neutron-beam scatterings are made in succession or where very small solid angles of detection are used;

b. High-resolution neutron diffraction studies;

c. Studies of the effects of neutron irradiation on the crystal structure and the mechanical properties of solids;

d. Investigations on the chemical stability and corrosive properties of fuel solutions and slurries at high power densities;

e. The preparation of transmutation alloys;

f. Studies on radiation damage and fission-gas release from solid nuclear fuels at high fission-power densities;

g. Production of radioisotopes of high specific activity.

2. By virtue of the flexibility of its operating schedule, and the fact that its neutron flux ($\sim 10^{13}$ n/cm^2-sec average) is the same as in many power-reactor applications, the LITR has been found particularly favorable for the following:

a. Preliminary screening tests of new materials, components, experiments, and processes prior to subjecting them to large doses of radiation in a higher-flux reactor;

b. Studies of the effects of radiation on the chemical stability, corrosion resistance, and mechanical properties of power-reactor fuel and fertile materials.

3. By virtue of its relatively low, constant, neutron flux ($\sim 6 \times 10^{11}$ n/cm^2-sec average) and its very low gamma heating rate ($\sim 3 \times 10^{-3}$ watt/gm), the OGR is particularly favorable for the following types of research:

a. In-pile irradiations at very low temperatures ($\sim$0 to 100°K);

b. Basic solid-state research on semiconductors and other highly radiation-sensitive materials requiring a low and constant rate of defect introduction;

c. Studies where neutron-induced effects are to be distinguished from gamma effects, and, therefore, where very pure fluxes of neutrons relatively free from gammas are required;

d. Fission product radiochemistry (yields and decay characteristics);

e. Studies on radiation effects in material in which annealing during irradiation is to be minimized;

f. Activation analysis of very heat-sensitive biological specimens.

Advantages, Disadvantages and Improvements

As found in this survey of experimenters, the main advantages and disadvantages of the three reactors from the viewpoint of their utility for experiments and some of the possible improvements which might be made are as follows:

ORR Facility Advantages

1. The neutron flux is an order of magnitude greater than at the LITR, and two orders of magnitude above that of the OGR. This permits some experiments to be done which can not be done at all at the other reactors; it also allows some experiments to be performed more rapidly or with results of higher quality.

2. Access to the reactor core is particularly good, by reason of the bottom-mounted control-rod drives. Experiments penetrating the tank are undisturbed by refueling operations.
3. The flexibility afforded by water shielding in the reactor pool during the placement, removal, and disassembly of experiments is a great convenience.
4. The 8-week operating schedule is optimum for the many experiments of a long-term nature that are performed at a high-flux reactor.
5. The large neutron-flux space gradient permits wide control of the irradiating flux by movement of the experiment.

ORR Facility Disadvantages

1. Generally the fabrication and installation costs of an experiment will be higher than for a lower-flux facility. This arises from a variety of causes and is particularly applicable to in-core experiments. High radiation levels increase the amounts of shielding required; high gamma-heating rates require effective and sometimes complex means of heat removal from the samples and the structure of an experiment; offsets or complex bends are required in access tubes to minimize radiation streaming; hydrodynamic forces arising from greater coolant-flow rates require strong and vibration-free access tubes; and the potentially greater amounts of activation or fission products in an experiment require greater structural integrity and usually double containment of the experiment.
2. The 8-week reactor operating cycle may be too long for some experiments. These then have to be designed so that their samples

can be withdrawn from the flux, removed during one of the brief refueling shutdowns that occur within the operating cycle, or completely removed while the reactor is operating. Adopting any of these alternatives generally results in a costlier experiment design.

3. Short shutdowns for experiment convenience are not practical. Quite apart from their undesirable effects on long-term experiments, short shutdowns ($<$ 1 hr) can very easily develop into long shutdowns (1-2 days) due to xenon poisoning. The alternative to this long shutdown (namely, an immediate refueling to remove poisoned fuel) could, if done frequently, entail an increase in the operating costs of the reactor because of the larger fuel inventory needed. It is necessary to adhere strictly to the established operating cycle in order to realize maximum reactor operating time. Short shutdown privileges granted to one experiment will, if extended to others, generally result in an unfavorable cycle for all.

4. Neutron-flux space gradients and mutual flux disturbances between experiments tend to be large for the relatively small-volume ($\sim$100 liter) ORR core. The neutron flux gradient at the poolside facility is quite steep.

5. The large gamma-heating rate (typically 3 - 10 watt/gm) often requires that cooling, additional to that normally provided by convection of the reactor or pool water, has to be provided. In the case of gas-cooled experiments, complex equipment may have to be used to provide this additional cooling.

6. Insufficient space exists in the reactor pool over the top of the reactor tank for the access tubes of the many complex in-core experiments currently installed.

7. Insufficient space exists on the reactor balcony for the installation and maintenance of the out-of-pile components of experiments being performed in the core and at the poolside facility.

8. There are no convenient provisions for making shielded connection between in-pool sections of experiments and those sections housed in shielded cubicles in the building basement. This lack is of concern mainly in those experiments in which large pieces of equipment need to be housed in a shielded cubicle. Due, however, to lack of space on the reactor balcony, other experiments can also be involved.

9. There is insufficient space in the beam-hole area for the equipment and instrument cabinets of experiments being performed at the six beam holes.

10. Acoustic and electrical noise, dirt, mechanical disturbances, and traffic from nearby work (construction, maintenance, welding, and crane operations) adversely affect experiments and delicate apparatus at the beam holes.

11. Thermal disturbances from nearby truck and personnel doors adversely affect electronic equipment at the beam holes.

12. The fast-neutron (epi-thermal) and gamma fluxes at the beam-hole ports are large enough to cause detector background problems and to require massive shielding around experiments. The presence of this shielding further aggravates the space problem.

13. The system for beam-hole flooding by experimenters (provided to

shut off the beam) is awkward.

14. The capacity of the building-exhaust ventilation system is too small to provide the ventilation required for large experiment-equipment cells.

15. The recessed window at the poolside irradiation facility restricts the size of some types of experiments and complicates the design of experiment conduits.

ORR Facility Possible Improvements

Only in a new reactor facility would it be practical to make some of the improvements listed below:

1. Make the pool above the reactor tank wider to relieve congestion in this area.

2. Provide additional pool-wall penetrations at various levels. More of these are needed for taking experiment conduits from the pool out to the balcony.

3. Provide additional floor space in the reactor building, particularly on the reactor balcony and at the beam-hole experiment areas. An additional 20 ft or so of radial space could be used at the beam holes. Additional building space in the basement could be used for shielded facilities to house loop equipment.

4. Provide a number of shielded pipe chases or trenches for running experiment lines and loop connections between basement cells and the reactor pool and balcony.

5. Increase the capacity of the cell-ventilation system.

6. As a reactor building service to experiments, provide a source of reliable electric power for use in experiments during normal-power outages.

7. At the poolside irradiation facility, provide forced-convection cooling for experiments; also reduce the magnitude of the neutron-flux gradient, possibly through use of neutron reflector materials other than light water.

8. In conjunction with 3 above, construct one or more rooms to enclose the beam-hole experiment area completely. These rooms should be sound-proofed and air-conditioned. Hatches would be needed so that shielding blocks close to the beam-hole ports can be moved when necessary. Traffic around the reactor should be external to these rooms.

9. Provide a simpler means for experimenters to flood beam holes when they desire to shut off the beams.

10. To save space at the beam-hole area, use a design in which the reactor and the experiment shields are integrated. It may be possible in this way at some beam holes to eliminate entirely the massive shields presently used.

11. Make provision for multiple use of each neutron beam, possibly by providing additional levels for setting up experiment equipment.

12. Increase the thermal-neutron flux at the beam holes, either by an increase in reactor power or by a fuel distribution favoring those beam holes where the flux is marginal for the experiments. The latter course would be at the expense of the neutron flux in other facilities and usually is impractical for this reason.

13. Reduce the high-frequency electrical interference emanating from arc welders and relay-operated equipment, especially in the neighborhood of the beam holes. To do this it may be necessary

to employ a variety of measures; for example, interference suppressors on relays, separate grounding systems for experiments, screened rooms around sensitive equipment, etc.

14. For thermal-neutron diffraction studies provide some beam holes tangential to the reactor core in order to reduce the unwanted fast-neutron and gamma backgrounds. This should also allow a reduction in beam-hole shielding and the consequent release of valuable floor space.

15. In a new reactor facility, take particular care to secure the as-built dimensions and relative locations of the reactor, pool, and experiment facilities. Without these data, design of experiments is difficult; and field measurements must be made, often in high radiation fields.

LITR Facility Advantages

1. The neutron flux is about the same as in many power reactors; its variation over a refueling cycle is moderately small ($\sim$ 2% in average flux).
2. The gamma heating is large enough to serve as a source of heat for achieving elevated in-pile sample temperatures, and yet is small enough that cooling of samples to room temperature, or below, is not difficult.
3. Direct access to the lattice for experiments is available.
4. After irradiation, experiments can be left in the reactor tank to decay prior to removal.
5. The operating cycle is both short (1 week) and flexible, permitting shutdowns at experiment convenience. The small magnitude of xenon poisoning allows this flexibility.

6. The lower fluxes, both neutron and gamma, result in lower experiment fabrication and installation costs compared to a higher-flux reactor. This comes from simpler cooling, less shielding, and less complex access-tube requirements.

7. The east and west experiment rooms provide ample space for locating control-instrument cabinets. The number of activities in these rooms is such that the noise level is usually reasonably low.

8. Considerable flexibility exists for modifying the neutron-flux distribution to suit the over-all needs of experiments through changes in fuel loading distribution.

LITR Facility Disadvantages

1. The limited number of reactor tank side-access penetrations forces many of the in-core experiments to be inserted through vertical-access penetrations in the reactor tank top. Experiments using vertical-access penetrations have to be disconnected each time the tank top is removed. Bends necessary in the present side-access facility tubes limit the size of some experimental samples.

2. Space in the reactor tank for experiment tubes and for storage of spent fuel, decaying experimental samples, and unused lattice components, is limited. This is a result of the control-rod drives being mounted on the top of the reactor tank and the lack of a true storage pool.

3. Transfer casks for spent fuel and irradiated experiments also have to be loaded within the confined space of the reactor tank.

This operation presents a potential hazard to the reactor core.

4. In general, each monthly refueling produces local neutron flux changes. Whether these changes are significant depends on the affected experiment. Even though only one or two fuel elements are replaced at each refueling, there is likely to be a relocation of 10 to 20 of the remaining elements as well.

5. The small size of the lattice increases the likelihood of mutual flux perturbations between experiments. Similarly, neutron-flux gradients are likely to be sharp near the edges of the core; the placement of experiments and flux monitors is critical.

LITR Facility Possible Improvement

Side ports near the top of the reactor tank would permit many of the experiment tubes now connected through the tank top to remain connected during shutdowns when the top is removed. The additional bend would, however, make insertion and removal of an experiment more difficult and would, to some extent, restrict the size of the experiment capsule that could be used. This improvement is about the only one of any significance for the LITR that is feasible from the point of view of cost.

OGR Facility Advantages

1. Space for equipment exterior to the reactor is adequate, and separate rooms are available for use as laboratories close to the reactor face. This is a consequence of the large size of the reactor and of its enclosing building.

2. In-pile space for each experiment is large (typically, 24-ft-long, 4-in.-square holes are provided). This follows from the large core size (24-ft cube) and fuel channel spacing (8-in. rectangular grid).

3. The neutron flux is very constant, and its space gradient is small. Flux perturbations due to experiments are generally localized and seldom affect neighboring experiments. These advantages result from the large core size and the fact that refueling is very infrequent. The low neutron flux is advantageous for certain basic solid state investigations and for experiments where low sample-container activation is desired.
4. Gamma heating is very low. This is due both to the low neutron flux and to the use of graphite as the moderator. The gamma heating is about an order of magnitude less than that of a water-moderated reactor having the same neutron flux.
5. A thermal-neutron irradiation facility having a very high cadmium ratio ($> 10^5$) and a very small gamma background is available.
6. A fast-neutron facility (with fission-neutron energy spectrum) is available. Though the flux is not high ($\sim 10^{12}$ n/cm^2-sec), it is very uniform over the sample volume.
7. Massive shielding at most experiment holes is not required. In many cases simple shielding provisions allow samples to be changed during reactor operation; the negative pressure existing in the reactor also simplifies sample changing.
8. Flexibility in fuel distribution allows some adjustment of the ratio of fast-neutron to thermal-neutron fluxes to be made for particular experiments.
9. Flexibility in the operating schedule allows frequent shutdowns to be made for experiment convenience. The nonexistence of a xenon-poison problem contributes to this flexibility.

OGR Facility Disadvantages

Other than the low neutron flux, which restricts many investigations but which actually is an advantage for some studies, there are no outstanding disadvantages to this reactor facility.

OGR Facility Possible Improvements

1. Sample changing in the slanted thermal-neutron facility in the top thermal column could be made easier. Presently, a massive 1-ft-sq x 8-ft-long sliding plug has to be moved. A 1-in. I D serpentine hole in the plug would be adequate for most experiments. The facility could be refrigerated for prolonged low-temperature exposures.
2. Small steps in the exterior of the reactor shield would allow recessed shields to be placed between adjacent experiment holes and thereby reduce radiation leakage between experiments.
3. A shorter pneumatic-rabbit transit time for Hole 22 (e.g., $\frac{1}{2}$ sec), would be advantageous for studies of very short-lived fission products.
4. Head room in those experiment rooms housing cryogenic apparatus needs to be increased.

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APPENDIX

Experiments in the ORR

Gas-Cooled ORR Loop 1

Experiment Description.-- ORR Loop 1 is a forced-convection, helium-cooled, fuel-irradiation loop, designed to operate at 300 psia.[5] The structure is designed to accommodate temperatures as high as 1400°F at the fuel-region outlet. Clad fuel-elements up to 1 in. in diameter by 18 in. long and having a total power generation up to 20 kw can be accommodated. Hermetically-sealed, regenerative-type compressors operating at 600°F are used for circulating coolant. Regenerative-type heat-exchange is used to maintain the large temperature differential in the loop. Supplementary electrical heating and wide-range cooling through a heat exchanger by means of a variable air-water mixture are provided.

The purposes of experimentation are: (a) to verify the performance of Experimental Gas-Cooled Reactor fuel rods under reactor operating conditions; (b) to verify the performance of specially instrumented fuel assemblies for fuel rods for the EGCR and for other clad-fuel reactors; and (c) to test features of fuel elements for advanced gas-cooled reactors including roughened or extended heat-transfer surfaces having variable diameters, structural features, and instrumentation. Although stainless steel will be used for most tests, various metallic cladding materials can also be used.

Experiment Facility.-- Lattice Position B-1.

The fuel-element section of the loop is in the B-1 lattice position of the ORR. Loop compressor equipment is located on the midriff balcony, and the instrumentation is in the basement (Fig. 11). Though samples can be changed only during reactor shutdowns, they can be withdrawn from

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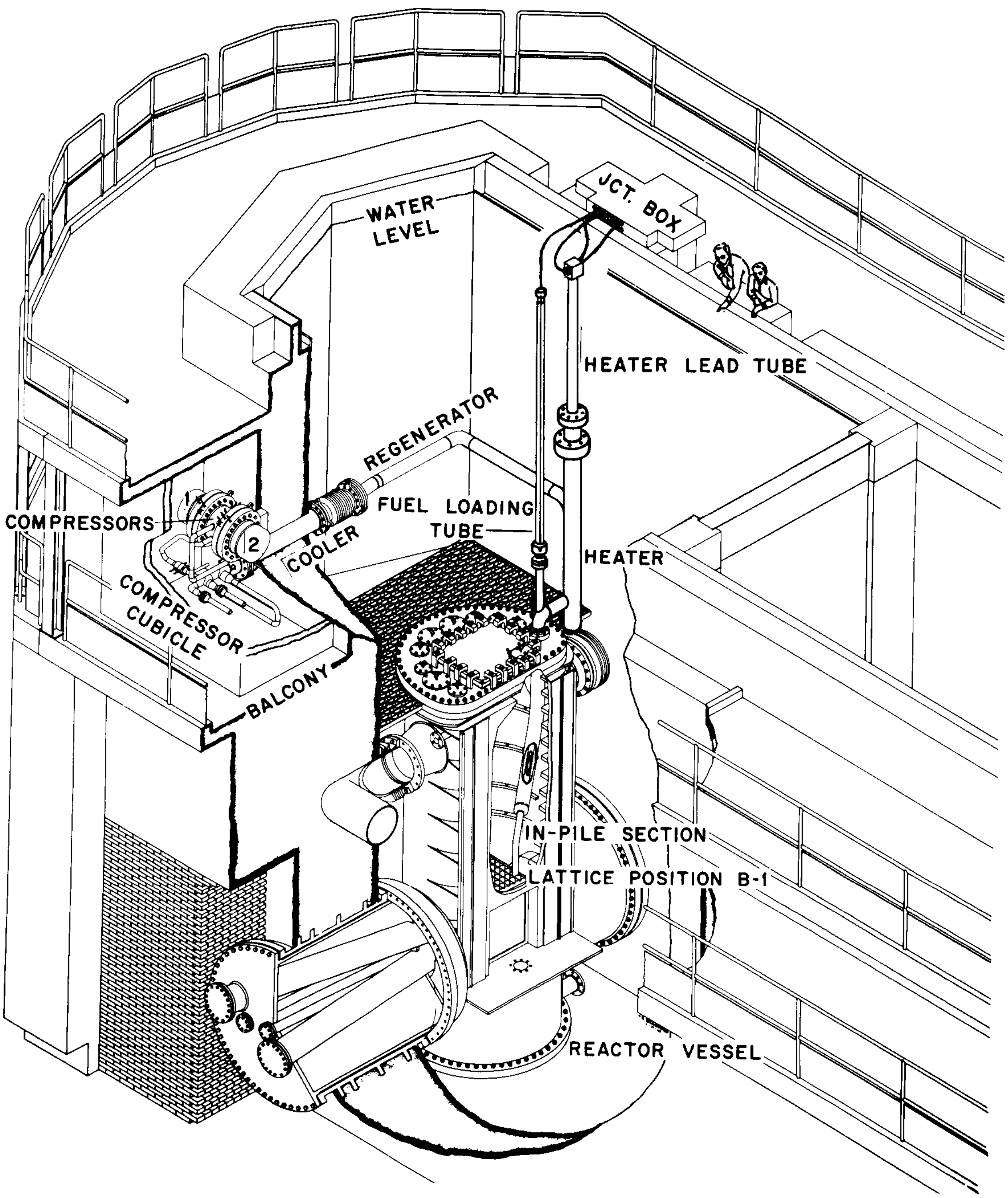

Fig. 11. GC-ORR Test Loop No. 1 at ORNL Research Reactor.

the high-flux region during operation. A special unloading tube makes possible the dry transfer of an irradiated sample element from the loop through the pool directly to the ORR hot cells without the use of shielding casks. This permits examination of samples immediately following irradiation. The long operating cycle of the reactor (8 weeks) is advantageous for this experiment. Short shutdowns do not affect loop operation, other than in loss of irradiation time and introduction of nonstandard operating conditions.

Some of the problems that have been encountered with the facility are:

1. Access to the irradiation space is difficult because of the offset required in the in-pile section of the loop for shielding and for preventing interference with reactor refueling. Also the midriff balcony was not originally intended for experiment equipment of this size and complexity; and, accordingly, space in that region is severely limited.
2. The thermal neutron flux of approximately 2.5×10^{13} n/cm^2-sec within the fuel sample is a little high for many gas-cooled reactor experiments. However, it does make convenient acceleration of certain tests possible. The steep flux gradient at the top and bottom of the ORR core necessitates adjustment of fuel enrichment and introduces nonuniform heat generation in the specimen.
3. The gamma heat, estimated at 3-5 watt/gm, is an inconvenience for most experiments.
4. The facility is affected noticeably by experiments in the adjacent lattice positions and by the over-all reactor fuel loading.

5. The entire loop has been doubly contained in stainless steel jackets built to ASA or ASME Code Specifications. This involved some additional complications in the facility. However, much of the structure was required for thermal insulation and environmental reasons.

<u>Possible Improvements</u>.-- While extensive alterations to an existing reactor facility of this type are probably not warranted nor advisable, a new facility constructed with experiments such as this in mind would be of greater convenience if:

1. The pool were somewhat wider.
2. Additional penetrations were designed and built into the pool wall at appropriate levels.
3. Additional floor space were provided in the reactor building, particularly at the balcony level approximating the top elevation of the reactor tank.
4. A motor-generator-type, reliable-power facility were designed into the reactor complex and considered a part of the reactor services. This service is needed for continuous operation of the loop compresser.

Actually, a poolside facility installation is more convenient for experiments of this type if suitable reflectors can be designed to give a uniform radial neutron flux.

<u>Irradiation of Gas-Cooled Fuel Capsules</u>

<u>Experiment Description</u>[6, 7].-- Eight facilities are provided for high-temperature irradiation of gas-cooled reactor-type fuel capsules (Fig. 12). Experiments conducted in these facilities are designed to measure fission-

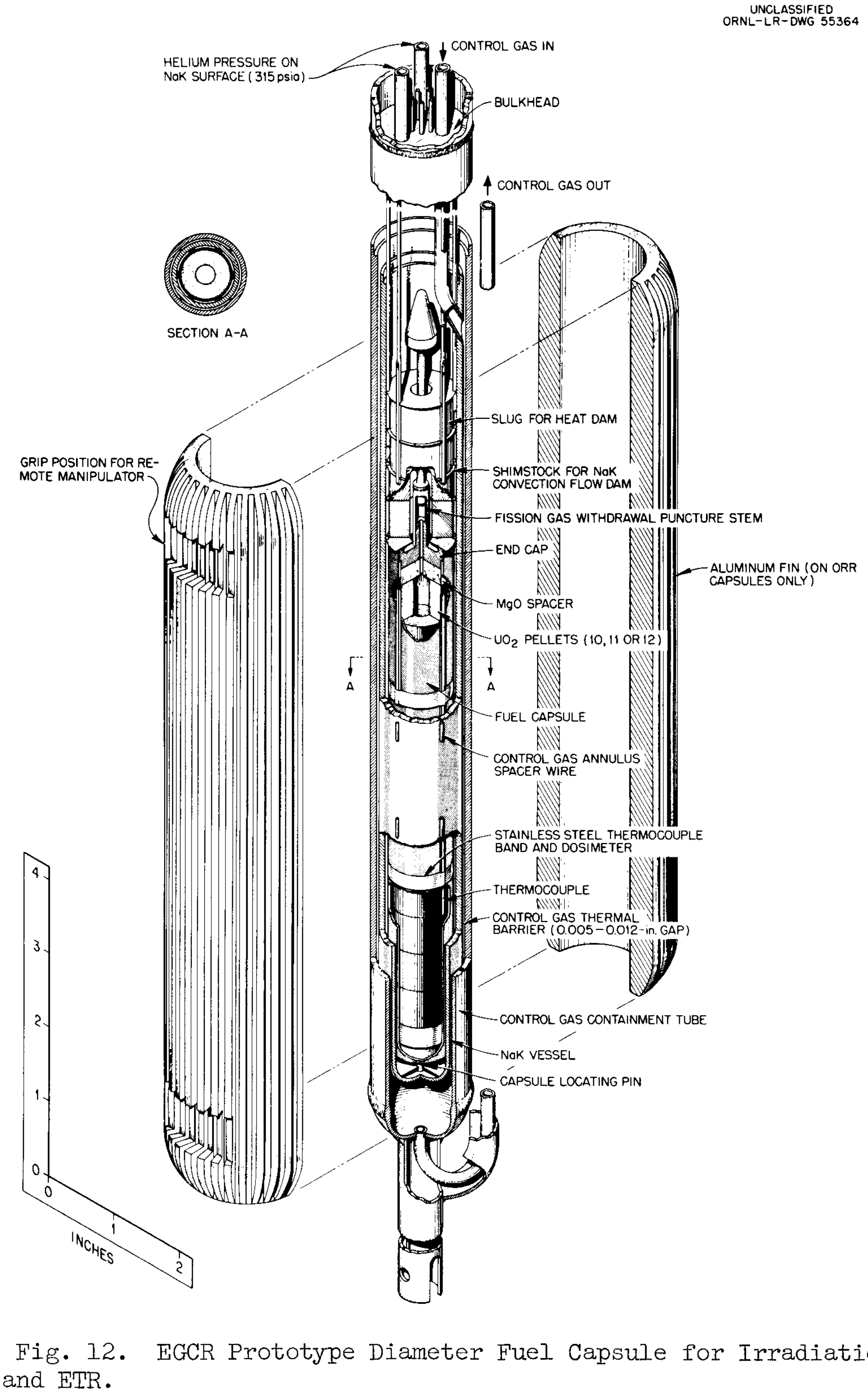

Fig. 12. EGCR Prototype Diameter Fuel Capsule for Irradiation in ORR and ETR.

gas release, determine fuel stability, examine interactions between fuel and cladding materials, and to study the structural and closure features of capsules under irradiation conditions. The heat transfer medium is NaK in contact with the fuel cladding. An inner gas-filled gap provides a thermal barrier to accommodate irradiation-induced temperatures up to 1600°F. Power densities up to 70,000 Btu/hr-ft of fuel length can be achieved, and specimen lengths up to 12 in. may be used. The capsule facilities are provided with cadmium shutters for thermal cycling, position adjustment for flux control, gas-mixture adjustment in the heat-barrier annulus for temperature control, fission-gas purge and sampling devices, and means for leak testing of specimens during irradiation (Fig. 13).

Experiment Facility.-- Poolside Irradiation Facility.

The fuel capsules are positioned in the poolside irradiation facility; gas-adjustment and sampling devices are located on the reactor balcony; and control panels are housed in a separate room (Fig. 14). The poolside facility provides a neutron flux whose energy spectrum and intensity (3×10^{13} n/cm^2-sec, thermal) are satisfactory for the experiment. Gamma-heat removal and the accompanying thermal stresses are satisfactorily accommodated in the experiment design. Samples cannot be changed during reactor operation. The present eight-week reactor cycle, however, is desirable for these experiments.

Some of the problems which have been encountered are:

1. Accessibility to the in-pool facilities has become difficult as other in-pile experiments have been added in the immediate area. Changes during shutdown are complicated by interference from the leads of other experiments.

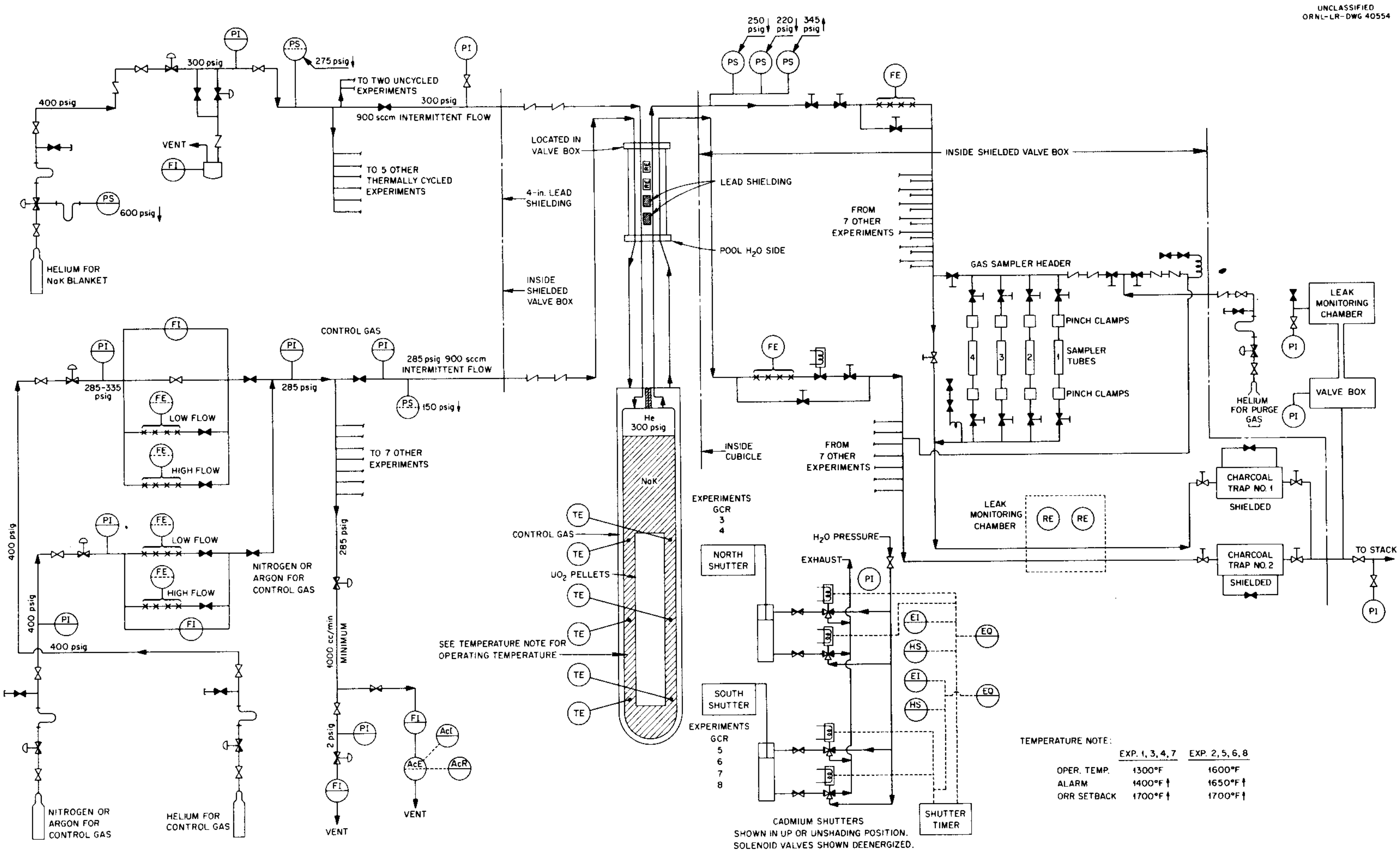

Fig. 13. Full Diameter Prototype Fuel Element, Irradiation Test Flow Diagram.

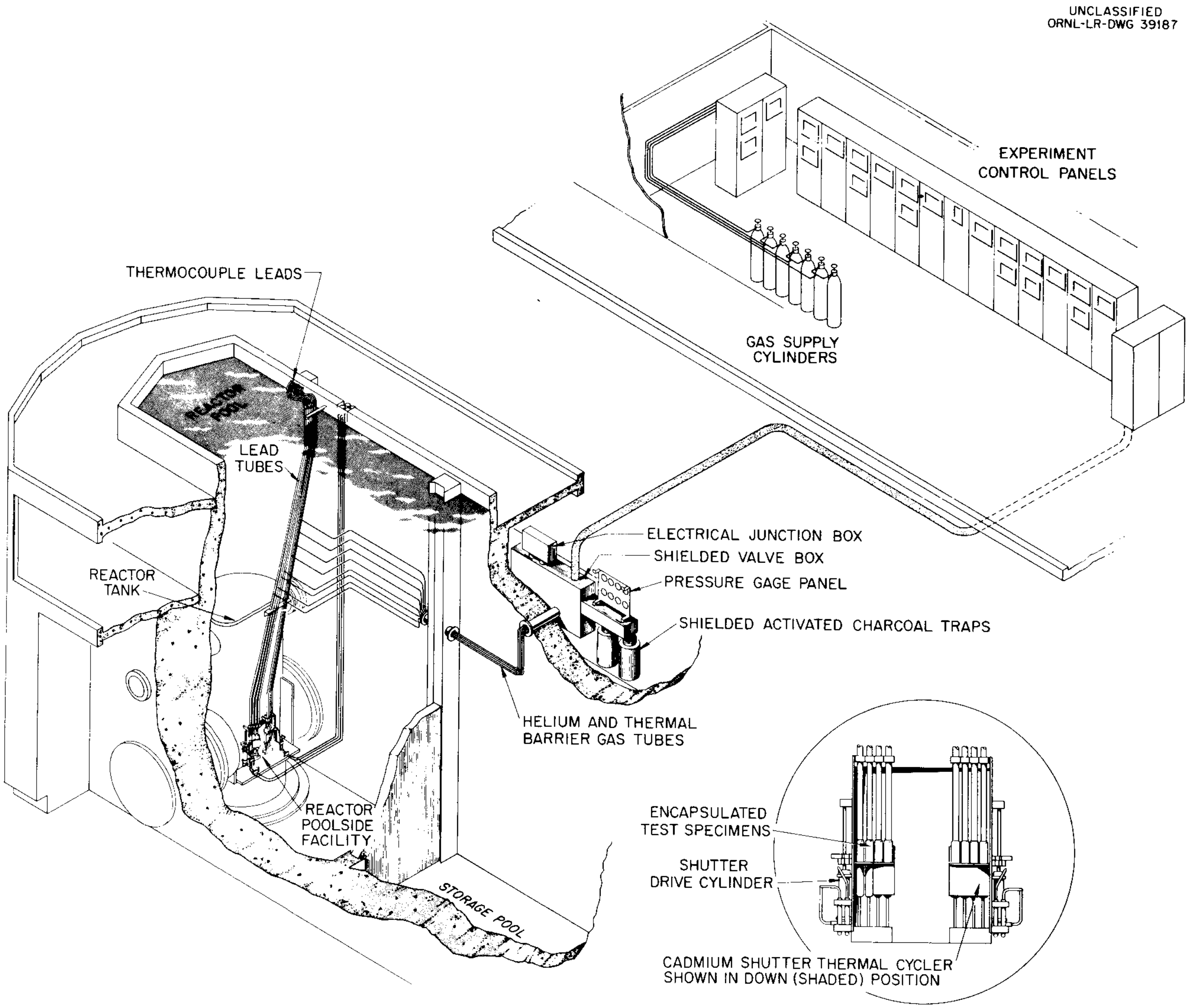

Fig. 14. Experimental Facilities for Irradiation of Full-Diameter Prototype Fuel Capsules in the ORR.

2. Space on the balcony for necessary equipment and for traffic is inadequate.

3. While flux variations arising from fuel loading changes, from other equipment, and from reactor control actions have been acceptable, less variation would be highly desirable. Both the horizontal and vertical flux gradients at the experiment capsules are much steeper than desirable.

4. The power density of the experiments is limited by the natural convective cooling available in the poolside facility. Forced convection would be desirable.

5. Unscheduled reactor shutdowns reduce the usefulness of the experiments and complicate their control. The resulting thermal cycling is undesirable.

6. The recessed window of the poolside facility complicates the construction of experiment lead conduits and limits the choice of design and the dimensions for the experiments.

Possible Improvements.-- In a new reactor the biggest improvements would come from providing a wider reactor pool and increased balcony space.

Pressurized Water Loop

Experiment Description[8, 9].-- In this loop, fuel specimens under irradiation are directly cooled by water flow. The loop proper is designed for in-pile operation at 625°F and 2250 psi with a maximum water flow rate of 80 gpm. Heat-exchanger capacity is 150 kw at a system water temperature of 300°F. Loop construction is of 300-series stainless-steels throughout. A bypass purification system provides for continuous water-chemistry control (Fig. 15). Fuel and material test specimens are irradiated in the space provided by two tubes, 1.5-in. I D x 24 in. long.

The loop has been in operation since December, 1959; and all experiments performed to date have been in support of the N. S. SAVANNAH reactor program. Four experiments involving both swaged and vibratory-compacted UO_2 fuel clad in 304 stainless steel have been irradiated at nominal N. S. SAVANNAH reactor operating conditions of $500^{o}F$ and 1750 psig. Thirty-two Charpy specimens of reactor vessel steel were irradiated in one experiment to an average exposure of 1.3×10^{19} nvt (>1 Mev). Six fuel pins 1/2 in. in diameter by 18 in. long are irradiated simultaneously.

Experiment Facility.-- Lattice Positions A-1 and A-2.

The in-pile test section of the loop occupies lattice positions A-1 and A-2. Equipment required to maintain water circulation at the desired conditions is located in the basement of the ORR building (Fig. 16). The space provided by lattice positions A-1 and A-2 has been adequate for all experiments performed to date. The vertical access to these lattice positions through the special reactor-refueling flange has proven to be a very desirable feature. Space for the loop out-of-pile equipment located in the ORR basement has proven to be adequate.

The maximum perturbed thermal neutron flux in this experiment is approximately 7×10^{13} n/cm^2-sec in lattice position A-2. A maximum gamma heat of 5 watt/gm is estimated for lattice position A-2. Low gamma-heating values are preferred, but the present value does not present a serious problem. Reactor cooling water which flows through the ORR core conveniently serves as a coolant for the removal of gamma heat from the secondary containment tube around the in-pile test section. The loop uses ORR pool water as its secondary coolant.

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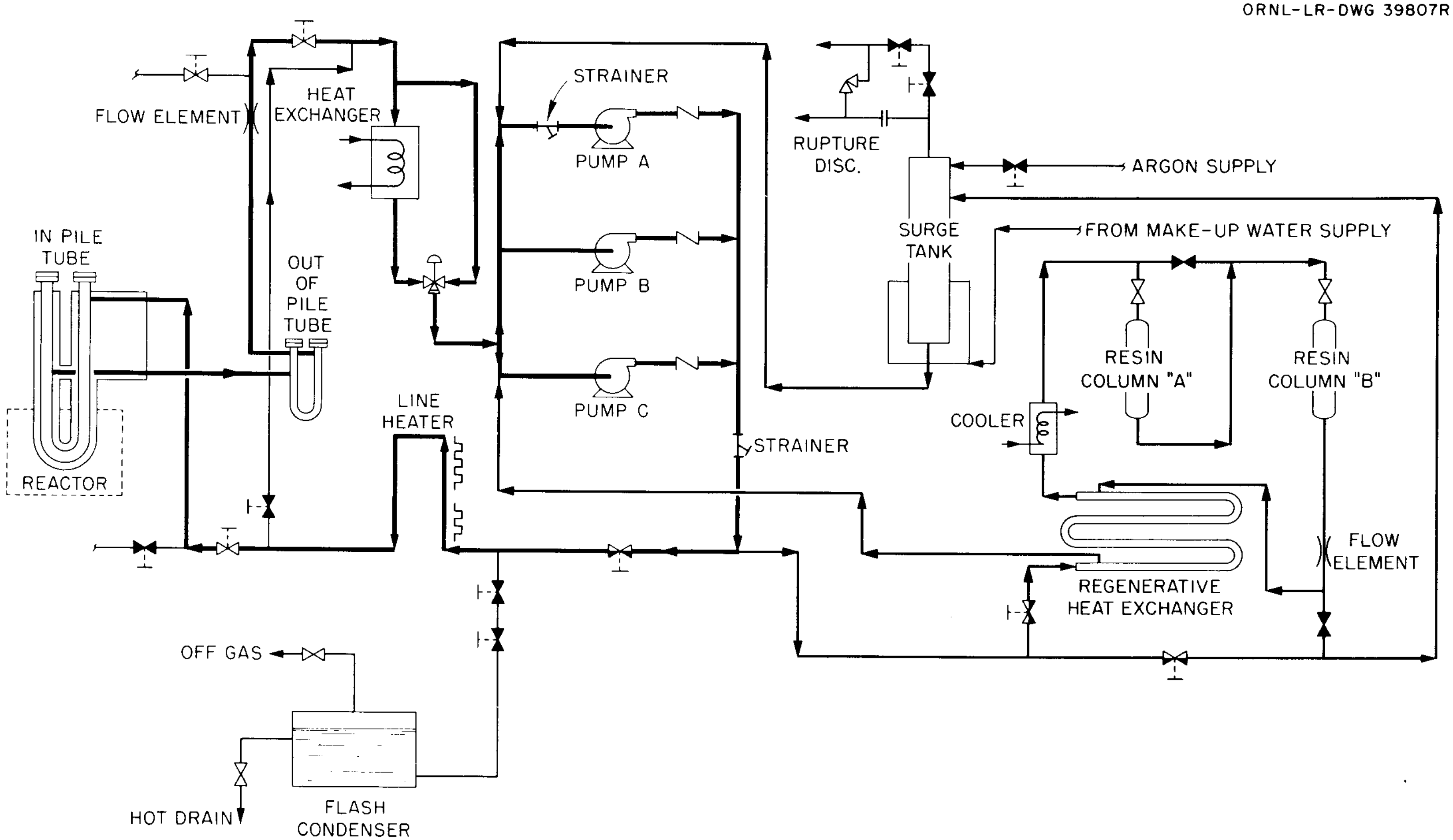

Fig. 15. MSR Pressurized Water Loop at the ORR; Simplified Flow Diagram.

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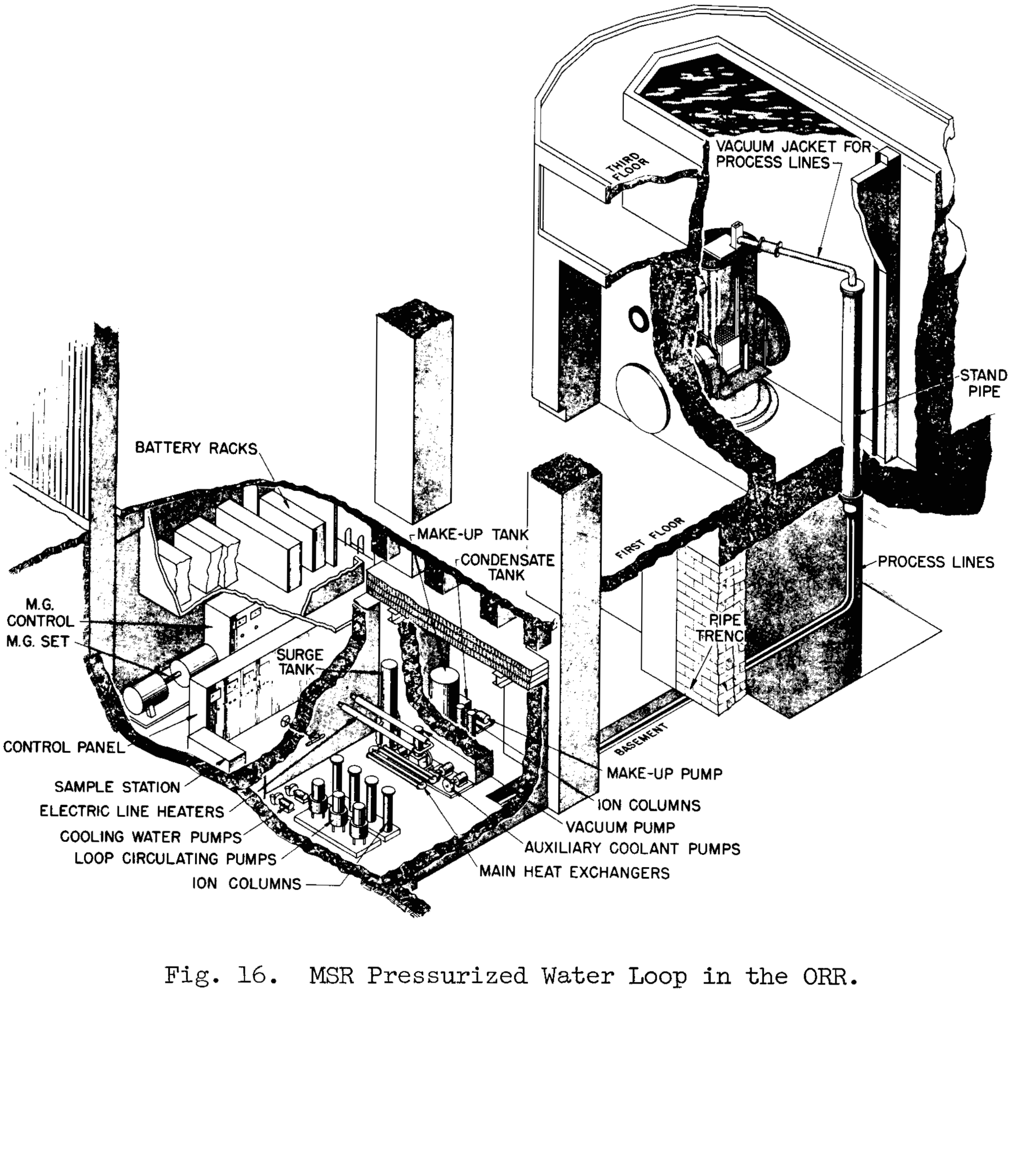

Fig. 16. MSR Pressurized Water Loop in the ORR.

Long reactor-operating cycles are favorable to this experiment. Normal shutdown periods provide ample time for routine maintenance of loop equipment. The reactor and loop must be shut down before test specimens can be removed or installed. During shutdown, the specimens normally can be removed and new ones installed within 30 minutes. A period of approximately 8 hours, after a specimen change, is required for the loop to reach operating conditions that permit reactor startup. Pool water above the in-pile test section serves as a shield during specimen removal operations. The loop, pool, reactor, and hot-cell arrangement is convenient for test-specimen removal, storage, inspection, and preparation for shipment.

There are no special loop operational problems associated with unscheduled reactor shutdowns.

Some of the problems that have been encountered are:

1. Space in the pool above the reactor has become crowded, a situation which could complicate loop maintenance.
2. The neutron flux in lattice position A-1 is considerably depressed by the experiments in neighboring lattice positions A-2 and B-1. A higher thermal-neutron flux would be desirable for obtaining increased fuel burn-up rates in the experiments.
3. The experiment cell-ventilation system appears to be almost inadequate. Additional capacity would have been advantageous for this experiment.
4. During experiment installation, considerable costs were incurred in running the shielded lines between the in-pool and the basement sections of the loop and in shielding the basement room.

Possible Improvements.-- The major improvements would include:

1. Providing more pool space for experiment lines.
2. Providing a reliable emergency electrical supply for experiments as part of the reactor-facility services.
3. Providing additional cell-ventilation system capacity.
4. Providing additional building space for shielded facilities to house loop equipment.
5. Providing built-in shielded passages for making loop connections between the reactor pool and the loop equipment area.

Fission-Gas Retention by Fuel Materials

Experiment Description.-- The purpose of the experiment is to evaluate the ability of high-temperature fuel materials to retain fission-product gases during irradiation.[10,11,13] The fuel sample is placed in a capsule which is hung vertically within one of the lattice positions of the ORR (Fig. 17 shows a typical sample assembly.). The fuel is heated by its own fission power which is adjusted by moving the fuel into, or out of, the neutron flux. At constant power, the temperature of the fuel is regulated by air cooling. Fission gases released from the fuel are entrained in a moving stream of inert gas and carried outside the reactor for analysis by gamma-ray spectrometry (Fig. 18).

Argon or helium is used as a sweep gas. When argon is substituted for helium, the temperature of the fuel increases due to the lower thermal conductivity of the argon. The temperature increase is proportional to the power and is sometimes 250°C or more. By using this method of increasing the fuel temperature as well as regulating the cooling-air flow, a wide range of temperatures can be attained at a constant fission

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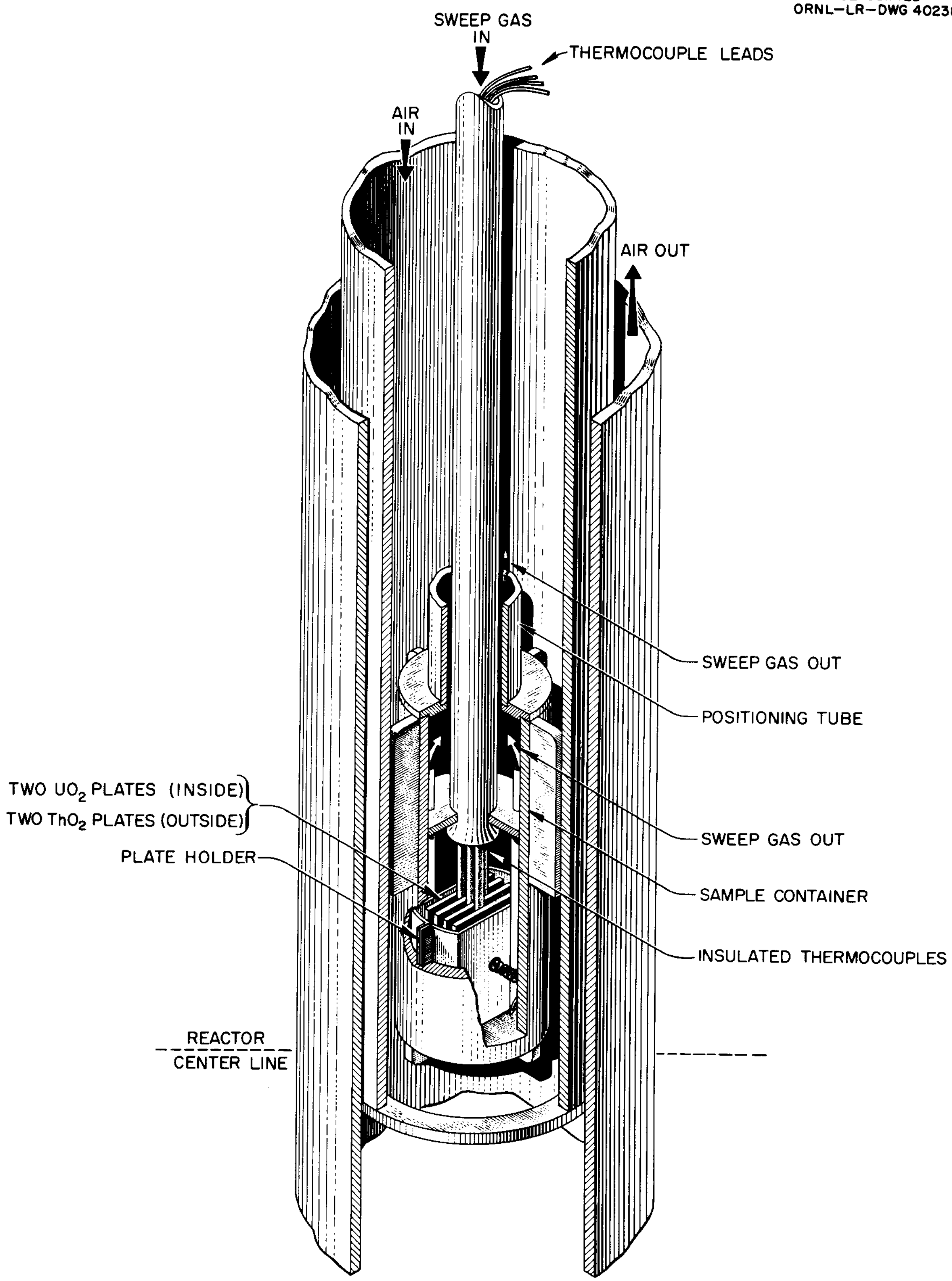

Fig. 17. Sample Assembly – ORR C-1 Experiment.

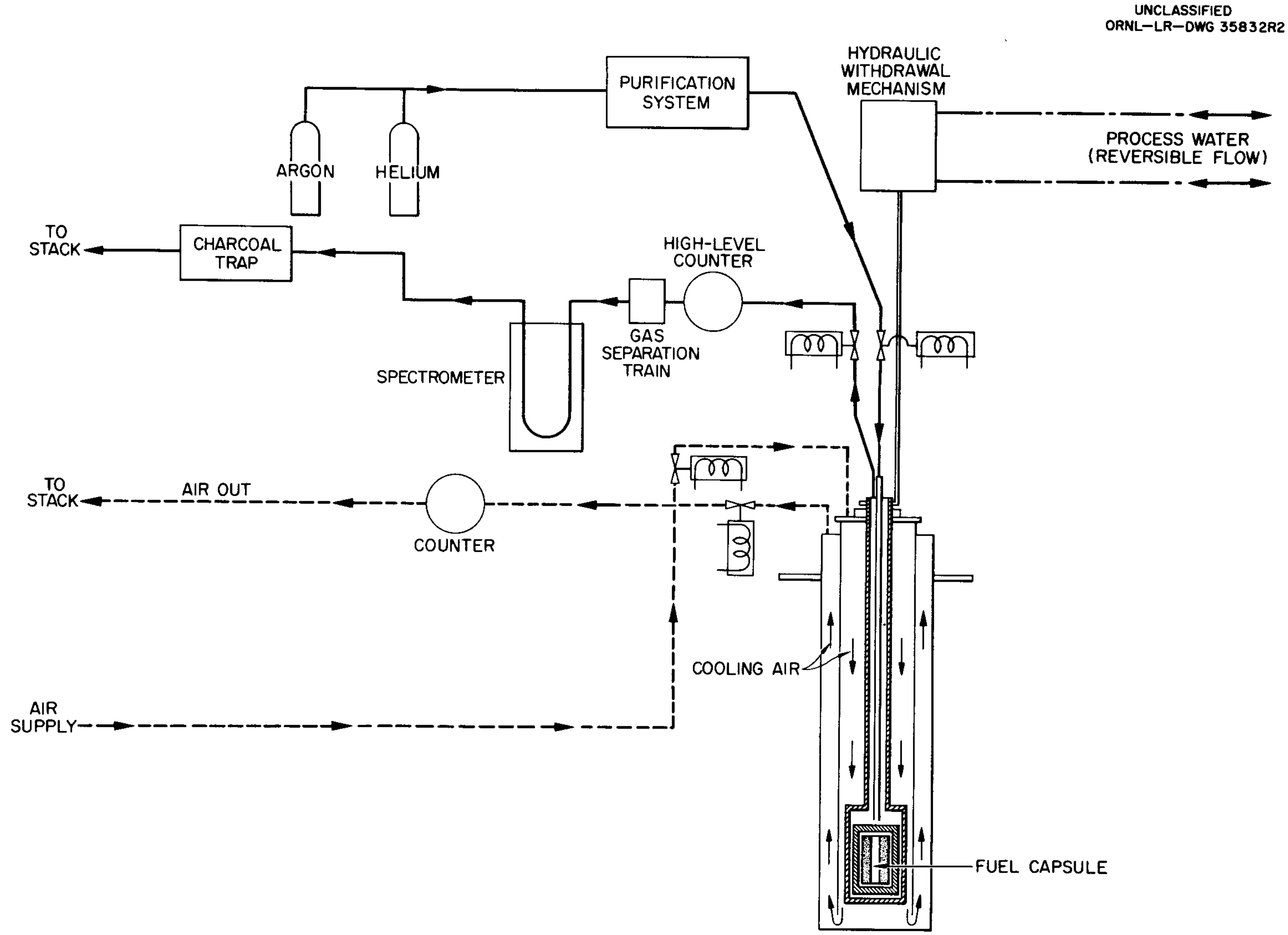

Fig. 18. Schematic Flow Diagram — Experiment ORR C-1.

power. The neutron flux is measured at any time by using argon as a sweep gas and then measuring the neutron activation of the flowing argon.[12]

Experiment Facility.-- Lattice Positions C-1 and B-9.

Two essentially identical experiments are being done--one in lattice position C-1 (Fig. 19), the other in position B-9 (Fig. 20). Components of the cooling-air and sweep-gas systems are located in a shielded cubicle on the reactor balcony for the C-1 experiment and in a shielded equipment cell in the ORR basement for the B-9 experiment. Control and instrument panels for both experiments are housed in a single room located on the third floor of the reactor building. These experiments have been designed to be independent of neutron flux perturbations from other experiments or from reactor fuel changes. Gamma heating (4.5 watt/gm) has also been allowed for in the design and presents no problem. Space for the experiments is adequate, access is excellent, and the flexibility afforded by the use of pool water for shielding in the ORR is a great advantage. The present eight-week reactor cycle is about optimum for these experiments. Unscheduled shutdowns present no special problems other than interrupting the collection of data. Samples are changed only during reactor shutdowns.

Reactor Materials Development

Experiment Description.-- Samples of reactor materials--fuel, cladding, structure, moderator, or shielding--are irradiated to determine effects on their physical and mechanical properties.[14] Initial screening tests of relatively short duration (100-300 hrs) are made at neutron fluxes of about 10^{13} n/cm^2-sec in order to evaluate new materials or fabrication processes. Engineering proof tests of longer duration (about 1000 hrs) are then made of selected materials at higher fluxes, 10^{14} up to

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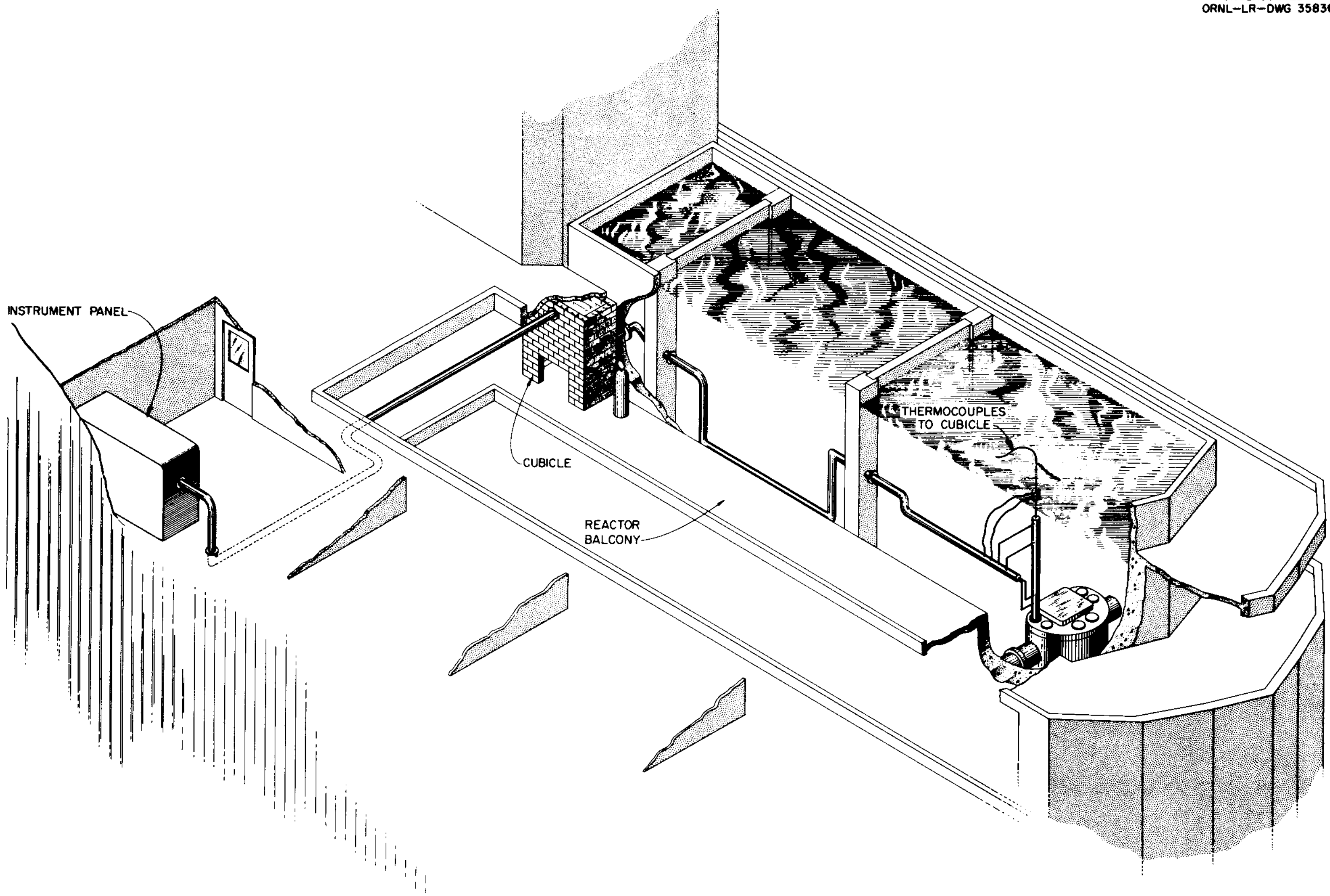

Fig. 19. Experiment ORR C-1.

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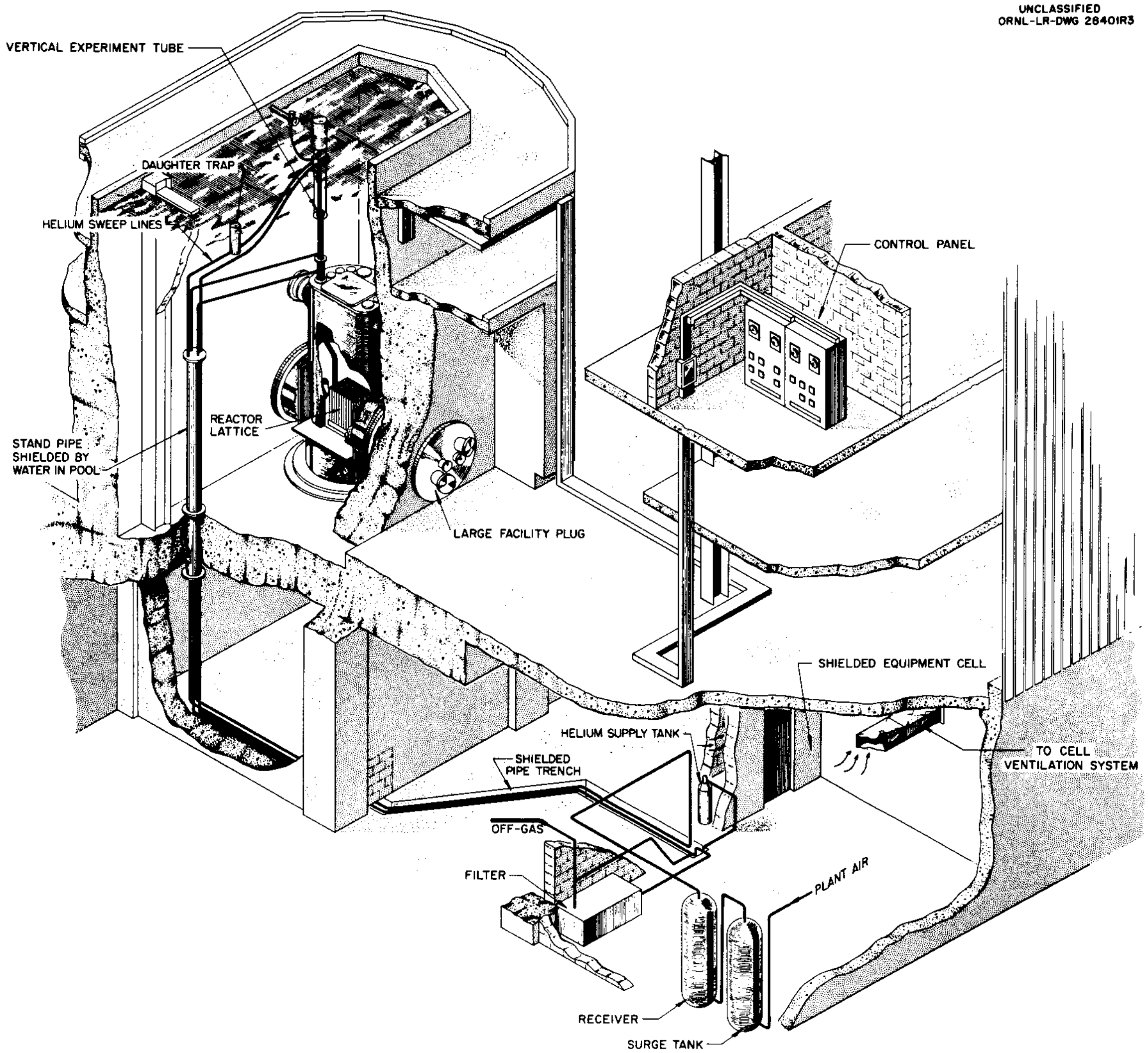

Fig. 20. Experiment ORR B-9.

10^{15} n/cm^2-sec. Samples are maintained at desired operating temperatures by air cooling.

Experiment Facility.-- Lattice Position F-2.

Engineering proof tests are performed in this facility, for the ORR operating cycle is not suited to the shorter duration screening tests. A facility tube, which doubly contains the sample capsule within concentric tubes, positions the capsule in the F-2 lattice position (Fig. 21). This facility tube enters the reactor tank through one of the top flanges and is constructed with several bends to prevent radiation streaming. The tube, which is typical of many reactor lattice access installations, and its in-pool piping are shown in Fig. 22. Cooling air flows to and from the capsule through the tube. Controls for the air and racks for recording instruments are located in a room in the reactor building. Fission gas and exit air sampling equipment is located in a shielded cubicle on the reactor balcony. The neutron flux in the F-2 facility is 1.2 x 10^{14} n/cm^2-sec. Samples can be changed only during reactor shutdowns.

Possible Improvements

1. A wider balcony would facilitate maintenance work at the shielded cubicle.
2. A shorter or more flexible reactor shutdown cycle would permit a greater variety of experiments to be performed.
3. A less expensive alternative to the complex bends that are required in the facility tube to prevent radiation streaming would reduce experiment fabrication and installation costs.
4. An increase in thermal-neutron flux, possibly through use of a flux trap, would be helpful.

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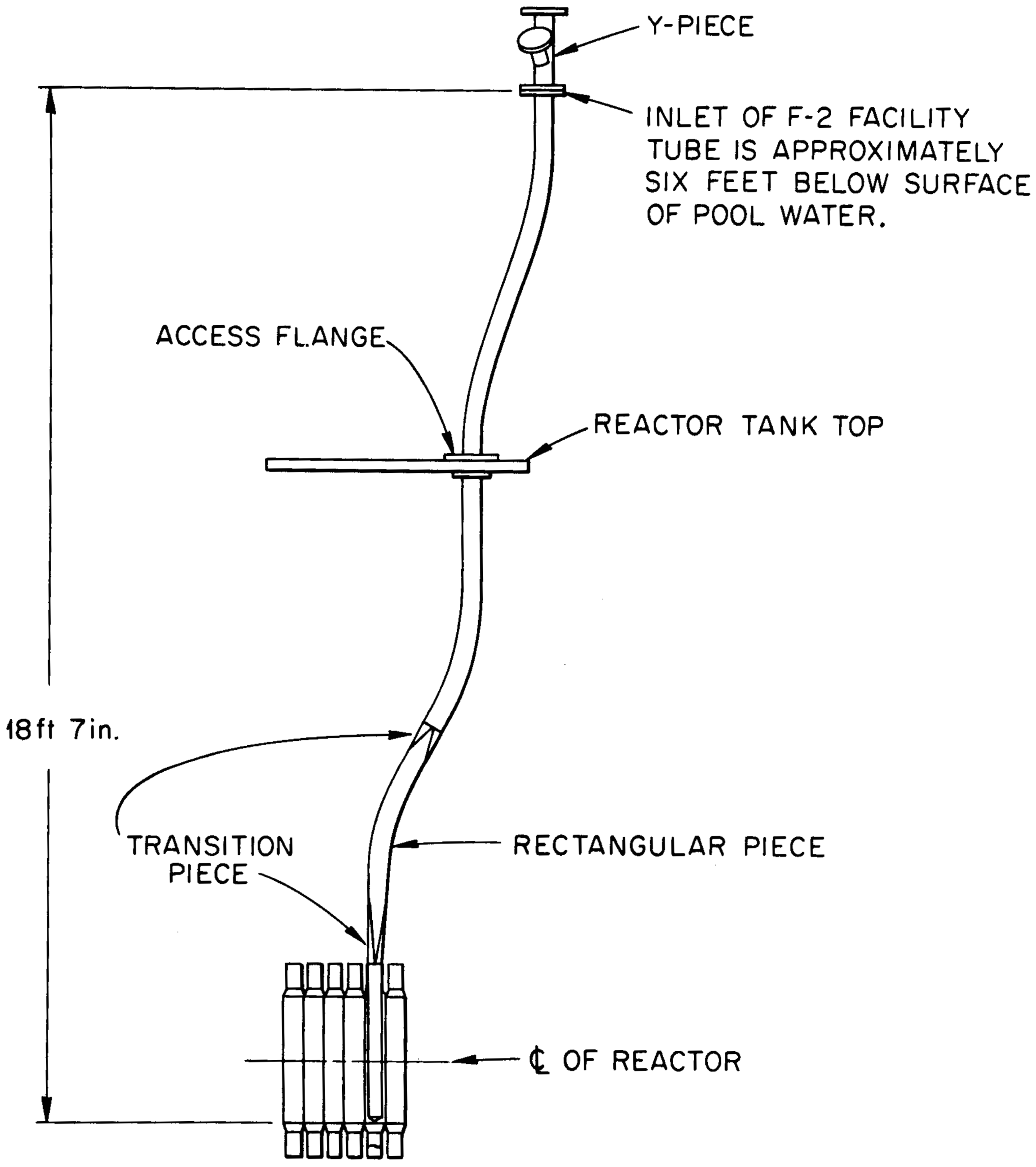

Fig. 21. Simplified Sketch of F-2 Facility Tube.

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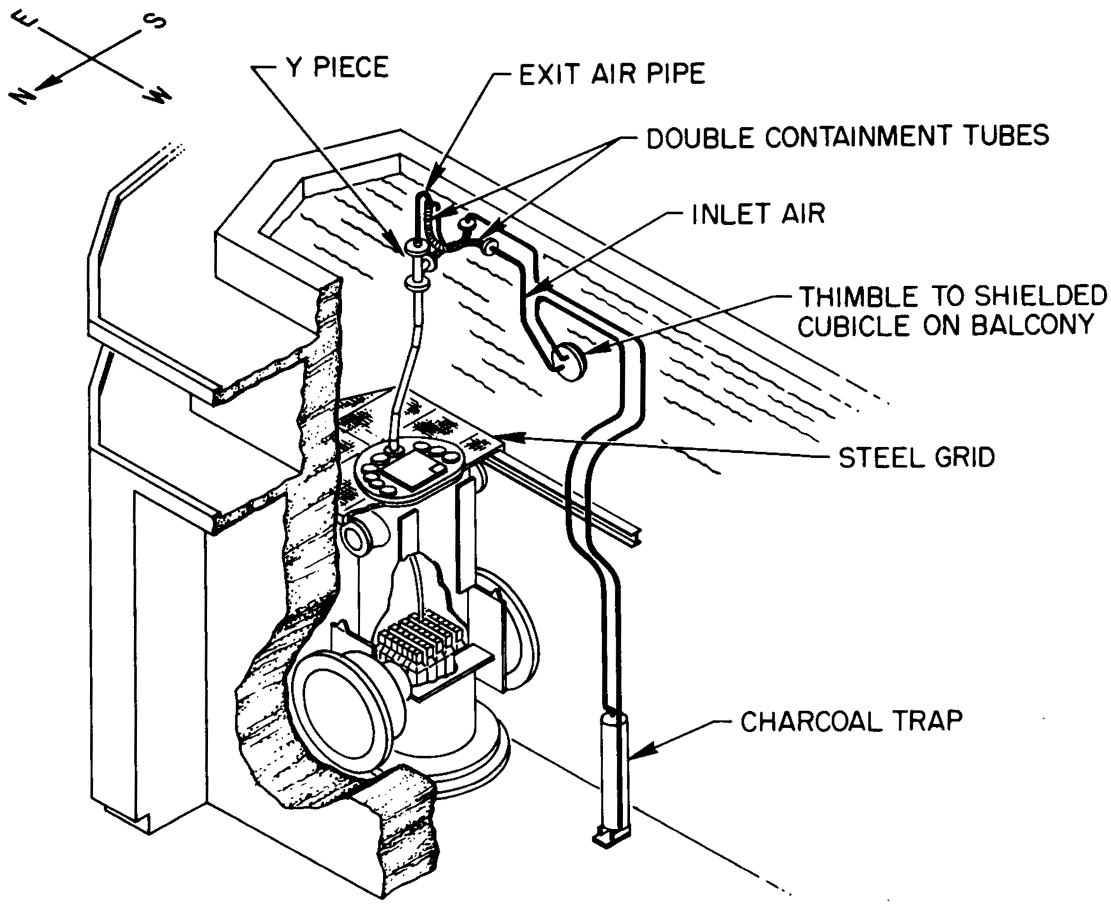

Fig. 22. Experiment ORR F-2.

In-Pile Fuel-Element Meltdown Studies

Experiment Description.-- In this experiment samples of reactor fuels which have been irradiated to the desired burnup are melted by insertion into a high neutron flux. The fuel is clad in stainless steel and is mounted within a thoria chamber. This chamber is a part of the reactor furnace shown in Fig. 23.

The furnace, together with a filter unit, is part of the experimental unit which is placed in the facility tube mounted permanently in the F-9 lattice position. This tube, shown in Fig. 24, is equipped with a hydraulic cylinder for positioning the furnace in the required neutron flux; a hydraulically controlled foot valve makes it possible to seal reactor water from the tube so that experiments can be installed or removed while the reactor is at power.

In addition to the meltdown experiment done in the F-9 lattice position of the ORR, an irradiation facility is installed in the F-3 lattice position. This will accommodate up to 7 specimens to provide fuel with the various degrees of burnup required for the meltdown experiments.

Fast-Neutron Damage in Solids

Experiment Description.-- This title covers investigations of neutron-induced damage in single crystals of various solid materials at normal temperatures.[15,16,17] As the principal interest lies in dimensional and ordering changes in crystal lattices, time-integrated fast-neutron fluxes of 10^{20} - 10^{22} n/cm^2 (> 1 Mev) are required.

Experiment Facility.-- Lattice Position C-3 (Partial Fuel Element).

To obtain the high fast-neutron fluxes required, it is necessary to place the samples close to fuel in the reactor core. A region of high

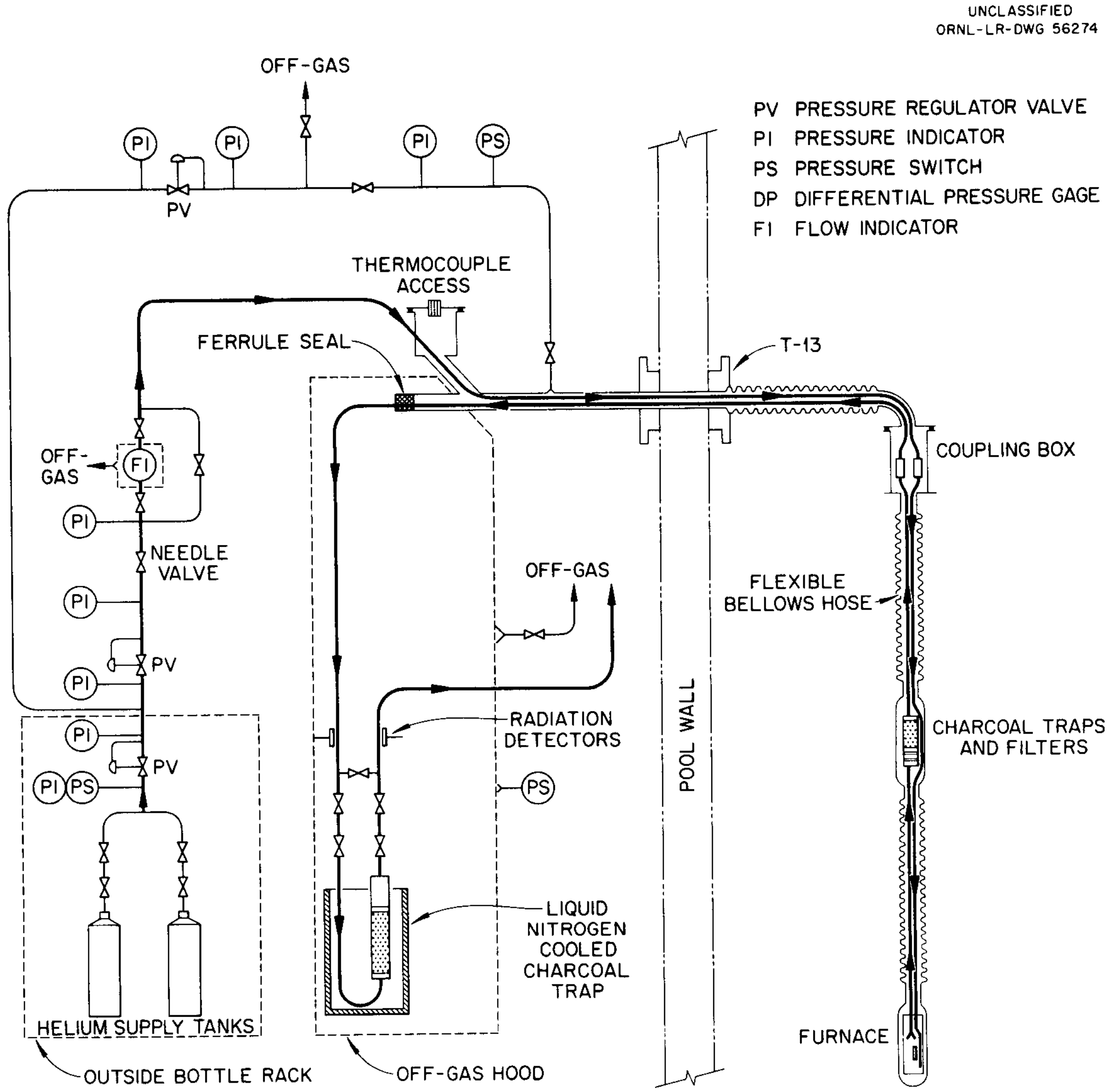

Fig. 23. Experiment Flow Diagram.

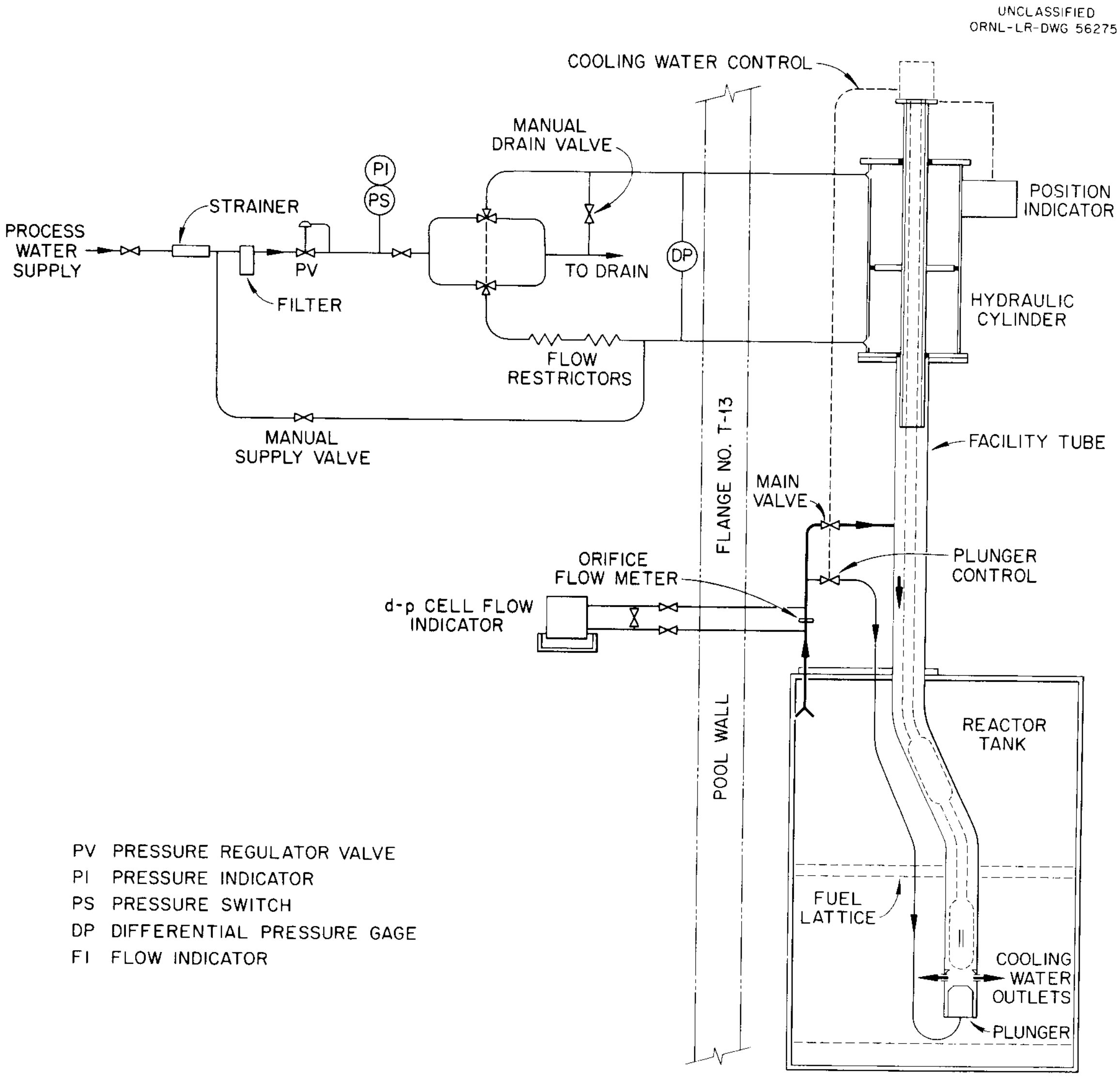

Fig. 24. F-9 Facility Flow Diagram.

fast-neutron flux is obtained within a cavity formed by omitting some of the fuel plates in the center of a fuel element (Fig. 25). Samples may then be placed in a container which is inserted into this cavity. The container is cooled by the normal flow of reactor cooling water.

In the C-3 lattice position of the ORR, the fast-neutron flux (>1 Mev) in the central portion of a partial-fuel element is about 5×10^{14} n/cm^2-sec. This flux falls by a factor of four at each end of the 2-ft-long irradiation space. With irradiation times up to one year, fast neutron doses up to about 10^{22} n/cm^2 are obtained.

Samples which do not yield water-soluble activation products can be irradiated within perforated containers in the facility. Otherwise, closed containers must be used. When using closed containers, some additional specimen cooling can be obtained by filling the containers with helium. Normally, however, the samples are small enough to require no additional cooling.

Fast-Neutron Damage to Reactor Materials

Experiment Description.-- Information on the effects of neutron irradiation on the mechanical properties of control-rod materials for a future high-flux reactor is being obtained. Tensile test specimens are irradiated in high fast-neutron fluxes, at least 10^{14} n/cm^2-sec (> 1 Mev).

Experiment Facility.-- Lattice position C-7.

A partial fuel-element facility, as described on page 60, is used to provide the high fast-neutron flux. Lattice position C-7 provides a flux at the specimens of about 3×10^{14} n/cm^2-sec (> 1 Mev). The specimen container is perforated to allow the cooling water to flow over the specimens.

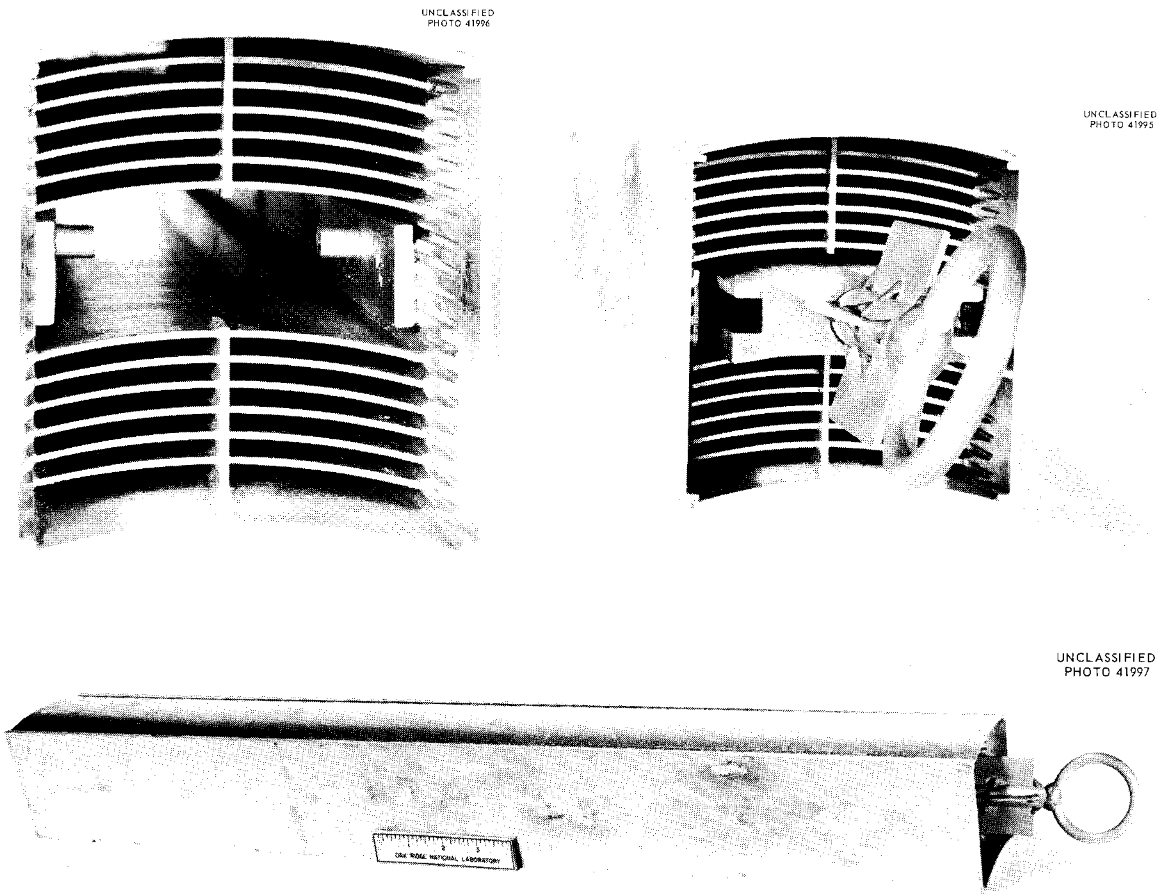

Fig. 25. Partial Fuel Element and Sample Container.

In this experiment the availability of the reactor pool for partial disassembly and reassembly of specimens is a great convenience.

Homogeneous Fuel Loops

Experiment Description.-- These loops are used in an in-pile test program for obtaining data on the effect of reactor irradiation on the chemical stability of fuel solutions (and slurries) and on the corrosion of materials of construction.[18,19]

Solutions (or slurries) of fuel material at controlled temperatures up to 300°C are circulated with a pump through a high-neutron-flux region (10^{13} n/cm^2-sec and above) in the reactor (Fig. 26). The reactor flux to which the loop is exposed can be varied by a manual retraction mechanism which is used to position the loop package within the beam hole (Fig. 27). Samples of the circulating material are taken at intervals during loop operation and analyzed.

In this advanced phase of the test program, long experiment runs are required (several months) at a high power density in the fuel solutions. The loops have been proven out in previous tests at lower fluxes (see Page 85.

Experiment Facility.-- HN-1 (North Engineering-Test Facility)

The north engineering-test facility of the ORR is closed with a large shielding plug having four smaller penetrations. One of these penetrations (10 in. in diameter and designated HN-1) is used for the homogeneous-fuel loops. This penetration gives a maximum thermal-neutron flux of 5 - 7 x 10^{13} n/cm^2-sec in the loop solution, or slurry, or about 2 x 10^{13} n/cm^2-sec when averaged over the loop circulation path. Necessary auxiliary equipment is contained in two shielded equipment chambers built

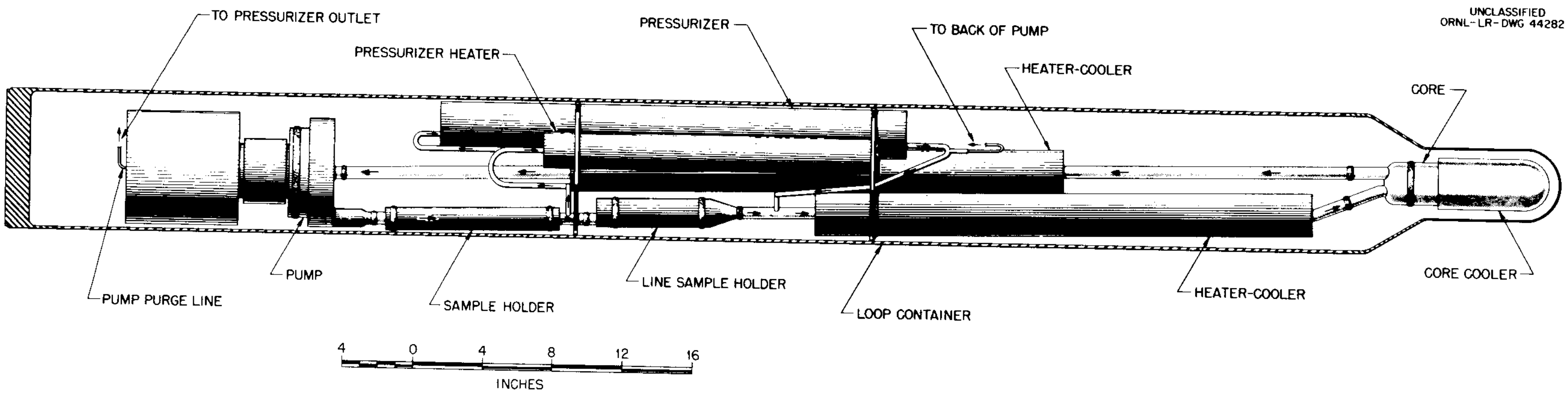

Fig. 26. ORR In-Pile Loop.

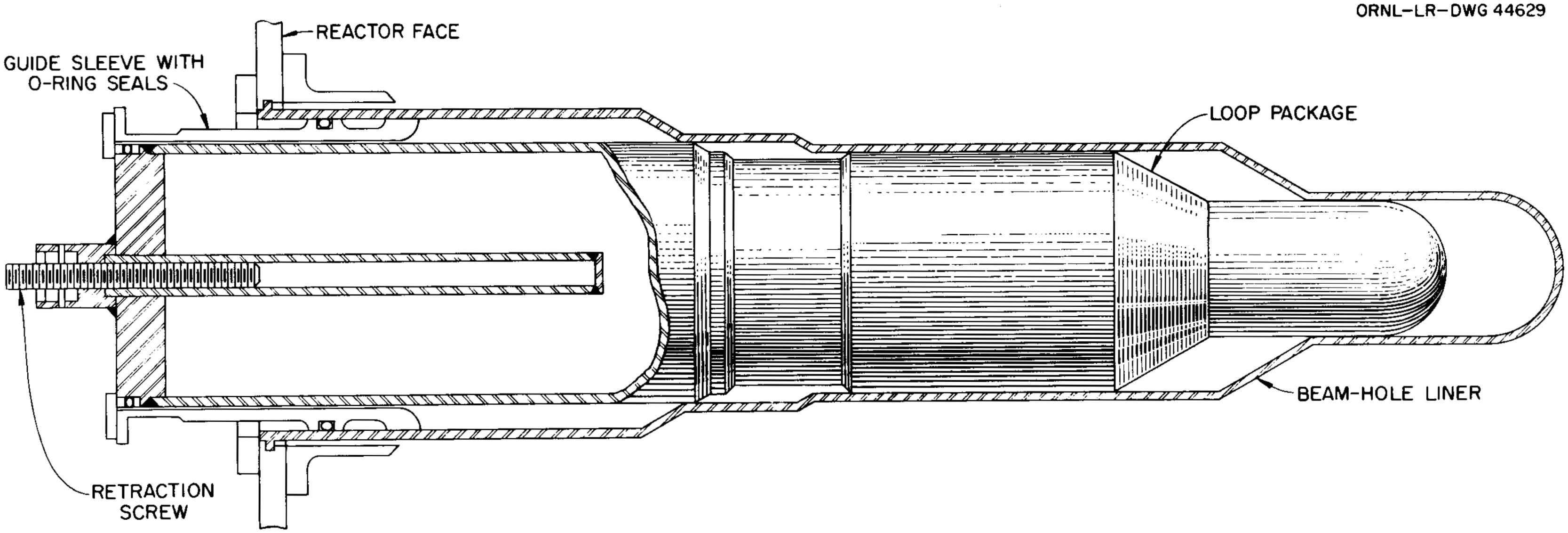

Fig. 27. ORR In-Pile Loop: Retraction Arrangement.

at the side of the reactor and external to the facility shielding plug (Fig. 28). Control instrument panels are located in an adjacent area. Reactor shutdowns do not adversely affect loop operation.

Analysis of Fission-Fragment Pairs

Experiment Description.-- (Fig. 29). Fission fragments from a U^{235} sample are correlated and analyzed using double time-of-flight methods and magnetic analysis of one fragment of each pair. A thermal-neutron flux of not less than about 10^9 n/cm^2-sec is required at the sample.

Experiment Facility.-- Beam Hole HB-1

This beam hole provides approximately 10^9 n/cm^2-sec at the sample. At this flux long experiment runs are necessary, and thus the long ORR operating cycle is favorable. Normal operating flux variations are of no concern. The sample chamber is surrounded by a massive concrete-shield assembly. By a combination of a steel shutter and beam-hole flooding (with water), the beam can be shut off if access to the chamber is necessary.

Some of the problems that have been experienced are:

1. Space for equipment around the beam hole is very limited. This is due mainly to the massive shielding needed and partly to the closeness of the adjacent beam holes.
2. Space in the general beam-hole area for electronic measuring and recording equipment is very limited. The floor space in the ORR building in this area is too small for the needs of experimenters.
3. The noise level (both acoustic and electrical) in the area is a very severe problem for delicate experiments like this.

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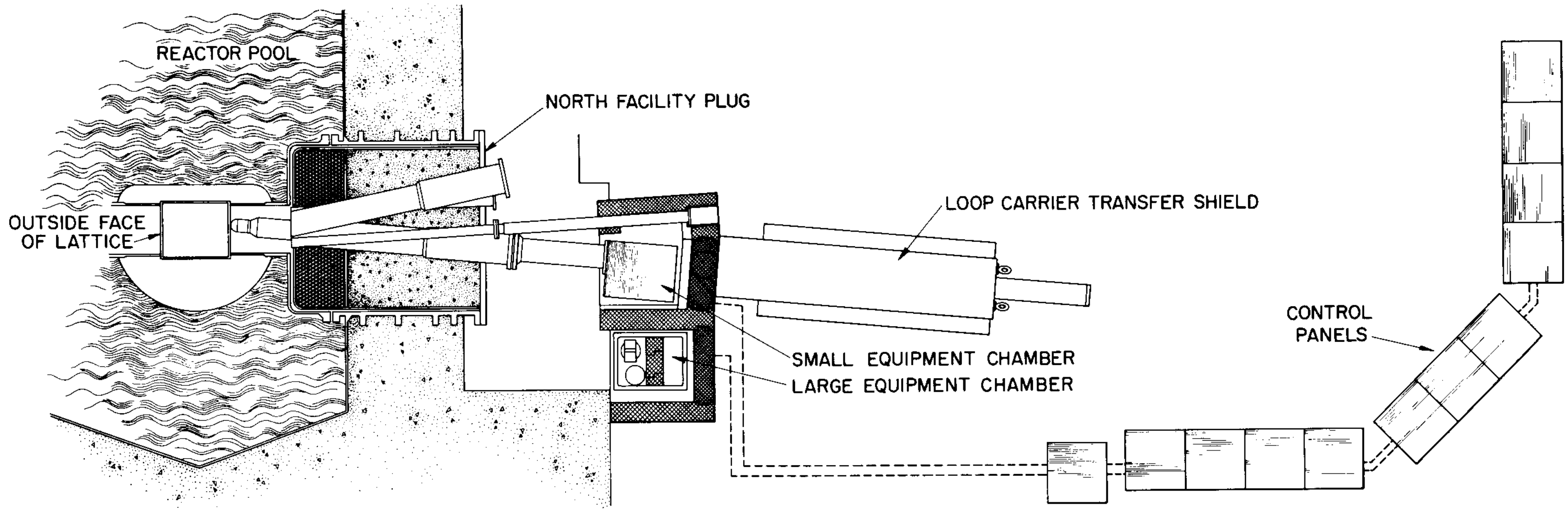

Fig. 28. ORR Loop Experiment: HN-1.

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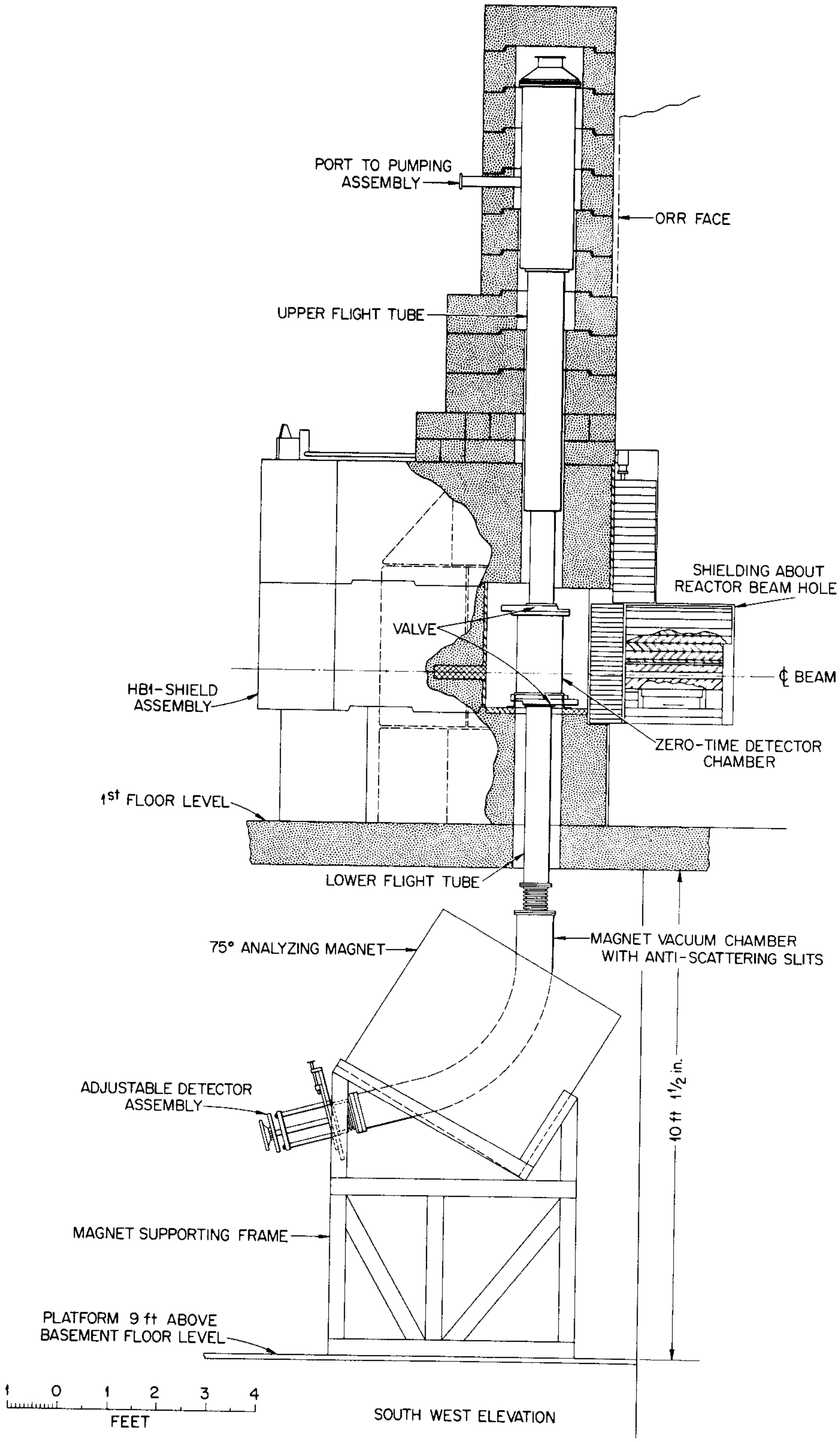

Fig. 29. Fission Fragment Experiment Assembly.

Radiofrequency interference from electrical equipment using relays (motors, compressors, etc.) is very troublesome.

4. Mechanical disturbances to equipment from traffic and maintenance or construction operations is too frequent.

5. Thermal disturbances to equipment from nearby truck and personnel doors are troublesome.

Possible Improvements

1. A higher thermal-neutron flux would be very advantageous.

2. Lower fast-neutron and gamma fluxes would enable a less massive shield to be used and would ease the space problem.

3. Extending the wall of the building would provide more space.

4. Completely walling in the area around the beam hole would help to minimize some of the disturbances. In effect, this would build a small laboratory around the beam hole. At present there is not enough room for this.

Dislocation Pinning in Metals by Radiation Defects

Experiment Description.-- Internal friction measurements are made in metal single crystals irradiated with neutrons.[20,21] The metal sample is maintained in continuous oscillation at its resonant frequency within a bath which may be held at temperatures from liquid helium up to 200°C. A fast-neutron flux of at least 10^8 n/cm^2-sec, which can be turned on and off, is required.

Experiment Facility.-- Beam Hole HB-2.

This beam hole provides, at the sample, a flux of 1 - 2 x 10^8 n/cm^2-sec of energies greater than 0.75 Mev which is just adequate for the experiment. The beam can be turned on or off within a few seconds by means of a rotatable 24-in.-thick steel shutter. The temperature bath and the sample assembly are surrounded by a massive shield. For this experiment the normal reactor flux variation through a fuel cycle does not cause difficulties. A shorter operating cycle would, however, be preferable. Unscheduled shutdowns cause difficulties in estimating the fast-neutron dose to a sample.

Problems which have been noted are:

1. Space for instrumentation away from the reactor face is very limited.
2. Levels of acoustic and of electrical noise (e.g., from arc welding) are high.
3. Thermal disturbances from the nearby truck door are severe.

Possible Improvements

1. An increase in space for electonic instrumentation in the general area is greatly needed.
2. Compartmentalization of the beam-hole area into separate laboratories would minimize disturbances.
3. A means of varying the neutron flux, and a somewhat higher flux, would be desirable.

Thermal Neutron Diffraction

Experiment Description.-- Monochromatic neutrons are selected from a beam of thermal neutrons and are scattered from samples of materials. A variety of investigations may be made using neutron diffraction.[22] These include, for example, crystal structure determinations, studies in nuclear physics, and investigations of magnetism at the atomic level. Thermal neutron fluxes of about 10^7 n/cm^2-sec are adequate, but higher fluxes are preferable.

Experiment Facility.-- Beam Holes HB-3 and HB-4.

These beam holes provide a thermal-neutron flux of approximately 10^9 n/cm^2-sec at the monochromator. The factor of about 100 in flux over the minimum adequate flux can be used to shorten the length of an experiment run, or it can be used for obtaining better data (for example, higher resolution). For both of these beam holes the monochromators are shielded with massive concrete blocks. The diffractometers, in which the monochromatic beams are scattered from samples, are located just outside these massive shields (Fig. 30). Both HB-3 and HB-4 have 35° diffractometers. In addition, HB-4 has a vertical 90° diffractometer (Fig. 31); therefore, in this facility, dual use is made of the original neutron beam. The long operating cycle of the ORR is favorable for these experiments. Minor flux variations are of no consequence.

Some of the problems which have been encountered are:

1. Space at the beam-hole area for equipment and instrumentation is severely limited.
2. The acoustic and electrical noise levels are high.
3. It is difficult to keep dirt away from the diffractometers.
4. Traffic and mechanical disturbances are troublesome.

Possible Improvements

1. Increase in space for instrumentation is desirable.
2. Provision is needed for a separate, sound-proofed room for each experiment.
3. Reduction in the fast-neutron and gamma fluxes from the beam holes would lessen shielding difficulties. In a new facility this might be done by providing tangential beam tubes for thermal-neutron diffraction use.

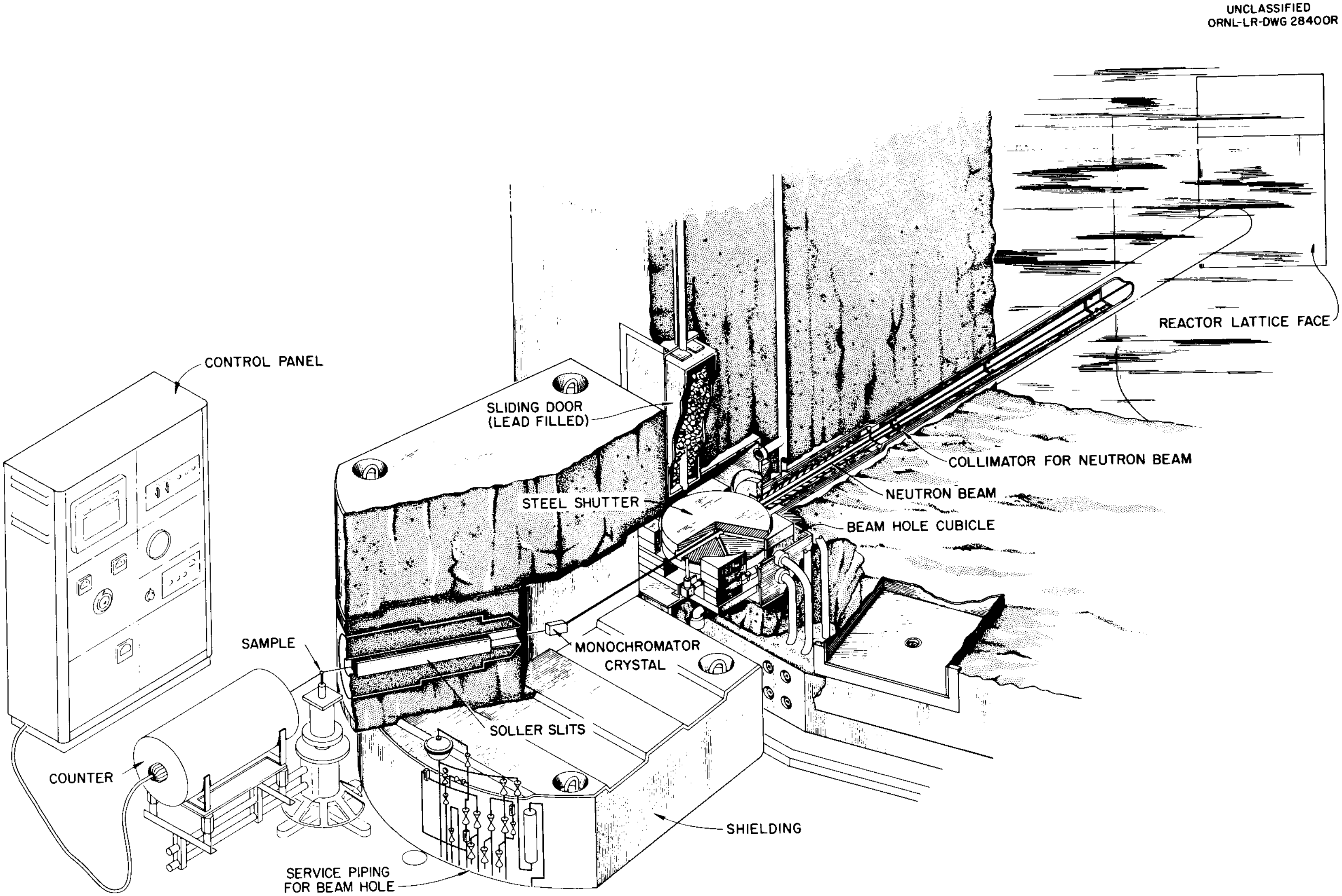

Fig. 30. ORR Neutron Beam Experiment.

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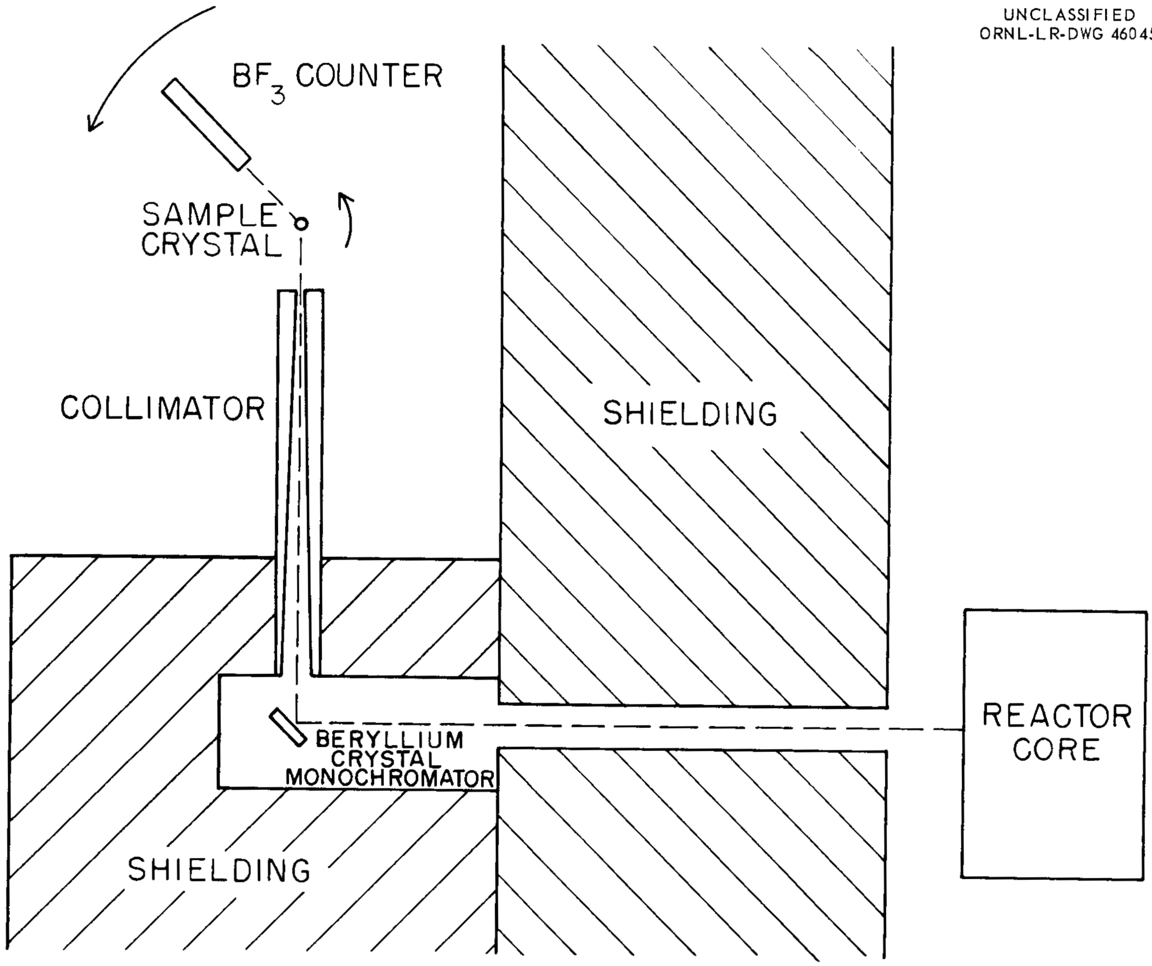

Fig. 31. Schematic of Neutron Diffractometer (Vertical Section).

Fission Process Studies

Experiment Description.-- Neutrons of resonance energies are selected from a neutron beam by diffraction from a beryllium crystal. These neutrons cause fission in a sample of uranium-235 contained in a cryostat and kept between 0.5 - 4°K. The uranium nuclei are oriented by the crystalline electric field gradient in $UO_2Rb(NO_3)_3$ and the angular distribution of the fission fragments is determined. A thermal-neutron flux of at least 10^9 n/cm^2-sec is necessary. Beam monitoring allows compensation for normal neutron flux variations.

Experiment Facility.-- Beam Hole HB-5.

The monochromating crystal is surrounded by a massive concrete shield at the beam-hole port. The cryostat and detection equipment are located outside this shield. The beam hole barely provides the necessary flux. For this reason, changes in fuel loading which may depress the flux at this beam hole are detrimental. The long ORR operating cycle is favorable for the long data-accumulation runs that are usual in this experiment. Except for interruption of data accumulation, shutdowns do not affect the experiment.

Problems which have been encountered are:

1. Floor space for equipment and instrument racks is too limited.
2. Acoustic and electrical noise levels are too high.
3. The method of flooding the beam hole (in order to shut off the beam) has been found to be awkward.

Possible Improvements

1. Increase in floor space and provision of an enclosed room for the experiment is needed.

2. A special reactor fuel distribution would be desirable to increase the local flux at beam hole HB-5.
3. A simpler arrangement for beam hole flooding should be provided.
4. Reduction in gammas and fast neutrons, possibly by use of a tangential beam tube would allow reduction in shielding.
5. A redesign should integrate or combine the reactor and the monochromator shields.
6. Provision of a completely separate electric grounding system for each experiment should be made.

Measurement of Neutron Cross Sections

Experiment Description.-- Using the time-of-flight technique, the cross sections of materials for neutrons of resonance energies (several ev to several kev) are measured.[23] In this technique neutrons in short bursts, from a fast mechanical chopper, pass through a sample of material; and their times of arrival at the end of a long (up to 180-meter) evacuated flight tube are recorded. The highest available neutron current in the resonance-energy region is required. Variations in flux, provided they are not too rapid, are of no consequence since the sample is alternated in and out of the beam. Long experiment runs are made.

Experiment Facility.-- Beam Hole HB-6. (Fig. 32).

An entrance collimator is housed in the beam-hole cubicle within the reactor shield. The fast-chopper rotor and housing assembly is contained in a massive shield of boron-loaded concrete. The evacuated flight tube passes through the wall of the reactor building. The resonance-neutron current into the beam hole at the reactor core is 10^{14} n/cm^2-sec ($>$0.2 ev, dE/E spectrum). Beam shutoff, for chopper maintenance work, is achieved by flooding the beam tube.

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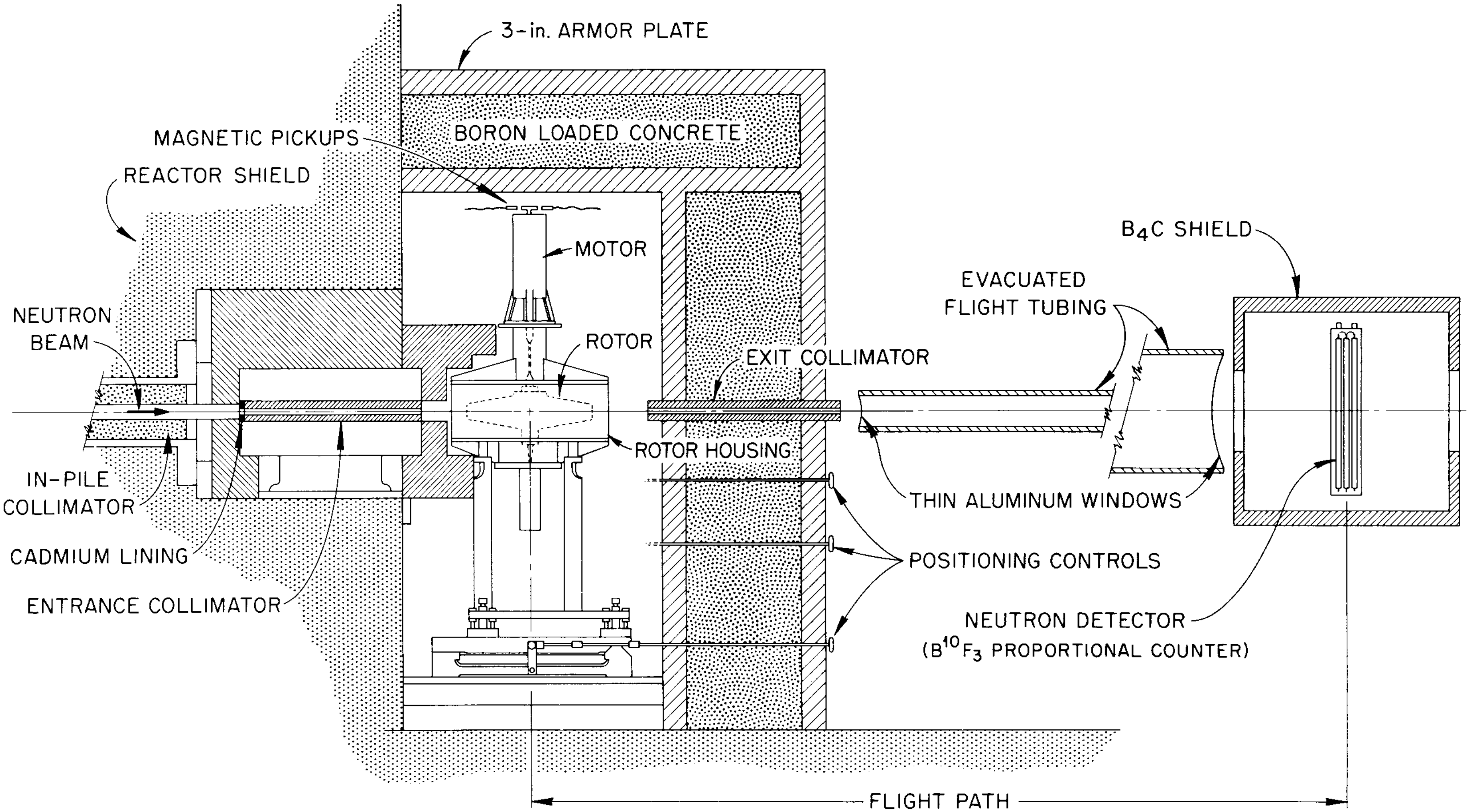

Fig. 32. ORNL Fast Chopper Time-of-Flight Neutron Spectrometer.

Possible Improvements.-- Some means of increasing the resonance-neutron flux, and at the same time reducing the fast-neutron and gamma fluxes, would be advantageous. Fast neutrons and gammas add to the background in the detectors and to the general shielding problems. While it may be possible to achieve small improvements in this direction with special fuel and reflector arrangements, the best long-term approach for cross sections in the resonance-energy region is to replace the reactor and chopper with a pulsed-electron linear accelerator. For thermal energies, however, the reactor is the best neutron source available.

Stress Rupture Experiments

Experiment Description.-- Tubular specimens of several reactor structural materials (e.g., Inconel, 304 stainless steel, Zircaloy-2, and columbium alloys) are operated at desired temperatures (500 to 2000°F range) under stress from internal gas pressure during reactor irradiation.[24] The time-to-rupture at various stress levels and temperatures is measured and compared with similar tests run outside the reactor. Postirradiation metallurgical examination of specimens is performed in a hot cell. Thermocouples on the specimens permit control of the temperature by using electrical heaters around the specimens. In the lower end of the temperature range it is necessary to remove some of the nuclear heat with air or water-cooled "fingers" inside the specimens. The stresses in the specimens range up to 50,000 psi, requiring internal gas pressures up to 5000 psi.

Experiment Facility.-- Poolside Irradiation Facility.

Up to 10 specimens are mounted in a watertight metal box which is positioned at the poolside irradiation facility adjacent to the reactor core (Fig. 33, 34). Tubes containing leads for thermocouples, heaters, and pressurizing gas are taken out over the pool wall to an instrument room. The fast-neutron flux in the facility is about 4×10^{13} n/cm^2-sec (> 0.7 Mev) which is adequate for obtaining the desired integrated doses of 10^{18} - 10^{19} n/cm^2 within the 8-week reactor-operating cycle. Due to the reactivity associated with the specimen box and to the closeness of other poolside experiments, samples may be changed only during reactor shutdowns. As shutdowns are spaced too far apart for maximum experiment benefit, the convenience of the poolside facility for these experiments is only fair. An improved experiment design, in which specimens will be individually canned, is expected to permit removal of single specimens at any time during reactor operation and to increase the utility of the facility severalfold.

Effects of Neutron Irradiation on the Mechanical Properties of Materials

Experiment Description.-- Typical of the experiments performed is a series to determine the effect of high-temperature reactor irradiation on some physical and mechanical properties of beryllium.[25] Some specimens are given exposures between 1 and 6×10^{20} n/cm^2 (> 1 Mev) at temperatures between 50 and 780°C, and properties are measured before and after irradiation.[26] Other specimens, in tubular form, are used in stress-rupture experiments at 600°C under neutron irradiation. An in-pile extensometer has been used to determine the creep of stressed materials at 1100 - 1300°F under reactor irradiation. To attain the higher temperatures nuclear heating is supplemented with heating from electrical resistance furnaces.

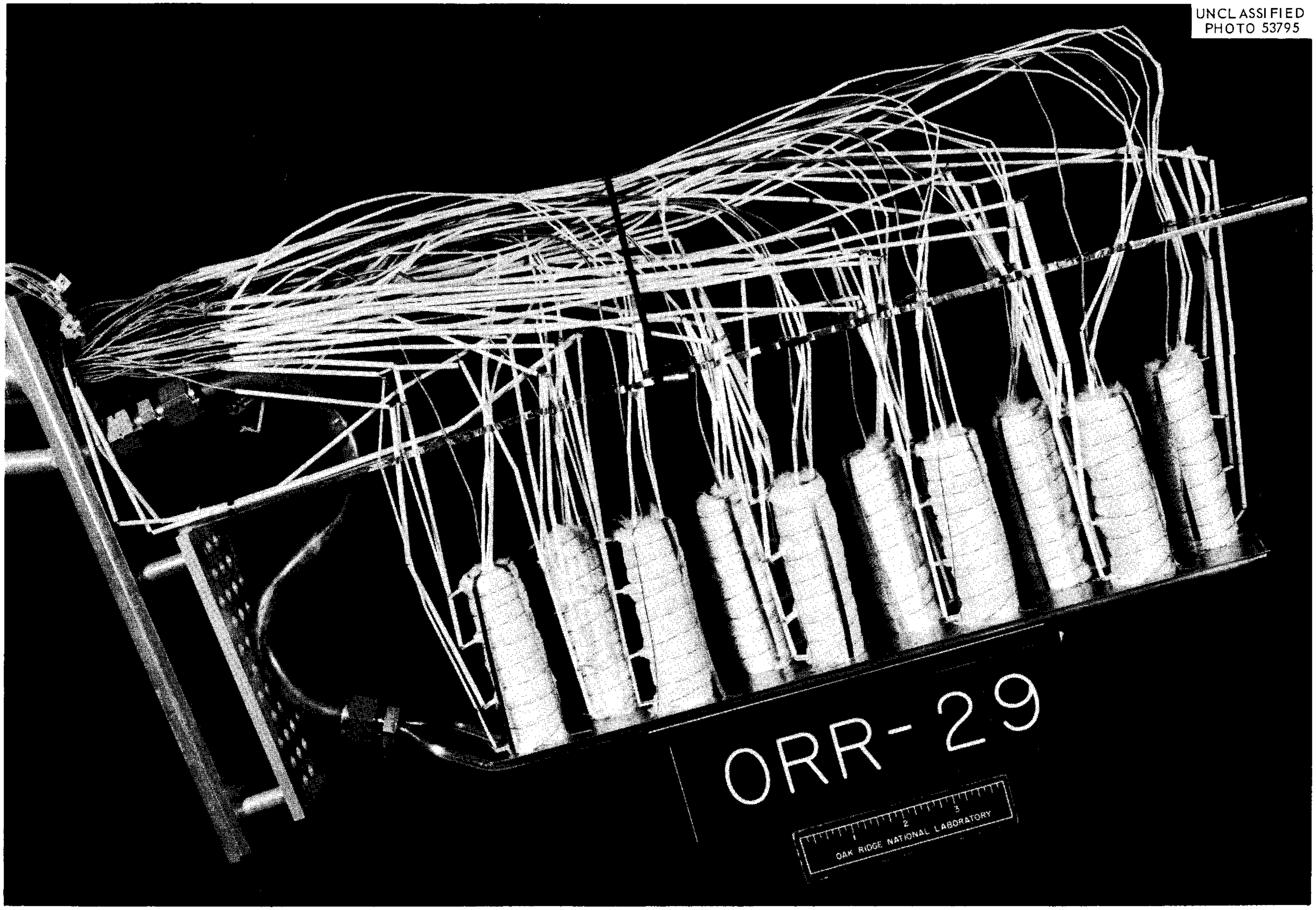

Fig. 33. Stress Rupture Experiment – Interior of Specimen Box.

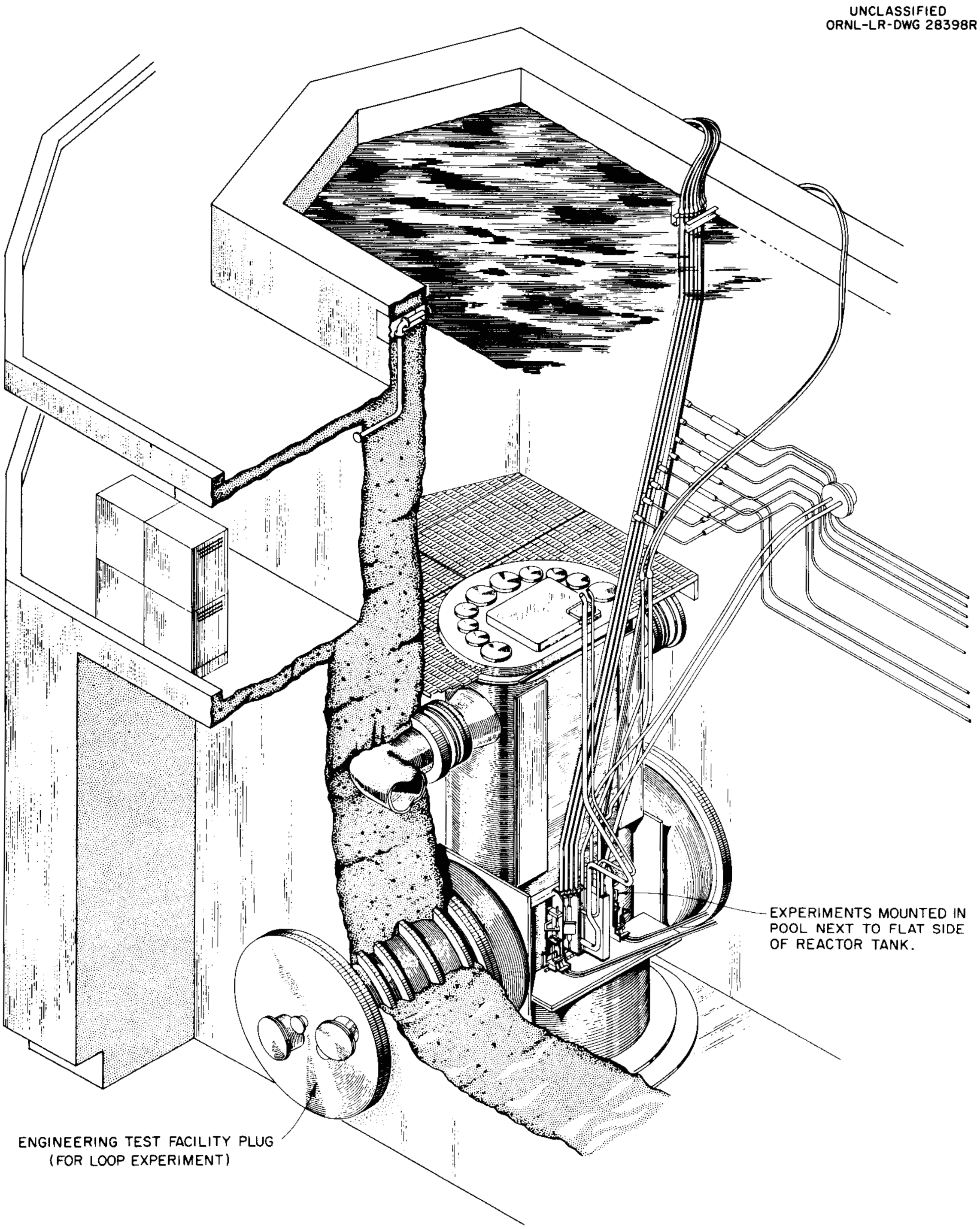

Fig. 34. ORR Poolside Irradiation Facility Experiments.

Experiment Facility.-- Lattice Position B-8.

The neutron flux in the position is approximately 9 x 10^{13} n/cm^2-sec (>1 Mev) which is adequate to provide the desired exposures within reasonable times. The lower-temperature (60°C) irradiations are performed with direct cooling of the specimens by the reactor cooling water. The elevated-temperature irradiations are conducted with the specimens mounted in an aluminum can having the same outside dimensions as a fuel element. An aluminum tube containing leads for heaters, thermocouples, and pressurizing gas passes through one of the access flanges in the reactor tank top to a junction box above the pool surface (Fig. 35). Control instruments are located in a laboratory on the second floor of the building. Sample removal is greatly facilitated by the provisions for taking irradiated items from the reactor to the hot cell under water shielding. Minor problems arise from slow flux variations with time resulting from motion of the shim rods during a fuel cycle. Otherwise, the reactor facility is quite adequate for the experiments.

Studies of Short-Lived Fission Products

Experiment Description.-- Small samples of fissionable materials are briefly irradiated and then transferred rapidly to a radiochemistry laboratory where the yields and half-lives of the short-lived fission products are determined. Rapid chemical separations are often necessary for determining independent yields and half-lives.[27] In such instances solution samples in plastic containers are used. (Fig. 7).

Experiment Facility.-- ORR Pneumatic Tube.

This facility is described on page 10. The high neutron flux in the facility (6.5 x 10^{13} n/cm^2-sec) permits the use of very small quantities

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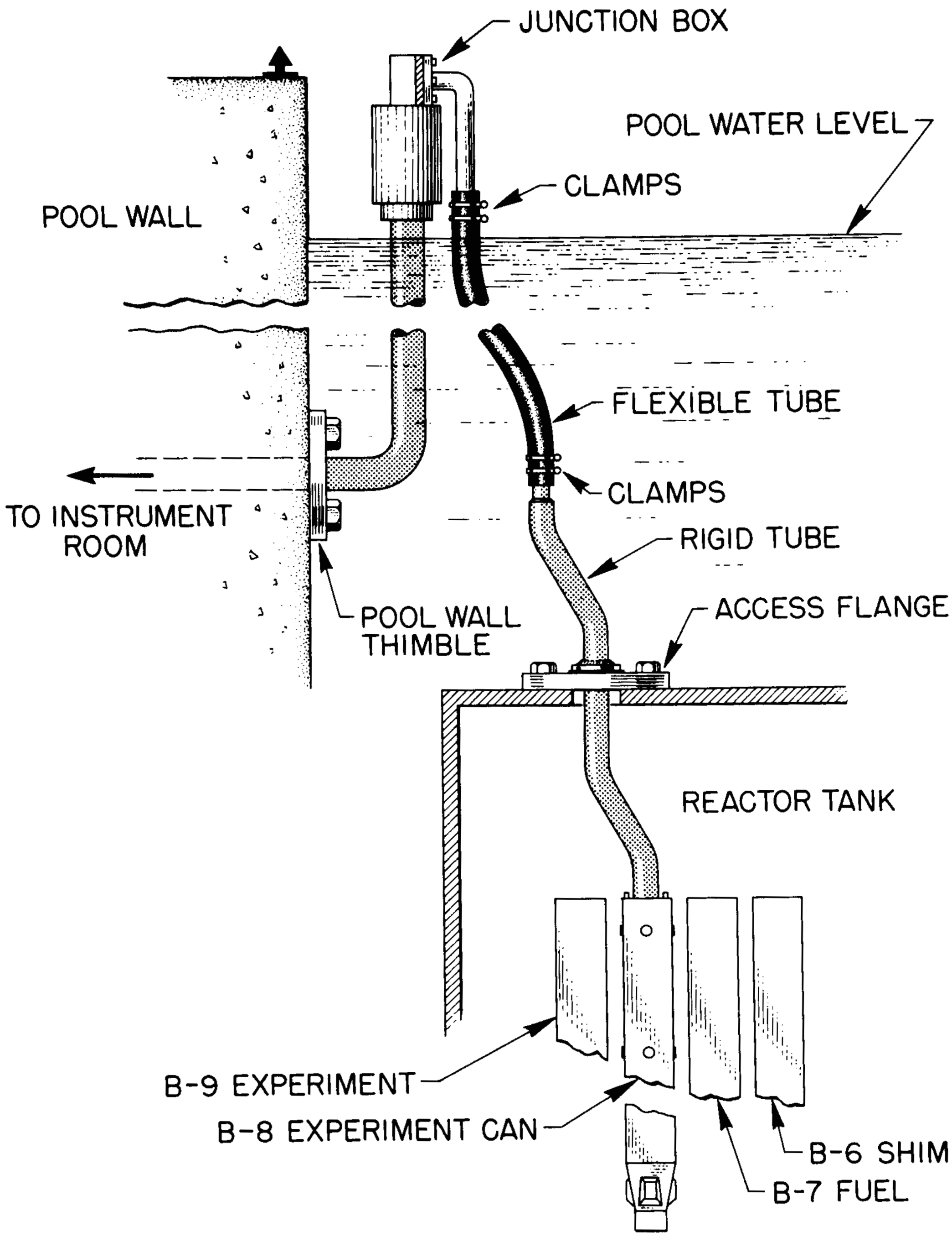

Fig. 35. ORR – Experiment in B-8.

of sample material when larger amounts would interfere with a separation procedure. After irradiation the plastic containers are discharged from the tube within a hood. The contents are removed using a specially designed hypodermic-needle assembly which pierces the plastic container and withdraws solution for processing within a matter of seconds.

Activation Analysis

Experiment Description.-- Samples of materials are irradiated with neutrons and the radioactivities produced measured with nuclear radiation detectors in order to determine trace constituents.[28,29,30] Samples are usually small and irradiation times seldom exceed 10 minutes. The higher the neutron flux the greater the sensitivity of this analytical method.

Experiment Facility.-- 1. ORR Pneumatic Tube; 2. ORR Hydraulic Tubes

1. This facility is described on Page 10. The high neutron flux in the facility results in high sensitivity for this method of analysis. The size of the rabbit is adequate for most samples. While biological specimens have been irradiated in this pneumatic tube, heat-sensitive materials may be damaged. A means of cooling specimens more effectively is desirable.
2. For samples where the desired irradiation time is in excess of one or more hours, the hydraulic-tube facility is used. This facility is also described on page 10. The neutron flux in the hydraulic tubes is $1 - 2 \times 10^{14}$ n/cm^2-sec, resulting in somewhat greater analytical sensitivity than for the pneumatic tube.

Experiments in the LITR

Homogeneous Fuel Loops

Experiment Description.-- These loops are used in an in-pile test program for obtaining data on the effects of reactor irradiation on the chemical stability of fuel solutions[31] and slurries[32] and on the corrosion of materials of construction. They are used also for testing loop components to be used in future test programs involving higher fluxes and longer irradiation times. Solutions (or slurries) of fuel materials at controlled temperatures up to 300°C are circulated by pumps through a region of high thermal-neutron flux (about 10^{13} n/cm^2-sec). Samples of the circulating fuel are taken, as required, and analyzed.

Experiment Facility.-- Beam Holes HB-2 and HB-4.

Loops have been operated at beam holes HB-2 and HB-4 at the LITR, but are now operated only in the ORR (page 65). The in-pile section of each loop contains a core section, a circulating pump, a pressurizer, a heater, and, in the case of a slurry loop, a filter (Fig. 36). The out-of-pile components and sampling stations were enclosed in shielded chambers, vented to off-gas, and built over the beam-hole ports (Fig. 37, 38). Control-instrument panels were located in the experiment area adjacent to the beam-hole ports. The thermal-neutron flux within the beam holes was 1 x 10^{13} n/cm^2-sec maximum; the flux to the fuel solution was about 5 x 10^{12} n/cm^2-sec, averaged over the entire loop-circulation path.

The flexibility of the LITR operating schedule for the initial experiments in this area of new technology is a useful asset; the higher neutron flux of the ORR is needed, however, to obtain information under conditions more closely approaching actual reactor operating conditions.

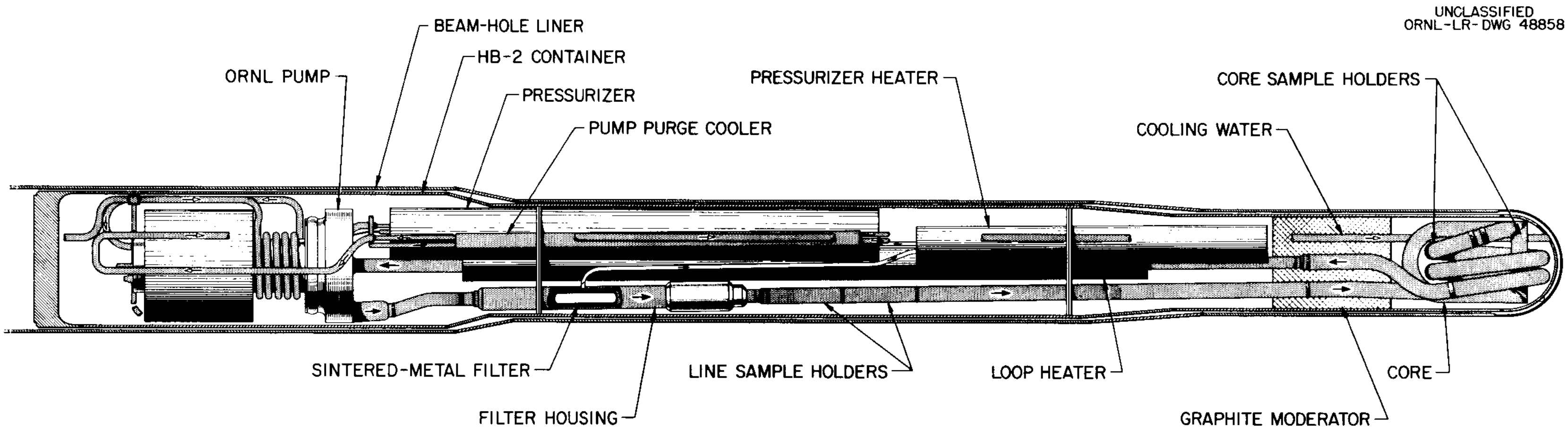

Fig. 36. Slurry In-Pile Loop.

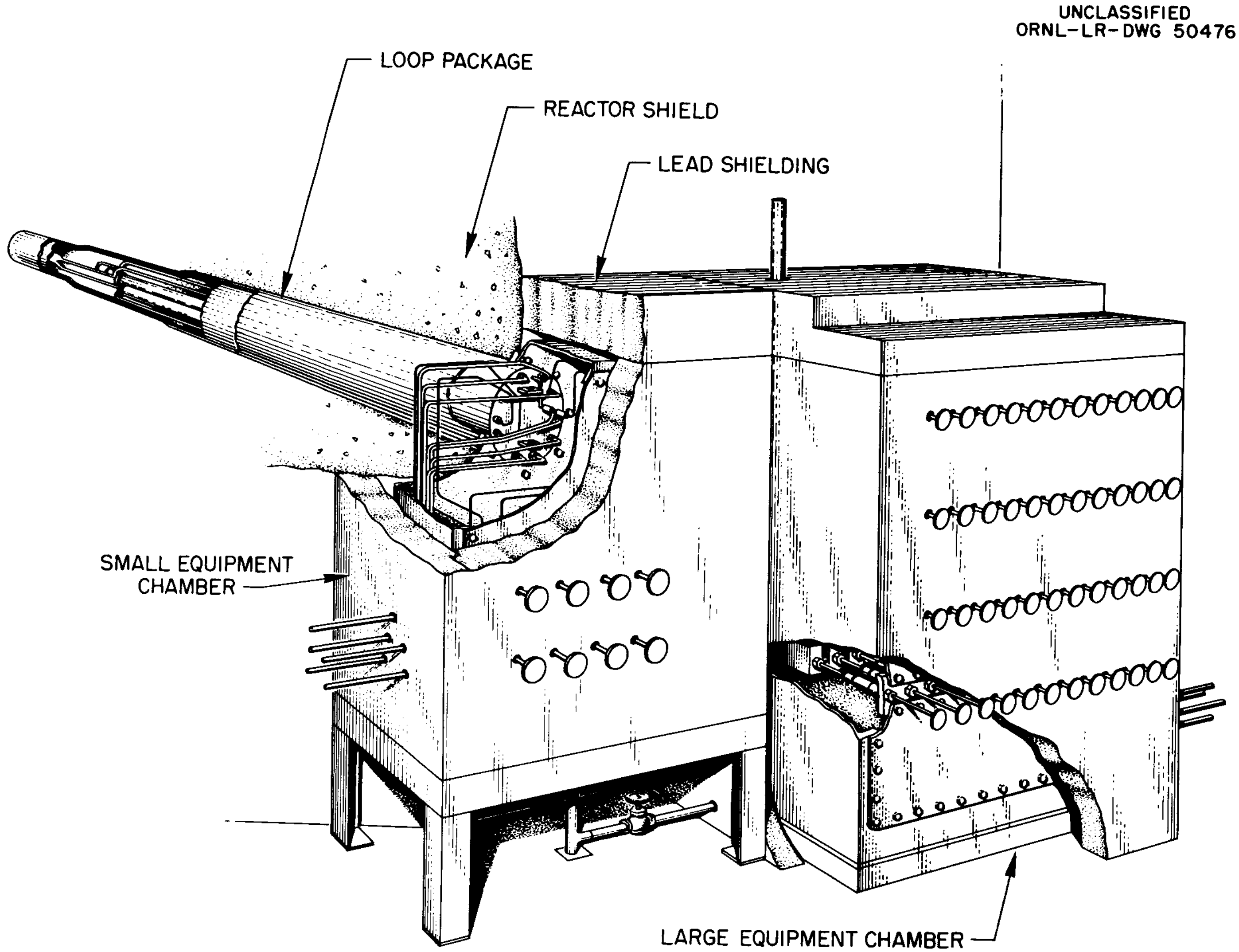

Fig. 37. LITR Loop Experiment Chamber.

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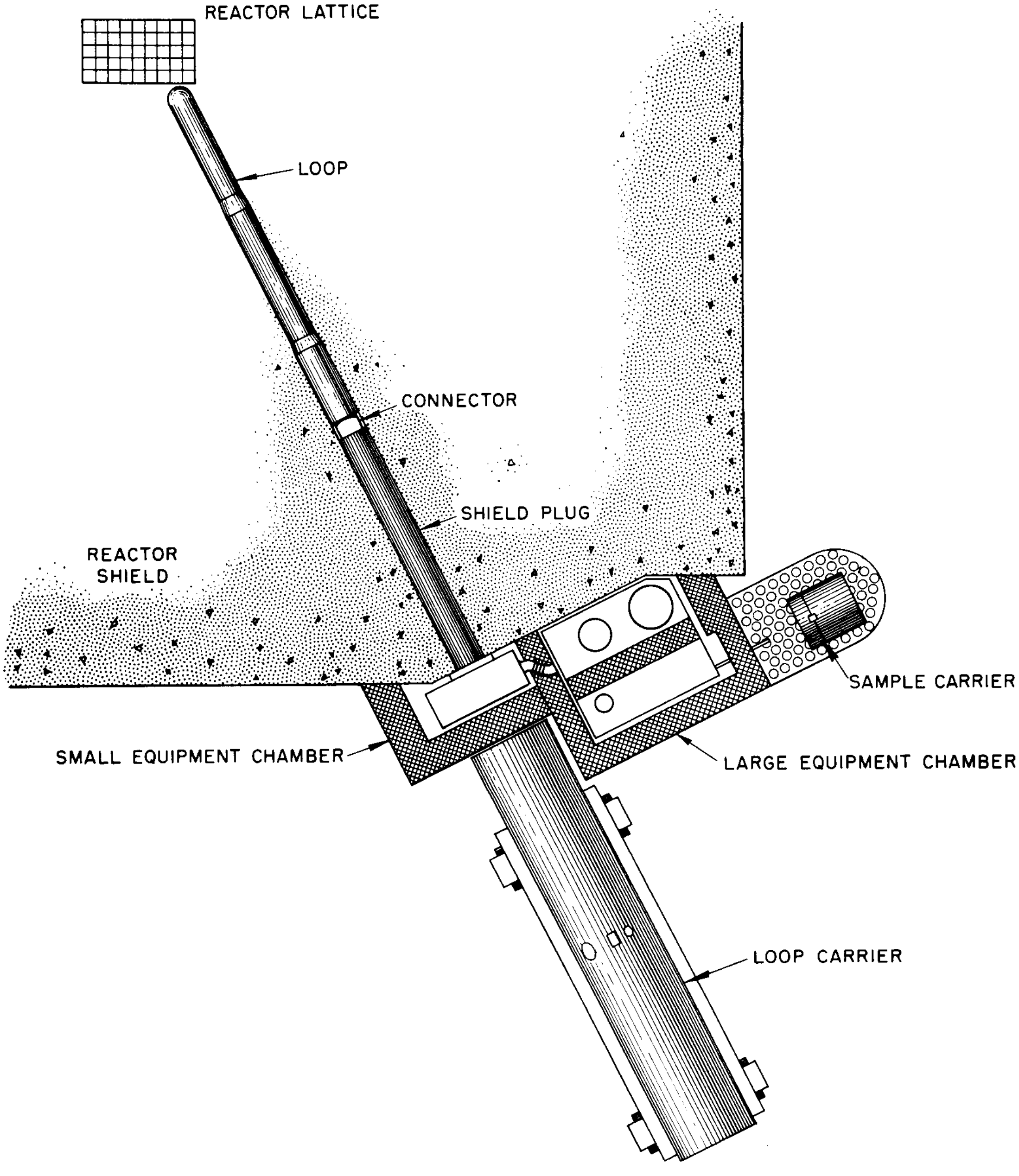

Fig. 38. LITR Loop Experiment (Plan View).

Radiation Stability of Fuel Materials

Experiment Description.-- Samples of fuel materials are irradiated in high-pressure autoclaves at elevated temperatures to obtain data on radiation damage to the materials.[33] Samples may be in the form of solution, slurries, or wetted pellets. Sample temperature, which may be as high as 300°C, is controlled by air cooling. Neutron fluxes of about 10^{13} n/cm^2-sec and integrated neutron doses of the order of 10^{20} n/cm^2 are required in the current phase of this experiment. An irradiation time of about a year is needed to give a radiation exposure equivalent to a thoria-blanket cycle.

Experiment Facility.-- Lattice Position C-43.

An access channel consisting of two concentric tubes extends from a connection box near the top of the reactor through a reactor tank side penetration and down into the lattice position. The autoclave (Fig. 39a) containing an experiment is lowered into position through the inner concentric tube which also serves to carry inlet cooling air and instrument leads. There are two types of autoclave, one of which permits the contents to be stirred (Fig. 39b). Control instrument panels are located in the west experiment room of the reactor building. This facility provides a thermal neutron flux of 2.5 x 10^{13} n/cm^2-sec. The amount of gamma heating in the steel autoclave is more than adequate to provide the desired temperatures and, in fact, requires that the amount of steel be minimized. A higher neutron flux, and the associated larger gamma heating, would result in cooling problems.

Some problems which have been encountered are:

1. The bend in the facility tube required for side entry of the reactor tank limits the size of the autoclave.

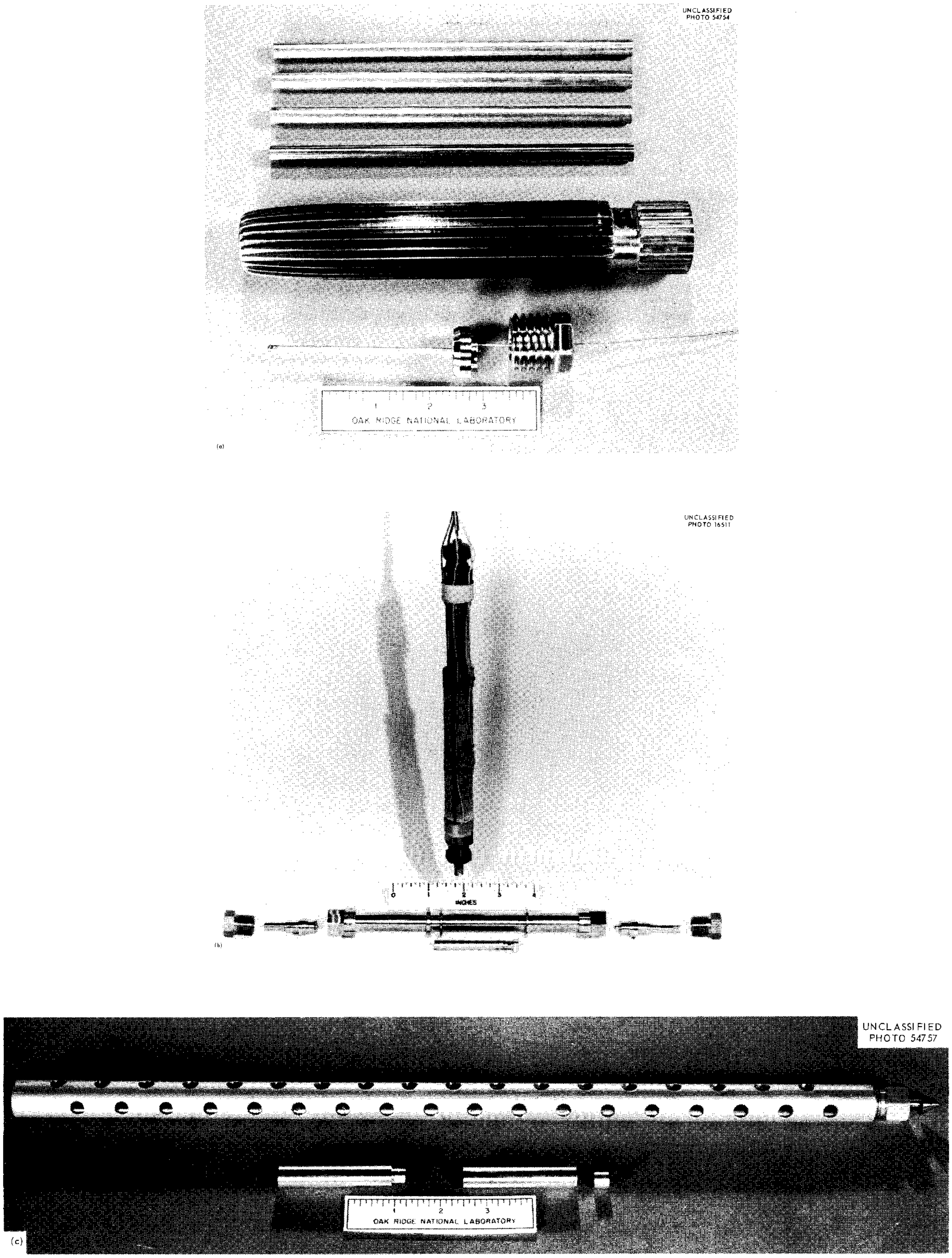

Fig. 39. (a) Autoclave for C-43 Facility: LITR, (b) Stirred In-Pile Autoclave, (c) Sample Container for C-41 Facility: LITR.

2. Because of the small core size, the flux gradients across it are steep. The placement of experiments and of flux monitors is therefore critical.

3. While the flux variation during an operating cycle is small, changes in fuel distribution upon refueling can cause a significant variation from one cycle to another.

Radiation Stability of Dry Fuel Materials

Experiment Description.-- Nonvolatile fuel materials are irradiated at normal temperatures in sealed containers to determine radiation damage.[34] A thermal flux of the order of 10^{13} n/cm^2-sec is needed.

Experiment Facility.-- Lattice Position C-41 (Partial Fuel Element).

In the cavity of this partial-fuel element (see Page 60) is placed an aluminum piece containing two holes 3/4 in. in diameter by 20 in. long. Into these holes are placed perforated holders containing the sealed sample containers (Fig. 39c). Reactor cooling water flows through the perforations and cools the sample containers. The thermal-neutron flux at the containers is approximately 3 x 10^{13} n/cm^2-sec.

Reactor Materials Development

Experiment Description.-- Samples of reactor materials--fuel, cladding, moderator, shielding--are irradiated to determine effects on their physical and mechanical properties.[14] Initial screening tests of relatively short duration (100-300 hrs) are made in thermal-neutron fluxes of about 10^{13} n/cm^2-sec in order to evaluate new materials or fabrication processes.

Engineering proof tests of long duration (about 1000 hrs) are then made of selected materials at higher fluxes, 10^{14} to 10^{15} n/cm^2-sec in other reactors. Samples are maintained at desired operating temperatures by air cooling.

Experiment Facility.-- Lattice Position C-48.

An experiment facility tube (Fig. 40) enters the side of the reactor tank near the top and extends down into the C-48 lattice position. Samples are placed in a capsule assembly provided with flexible metal-bellows tubing and instrument leads, and the capsule is lowered into the facility tube. Cooling air flows through the flexible tubing. Cooling air returning from the sample flows through an air cleanup and sampling station, located in a lead-shielded cubicle on the reactor midriff, before being exhausted into the reactor off-gas system. Instrument and control panels are located in the east experiment room of the reactor building. A typical installation is diagrammed in Fig. 41.

This facility is well suited for the screening tests. The thermal-neutron flux in C-48 is 10^{13} n/cm^2-sec and varies little over the operating cycle. The operating schedule of the LITR has the needed flexibility for these types of tests. Costs of experiment facility construction and installation for the LITR are also less than for the ORR.

Effects of Radiation on Mechanical Properties of Metals

Experiment Description.-- The objective of this series of experiments is to determine the effect of nuclear radiation on the mechanical properties of reactor structural metals with special emphasis on the neutron embrittlement of steels.[35,36] Metal specimens, enclosed in a stainless steel can, are irradiated at various temperatures with neutrons. Temperatures in the range 200-600°F are used, and integrated neutron dosages of the order of 5×10^{18} n/cm^2 (>1 Mev) are required.

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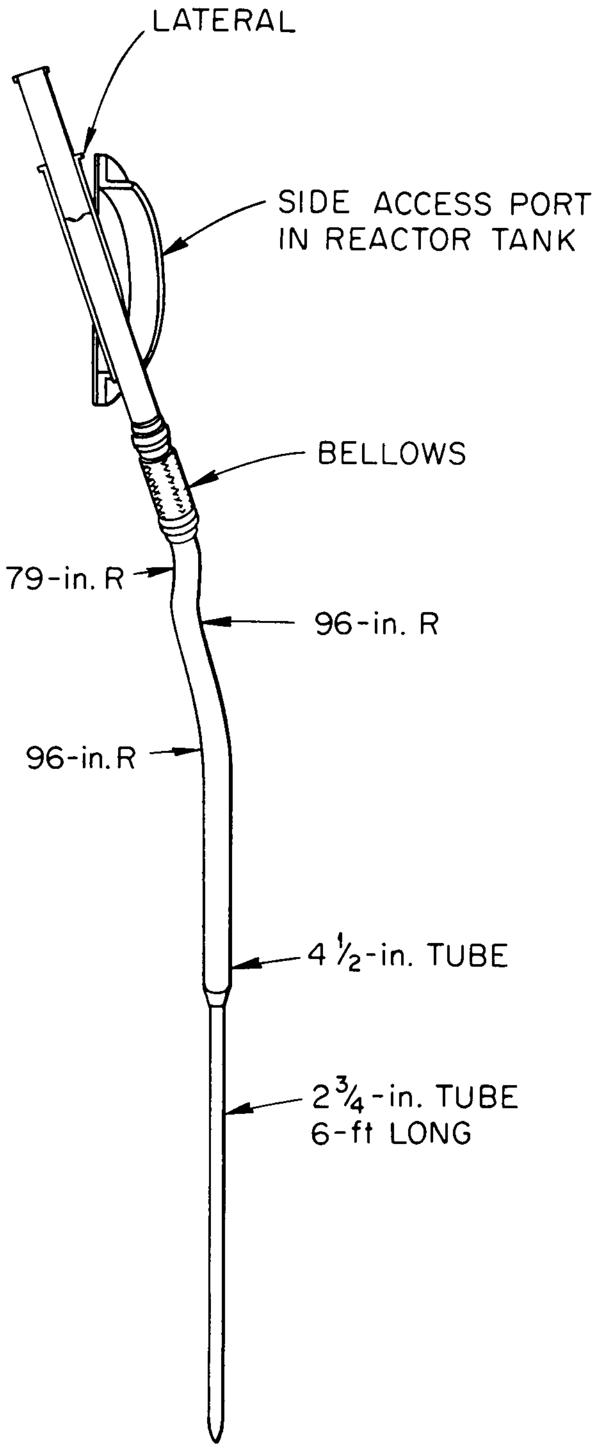

Fig. 40. Simplified View of the C-48 Facility Tube: LITR.

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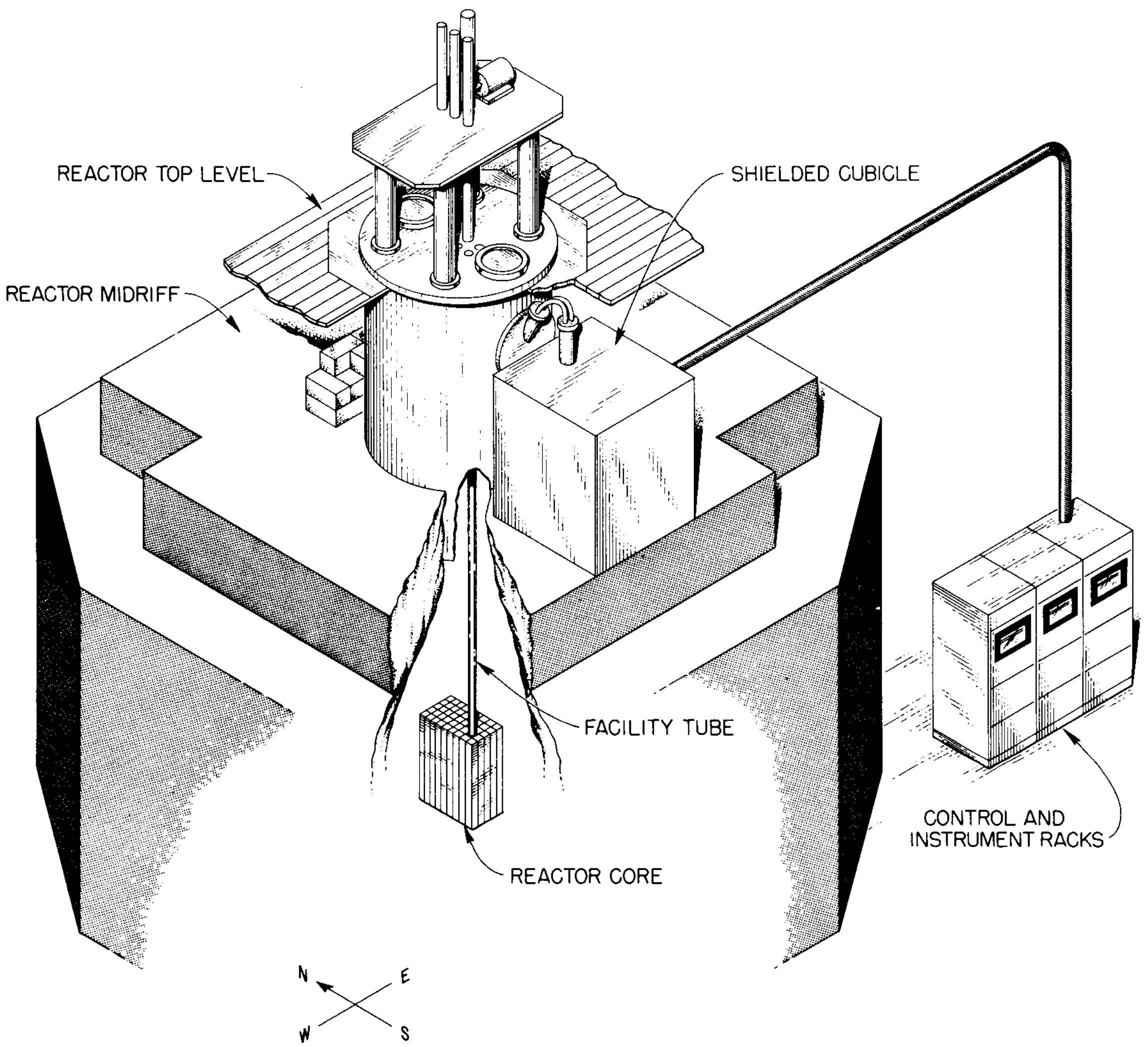

Fig. 41. LITR In-Core Experiment.

Experiment Facility.-- Lattice Positions C-18, C-49, and C-55.

The fast-neutron flux in each of these positions is from 3 - 6 x 10^{12} n/cm^2-sec (>1 Mev) which gives the required total dosage within the normal one-month operating cycle of the LITR. The magnitude of the gamma heating in these positions (about 0.5 watt/gm) is such that good temperature control of the specimens can be achieved through the simple means of applying a variable air pressure to the interior of the sample can. In this way the contact area, and therefore the heat transfer, between the can and the specimens can be varied. The exterior of the can is cooled by the flow of reactor water through the core.

Fast Neutron Damage in Solids

Experiment Description.-- This title covers investigations of neutron-induced damage in single crystals of various solid materials at normal temperatures.[15,16,17] As the principal interest lies in dimensional and ordering changes in the crystal lattice, integrated fast-neutron fluxes of 10^{20} - 10^{22} n/cm^2 (>1 Mev) are required.

Experiment Facility.-- Lattice Position C-28 (Partial Fuel Element).

This type of facility has been described on Page 60. In the C-28 lattice position of the LITR the fast-neutron flux in the central portion of a partial fuel element is 5 x 10^{13} n/cm^2-sec (>1 Mev). With irradiation times up to one year, neutron doses up to about 10^{21} n/cm^2 are obtained. For the higher doses (10^{22} n/cm^2) the ORR is used (Page 60). Damage-rate effects can be determined by using both reactors.

Gas-Cooled Reactor Fuel Studies

Experiment Description.-- Miniature fuel samples of types which are of interest in the gas-cooled reactor program are being irradiated.[37]

The samples are sealed into an Inconel capsule containing two separate compartments in tandem (Fig. 42). This capsule is inserted through a vertical, re-entrant, facility tube into the reactor. During irradiation, the wall of the capsule is maintained at a temperature of 1300°F by forced air cooling from the plant air supply. The air flow is controlled automatically by a temperature controller-recorder that operates a pneumatic control valve. The air passes down through the central tube of the facility tube, over the capsule, and returns up through an outer annulus to the off-gas system (Fig. 43). Thermocouples give continuous readings of central fuel temperature and capsule-wall temperature during irradiation.

Following irradiation, the capsule is examined in a hot cell to determine fission-gas release as well as changes in dimensions, density, microstructure, or other characteristics of the fuel.

Experiment Facility.-- Lattice Positions C-42, 44, 45, 46, 47, and 57.

Access to these lattice positions is through the top cover of the reactor tank. Cooling-air and thermocouple junction boxes are located on the reactor top level with control-instrument panels in the west experiment room (Fig. 9). Cooling-air cleanup equipment (filters and charcoal traps) is located outside the reactor building. The peak thermal-neutron fluxes in the lattice positions range from 2 - 4 x 10^{13} n/cm^2-sec and are adequate for the screening-type tests performed in this program. Flux gradients are of no concern, for the test specimens are small. For most of the experiments gamma heating is low enough (1 - 1.5 watt/gm) to be unimportant. The experiments have not been greatly affected by other experiments in the lattice. The reactor operating cycle has been found to be satisfactory.

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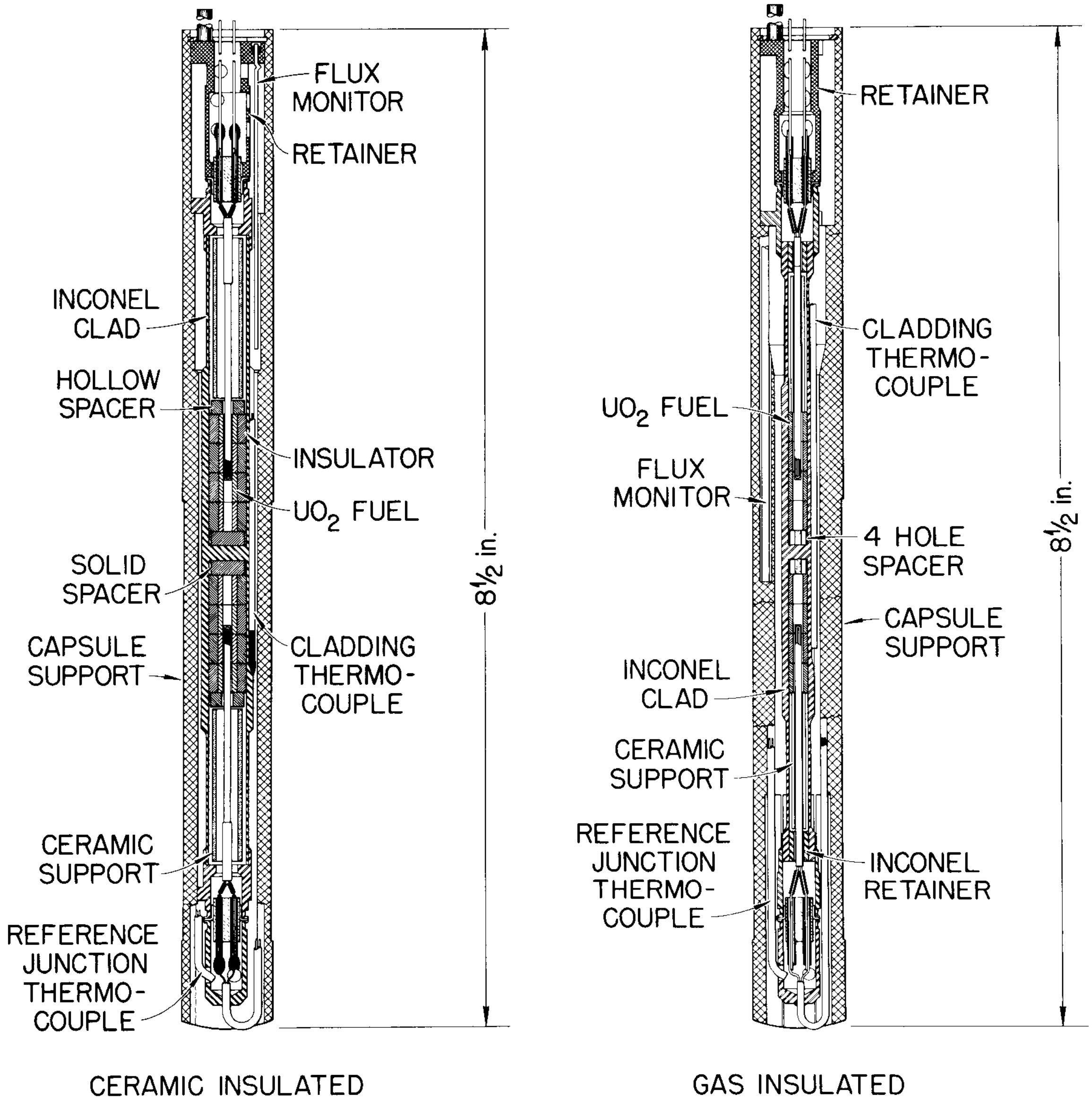

Fig. 42. Capsule Assembly.

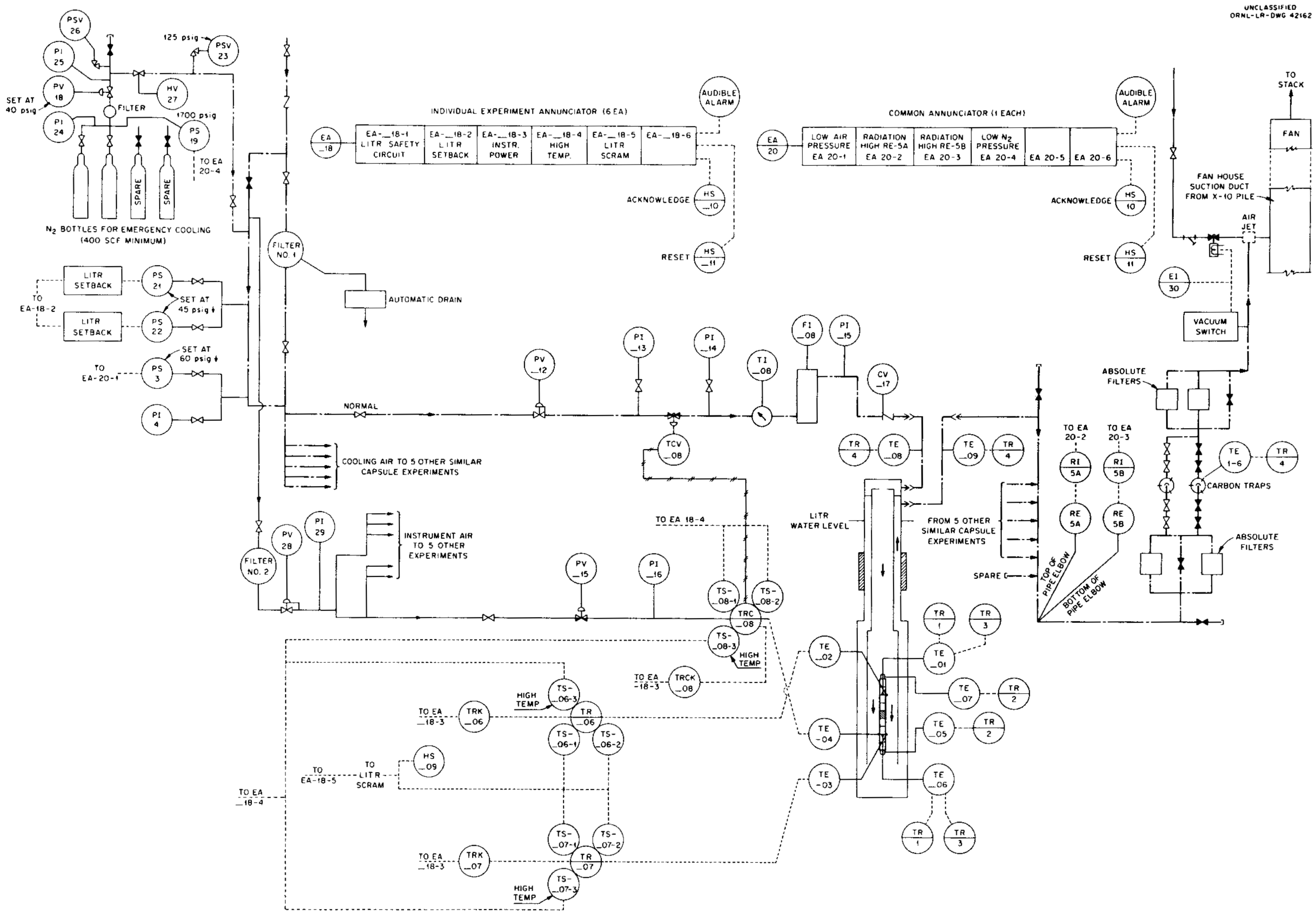

Fig. 43. Flow Diagram; LITR-GCR Experiments.

Some problems which have been experienced are:

1. Accurate predictions of sample heat-generation rates and burnups are made rather difficult by shifts which have occurred in the thermal-neutron fluxes in the sample positions (about $\pm$ 25%) over a three-year period.

2. Unscheduled shutdowns have produced more thermal cycling of samples than is desirable. Such cycling is liable to cause thermocouple and, perhaps, capsule failure.

3. The top-cover access for these experiments is highly undesirable. Each time the reactor top is removed for refueling or maintenance every one of the experiment facility tubes must be dismantled and disconnected from its air and instrument lines. After removal of the top, the tubes (with their experiments) must be lifted out of the lattice and stored at the side of the tank. Due to the delicate nature of the capsules, these operations with the experiment assemblies are performed only by an experiment technician. Aside from the inconvenience of having to provide a technician each time the top is removed, there is the risk of damage to experiments from handling and the danger of misconnecting cooling-air lines and thermocouples.

4. Although experiments can be installed or withdrawn from the flux during any shutdown, they can be removed from the reactor only during the monthly major shutdown when the reactor top is removed.

Possible Improvement.-- Side access through the reactor tank wall would be a great improvement for these experiments. This would end the need to disconnect experiments each time the top is removed and would permit experiment removal during the weekly shutdowns.

Experiments in the OGR

Thermal-Neutron-Induced Recoil and Transmutation Effects in Semiconductors

Experiment Description.-- Small specimens (typically, 0.1 gm) are irradiated with thermal neutrons at reactor ambient or at liquid-nitrogen temperatures and their electrical properties subsequently measured.[38] To minimize fast-neutron effects a very high cadmium ratio is required. The thermal-neutron flux can be relatively low for these radiation-sensitive materials, but it should be constant for long periods. To reduce heating effects the gamma flux should be low.

Experiment Facility.-- Inclined Biological Tunnel (Fig. 44).

This facility consists of an inclined hole leading to a bismuth-shielded cavity within the vertical thermal column of the OGR. The thermal neutron flux in the cavity is 1.5×10^9 n/cm^2-sec and is constant (within 5% over a week), the cadmium ratio is greater than 10^5, and the gamma exposure rate is only 80 r/hr. The facility can hold a 2-liter dewar of liquid nitrogen which provides sufficient sample cooling for about 20 hrs. Samples can be changed while the reactor is at power. The gamma radiation is sufficiently low that ozone formation from oxygen in the dewar is of no consequence.

Possible Improvements to the Facility.-- To permit prolonged low-temperature exposures, the facility could be refrigerated. To facilitate access, the present massive shielding plug (1-ft sq x 8 ft long) could be provided with a small 1-in. I D serpentine sample-access hole.

Basic Studies on Radiation Damage in Metals

Experiment Description.-- Metal specimens are irradiated at very low temperatures (down to 3°K), and the kinetics of their annealing

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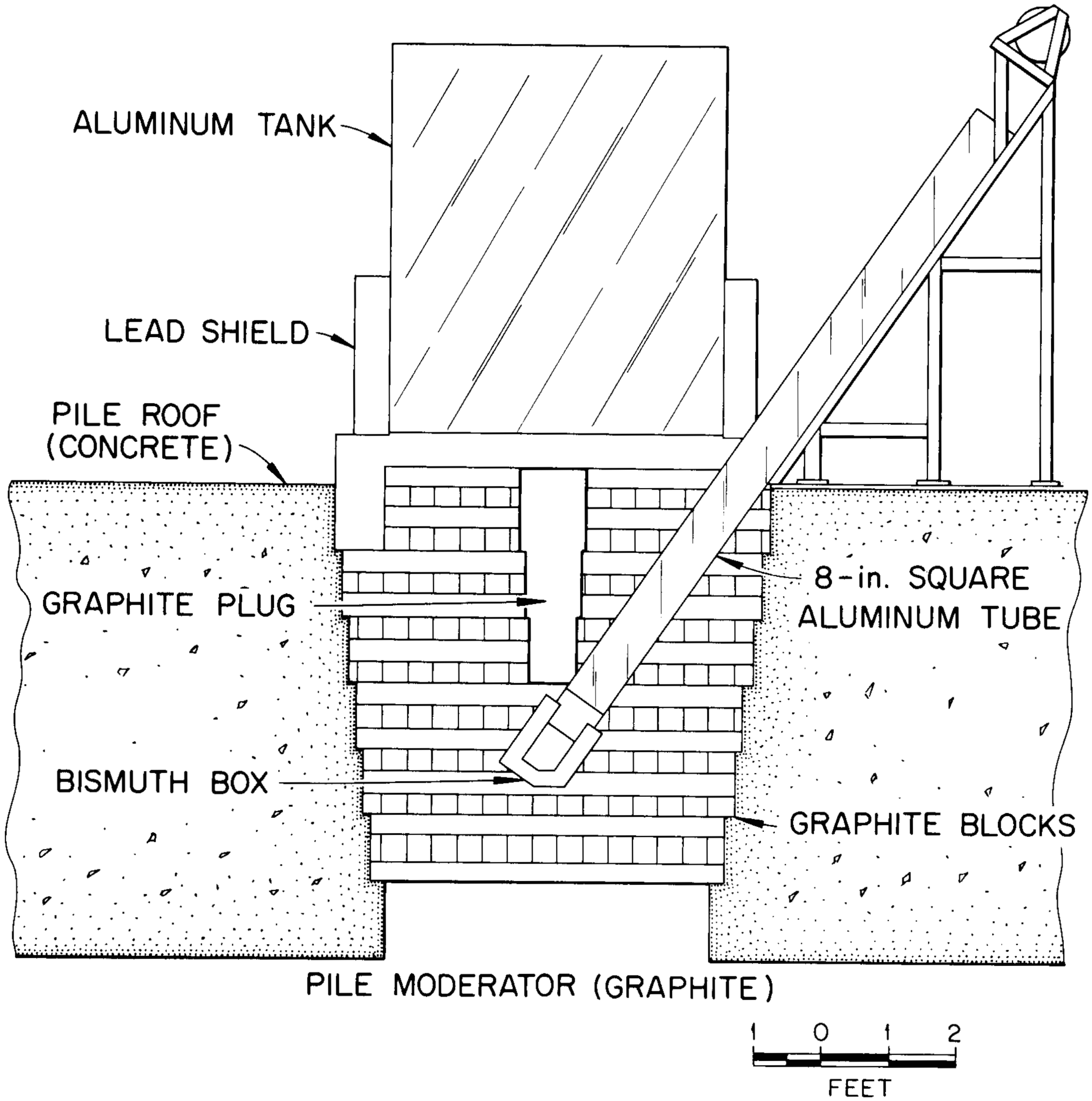

Fig. 44. Vertical Thermal Column and Inclined Biological Tunnel.

determined in situ.[39,40] A thermal-neutron flux between 10^{11} and 10^{12} n/cm^2-sec is satisfactory for most studies. Gamma heating must be low. For (n, γ)-recoil-damage studies at very low temperatures, a high thermal-neutron-flux to fast-neutron-flux ratio is necessary.

Experiment Facility.-- Hole 12.

This vertical hole contains a helium cryostat which is capable of maintaining sample temperatures, during irradiation, down to 3°K. The thermal-neutron flux is 6×10^{11} n/cm^2-sec and the gamma heating is 3.2×10^{-3} watt/gm. Some adjustment of the ratio of thermal-neutron flux to fast-neutron flux is possible through changes in reactor fuel loading in the vicinity of the hole. The facility will hold specimens up to 1/2 in. in diameter x 5 in. long. Samples can be changed only during reactor shutdown.

Possible Improvements to Facility.-- Means for greater adjustment of the neutron spectrum would be desirable (for example, a uranium converter for decreasing the ratio of thermal flux to fast flux and a moderating arrangement for increasing this ratio when desired). There have been occasions when a larger specimen space would have been useful.

Effect of Irradiation on Soft Magnetic Materials

Experiment Description.-- Sample toroids of various nickel-iron magnetic alloys (mumetal, permalloy, etc.) are irradiated at temperatures near 90°K. Hysteresis loops on the samples are obtained before, during, and after irradiation and also during subsequent high-temperature annealing.[41] Fast-neutron (> 1 Mev) fluxes of at least 10^{11} n/cm^2-sec are desirable. A typical integrated dose is 5×10^{17} n/cm^2. Gamma heating should be small enough for the desired low temperature to be attained.

Experiment Facility.-- Hole 50-N.

The in-core end of this horizontal hole is cooled with helium gas that has been passed through a bath of liquid nitrogen kept outside the reactor shield. Sample tubes up to 1 in. in diameter can be placed in the facility. The thermal-neutron flux is 3.5×10^{11}, and the fast-neutron (>1 Mev) flux is 1.3×10^{11} n/cm^2-sec. Sample temperatures down to about 90°K are obtained. Samples may be inserted or removed while the reactor is operating.

Possible Improvement to Facility.-- Better control of the facility temperature would be advantageous.

In-Pile Studies of Radiation-Induced Reactions in Cu-Al Alloys

Experiment Description.-- When samples of a metastable Cu-Al alloy are bombarded with reactor neutrons, the radiation-produced vacancies enable the alloy to proceed to equilibrium. This reaction is accompanied by a decrease in electrical resistivity. By means of in-pile electrical resistivity measurements, the rate of the reaction is being studied as a function of instantaneous neutron-flux level.[42,43] Thus, the experiment requires a variable flux level and, at a given level, constancy of the flux and knowledge of the neutron spectrum. Furthermore, since the rate of the reaction also depends on temperature, the temperature must be controlled to within $\pm$ 1°C. It normally takes about one week to make a run.

Experiment Facility.-- Hole C.

This 1 1/4-in. diameter horizontal hole provides fast-neutron fluxes from about 3×10^8 to 7×10^{10} n/cm^2-sec (> 1.6 Mev), depending upon how far the sample is inserted into the hole. Sample temperatures from 45 to 250°C are attainable using an electrical heater integral with the sample irradiation capsule. The one-week shutdown schedule of the reactor is ideal for this experiment.

Possible Improvements to Facility.-- A larger diameter hole would enable several samples to be studied simultaneously.

The high volume of cooling air passing through the hole makes temperature control somewhat difficult.

Effect of Radiation on Plastics and Rubbers

Experiment Description.-- Samples of plastics and rubbers are irradiated with neutrons, and changes in physical and chemical properties and in molecular structure are subsequently determined.[44] A high ratio of fast-neutron flux to gamma flux is required, for it is desired to determine the effects of neutron dose alone.

Experiment Facility.-- Hole 19

This horizontal hole is water-cooled to temperatures between 18 and 22°C. The sample space is 1 1/4 in. in diameter. The neutron-flux energy spectrum in the hole is 6×10^{11} (thermal), 1.4×10^{10} (>0.75 Mev), and 1.0×10^{10} (>2.3 Mev) n/cm^2-sec. The gamma heating (in carbon) is about 10^{-3} watt/gm. Samples can be removed while the reactor is operating.

Possible Improvements to Facility.-- A larger diameter hole (e.g., 4 in.) would permit physical measurements to be made in situ.

Direct Polarization of In^{115} Nuclei

Experiment Description.-- A monochromatic beam of polarized neutrons (Fig. 45) was used for the purpose of detecting nuclear polarization of In^{115} nuclei.[45,46] Polarization of the neutrons was effected in several ways one of which was diffraction from a Fe_3O_4 crystal; this also selected neutrons of .075 ev energy. Subsequent diffraction from a copper crystal

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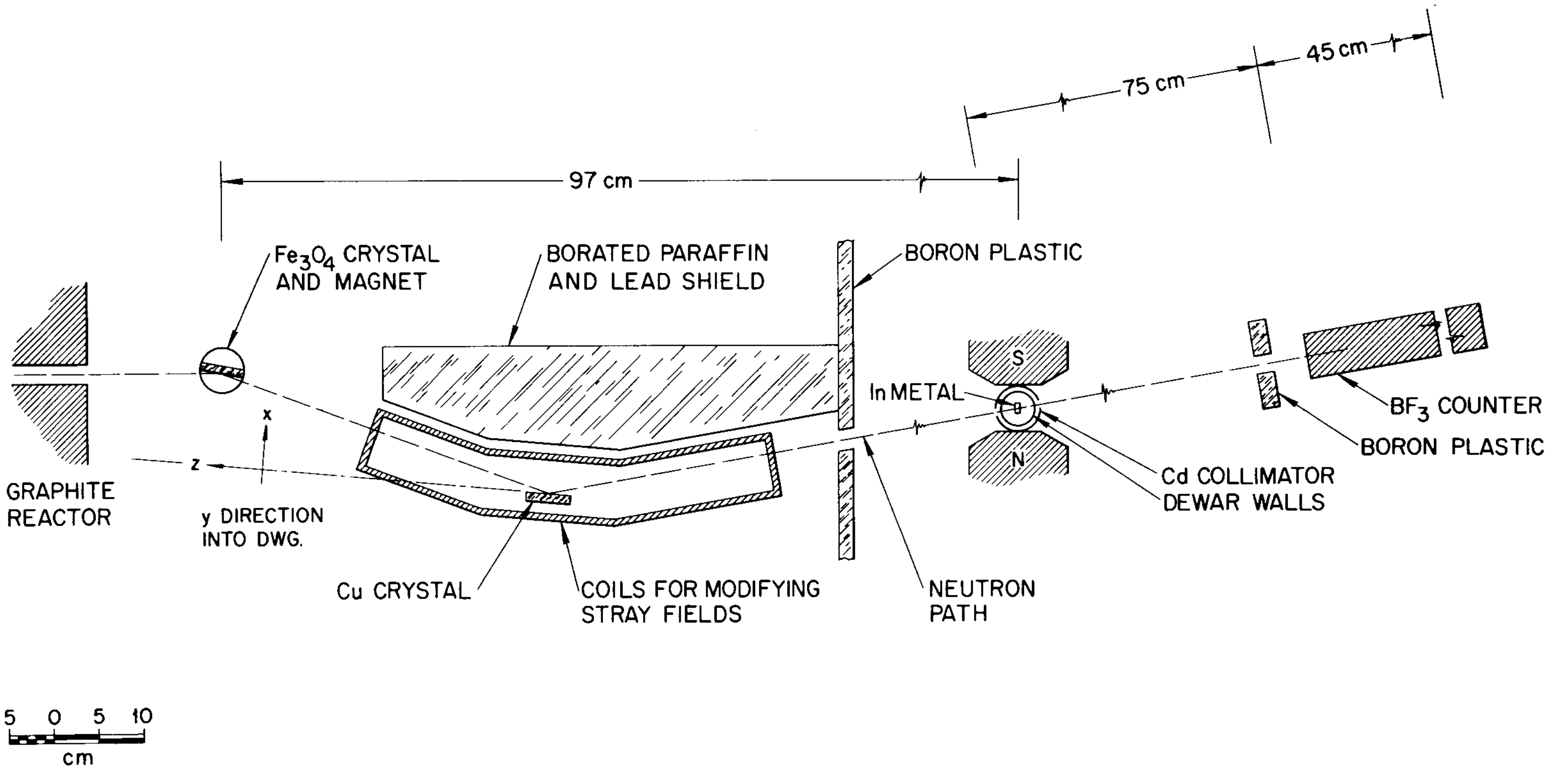

Fig. 45. In^{115} Experiment.

reduced higher order contamination. The indium sample was cooled to $0.04^{\circ}K$ using adiabatic demagnetization. A relatively low thermal-neutron beam flux (about 10^6 n/cm^2-sec) is sufficient for this experiment. It is desirable to minimize fast neutron and gamma radiations for shielding reasons.

Experiment Facility.-- Hole 52-S.

This horizontal beam hole provided an adequate flux, about 5×10^6 n/cm^2-sec, at its exit.

Possible Improvements to Facility.-- For this experiment a special fuel loading at the inner end of the beam hole would have reduced the fast neutron flux and reduced the shielding problems. If the shields between this facility and its neighbor had been recessed, problems arising from leakage of radiation from the latter would have been reduced. Much greater head room in the experiment cubicle is desirable for accommodating cryogenic apparatus.

Fast-Neutron Effects in Semiconductors and in Alkali Halides

Experiment Description.-- This title covers a great variety of basic solid-state investigations of semiconducting materials (e.g., germanium) and of alkali halides (e.g., KCl) in which fast-neutron irradiation is used as a means of introducing defects, removing carrier electrons, and so on. In general, it is desired that defects be introduced at a constant, relatively low rate into a sample held at a fixed temperature. Gamma heating should be low so as to avoid annealing effects in the samples.

Experiment Facility.-- Hole 51-N.

The in-pile end of this horizontal hole is equipped with a cylindrical uranium (93% U^{235}) converter for fast-neutron production. A sample carrier is provided and samples may be changed during reactor operation. The sample space is 2 7/8 in. in diameter x 12 in. long. The facility is water-cooled to about 25°C. The neutron flux within the converter is approximately 10^{12} n/cm^2-sec and has a fission energy spectrum. The flux is closely uniform throughout the sample space.

This facility has been used to irradiate samples of semiconductors and of alkali halides with fast neutrons.[47]

Decay of N^{17}

Experiment Description.-- The short-lived radioactive isotope N^{17} is produced by neutron irradiation of Li_3N enriched in Li^6 and N^{15}. The decay products of N^{17} are measured. A relatively low neutron flux ($\sim 10^{11}$ n/cm^2-sec) is adequate, but it is essential that samples be transferred rapidly from the reactor to the laboratory and that activation of the sample holder be small.

Experiment Facility.-- Hole 56-N

This horizontal hole is provided with a fast pneumatic tube that yields a very short ($\approx$ 0.1 sec) sample transit time from reactor to laboratory. The thermal neutron flux is 2.4 x 10^{11} n/cm^2-sec. The low gamma heating in this hole permits the use of plastic sample containers which do not activate sufficiently to perturb the decay measurements. The pneumatic tube has a rectangular cross-section, and the sample containers are discs of high-density polyethylene 13/16 in. in diameter x 5/16 in. thick.

Radiochemical Studies of Fission Products

Experiment Description.-- Small (10-20mg) samples of U^{235} are irradiated in solution. The yields and decay characteristics of short-lived fission products are determined in the laboratory using rapid chemical separations and nuclear radiation measurements.[48,49,50] A neutron flux of about 10^{12} n/cm^2-sec is adequate. It is essential that samples be transferred rapidly from the reactor to the chemistry laboratory preferably in less than one second. To facilitate rapid handling of samples within the laboratory, activation of sample containers should be low.

Experiment Facility.-- Hole 22.

This horizontal hole is provided with a pneumatic tube having a terminal in a chemistry laboratory. Transit time of the linen-micarta "rabbits" (Fig. 46) used in this tube is 4-5 seconds from reactor to laboratory. The thermal-neutron flux in the hole is 6.6×10^{11} n/cm^2-sec. This relatively low flux, coupled with the short irradiation times used, enables rubber-sealed stainless-steel containers (Fig. 47) to be used for holding the solutions. Activation of, and radiation damage to, the containers is small. At the laboratory terminal, a hypodermic-needle arrangement (Fig. 48) allows solution transfers to be made rapidly.

Possible Improvement.-- A still shorter rabbit-transit time (about 1 second) is desirable for some fission products having very short lives.

Studies of Volatile and Gaseous Fission Products

Experiment Description.-- A U^{235} sample is to be contained in a cadmium box with a shutter for controlling the thermal-neutron irradiation. Halogen and rare-gas fission products are to be swept rapidly out of the box for study in the laboratory. A relatively low neutron flux is sufficient ($\sim 10^7$ n/cm^2-sec) and also is desirable in order to minimize activation of the experiment components. For the same reason it should be

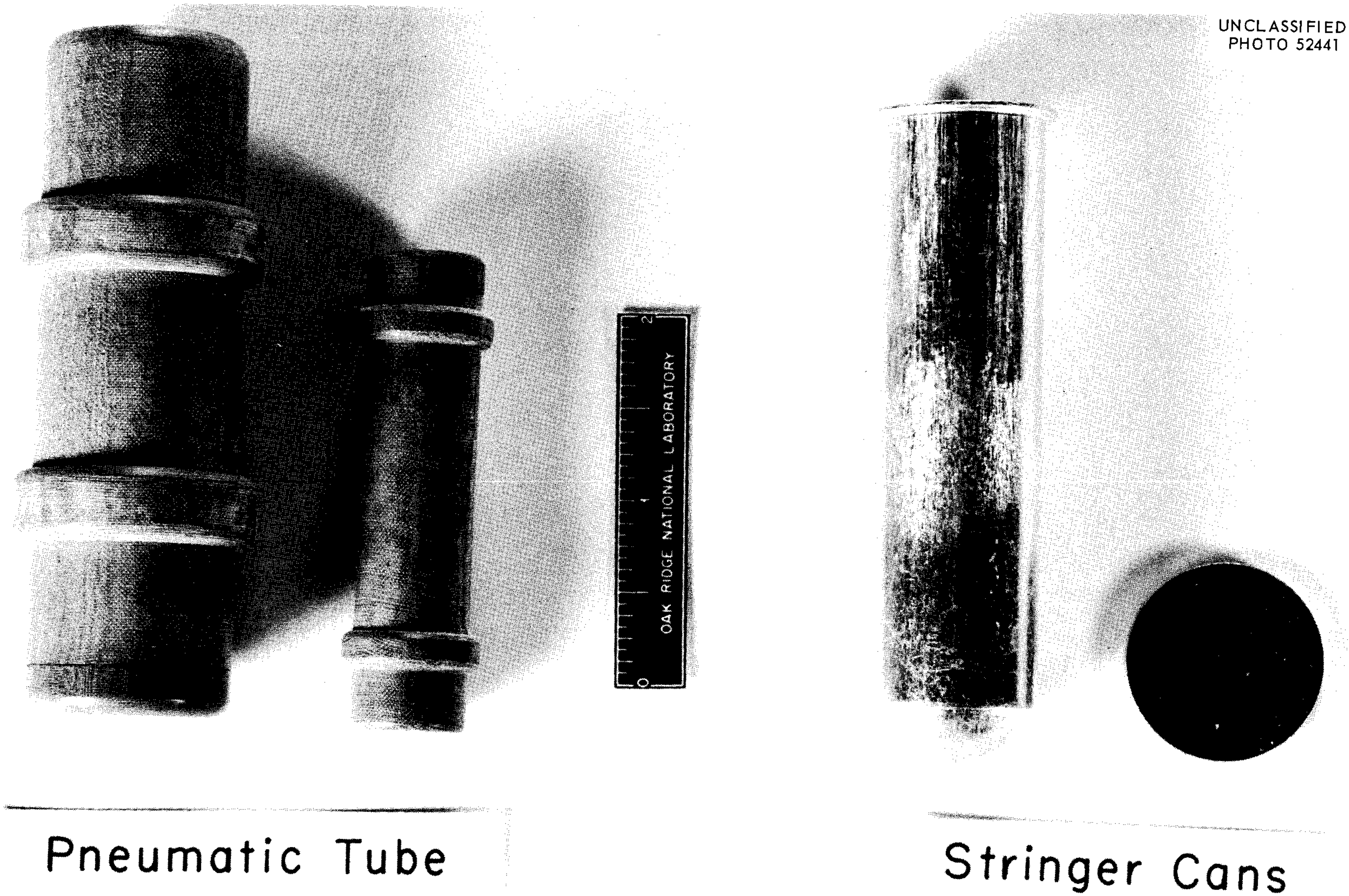

Fig. 46. Graphite Reactor Irradiation Containers.

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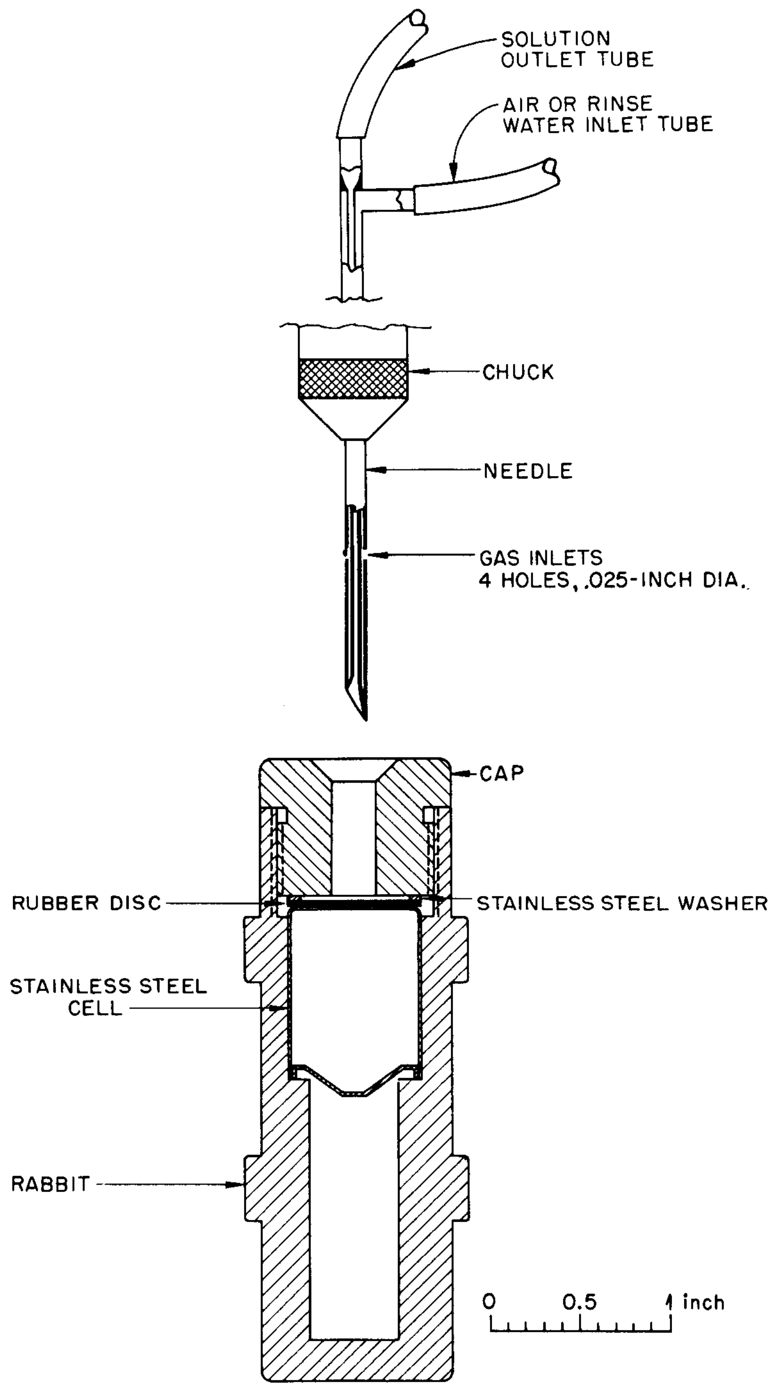

Fig. 47. Solution Container.

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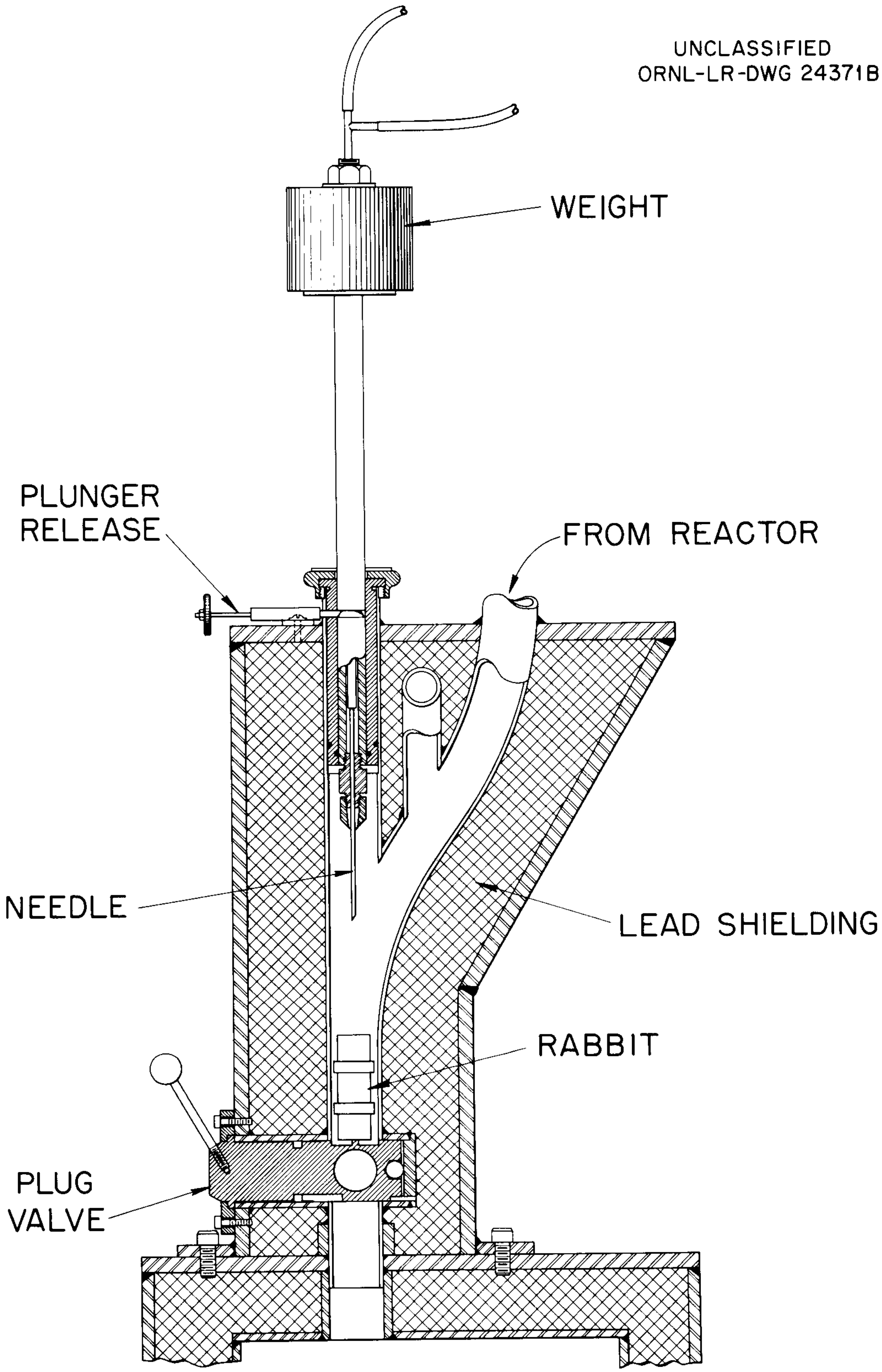

Fig. 48. Hypodermic-Needle Assembly.

possible to withdraw the apparatus from the reactor flux after each experiment run is completed.

Experiment Facility.-- Hole 57-S.

The 4-in.-square hole can provide a thermal-neutron flux of about 10^7 n/cm^2-sec at the edge of the reactor core and can readily accommodate the experiment. The low gamma heating simplifies the design of the experiment; and this, in turn, reduces the amount and kinds of material that could become activated. The capability of shutting down the OGR as required for experiment convenience will enable the experiment to be withdrawn between runs.

Shielding Research and Engineering

Experiment Description.-- The attenuation properties of various shielding materials for neutrons and gammas are measured. Mock-ups of calculated shield designs are tested experimentally. A plane source of fission neutrons approximately uniform in strength over a large area is obtained by allowing thermal neutrons to irradiate a 28-in.-diameter U^{235} fission plate.[51] This plate is at the wall of a large tank of water (about 11- x 7- x 7 1/2-ft high) in which the experiments are performed. The thermal-neutron flux incident on the plate should be at least 10^8 n/cm^2-sec and should be uniform across the plate. The general radiation background should be low.

Experiment Facility.-- Core Hole.

This hole, which is about 30 in. square, provides (at the fission plate) a thermal flux of about 10^8 n/cm^2-sec that is uniform within about 15% over the plate diameter. The entire arrangement of source and experiment tank is called the Lid Tank Shielding Facility (Fig. 49).

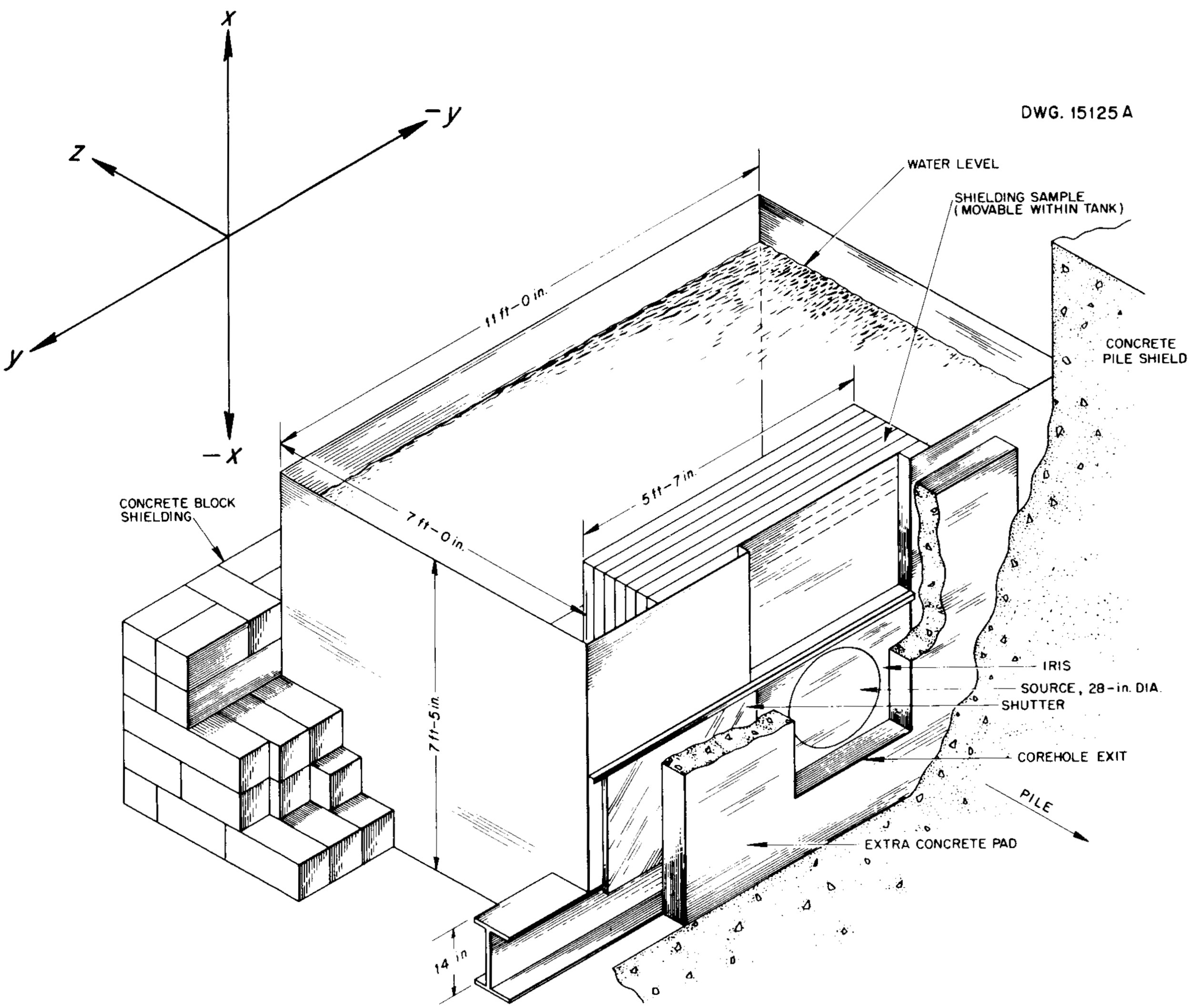

Fig. 49. ORNL Lid Tank Shielding Facility.

Possible Improvement.-- It would be a decided advantage to have a higher thermal-neutron flux incident on the fission plate. For example, an improvement of at least 100 would result from using one of the ORR large engineering test facilities as the neutron flux source for irradiating the fission plate.

Neutron Diffraction

Experiment Description.-- This title includes a great variety of experiments in which monochromatic neutrons are selected from a beam of thermal neutrons by diffraction from a crystal and are then allowed to interact with matter. These interactions provide information for studies in nuclear physics, for crystal structure determinations, and for investigations of magnetism at the atomic level.[20] While relatively low thermal fluxes (e.g., 10^6 n/cm^2-sec) are usable, increased flux intensities can be used to decrease the time required for an experiment or to increase the quality of the data (e.g., the resolution). To reduce shielding problems, both the fast-neutron and the gamma fluxes should be as low as possible.

Experiment Facilities.-- Holes 58-S, 51-S, and 50-S.

Holes 58-S, 51-S, and 50-S provide beams of thermal neutrons with a flux of about 10^7 n/cm^2-sec at the monochromator. The stability of the OGR is a decided advantage for the long runs that are usually required with this low thermal flux. Space for the diffractometer is adequate, and unusually massive shielding is not required. The fast neutron and gamma fluxes are very low. With the thermal flux available from these holes, single-crystal diffraction experiments may be performed readily. Experiments with powdered or highly absorbing samples are better performed with a higher flux.

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