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OAK RIDGE NATIONAL LABORATORY

Operated by
UNION CARBIDE NUCLEAR COMPANY
Division of Union Carbide Corporation

Post Office Box X
Oak Ridge, Tennessee

ORNL
CENTRAL FILES NUMBER

58-12-158

COPY NO. 118

DATE: December, 1958

SUBJECT: SAFETY AND OPERABILITY REVIEW OF EXPERIMENTS TO BE OPERATED IN
NUCLEAR REACTORS AT ORNL

TO: Distribution

FROM: C. D. Cagle

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SAFETY AND OPERABILITY REVIEW OF EXPERIMENTS TO
BE OPERATED IN NUCLEAR REACTORS AT ORNL

C. D. Cagle

December, 1958

Introduction

A nuclear reactor used as a research tool is unique in the field of research since it can provide for the performance of many experiments simultaneously. As a consequence, these many experiments must be compatible with each other as well as safe with respect to personnel and the reactor itself. The OGR (Oak Ridge Graphite Reactor) has more than 60 research facilities, the LTR has more than 20, and the ORR has more than 40. The operation of the experiments and tests conducted in these facilities necessarily requires that large numbers of personnel be in any of the reactor buildings from time to time. It also requires the close attention of certain personnel to maintain compatibility and safety.

The types of experiments and tests conducted in and around a reactor can vary greatly; some use beams of radiation emerging from ports within the reactor shield while others use equipment placed within or near the reactor core. Any of these types of experiments or tests are, to some degree, hazardous because of radiation, either directly from the reactor (beam ports) or because of induced radioactivities in the equipment used in the experiment or test. Frequently the conditions of the test itself, such as high temperatures and/or pressures, introduces other hazards. Operating procedures, insertion and removal of test specimens, and disposal of radioactive wastes and other materials can also be hazardous, particularly where many people other than those attending the particular experiment may be nearby.

In order to minimize the possibility of any hazardous conditions developing into an incident involving the safety of personnel, the reactor, and other equipment, any experiment design and installation should be checked or reviewed by several qualified, experienced people. The main purpose of this review should be to insure that all conceivable dangers are recognized and that appropriate safeguards have been incorporated into the design.

In addition to the problem of hazards which might be involved in the operation of any particular experiment is the problem of its effect upon the operation of the reactor. Any experiment which requires frequent reactor shutdown or power level change is not only burdensome but may cause other experiments to either fail or become hazardous. Experiment designs and methods of operation must be such that they are compatible with the best reactor operating and shutdown schedules. The persons who review experiments must insure this.

Equipment such as pumps, electrical relays, recorders, and sensing elements are subject to failures which can either cause hazardous conditions, reactor down time or both. The experiment review should include a competent examination of the reliability of these pieces of equipment.

A number of undesirable events have occurred at ORNL which serve well as illustrations of the need for careful reviews of the design, installation and operation of experiments and tests to be performed in reactors. These incidents have also aided in developing a group of experienced personnel to review experiments to prevent their recurrence and have led to the development of safeguard methods which greatly minimize the seriousness of such events. A number of these experiences are described in the appendix to illustrate some of the things which must be considered in the review of experiments and tests.

INITIAL REVIEW AND PLANNING OF EXPERIMENTS

Beginning with the earliest stages in the planning of an experiment to be performed in a reactor, the guidance of experienced personnel should be sought to minimize the possibility of making gross errors in the design and in the intended method of operating the equipment. Before the design is undertaken in great detail, consultation with Operations personnel is required to review the experiment or test for operability and the availability of a reactor facility as well as space for equipment and personnel. During this review the following details must be considered:

1. Overall Design and Equipment Location - The physical arrangement of the experiment or test and the associated components must be fitted to the existing facilities in such a manner as to make its installation and operation as easy and economical as possible and to interfere as little as possible with existing experiments and reactor components and their operation. The design and location of equipment must also be such that: erection of shielding does not overload floors; maintenance of equipment is easy; thoroughfares are not blocked; installation can be done while the reactor is in operation or during the regularly scheduled shutdown; operation of the equipment is not hazardous; removal of the in-reactor portions can be done within a minimum period of time in the event of failure; and all equipment can be removed during regularly scheduled shutdowns or while the reactor is operating.

2. Selection of Materials of Construction - The materials used in the construction of the experiment equipment must be compatible with each other and with the materials within the reactor. They must also be able to withstand all the conditions of operation to be encountered in the performance of the experiment or test. Materials which are difficult to use in fabrication should be avoided.
3. Operating Procedures for the Experiment or Test - The formulation of the operating procedures must be started as early as possible to insure that they are compatible with the design and the location of equipment. These procedures must also be reviewed in detail with respect to personnel and reactor safety.
4. Utilities and Waste Disposal - The quantities of electricity, compressed air, process water, demineralized water, and steam required in performing the experiment or test must be evaluated as early as possible to insure that sufficient supplies are available or to include the provision of additional supplies in the planning.

Waste disposal facilities must also be adequate and properly used. The decision on how much radioactive wastes may be discharged to the off-gas and drains must be made early in order to provide for any necessary liquid holdup tanks or charcoal traps for the off-gas.

It must also be known whether existing removal, transport, and storage shields will be adequate for the experiment or if new shields must be designed and built.

5. Hazards Evaluations - All conceivable hazards to personnel and the reactor must be listed and their seriousness evaluated. In addition to the hazards of radiation there may be others due to pressures, temperatures, materials, utilities, handling and operating procedures, and reactor power changes. Provisions for eliminating or precluding these hazards must be incorporated into the design and instrumentation for the experiment or test. If such provisions cannot be made and the hazards are sufficiently serious, the experiment or test must be rejected at this stage.
6. Instrumentation and Safeguards - In addition to the instrumentation required to furnish data for evaluating the results of the experiment or test, other instrumentation must be provided to insure safety of personnel, the reactor and other valuable equipment. It must be ascertained that all the properties which must be monitored to insure safety are recognized and that sensing elements will be properly located and in sufficient number.

In addition to providing the safe amount of instrumentation, it must be ascertained that this instrumentation is reliable. Since some instruments may be connected to the reactor controls to cause a reactor shutdown or power reduction to help alleviate

certain abnormal conditions which might develop, the possibility of their sending false signals must be minimized without risking the possibility that they will fail to respond if a shutdown or power reduction becomes necessary. Also the instruments which perform control and safety functions on the experiment or test components must be equally reliable. Assurance of the dependable performance of the instrumentation can best be had by the use of types of indicators, sensing elements, relays and circuits which have been proved reliable by experience. An up-to-date compilation of such components is maintained by the Instrumentation and Controls Division and experienced personnel are available to aid in the design of instrumentation.

7. Tests and Checks of Equipment - During and following the installation of equipment, piping and wiring, certain tests and checks must be made to insure the integrity and proper layout of the installation. The methods of insuring the leak-tightness of welds, continuity of circuits, proper routing of pipes, use of desired materials, etc., must be prescribed and a guarantee of their being followed provided. Also arrangements must be made to allow safe, approved departure from original plans should it become necessary or desirable to do so.

8. Personnel Requirements and Training - Depending upon the complexity of an experiment or test, continual manning may or may not be necessary or desired. Since the instrumentation for an unmanned experiment generally must be somewhat more elaborate than for one which is continuously attended, the decision concerning manning must be made before the instrumentation is designed.

Personnel who are to operate the experiment or test should be selected early to insure that its operation will not be started by people who are not thoroughly familiar with the components and operating procedures. Arrangements must also be made to train Reactor Operations personnel sufficiently that they can cope with any emergency situation which might arise from the operation of the experiment and can aid in the installation and removal of the in-reactor components.

EXPERIMENT OR TEST INSTALLATION, FINAL
REVIEW AND PRE-OPERATIONAL TESTS

Upon completion of the initial review of the experiment or test with Operations personnel to establish operability, the final design may be undertaken and some installation work started. At this time a technical man from the Operations Division is assigned to follow the progress of the design and installation, to provide Operations' approval of the design, and to otherwise act as liaison man between the research group and Operations.

Design Completion and Final Review

As soon as possible following the completion of the design, a review of the experiment or test by the ORNL Experiment Review Committee must be requested since the approval of this committee must be had before the experiment can be operated. The Experiment Review Committee is made up of senior staff members from several divisions who have had considerable experience with the reactors and the performing of experiments. The purpose of this review is to insure, as far as possible, that the hazards have been completely evaluated and that the safeguards are adequate. In order to initiate this review, a questionnaire which provides most of the necessary information for the review must be completed by the research personnel and submitted to the Operations Division liaison man for approval by Operations before it is presented to the Experiment Review Committee for their review. If approval is given by the committee, the installation may be completed and the experiment or test performed if the conditions for approval are met.

The Experiment Review Committee must be assured of the following conditions:

1. All radioactive gases and liquids must be contained both during normal operation and in the event of any foreseeable abnormal condition which might develop during the operation of the experiment or test. This means that all piping and tanks must be built to withstand the maximum pressures and temperatures which can be developed. If there is a possibility of internal explosion from any cause, the containment must be sufficient to withstand the pressure and shock of the explosion at the highest operating temperature.

The rate of release of radioactivities to the off-gas system and the liquid waste disposal system must not exceed safe limits.

2. Shielding requirements for all phases of the work must be adequately met. These include stationary shielding, removal shields, transport shields and storage shields.
3. Coolant supplies and their velocities must be somewhat more than just adequate for normal operation to allow some safety factor.
4. Materials of construction must be compatible with each other and the operating conditions to which they will be subjected.
5. It must be guaranteed that the experiment, even in the event of some failure, can in no way alter the reactivity of the reactor so rapidly that the reactor controls cannot prevent a dangerous

power excursion. Also there must be no uncontrolled motion of parts during normal operation which changes reactivity and causes the reactor power to fluctuate. Any mechanisms which are built to change the location of a specimen while being irradiated must be speed limited to allow compensation by the reactor controls for any reactivity changes which might occur.

6. The time required for the instrumentation to respond to signals from sensing elements must be short enough that the corrective action to alleviate any hazardous condition can be accomplished soon enough.
7. When hazardous conditions in the operation can be introduced by human error, it is necessary to have instrumentation which can prevent such an occurrence. It is also necessary that the instrumentation, as much as possible, protect itself from tampering by the personnel. It is sometimes necessary to require that alarms be sounded if such tampering is done.
8. The entire experiment design and the proposed operating procedures must be carefully examined for all possible hazards. These should be listed and each one evaluated. The likelihood of the occurrence of these hazards will dictate the extent of safeguarding against them. Frequently, a condition whose occurrence seems very remote may be of such consequence if it

should occur that elaborate means must be taken to prevent it. Also some seemingly remote possibilities become much less remote when viewed in the light of past experience.

The assurance of all of these conditions and any additional ones which might arise must be confirmed by acceptable calculations or actual tests and measurements. Supposition must never be accepted as proof.

Fabrication and Installation of Equipment

The equipment installation work must be done under the surveillance of both the research personnel and the Operations engineer to insure that it is done according to the approved plans and particularly that the proper materials are used and that the necessary checks and tests are made to insure reliable performance of the equipment. This phase of the preparation for operating an experiment is as at least as important as the design and in some respects more so since the approved design must be followed or the experiment may not be performed. Any departures from the approved design must be acceptable to the research personnel, Operations, and the Experiment Review Committee. The Operations technical man assigned to aid with the experiment preparation obtains the necessary approvals for such changes when requested to do so by the research personnel.

Final Inspection and Checkout of Equipment

When the installation of all the equipment has been completed, a final checkout and inspection of all components must be made before operation is begun. This checkout and inspection is done under the surveillance of Operations technical personnel. The thoroughness of this final checkout depends upon the complexity of the experiment equipment and the seriousness of any hazards associated with its operation.

If a loop is to be operated under conditions of high pressure and/or high temperature, it is wise to insist upon test operation with little or no radioactivity involved before test specimens are installed or before the assembly is actually put into the reactor if possible to be assured of containment and the operability of all components. If specimen removal must be done by the use of untried complicated procedures, test runs must be made of the full removal procedures using the actual equipment in place but with dummy specimens. The shields, if new, must be checked with radioactive sources to insure that no voids exist in the shielding material.

Less complex experiments and tests may require less elaborate checkouts; however, the simplicity of an experiment must not be allowed to lessen the attention required to insure that it is completely safe and reliable. Experience has shown that simple irradiations of encapsulated materials can be hazardous. The first instances of high air radioactivity encountered at the ORR were due to this type of irradiation; these events are described in the appendix.

Checkout of Initial Operating Conditions

The initial period of operation of any instrumented experiment or test must be carefully attended. This is true both of the "manned" and "unmanned" types. Since the knowledge of the operating conditions, until then, are the results of calculations and possibly extrapolations or inferences from pretests and similar experiments, the actual conditions may vary considerably from those expected. At the least, some of the controls settings of instruments may have to be changed and in the event of equipment failure or where severe oversights have been made such as in coolant supply, shielding, pressures, leak-tightness, or temperatures, the reactor may have to be shut down and the experiment removed. While the initial operating conditions are being determined, it is usually necessary to start the reactor up slowly in steps of increasing power in order to minimize any hazard which might develop and to allow sufficient time for the operating conditions of the experiment or test to be completely evaluated at each reactor power level.

Routine Checks and Inspection During Operation

At ORNL the primary responsibility for insuring the safe operation of an experiment or test is given to the research personnel; however, all the research personnel are not equally experienced, competent and reliable. There sometimes are hazardous conditions which develop and are not recognized due to lack of experience in evaluating such conditions. For this reason occasional inspection of the experiments by Operations

technical personnel, Instruments and Controls technical personnel, and Health Physics surveyors is desirable. These people gather a great deal of experience by their association with all types of experiments and tests and with the operating conditions of the reactors, so that many times they are better equipped to evaluate some conditions than the research personnel. These checks need not be done on a formal basis and frequently can be done best by simply inspecting the operating equipment and discussing the performance of the experiment or test with its operators at the location. This should be done by individuals rather than by groups of inspectors.

In addition to the hazards which are peculiar to reactor experiments, the ordinary industrial hazards must also be sought out and eliminated. These include such conditions as

1. Unchained high-pressure gas containers,
2. Tripping hazards in thoroughfares,
3. Overloaded electrical outlets,
4. Unprotected electrical wiring,
5. Uninsulated steam or hot water pipes,
6. Dangerous stacking of heavy materials such as lead bricks, concrete blocks, electronic instruments, etc.,
7. Slick floors caused by spilled liquids, and
8. Overloaded floors or shelves.

Re-runs of Approved Experiments or Tests and Change of
Specimens in Approved Experiment and Test Facilities

Before an approved experiment or test can be re-run, an inspection and checkout must be done to insure that the equipment still performs correctly. Also any improvements which past operation has shown to be necessary must be incorporated. New specimens which are to be put into test assemblies or experiments which are already approved must be inspected to insure that they meet the specifications which were approved for the specimens already used. Any departure from the approved types of specimens must be reviewed by Operations technical personnel and, if deemed advisable, by the Experiment Review Committee.

A P P E N D I X A
HISTORICAL BACKGROUND

The practice of having experiments reviewed by experienced personnel as a prerequisite to their being installed and operated in a reactor is the result of years of experience. A long list of incidents due to equipment failures, oversights by personnel, and inadequacies of procedures can be cited to justify such reviews to prevent their recurrence. Some of these are described here as examples.

Incidents at the OGR

1. During the early stages of radioisotope production, a gold target was put into the Graphite Reactor and left to attain near saturation radioactivity. In some records, the target weight was erroneously listed as so many grams when it was actually that many ounces. When plans were made to remove the target, the gram weight was used to calculate the radioactivity which would have been less than 5 R/hr at handling distance using long-handled tongs. Because of this, the use of shielding during removal from the reactor to a storage shield (a 10-second job) was considered unnecessary. The actual radioactivity at that distance, however, was greater than 100 R/hr. During the removal, the radiation instrument of the health physics monitor went off-scale (showing greater than 40 R/hr) so the operator ran. The target was finally put into a storage shield by use of the hoist and improvised handling methods. One whole side of the reactor building had to be kept evacuated of personnel during this procedure.

This incident could have been prevented by better liaison between the people who prepared the target and the people who were responsible for its irradiation. Calculation of shielding needs should have been made before the irradiation was started and should have been checked by the person who prepared the target as well as by the Reactor Operations supervision.

2. During a series of measurements to determine the path and dilution rate of radioactive gases emerging from the Graphite Reactor stack, a tank made of a long section of thick-wall aluminum pipe was put into one of the 4-inch square experiment holes. It had externally attached piping for filling the pipe to a high pressure with argon gas which was to be made radioactive. The radioactive gas was then discharged, as a batch, through the external piping to the reactor exhaust duct. At saturation, the total radioactivity contained in the tank was approximately 200 curies. During one of the irradiations, the external piping developed a small leak into the reactor building. In an effort to stop the leak by reducing the pressure in the tank, the discharge valve was opened. A rubber hose, in series with the discharge line, was blown off due to the pressure change in the line. This allowed the full 200 curies of argon-41 to be discharged into the reactor building. The building, of course, had to be evacuated of personnel for more than an hour.

The gas dissipated over the entire plant area, raising the radiation level considerably. The nature of the gas prevented it being absorbed into the body so the effect was the same as being in a radiation field only. No one received what could be considered a high exposure to radiation, but, if the gas involved had been mixed fission product gases, the situation could have been much more serious.

Proper design of the equipment with consideration given to the possible pressures to which all parts of the equipment might be subjected could have prevented the incident. The original small leak which triggered the incident could have been no problem if double containment of the external parts had been provided. This double containment could have been accomplished by having all valves and external high-pressure components enclosed in a box which had a vent to the off-gas system.

3. During the early development of aqueous homogeneous reactor fuels, small capsules of uranyl sulfate solution were being irradiated from time to time in a vertical hole. These capsules were maintained at about 250°C and 2000 psi. The pressure was monitored by a pressure transducer connected to the capsule by a long stainless steel capillary tube. These tubes were unprotected and unenclosed between the transducer and the entrance to the vertical experiment hole.

One of the capillary tubes burst once and released a sufficient amount of gaseous fission products to require evacuation of personnel from the building. Even though the number of curies involved was much less than for the argon incident, a greater health hazard existed. Surfaces of equipment near where the burst occurred were sufficiently contaminated with solid daughter products of the fission gases to require decontamination. Again no high exposure of personnel to the radiation occurred.

Further occurrences of this type were prevented by enclosing the external experiment equipment, along with the opening of the experiment hole, in a small room which was vented to the off-gas system. A further hazard was the possible injection of fission products through the skin of any person who might have been handling the capillary tube when it burst. This, fortunately, never occurred. To prevent any possibility of this happening, the capillaries were enclosed in a tough plastic envelope.

4. A capsule containing unclad, dry uranium oxide and having a vent line connected to it was irradiated in a vertical experiment hole. At the termination of the test, the capsule was pulled into a lead shield and the vent tube cut off. The shield was left sitting upon the top of the reactor while other shutdown work was being done. The vent tube had not been well crimped by the cutting tool so fission product gases still being released from the uranium oxide seeped out and

and raised the radioactivity of the building air sufficiently to require the evacuation of personnel. Health Physics personnel and the research man to whom the capsule belonged re-entered the building wearing gas masks and succeeded in sealing the capsule.

Since this incident, careful crimping of any vent lines from any container of irradiated uranium is required before cutting the tube. Such crimping is generally insured by using clamps which remain on the tube during any subsequent handling outside a hood. It is also forbidden to expose unclad, freshly-irradiated uranium to the building atmosphere.

5. A water loop was being installed in a vertical experiment hole. This loop was made of stainless steel tubing about 3/4-inch in diameter and would contain small fuel elements made of enriched uranium oxide clad with stainless steel. All equipment and shields were built at another national laboratory and sent to ORNL for use. The method of removing specimens was to withdraw the in-reactor portion of the loop into a portable lead shield which contained a large hydraulically operated tubing cutter to cut the tube into short enough lengths for storage in the shield. The fuel specimen would be in the last section to enter the shield. Since this removal technique was complex, the experimenter was requested to perform a test run using only a length of stainless steel pipe irradiated in the facility for one week but containing no fissionable material. When this pipe was removed, the withdrawal and cutting mechanisms worked well but the radiation

through the portable shield was 10 R/hr at about three feet from the outside shield surface. The shield containing the irradiated stainless steel had to be lifted from the top of the reactor and loaded on a transfer cart at ground level, using the building hoist. In order to avoid exposure to personnel much greater than permissible, several people were used during the withdrawal operation, dividing the exposure time. The shield then had to be carted to the canal hatch where it was attached to another hoist to hang just over the canal water surface. The stainless steel was then allowed to fall to the bottom of the canal by opening a release door in the bottom of the shield. Although no one person received a very great radiation exposure, a great deal of disturbance was created by the event and several people received a low but still objectionable radiation exposure. Later examination of the portable shield revealed large voids inside the lead walls caused by improper manufacturing methods.

This event could have been avoided by checking the shielding with a low-intensity gamma source. It was fortunate, however, that the test run had been required; otherwise, the radiation exposure of personnel would have been greater.

6. A 3-3/4-inch-square by 12-inch-long aluminum can loaded with slabs of antimony spaced apart within the can to minimize self-shielding was put into a 4-inch-square horizontal experiment hole to produce more than 200 curies of Sb-124 (60-day half-life). One end of the

box was equipped with a threaded funnel for attaching a pull rod to pull the assembly into a portable lead shield after the irradiation.

Careful calculations had been made to insure that the shield was sufficiently thick for all radioactivities. When the irradiation was completed, the pull rod was attached and the can pulled toward the shield through an unshielded bridge trough. When the can reached the entrance to the trough, the threaded funnel broke off the can with the end of the can at the reactor shield opening. Attempts to push the can back into the reactor by use of the pull rod were unsuccessful since the back of the can had just passed a stepped enlargement of the experiment hole one foot from the outer end.

Pushing the can into the shield from the opposite end of the experiment hole was impossible because the bridge trough had a stepped depression in the bottom to allow a guide block, used with the pull rod, to fall from the rod and prevent its entering the shield. The end of the can would have snagged on the edge of this depression. The trough could not be removed and the shield pushed up to the hole opening to allow the can to be pushed into it because of the high radiation level emerging from the hole. The problem was solved by having one man quickly pull the shield support and shield backward sufficiently to allow the trough to be removed by working from the side of the hole. (The shield support platform was on a small hand-operated lift truck.) With the trough out of the way, a man

standing to one side of the hole opening was able to raise the can over the obstructing step and push it a short distance into the reactor by use of a rod bent into the shape of an "L". A straight rod was used to push the can back to the center of the hole so that the shield plugs could be re-inserted. Due to the radiation exposure of the personnel involved and the lost time, the final removal had to be postponed for a week. At that time the can was pushed into the shield from the opposite end of the hole. Special equipment also had to be built to allow the shield to be positioned against the opening of the hole.

Close inspection of the fabrication methods used in making the can could have averted this incident. The cause of the trouble was that the welds had been ground smooth and too much of the weld metal had been ground away leaving only a very thin foil of metal holding the end of the can.

7. During a series of tests to find the types of lubricating oils which are least damaged by radiation, approximately thirty specimens of oil were sealed in quartz ampoules and put into the standard 7/8-inch diameter by 3-inch long aluminum cans for irradiation in the "stringer" holes. (The term "stringer" is used to describe a series of 3 3/4-inch square by 4-foot long graphite trays connected end-to-end.) Before the desired irradiation period (4 weeks) was completed, the trays were pulled into shields to remove specimens other than the oil and it was discovered that several of the quartz ampoules had burst with such force that the tops had been blown off the aluminum cans. Some of

these caps became wedged between the trays and the sides of the hole, making removal of the tray difficult. All the oil specimens were removed to a storage shield and the aluminum caps and quartz shards cleaned out of the hole. When the research personnel attempted to open the intact ampoules in their laboratory, some of them exploded violently. No one was hurt, but if any of the ampoules had exploded during transfer from the graphite trays to the storage shield a large area of the building might have been contaminated.

The high pressure in the ampoules was caused by decomposition of the oils by radiation. The gases were hydrogen, methane and other volatile, low-molecular-weight compounds of carbon and hydrogen. The decomposition process probably does not reach any sort of equilibrium at less than several thousand pounds per square inch of pressure. For this reason, any sealed compartment containing organic compounds or water is apt to burst under the influence of radiation. (Certain catalysts can, under certain conditions, cause recombination of the hydrogen and oxygen resulting from irradiating water.) Subsequent irradiations of oil have been made in vented quartz ampoules put into vented aluminum cans.

8. A measurement with a neutron beam was to be made of a property of a radioactive material. In order to provide shielding for the radioactive material during the measurement, the research group had a lead wall erected between it and the location of the instruments where personnel had to stay. The floor upon which the wall was built was

made of wood with a calculated load limit of 400 pounds per square foot. During the assembly of the wall, the floor supports began to break and additional support columns had to be placed beneath the floor. The allowable floor loading had been far exceeded before the wall was even completed.

This near-serious incident could have been prevented had an engineering study been made of the situation and ample additional floor supports provided before the wall erection was started. Since this occurred, the floor involved has been replaced with one made of heavily-reinforced concrete with a load limit of 1000 pounds per square foot, but still the floor loading must be carefully watched.

9. A piece of experiment equipment was put into one end of a 4-inch square hole which already contained an experiment inserted from the other end and occupying one-half of the hole. The second experiment was pushed too far into the hole and displaced the other equipment a small distance. The first experiment was of such a nature that the data became unreliable after the disturbance.

A careful check of the space available for the second experiment would have avoided this occurrence. It is also necessary to insure that any experiment equipment does not exceed other dimensions of any experiment facility and that the external working room required does not encroach upon the space assigned to other experiments or reserved for other reasons.

10. An experiment to be performed in a 4-inch square horizontal hole required that an aluminum liner be put into the hole for the duration of the experiment. The research group performing the experiment was asked to use 2-S aluminum for the liner so that a heavy shield would not be required for its removal. The research group requested the Mechanical Department to make the liner of 2-S Aluminum. The liner was to be made of 3 3/4-inch O.D. pipe which was not in stock but had to be specially ordered. Not realizing the importance of the 2-S aluminum, the Purchasing Department, without consulting the research group, accepted 3-S aluminum as a substitute since 2-S was not immediately available. The research group assumed that the finished liner was made of 2-S aluminum and put it into the experiment hole. After the experiment was completed, the liner was partially removed and found to be more than 1000 times as radioactive as expected and could not be disposed of as planned. A small sample of the aluminum was cut from the outer end and by activation analysis was found to be 3-S which contains about 1% manganese having a 13 barn neutron activation cross section and a resulting half-life of 2.6 hours. Removal of the liner was accomplished by cutting off as much as could be safely handled unshielded from the outer end each week. This allowed a new portion (about 3 feet) of the tube to remain in that portion of the experiment facility within the reactor shield. (Only 3 feet could be accommodated since the other 4 feet were required for shielding the hole opening.) This process required five weeks.

This inconvenience and loss of time could have been avoided only by careful checking of materials and requiring that an analysis of the material be furnished. It is not possible to guarantee the quality of any material or workmanship simply by listing specifications. Checks, tests, and analyses must be made and approved by a responsible person who understands the requirements and the reasons for them.

The foregoing are specific examples which illustrate some of the things which must be considered in a review of an experiment. There are other examples which have occurred in the performance of several experiments:

1. Several small explosions have occurred in apparatuses using liquid nitrogen within the reactor. These did not damage the reactor due to its massiveness, but had they occurred in a more fragile reactor the consequences could have been serious. The mechanism of the explosions which occur in liquid nitrogen systems in radiation are not well understood so the usage of such systems must be avoided if possible.
2. Water leaks into the reactor have happened on several occasions from water-cooled experiments. During the time the moderator is wet, a loss of reactivity exists; and, if the water carries a neutron-absorbing material in solution, the damage may be permanent. Close attention must be paid to both the specifications and workmanship of water line installations on such experiments.

3. The handling of any material having a high neutron absorption cross section must be carefully controlled around the graphite reactor due to the in-leakage of air at any opening through the shield. The materials of particular concern are those which are normally in particulate or liquid form. Boric acid, lithium hydroxide, and mercury are most troublesome since the first two are commonly used in the building of neutron shields and mercury is used in manometers, electrical switches, and diffusion vacuum pumps. When either boric acid or lithium hydroxide is used, mixed with paraffin, to make neutron shields, the mixture must be enclosed in wood or metal to prevent fragments from becoming airborne and getting into the reactor. Great care must be exercised in preventing any spills of mercury particularly upon top of the reactor where it might get into one of the vertical holes. Any mercury getting into the graphite is far less a hazard to it than mercury in the LITR or ORR since the only harm will be in reactivity loss which will probably be recovered as the mercury vaporizes. This might require a long time, however, so any such occurrence must not be risked.
4. There are other episodes which are common to all three reactors and will be discussed under a group heading.

Incidents at the LITR

1. An experiment using one of the horizontal beam holes required a one-inch beam of neutrons from the reactor. Using the best data available, a minimum-sized beam catcher and side shield for the experiment equipment was built to protect personnel from neutrons and gamma radiation. The minimum thickness shielding was chosen because of space limitations. When the beam collimator and other equipment were installed, a slow reactor startup was done stepwise with checks of the radiation leakage from the shielding at each power level. Before full power was attained, the radiation leakage proved to be excessive and additional shielding had to be provided plus roping off of the area to limit personnel access.

Frequently there are quantities which cannot be adequately calculated and must be ascertained after the installation of the experiment generally by extrapolating from measurements made at low power levels. These quantities generally are temperatures, coolant flow rates, and shielding thickness is required. A certain degree of risk is taken by the experimenter in depending upon this type of measurements, however since it might be necessary to remove the experiment equipment in order to operate the reactor at full power. It is generally best to require over-design of all parts and especially of coolant velocities and capacities.

2. Some aluminum-clad natural uranium fuel slugs of the type used in the Graphite Reactor were loaded end-to-end into an aluminum pipe pierced with holes along the sides to provide paths for water flow as coolant. This assembly was loaded into the LITR in a hollow reflector piece. Shortly after startup of the reactor the water pipes from the reactor became excessively radioactive. It was found that the aluminum cladding on the uranium slugs had ruptured due to insufficient cooling. During the removal of the slugs and transfer in a lead shield from the top of the LITR to the OGR canal, water containing fission products dripped from the transfer shield upon the roadway. Chunks of pavement had to be removed from the road in order to dispose of the contamination.

There were two major faults involved in this incident. The first was that an assumption was made that the exposure of the uranium surface to a large quantity of water would take care of the cooling. Flow measurements were not made nor were sufficient calculations made to assure that the water velocity past the uranium would be sufficient to prevent bulk boiling and water expulsion from the annulus around the uranium with the subsequent failure of the aluminum cladding. The other fault was in not foreseeing the possibility of contamination spread from the transfer shield which had an open bottom drain.

3. A liquid fuel loop was designed and installed in one of the horizontal beam holes. The circulating pump for this loop was located outside the reactor shield within a lead shield whose thickness was carefully calculated to be more than adequate for the gamma radiation which would come from the circulating fuel. After startup of the reactor was begun in stepwise fashion, it was found that a large quantity of fast neutrons were leaking from the shielding around the pump--- the delayed neutrons had been overlooked in the shielding calculations. In order to allow the reactor to be operated at full power, additional paraffin and concrete shielding had to be stacked around the pump shield. The additional shielding thickness averaged about two feet. The delay in bringing the reactor to full power was about 16 hours.
4. A stainless steel capsule containing a uranyl-sulfate solution enriched in U^{235} was being irradiated within a double-walled aluminum tube located in a vertical hole. To cool the capsule, a stream of air was being passed over it and exhausted to the off-gas system through a hose which lay on the floor between the top of the reactor and the outside wall of the room where the off-gas connection is located. During the irradiation, the electrolytic gases which were produced by the irradiation of the water in the solution became ignited and exploded causing the capsule to burst. The pressure surge developed by the explosion broke the hose to the off-gas system loose at the place where it connected to the aluminum tube in the reactor and allowed fission products to be

blown out into the room. The pressure surge within the capsule caused the reactor to be shut down by way of the safety instrumentation on the experiment, and the release of the fission products into the atmosphere of the room caused the constant air monitor and the gamma monitron located there to sound alarm bells. When the reactor supervisor went to the top room of the reactor to check the situation he found several craftsmen within the room still working in spite of the alarm bells ringing on the radiation monitors. These men were contaminated with fission products but, fortunately, had not ingested dangerous quantities because the fission product gases had quickly been dispersed by wind blowing through open windows in the room.

The possibility of explosion of the gases within the capsule had been foreseen since pressure surges due to this cause had been observed before, but actual rupture of the capsule had not been expected to occur. Later examination of the capsule revealed that a jet of flame had erupted from the upper end and melted a portion of the stainless steel capillary tube used as the pressure transmitter to the external monitoring device. Had this flame been directed toward the aluminum tube, it would likely have caused a hole to have melted through it allowing water from the reactor to enter the tube and possibly wash large quantities of contamination out through the top of the tube onto the floor of the room. Subsequent capsules were

irradiated within a steel explosion shield built into the aluminum access tube. More reliable hose connections to the off-gas were also installed.

With respect to the personnel contaminated by the fission gases, some degree of contamination would have been experienced by them due to the type of incident which occurred; however, they should have immediately left the premises and reported to the nearest health physics office or to the reactor operator who would have obtained health physics aid for them. Although a sufficient number of radiation alarm signals sounded, the craftsman had not been instructed as to the meaning and purpose of the alarms so they ignored them. Alarm systems are of no benefit if personnel are not informed about what to do if the alarms are activated.

5. A molten salt fuel loop was being operated in a vertical hole. The coolant was pressurized air which made one pass through the apparatus and was exhausted to the off-gas system. One of the safety arrangements built into the coolant system and instrumentation was that, if an excessively high temperature were experienced, the reactor would be shut down and a large increase in the coolant flow would be initiated. The temperature monitors were fail-safe so that opening of a thermocouple would cause the recorder to drive up scale and initiate a reactor shutdown and the increase in the coolant flow. During operation a fission gas leak had developed through a glass seal around the thermocouples where they penetrated the fuel region. This gas was being swept into the off-gas system by the coolant and was not hazardous.

Then either a loss of a thermocouple or an actual high temperature occurred and initiated a reactor scram and the coolant flow increase. The pressure surge in the system produced by the flow increase caused a gasket on a thermocouple and heater-lead junction box, through which the off-gas passed, to be blown loose allowing fission product gases to be discharged into the atmosphere. The area in and around the LITR building had to be evacuated of personnel until the rate of gas release diminished due to solidification of the molten salt in the loop. More than a day of reactor operating time was lost.

There were two faults which led to the occurrence of this incident. One was the use of the glass thermocouple seal which was not reliable. It was known that the seal was likely to fail and it was assumed that the fission products would be safely handled by the off-gas system. This is why operation of the loop was continued after the seal leak occurred. The major fault, however, was in not testing the installed coolant piping at a pressure in excess of the maximum pressure to be encountered during operation of the loop.

6. A capsule containing molten salt fuel was being irradiated in the reflector within a double-walled aluminum tube in a vertical facility. The temperature of the capsule was monitored by thermocouples and their readings were being recorded on a strip chart recorder. Relays in the recorder would initiate a signal to sound an alarm and cause a reactor shutdown should the temperature become excessively high. The capsule was cooled by an air stream which exhausted to the off-gas system.

Loss of temperature monitoring was a condition which required a reactor shutdown and removal of the capsule. One day a sudden elevation of the radioactivity in the top room occurred and caused the monitron to alarm. The source of radioactivity was traced to the exhaust line from the molten-salt capsule coolant system. Upon checking with the research group in charge of the experiment, it was found that they had noticed earlier that the temperature of the capsule had become erratic so they turned off the power to their instruments and were going about their other work without any concern as to the consequences. In addition to their failure to notify the reactor supervisor of the temperature behavior of the capsule so a shutdown and removal could be arranged, they had voided the required safeguards by turning off the instruments so that a safety shutdown could not be initiated by a high temperature.

The cause of this incident was primarily unreliability of the personnel involved. In most subsequent experiments where turning off the power to any instrument could remove a safeguard from service, it is considered best not to trust the personnel but to connect the power supply to the instruments through an alarm or even a reactor shutdown relay to guarantee that it is never turned off without causing immediate safeguard response.

7. A research man was given approval to irradiate a small quantity (about 30 mg) of U-235 in the form of U_3O_8 in one of the pneumatic tubes for 1 minute. He brought the material already prepared in a pneumatic tube capsule after day-shift working hours so that it was not handled in the routine manner by the personnel who normally checked and routed the capsules. When he informed the reactor supervisor that he had already obtained approvals, the capsule was inserted for 3.5 minutes as requested by the research man at the time of the insertion. When discharge was attempted, all the monitrons and constant air monitors in the LITR area sounded alarms. The reactor was shut down and personnel evacuated from the area. Further attempts to discharge the capsule failed. A check with the research man revealed that he not only had increased the irradiation time beyond the approved period of one minute but had increased the target weight to 1 gram. It was obvious that the capsule had ruptured, probably due to melting. In order to restart the reactor as soon as possible, water lines were connected to the pneumatic tube to provide water cooling to prevent further damage until the pneumatic tube could be replaced. This water was discharged to the reactor cooling system through the demineralizer to remove fission products. When the pneumatic tube was later removed, it was found that a part of the aluminum tube, as well as the capsule, had melted. The new pneumatic tube installed was made of stainless steel.

Probably several people were at fault in this incident. The primary fault, of course, was that of the research man who violated the approval obtained from Operations technical personnel. A second fault was that of the reactor supervisor who accepted for irradiation a target which had not been routed and checked by the proper personnel. Strict rules must be made for obtaining permission to irradiate any material in a reactor, and must be rigidly enforced. The permission must be granted only a person or persons sufficiently trained to recognize any hazards which might be involved and to evaluate the adequacy of any safeguards to be employed. When any steps in the proper handling of a target have been by-passed, the person who is authorized to make insertions of materials into an irradiation facility should be instructed to refuse to make the irradiation.

8. A capsule containing a U-235 compound had been irradiated in a vertical hole and was to be removed. The method of removal was to place a lead shield with top and bottom opening over the hole and then pull the capsule up into the shield by use of a wire attached to the capsule. The bottom of the shield was equipped with a shutter to close after the capsule was inside and the hole in the top through which the pull wire extended could be plugged after the wire was cut off. As the capsule was being pulled into the shield, it was pulled too far and came out the top to fall upon the floor. It had to be

picked up with long-handled tongs and put into the shield. Although no dangerous personnel radiation exposure occurred, a higher exposure did result for the research man than is normally permitted.

As great an effort as possible should be expended to make equipment foolproof. In this case, if the opening through the top of the shield had been too small to permit passage of the capsule but large enough for the pull wire the incident could not have happened. Sometimes it is necessary to use such a shield to remove a tube which is of the same diameter over its full length and is radioactive only over the lower two feet of length. When this must be done, the tube should be marked before it is put into the reactor so that withdrawal can be stopped when the desired section is within the shield.

9. An aluminum capsule weighing about 10 grams and containing a material of low absorption cross section was suspended in a vertical hole for irradiation. Instructions had been left with reactor operations personnel to pull the capsule up out of the core region after a certain period of irradiation to allow the radioactivity of the aluminum to decay before the research man came back to completely remove the capsule from the hole. If this had been done, the radioactivity would have been sufficiently low to allow handling of the capsule unshielded. The instructions were overlooked by Operations, however, and when the research man came to claim the capsule he failed to check

with Operations to be sure that it had been elevated from the core to allow decay. He did, however, have a health physics surveyor accompany him to check the radioactivity of the capsule. Since he expected the radioactivity of the capsule to have mostly decayed, he pulled it completely from the hole. The room radiation monitor sounded an alarm and the reading of the radiation survey instrument carried by the health physicist went off scale. The research man and health physicist immediately left the vicinity. A calculation indicated that the radiation level was about 100 R/hr at 10 feet from the capsule immediately after it was removed from the core. Due to the quick action of the research man and health physicist in leaving the vicinity, they did not receive an over-permissible exposure, but the radiation was sufficiently high in the nearby BSF building to cause the radiation safety instruments in that building to shut down the BSF reactor. Since the predominant amount of the radiation was due to Al-28 which has a half-life of 2.3 minute, the capsule could be handled with tongs after little more than 0.5 hour decay.

The occurrence of this incident was caused by three consecutive instances of negligence on the part of the responsible personnel. First, the instructions to Operations to elevate the capsule were overlooked; second, the research man failed to verify that the capsule had been elevated; and third, the research man should have withdrawn the capsule slowly enough that the excessively high radiation from the

capsule could have been detected before it was completely out of the tube and could have been re-inserted part way to allow decay. When it is necessary to withdraw any material on a wire or rod, or within a tube, any particular distance from within a reactor, it is always best to have a marker on the wire, rod, or tube so that it is obvious that the withdrawal has been made and for the correct distance. It is also very important that, in the performance of any procedure which consists of a sequence of necessary jobs, that a guarantee that all preceding jobs have been successfully completed before the next job is started.

In addition to these specific cases, a number of incidents common to experiments in all three reactors have occurred from time to time and will be discussed under a general heading.

Incidents at the ORR

At the time of this writing, the ORR has been operating with experiments installed for less than a year. Although some minor incidents have occurred, the reviews of the experiments done on the basis of the experience gained from experiments operated in the OGR and the LITR has done much to minimize the possibility of serious incidents at the ORR. Some of these minor incidents which have occurred are:

1. The gaseous radioactivity evolving from the reactor coolant water increased by more than a factor of two over the normal for preceding operation. This amount of gaseous radioactivity was not enough to warrant a lengthy search for the source which could have been a faulty fuel element or a leaking target capsule. Later, when a stainless steel capsule containing natural uranium was removed from the reactor and stored in the pool, the gaseous radioactivity evolving from the pool increased considerably indicating that the capsule was the source of the gas. A careful check of the history of the capsule revealed that the capsule design, material of construction and the leak checks used were questionable. Upon this basis, other capsules fabricated in the same way were discarded.

It is not always possible to safely accept the statement of any person that any equipment or fabricated item is reliable unless proof of the completion of well-accepted testing procedures is furnished. Due to the failure of the capsule in the ORR and the subsequent rejection of similar capsules (some containing enriched uranium), more rigid inspection procedures have been devised for this type of target container.

2. In the hydraulically operated irradiation tubes, target capsules are driven into and out of the reactor by use of reactor pool water. This water is taken from the pool and discharged back to the pool at the loading station and must, therefore, be kept free of dissolved radioactivities and radioactive gases. A research man wished to

irradiate elemental iodine in the facility so a series of tests were made with small empty polyethylene containers to determine how much irradiation time they would withstand. It was found that one-half hour could be tolerated without causing the capsules to become too brittle. Within a very few minutes after the capsule containing iodine was inserted, the gaseous radioactivity from the pool increased. The capsule was discharged as soon as possible and isolated but not before four people had breathed enough radioiodine to increase the count from their thyroid glands a measureable amount above background. This was I-128 with a half-life of only 25 minutes so did not constitute a health hazard in the personnel affected because of the low amount ingested. It could have been more serious if the event had occurred during a time when the building contained more personnel or if any delay in the discharge of the capsule had occurred. Later examination of the capsule showed that it had ruptured from internal pressure. Since polyethylene is a poor heat conductor, nuclear heating elevated the temperature of the iodine sufficiently to increase its vapor pressure sufficiently to cause rupture although the capsule was adequately cooled with water externally.

The pretesting done by the research man was incomplete; he did not test the capsule under all the conditions of the actual irradiation. All pre-tests must be checked to establish their applicability to the actual situation which will exist.

3. A pressurized-air-cooled experiment was put into a vertical facility in the reflector. The piping was carefully checked for leaks and all flanges were made to be continuously leak checked. When the reactor was started, the air radioactivity in the building became objectionably high and the experiment had to be removed. Examination revealed that a glass insulating seal around some electrical leads had been cracked, allowing radioactive gas to pass from the pressurized region to the electrical junction box from which it was leaking to the atmosphere.

Since glass insulating seals for electrical wires have never proved reliable, the junction box should have had a sweep of air drawn through it to the off-gas system as a safeguard against any gas leakage through the seal.

4. A water-cooled irradiation of a material was to be made in a vertical facility in the reflector. The coolant was to be circulated by a pump which received water from the supply to the large beam holes and forced it through the in-reactor section of the irradiation assembly then out through a tank in the reactor pool where the velocity was slowed to allow decay of nitrogen-16. From the decay tank the water passed through unshielded pipes to the discharge line from the large beam holes. When the assembly was put into the reactor and the reactor operated, the water discharge piping became excessively radioactive so that the assembly had to be removed from the reactor. It was found that a part

of the piping system had been incorrectly installed so that the coolant entered the assembly through the decay tank and was being discharged through what was supposed to be the inlet line. The high radioactivity was due to the nitrogen-16 which had not had time to decay before the water reached the unshielded portion of the piping.

It cannot be assumed that the installation work will be acceptable and done correctly regardless of how carefully planned an experiment may be. The as-built equipment must be checked for performance after installation. In this case, checks of water flow were made, but no checks were made to determine its exact path.

PROBLEMS COMMON TO THE OGR, LITR AND ORR

A number of events have occurred with sufficient frequency at the OGR and the LITR that they can be expected to be repeated both there and at the ORR unless careful attention is used to prevent them. Some of these have bordered upon being extremely serious and some are little more than expensive nuisances. Specific examples of the events will not be described here but statements of the problems will be given with some attempt made as to the methods of preventing them.

1. Dependability of Instruments and Circuits -

It is necessary that the experiments which might develop some hazard due to a component failure should, by way of its instrumentation, be connected to the reactor control system to either reduce the reactor power or shut it down if such action can prevent or minimize a threat to the safety of personnel, the reactor or expensive equipment. From the standpoint of money and time, it is necessary that the experiment instrumentation not send false signals which shut down the reactor. On the other hand, it is absolutely necessary that the instrumentation not fail to send signals for reactor shutdown if a hazardous condition actually exists. This requires the most dependable indicators, sensing elements, relays, and electrical circuits that are available.

The years of experience gathered with the use of various types of instrumentation at the OGR and LITR have done much to aid in setting up standards for types of circuits and components. Since fail-safe instruments have always been used where a demand for a reactor shutdown or

power reduction is required, instrumentation failures have predominantly caused unnecessary shutdowns rather than failures to produce shutdowns. The principal effort, then, has been to reduce the number of unnecessary shutdowns without the risk of having needs for shutdowns with a failure to produce them. This means a continuation of the philosophy of one out of two signals producing a shutdown for any abnormal condition but using the best, time-tested components and circuits. This is opposed to the philosophy of requiring the coincidence of two signals out of three to produce a shutdown. Since the consequences of not having a shutdown when required are usually much more serious than those caused by an unnecessary shutdown, the one-out-of-two philosophy is considered to be the safest. The use of the developed standards has reduced the occurrence of unnecessary shutdowns to such an extent that they are no longer a major problem. All instrumentation and its installation must, however, be checked to insure that the standards are met.

2. Use of Regulated Voltage Supplies -

In some locations, electrical circuits to be used only for sensitive instruments are supplied. To guarantee constant voltage with no high-frequency noise, the usage of these circuits must be carefully controlled. It is also necessary to ascertain, before installation, that the intended use of these circuits by any experiment will not overload them.

3. Use of Normal Utilities -

As in the case of regulated voltage supplies, the usage of any of the utilities (water, compressed air, steam, electricity and waste drains) must not over load these systems. Since the usage rate varies greatly

with the number of experiments being operated simultaneously, a close watch must be maintained to insure adequate utility supply. This can frequently be done by limiting the number of experiments using them.

But in some cases, and particularly where long-term experiments are to be installed, additional utilities must be provided. These decisions must, of course, be made during the planning stages of the experiments.

4. Off-Gas Usages and Limitations -

The off-gas systems for the three reactors discharge to the atmosphere through stacks, so there are upper limits to the gaseous radioactivities which can be discharged, and all possible radioactive particles must be retained on filters. The off-gas system at the OGR discharges to the reactor exhaust system and uses the reactor exhaust-air filters. The LITR off-gas discharges to the OGR suction fans on the down-stream side of the filters so must have its own filtering system. At the ORR the off-gas discharges to a general-purpose stack through a filter located near the stack. Regardless of these filters, however, if there are long lengths of piping between an experiment location and the shielded off-gas line, radioactive particles may be deposited in the piping, requiring that it be shielded or that filters within shields be located near the experiment exhaust.

The amounts of radioactive gases which may be discharged directly to the off-gas systems depend upon the constituents of the gases. Frequently, charcoal traps or other holdup systems such as large decay tanks must be provided to insure that permissible discharge limits are not exceeded. Mixed fission-product gases deposit radioactive, non-gaseous daughter

products on the inner walls of any pipes through which they pass so that the radioactivity of such pipes generally greatly exceeds the radioactivity of the gas volume which they contain. Such exhaust lines require some shielding unless the amount of fission-product gases involved is very low or the pipes are well isolated from personnel.

5. Use of Waste Water Drains -

There are four types of waste water drains in use, and great care must be used to insure that wastes go to the proper drains.

Sewage drains generally cause few troubles due to their locations; however, they must not be used for dumping radioactive wastes.

Process drains are those through which all non-radioactive wastes other than sewage are discharged. Due to the location of these drains at many places throughout the buildings, they are susceptible to having radioactive wastes discharged to them if close control is not practiced. Since this drain system discharges into streams without decay time or processing to remove radioactivities, the consequences of dumping radioactive materials into them could be serious.

Warm drains discharge to retention ponds where decay of radioactivities can occur or concentrations can be reduced by dilution before discharge to streams. The draining of wastes which cannot be radioactive to this system unnecessarily overloads it and must be avoided. Drains from air-conditioners, diffusion pumps, and heat exchangers are the types of equipment most frequently found being erroneously discharged to the warm drains.

Hot drains are generally low volume drains which lead to shielded storage tanks where radioactivities are removed by chemical processing or are concentrated by evaporation and stored indefinitely. Due to the expense of handling these wastes, it is necessary that the volume be kept as low as possible. It is also necessary that highly concentrated radioactive wastes be discharged to this system rather than to the warm drain.

6. Working Space -

One of the most troublesome problems at all three reactors has been the assignment and control of equipment space and working space for experiments. Since the access openings to experiment facilities are close together, the space around them must be carefully apportioned to the users. Floor space around beam hole openings is usually apportioned by allowing the research personnel to use the space between the half-way distances from their facility to the next facility on each side and extending away from the reactor any distance that does not interfere with other necessary work. The assignment of core space in the LTR and ORR ranges from the simple selection of the location for an unmonitored capsule to the selection of a three-dimensional path for a loop. Since several loops are usually in operation, the path for a new one may have to intertwine among those already installed. It has been found necessary, especially for the ORR, to have the routing of loop piping done under the combined direction of the Reactor Operations Department, the research personnel, and the Engineering and

Maintenance Division. It is also necessary that an up-to-date set of dimensioned drawings be maintained to show all the installed and planned loops and their locations relative to each other so that available routing space is always known. Since the instrumentation and other external components of loops are generally located away from the reactor, the routing of piping and wiring for them involves the entire reactor building and must take into consideration all the already-installed reactor and experiment piping and wiring.

The major problems with space assignments have arisen from the assumption, on the part of research personnel or design engineers, that just a little more than the assigned space could be used. Because of this, it is necessary that the Operations Division supervision examine all designs for compatibility with other existing or planned installations.

7. Proper Physical Clearances for Equipment Inserted into Experiment Facilities -

Experiment containers and shielding plugs are made by a variety of crafts. Most of those used in the OGR, LITR, and ORR are fabricated at ORNL; but some are made by outside agencies. Some are precision built and some are roughly constructed depending upon the needs. There must be a sensible set of standards to which the dimensions and workmanship must conform, but these standards must not be so strict that the fabricating of experiment equipment becomes unnecessarily expensive. Precision fitting is necessary only where it is required to prevent

radiation leakage, excessive water flow or vibration; otherwise, large clearances should be allowed between the experiment equipment and the walls of the facility.

The principal troubles encountered have been oversized or slightly elliptical beam hole plugs for the LITR. These have sometimes stuck in the holes and were difficult to remove. An additional trouble has been with beam hole plugs which were not straight. Some misfits have also been encountered in experiments installed in the LITR and ORR lattices. Due to the bends which must be made in most of the access tubes for the lattice positions, it has been found that trial installations to check the fit of the assembly must be made for most of these tubes before the final welding of the seal flanges where the tubes enter the reactor tank. If this is not done, sidewise or rotational pressure from the tubes may cause the surrounding fuel elements or beryllium reflector pieces to be pushed out of alignment so that they cannot be easily removed from the core lattice. It also must be determined that any new access tube can be inserted and removed without interfering with any of those tubes already installed or with fuel handling and reactor servicing.

8. Material Selection -

The selection of materials to be used for the fabrication of, or use in, equipment for performing experiments or tests in the reactors must be based upon many factors which include:

- a. the function of the material in the experiment or test,
- b. the effects of radiation upon the material,
- c. compatibility of the material with surrounding materials or the structural material of the reactor,
- d. the method of disposal after the experiment or test is performed.

The usage of any particular material must, of course, be judged upon its merits for any particular case; however, experience has shown that the avoidance of the use of certain materials and types of materials for some purposes must be stressed and repeated time after time.

- a. Copper or alloys containing copper must not be exposed to the water systems of the LITR or ORR since there are some indications that copper may plate out on aluminum surfaces, even from very small concentrations in the reactor water, and set up galvanic cells which cause pit-type corrosion. Also corrosion of aluminum will result from the galvanic action of nearby pieces of copper or copper alloys.
- b. Elemental mercury must be kept away from both the inside and outside of the aluminum reactor tanks and other parts of the reactors which are made of aluminum. One of the most rapid forms of aluminum corrosion occurs from mercury penetrating the oxide layer on aluminum and preventing the formation of a stable oxide layer. Deep pits will occur within hours with

the rapid formation of aluminum hydroxide just from the moisture in the atmosphere.

- c. Elemental carbon in the form of graphite or amorphous carbon must also be kept away from aluminum surfaces which are to be wetted. Pencil marks must be removed from all aluminum surfaces before they are put into the water cooled reactors or in the ORR pool. The corrosion of aluminum induced by the presence of carbon is not as rapid as for mercury, but can be damaging within a short time--a matter of days.
- d. Organic lubricants can be used in high-intensity radiation only for very short times or if they are continuously changed as in circulating systems with cleanup provisions which remove volatiles and tars produced by the radiation. Also, organics or water must never be irradiated in unvented enclosures except for very short times and then only if provisions are made to prevent rupture of the container or to handle the consequences of a rupture. Not only do the gaseous products caused by irradiating organics or water build up pressure, but they may produce explosive gas mixtures within any container or even in vent pipes if a gas sweep is not used to dissipate them.
- e. Aluminum surfaces rubbed against aluminum or stainless steel surfaces rubbed against stainless steel may cause galling and

sticking of the surfaces. For this reason, aluminum bolts with aluminum nuts or those made of stainless steel cannot always be relied upon to be easily loosened after use. Bearing surfaces and tight-fitting parts which must later be disassembled should not be made of all aluminum or all stainless steel. Aluminum rubbed against stainless steel will not gall, however.

One of the contributing factors in causing some beam hole shield plugs to stick at the LLTR was that they were clad with aluminum and used in beam holes which are lined with aluminum. After stainless steel inner liners were installed in the beam holes, no further trouble with galling of aluminum-clad shield plugs has been encountered.

- f. The use of materials which have high neutron absorption cross-sections should be avoided in so far as possible within the reactors to minimize reactivity losses and induced radioactivities. In the LLTR and the ORR, the induced radioactivities extend over little more than a two-foot length in any experiment facility so are easily contained in a removal or transfer shield of reasonable size. In the OGR, however, the radioactive length of a piece of equipment used in a research facility can be as much as twenty-five feet so that it must be sectioned to be contained within a removal shield of reasonable size or

must be removed a little at a time over a period of weeks or even months by cutting off successive outer portions which have been allowed to decay in the reactor shield.

- g. Materials which form dust by their usage or because of radiation, oxidation, etc., should be avoided, or means must be devised to contain the dust. Instances of contamination of personnel, equipment, and building surfaces have occurred due to dust from such materials as graphite, dry bronze bearings, wire insulation, wood, unclad concrete, iron rust, and plastics.

9. Buoyancy of Irradiation Capsules -

There have been several instances of very radioactive irradiation capsules floating to the top of the LITR tank after irradiation and during the removal procedure. This could have been due to weight loss from the capsule wall by corrosion during irradiation, change of water density in the reactor due to temperature, or expansion of the capsule due to internal pressure. It could also have been that the capsules were buoyant enough to float at the time they were inserted. In either case, the capsules were not sufficiently weighted to be safe. Weight versus water displacement calculations or submersion tests must be made to insure that all such capsules will remain submerged even with some weight loss.

There have also been instances of irradiation capsules being pushed from fuel channels in the OGR then failing to sink through the water in the discharge chute to the canal. These capsules must also be tested for buoyancy.

10. Spills of Radioactive Dust or Liquids -

Many experiments require sampling of liquids, changing of gas and liquid filters, or other operations which can cause spills. All such operations must be carefully reviewed and equipment provided to prevent or contain such spillage. Also the personnel who are to be involved must know exactly what to do if such spills do occur. Health physics personnel must be kept informed of such operations and their locations so that routine or special checks may be made to minimize the spread of contamination if unnoticed spills should occur.

11. Handling and Storage of Radioactive Sources -

Radioactive sources of varying intensities exist or are used around nearly all reactor experiments. Some of these are:

- a. Standard gamma, beta, alpha, or neutron sources used to check the response of instruments,
- b. Irradiated materials either bare or within temporary shields which do not afford sufficient shielding for permanent storage,
- c. Neutron and gamma beams from the reactor,
- d. Pipes which contain radioactive gases or liquids.

Personnel exposures to unnecessary amounts of radiation and difficult working conditions have occurred due to inadequate attention to shielding considerations during the planning stages of experiments and due to inadequate training of personnel.

Some standard sources are very weak and can be handled for long periods of time; these, of course, are of little concern unless they are not

encapsulated and can cause contamination of objects which touch them. Other sources are of sufficient strength to be of concern if handled unshielded at close distances from personnel. The presence of such sources must be known to Operations supervision and to health physics personnel to insure that they are not improperly stored or used. Neutron sources generally contain polonium or radium either of which can cause severe contamination of surroundings if the capsules in which they are sealed should be ruptured. Periodic checks of these sources should be made by health physics surveyors to insure that they are leak-tight.

The adequacy of transport and storage shields must be determined during the planning stages of any experiment, and no experiment should be permitted to be installed in a reactor before a transport shield is available for its removal from the reactor. Such shields should be checked for workability and adequacy of shield thickness before actual use. If any shield containing radioactive material allows a radiation leakage above the maximum permissible level for indefinite storage, warning signs should be affixed to the shield and the area around it should be roped off if it is to be left untended. If such a shield is being transported, warning must be provided to insure that personnel are evacuated from the areas through which it must pass. If such transfers must be done frequently or must be made through areas from which it is inconvenient to evacuate personnel, the transport shields must be designed to adequately attenuate the radiation. This must be ascertained and the shields designed during the planning stages of the experiment.

Neutron and gamma beams from the reactor result from leakage through or around shielding material, or are intentionally allowed to emerge through collimators for experiment purposes. In either case proper shielding must protect personnel. When shield leaks occur, additional temporary shielding must be erected. Beams from collimators must be absorbed by shielding placed as near to the experiment quipment as is feasible. Any region between the "beam catcher" and the experiment apparatus must be blocked in some manner to prevent personnel from entering it.

All pipes, from any experiment, which will contain radioactive material either normally or under abnormal conditions must be shielded or blocked from personnel access. Since it sometimes is quite difficult to build shielding around installed pipes when no provision has been made for supporting the shielding, it is necessary that the shielding be included in the design for the experiment. Frequently it is not possible to determine the minimum adequate shield thickness for some applications accurately before usage. In such cases provision must be made for installing additional shielding after operation begins unless the equipment is intentionally very much over-shielded during the initial installation.

10. Disposal of Equipment -

When any experiment or test is terminated, the equipment must be dismantled and/or removed from the reactor and the experiment facility left in condition to have a succeeding experiment installed. Disposal of the equipment must be arranged for during the planning stages of the experiment.

so that adequate shields are provided for the removal, transfer and storage of all radioactive parts and that the experiment facility is not damaged by the removal of any of the equipment. There must also be an understanding as to who is to be responsible for the disposal of the equipment. It is generally best that the people who have the equipment installed also have it removed. Also, removal must be interpreted as complete removal to some prepared storage location and not just to the nearest vacant floor space. A great deal of trouble has resulted from the accumulation of equipment stored in corners, under stairs, along the walls of aisles, and other such places. It has become necessary for the Operations personnel to rid the buildings of such equipment occasionally by sending it all to be salvaged. Such action is necessary to enforce proper storage procedures.

11. Personnel Competence -

Since a large number of personnel are associated with the performance of experiments and tests in the reactors, varying degrees of competence, reliability, and experience are encountered. Because of this the safety instrumentation prescribed for experiments must be designed for the needs of the least competent, least experienced, and least reliable personnel which means that the instrumentation not only must completely protect personnel, the reactor and the experiment equipment, but must also, as far as is feasible, protect itself from being disarmed by either research or other personnel while the experiment or test is in operation.

It is also necessary that some sort of policing be done by Operations and health physics personnel to insure that no hazardous conditions are allowed to arise from any negligence or deliberate violation of safe operating practices by other personnel. There have been several instances of personnel doing the following types of things:

- a. Turning off a safety recorder if the reading approaches the relay trip point,
- b. Installing jumper wires across safety relays,
- c. Changing resistors to cause a safety recorder to read lower than the actual value,
- d. Intentionally failing to wear pocket meters and film badges while working in radiation so that the exposure would not be known by supervision,
- e. Wearing radioactive clothing home,
- f. Entering known contaminated areas without wearing shoe-covers and disposable clothing,
- g. Pouring wastes into the wrong type of drains,
- h. Drinking non-potable water from process water outlets,
- i. Overloading floors, hoists, etc.,
- j. Leaving unattended some experiments which are supposed to be constantly watched.

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