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CONSIDERATIONS INVOLVED IN THE SAFETY REVIEW* OF EXPERIMENTS TO BE OPERATED IN NUCLEAR REACTORS

C. D. Cagle

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CONSIDERATIONS INVOLVED IN THE SAFETY REVIEW* OF EXPERIMENTS TO BE OPERATED IN NUCLEAR REACTORS

C. D. Cagle

*Except for minor revisions, this is the same report issued by the author as RCN-Int-64-010 at the Reactor Centrum Nederland, Petten, The Netherlands.

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CONSIDERATIONS INVOLVED IN THE SAFETY REVIEW OF EXPERIMENTS TO BE OPERATED IN NUCLEAR REACTORS

C. D. Cagle

ABSTRACT

The reasons for safety and operability reviews of experiments are discussed along with the qualifications of reviewers and the methods of reviewing. Examples of the questions that must be answered in reviewing noninstrumented and instrumented capsules, loops, and beam experiments are included with some comments pertinent to the questions.

1. INTRODUCTION

It has become necessary that all experiments which are to be performed in reactors at well-established research centers pass a safety and operability review. It is of great benefit to experiment designers to be familiar with what the review will involve. It is of further benefit to the reviewers themselves to know exactly what their function is and what the review must accomplish. The author has found that the answers to the following questions are not always known by the groups involved. Why are there experiment reviews? What is a review? By whom is it done? When does it begin? When does it end?

Conceivably, there are two types of experiment review. One is the review to determine if the experiment is worthwhile and if it will accomplish its intended purpose. This type of review should be done by the experimenter and his supervision. The other type is the safety and operability review with which this paper is concerned. An attempt will be made to supply some of the answers to the questions in the above paragraph and to illustrate some review considerations.

1.1. Some Review Difficulties

Many instances have been observed when a better understanding and closer cooperation between experiment designers and reviewers could have averted much waste of money and time. Some of the symptoms of a poor understanding of the necessity and purpose of the safety and operability review of experiments, both by the experimenter and reviewer, are:

1.1.1. Not presenting an experiment design for review until after the fabrication of the equipment.

1.1.2. Not supplying adequate information for an adequate review.

1.1.3. The experimenter requesting a "last-minute" review when there is not adequate time to perform a review or to make desirable revisions of equipment.

1.1.4. The reviewer spending insufficient time and effort in performing the review.

1.1.5. The reviewer intruding into aspects of the experiment which do not concern him.

1.1.6. Inadequate communication between the reviewer and those whose concern it is to implement the decisions of the reviewer.

1.1.7. Inadequate followup by the reviewer to determine if imposed conditions were adequate or justified.

It is hoped that the following discussions may be of some benefit in avoiding some of these difficulties.

1.2. Why There Are Experiment Reviews

Perhaps the best answer to the question, "Why are there experiment reviews?" is that historically they have proved to be necessary. The early experiments and tests performed in low-flux reactors provided ample illustration of what the consequences of experiment failures in the newer higher-flux reactors could be. Already there were personnel overexposures because of open beam holes, materials becoming more radioactive than expected, and failure to supply adequate handling tools and shields. There also were building evacuations because of the release of radioactive gases; and there were numerous instances of contamination from ruptured capsules, spills of radioactive dusts and liquids, and mishandling of radioactive tools and other items.

Although there was concern about these incidents, the consequences were usually more annoying than severely hazardous; and what review work was done was left to the discretion of the reactor operating staff. However, the advent of the high-flux reactors, which could magnify the degree of hazard by a factor of ten to a hundred or more, made it apparent that better guarantees of safety were needed. It was obvious from reviews of

the problems with the experiments in the low-flux reactors, that most or all were due to inadequacies of operating safeguards, containment, handling equipment, and personnel training and concern. In order to insure proper attention to these aspects, formal review committees were established.

Research reactors and their associated equipment represent large investments of money and time. Any contamination incident could, therefore, not only endanger personnel but could also cause losses of expensive equipment and operating time. Even when contamination does not result, certain types of experiment failures could jeopardize the reactor or cause long shutdowns. It is, then, imperative that experiment and test equipment be made as reliable as possible and that all hazards are either eliminated or provisions made for coping with them if any should occur.

From management's viewpoint, a reactor and its associated experiments and tests must provide the maximum amount of accurate test results, and perhaps a product like radioisotopes, per unit time for the minimum cost and should continue to do this for as long as possible. From the experimenter's viewpoint, the reactor should provide him with an opportunity for getting test results and other data as rapidly as possible with the least expensive equipment and the least amount of inconvenience. From the reactor operator's viewpoint, there should be as little disturbance of the operating routine as possible to insure the maximum amount of operating time and also with the least amount of inconvenience. It is the reviewer's task to see that each experiment, test, or irradiation device is designed, built, installed, operated, and disposed of in a manner as consistent as possible with the desires of management, the experimenter, and the reactor operator. The review he conducts is usually called a "safety and operability review" since these aspects are of major concern with respect to continuity of operation of the reactor.

1.3. What a Safety and Operability Review Is

An adequate safety and operability review must consist of a detailed check of the following items by a knowledgeable person (or persons) to see that they conform to the requirements necessary for safety of personnel and the reactor and cannot jeopardize continuity of operation unnecessarily:

1.3.1. The complete equipment layout.

1.3.2. Compatibility of all materials and environments.

1.3.3. Strength of all structural and piping components.

1.3.4. Reliability of all working parts and instrumentation.

1.3.5. Containment provisions.

1.3.6. All critical dimensions.

1.3.7. Fabrication, installation, operation, removal, and disposal procedures.

1.3.8. Handling tools and shields.

1.3.9. Supplies of electrical power, water, gases, etc.

1.3.10. Waste disposal.

1.3.11. Stationary shielding.

1.4. By Whom Safety and Operability Reviews Are Performed

Although formal review committees are established at each research reactor center, reviews are participated in by other personnel as well. It is obvious from the foregoing list of items which must be checked in detail that a committee meeting for a few hours cannot always have time or opportunity to perform the true details of a review. It is rather their task to see that the details of review have been conducted and that the results are acceptable.

At most research reactor installations, both necessity and convenience have required the appointment of one or more specialists whose task it is to assist experimenters in the planning, design, fabrication, installation, operation, and disposal of experiment and testing devices. It is these people, together with the experimenters themselves, who do the major part of the actual reviews. In this type of arrangement each detail is reviewed as rapidly as it is developed so that the finished design is generally acceptable to the review committees. This naturally saves a great deal of time and money during the design and fabrication stage as well as insures that the best attention is given to safety and operability aspects. These specialists who work to assist the experimenters must maintain close contact with the reactor operator and the review committee as well as with the experimenters. For this reason, they are frequently referred to as "operations-research liaison" personnel.

Regardless of the type of position the reviewer occupies, he must have certain qualifications in order to do an effective job:

1.4.1. He must have an extensive knowledge of the following subjects or have associates at his service who have this knowledge:

a. Reactor physics.

b. Properites of materials.

c. Compatibility of materials with one another and with various environments.

d. Behavior and durability of materials during and subsequent to irradiation.

e. Temperature effects on materials.

f. Heat production and dissipation mechanisms in irradiation facilities.

g. Handling of radioactive materials.

h. Biological hazards of various radioactive species.

i. Explosion hazards.

j. Instrumentation and controls systems.

k. Corrosion.

l. Use and limitation of the waste disposal systems for radioactive liquids, gases, and solids.

m. Details of the various irradiation facilities and the related operating procedures.

n. Types and degree of hazards considered both tolerable and intolerable by management.

1.4.2. He must be able to judge objectively and know when he must ask for assistance from others.

1.4.3. He must be experienced in the accumulated history of making irradiations both by study of the available literature and by participation, if possible.

It should not be expected that all research personnel who perform work in reactors or who prepare irradiation targets can become expert in determining the hazards or even the feasibility of performing work or irradiations. This can readily be judged from the required qualifications of reviewers. It is obvious that a great deal of time must be spent in meeting these qualifications and that a few people can, therefore, be more

efficiently used to do the review work for a large number of research people rather than to require everyone to qualify himself so that reviews are unnecessary.

1.5. When a Review Begins and Ends

Although the formal review of an experiment or test may be in the form of a short-term meeting with a group of experienced people who give final approval or rejection, the actual review should begin in the earliest stages of the planning. This was indicated in the foregoing section on who reviews experiments. When this is not done, as is the case sometimes with experiment rigs built at one site to be irradiated at another, the experimenter may find himself in the unhappy situation of having to greatly revise an expensive rig or not be able to use it at all with the consequence, in either case, of losing considerable time and money. Sometimes such questionable rigs may be installed anyway in an attempt to avoid a loss. Frequently this practice will greatly magnify costs because of failures which cause losses of reactor operating time and perhaps undue hazards to personnel.

A review should end only when the experiment or irradiation has been completed and all equipment disposed of. The reviewer must see that the requirements made during the design stage are met during the fabrication. He must also see that operating requirements are met and must then ascertain if such requirements were justified or if more stringent requirements are necessary for future experiments of a similar nature. It has been found that some safeguards may be imposed time after time even though the first rig proved them to be unnecessary. The need of additional safeguards generally is discovered more dramatically so that they get immediate attention.

1.6. Review Decisions

The result of a review is naturally either acceptance or rejection of a total assembly or the portion being reviewed. Acceptance may be conditional--that is, requiring special checks, special handling, etc. Rejection should include the reasons for the rejection and possibly recommendations to make the device acceptable. In making such recommendations, the reviewer may

find himself responsible for the success or failure of the experiment or irradiation.

The reviewer may be in a position of authority where his acceptance or rejection is final, or he may be only in an advisory position. In either position, he will occasionally find himself under persuasive pressure to accept a device which should be rejected.

Some assurance should be had that all conditions of acceptance are relayed to the proper people. It is especially important that facility operators are made aware of any special hazards or handling.

2. REVIEW CONSIDERATIONS

These considerations are presented in the form of the questions a reviewer must ask himself along with some comments that are pertinent to the questions. Of course, the reviewer will not be expected to follow through this entire routine when he reviews each rig or irradiation specimen since, as experience is gained, many of the properties will be obviously acceptable or unacceptable. However, when new situations are encountered, this type of routine will be of considerable assistance in insuring both that no hazard is overlooked and that unreasonable demands are not imposed upon the experimenter.

It is not possible to completely separate the various considerations into independent topics because most of them are interrelated. It will be found that this is essentially an examination of the materials and construction of the assembly from several points of view.

2.1. Radioisotope Capsules and Other Noninstrumented Irradiation Targets

The reviewer of irradiation capsules for radioisotope production and other purposes will encounter a large miscellany of materials, material forms and methods of packaging. In addition to those specimens irradiated for radioisotope production, there will be those irradiated for radiation damage studies, etc., which can be adapted for irradiation in standard or special radioisotope production facilities. This discussion, then, will concern the reviewing of all noninstrumented irradiation targets including those for loops.

2.1.1. The Outer Container (See 2.3.7)

a. Is the material compatible with its intended environment?

The usual encapsulating materials are aluminum and stainless steel. For long-term usage in dry air or inert gases, no special consideration of the surface is usually necessary. For long-term usage in water, however, aluminum surfaces should not be marked with pencil lead (graphite), should not have been in contact with mercury, and should certainly not have foreign materials embedded in them. Perforations may develop due to corrosion in such cases.

Certainly the capsule must be adequate for the normal irradiation temperature and may need to survive a loss-of-coolant incident if a very hazardous material is enclosed.

b. Are the dimensions correct?

A great deal of difficulty has been experienced because of specimens sticking in pneumatic and hydraulic tubes because of being too large in diameter to clear certain restrictions, being too long to move through turns, or being so small that much of the driving air or water leaks past them.

c. Are there any dents, cracks, or deep scratches or other surface imperfections which could cause a containment failure?

d. Is the capsule sturdy enough to withstand the abuse it will receive in normal handling, insertion, and removal procedures? Will special precautions have to be observed to prevent its being damaged?

e. How is the container sealed? Will the seal endure the radiation and other conditions to which it will be subjected?

Containers requiring perfect sealing should be welded closed for most irradiation facilities. In cases where a leak will cause no contamination hazard or other safety problem, the degree of leak-tightness may be left to the discretion of the customer.

Silver solder should be avoided as a sealing material since it will contaminate any surface rubbed against it with long-lived radioactivity after it has been irradiated.

Aluminum solder generally contains a high percentage of cadmium. If this material is used in such a way that it can wear off onto the walls of the irradiation facility, the neutron flux will be reduced.

Lead gaskets may lose their sealing ability when the container is subjected to impact in pneumatic and hydraulic tubes or when there is thermal cycling.

f. If the capsule is to be handled under water for shielding purposes, is it heavy enough to stay submerged?

If the capsule is barely heavy enough to sink prior to irradiation, a slight swelling during irradiation may cause it to float afterwards.

2.1.2. The Target Material

a. Is the material one that the irradiation facility is obviously not intended to accommodate?

Special precautions must be observed for fissionable materials, liquids, gases, and powders. Pneumatic and hydraulic tubes which are not well contained should not be used for large quantities of these materials since a leak may cause widespread contamination. A milligram of some materials may be a "large" quantity.

If available shielding and shielded carriers are not adequate for the radioactivity of the specimen, it should, of course, not be irradiated. If the amount of radioactivity is to be limited by the irradiation time in order for the specimen to be able to be handled in the available shielding, preparations should be made to shut down the reactor if the specimen cannot be removed at the specified time.

b. Is the material one that is well known to the reviewer, and are all its properties well understood? Has the material been irradiated before under similar circumstances?

Water of crystallization may be evolved as water vapor due to an increase in temperature or may be broken down to hydrogen and oxygen by radiation to cause a pressure increase in a capsule as well as an explosive gas mixture.

Most organic materials release gases during irradiation. These gases can become a source of airborne contamination (chlorine from vinyl chloride) or may cause a pressure increase in a capsule. Explosive gas mixtures may also result.

Some materials may exhibit quite unexpected behavior. Rhenium, for instance, undergoes no appreciable corrosion in boiling water; but, during neutron irradiation in contact with water, enough soluble oxide will form on the surface to contaminate the water appreciably. Furthermore, this oxide sublimes at a rather low temperature and easily passes through most "absolute" filters.

c. Is the weight of material actually that stated?

There is on record a case of a pneumatic tube capsule and part of the pneumatic tube itself having been melted because the person who put a fissionable material in a capsule arbitrarily increased the amount far above the amount approved by the reviewer.

There is also on record a case of considerable personnel exposure to radiation resulting from a number of "ounces" being misread as that number of "grams".

d. What degree of containment is required for the material? Is the leaktightness of the container dictated by safety or simply by the needs of the customer?

For safety considerations, powders should be contained to the extent that they cannot sift through any leak that might exist. Radioactive gases and liquids must be contained unless the facility is equipped to dispose of them. (It should be remembered that a leaking gas or liquid container can continue to leak after being removed from the irradiation facility.) Soluble materials irradiated in water-cooled capsules require good containment.

The form of a material can have a considerable influence on the degree of containment required. A uranium-aluminum alloy, or UO_2 powder well dispersed in a solid aluminum matrix, clad with a well-bonded aluminum sheath so there are no gas gaps or other voids will evolve very little fission-product gases if the cladding is

punctured. The same amount of uranium in the form of a salt or oxide contained in a capsule so there is a gas gap will, however, evolve an appreciable amount of fission-product gases during (and after) irradiation if there is a leak in the capsule.

Particular attention should be given to solids which easily sublime, such as sulfur and iodine.

Simple halogen compounds, such as NaCl, will likely evolve very little, if any, radioactive gases during irradiaton; complex compounds, particularly organics, may, however, be expected to evolve some radioactive gases.

2.1.3. Internal Packaging

In many cases, the person preparing the specimen prefers to package the specimen in some chemically clean material which is then put into the containment capsule. This procedure may be necessary to keep powders collected together, to protect the specimen from contact with the outer container wall, to facilitate handling subsequent to irradiation, etc. In addition to the packaging material, other materials may be used to pack the inner package into the containment capsule to prevent rattling or damage due to impact or to separate two or more internal packets. Persons preparing capsules frequently will not consider these materials when listing the materials to be irradiated. The reviewer must be sure that he is made aware of the amounts of all materials in the capsule and also of their arrangement.

a. Is the packaging and packing material compatible with the expected radiation exposure?

   Capsules have been found to contain such things as paper tissues for packing, cork or rubber as stoppers for small vials, wax crayon marking on packets, etc. Although such items may be used for short irradiations in low-flux facilities, they are not at all suitable for long irradiations or for even relatively short irradiations in high-flux facilities.

b. Will the packaging or packing material absorb neutrons to such an extent that the expected flux at the specimen will not be realized?

Vials made of high-boron-content glasses should not be used unless the thermal neutron flux is unimportant.

The neutron depletion caused by stainless steel, tantalum, etc., should be considered when these are used as packaging materials, heat shields, etc.

Although these effects may cause no hazard, it should be known that the customer is aware of the situation and that it is acceptable to him.

c. Will the type and arrangement of the packaging or packing materials cause excessively high temperature of the specimen?

Quartz wool is frequently used as a packing material. If this or a similar material isolates the specimen from the side of the capsule, the subsequent insulating effect may cause the specimen to be subjected to a high temperature when gamma or fission heating is appreciable.

Specimens in quartz ampoules can be expected to be subjected to high temperatures. (Fragile inner containers of this type must never be relied upon as enhancing containment. The reviewer should always assume that they become broken.)

Again, a high temperature of the specimen may not be a hazard. The customer, however, should be made aware of what the effect might be.

d. Will the induced radioactivities in the packing or packaging materials be a hazard or interfere with subsequent handling?

Ordinary glass sometimes gets substituted for quartz wool or vials either accidentally or intentionally. The high sodium content of the glass may cause serious shielding and handling difficulties in such cases.

Unnecessary uses of silver, tantalum, cobalt, bismuth, etc., should be avoided since these produce long-lived radioactivities and increase the burden of waste disposal.

Powdered materials used for packing, or those that crumble easily, can cause serious contamination problems if the customer is not well prepared to handle them.

2.1.4. Heat Production and Dissipation

Any material placed in a radiation field becomes a heat source. The temperature which it attains will depend only on the ease with which the heat can be dissipated. The temperature continues to rise until the rate of heat loss equals the rate of energy absorption from the radiation. The arrangement of the materials in the capsule and the choice of materials to have high or low mass and good or poor thermal conductivity can, therefore, be used to enhance either high or low temperatures. The choice of filling gas for voids or gaps can also play an important role in temperature control. Helium enhances cooling; and a heavier gas, such as air or nitrogen, will reduce heat losses across gas gaps.

a. Is the coolant flow through the irradiation facility adequate for both the heat flux and total heat from the capsule?

It must be remembered that in most pneumatic and hydraulic tubes the coolant flow must be reversed to expel the capsule. If such an interruption of the coolant flow cannot be tolerated, the capsule should either not be irradiated or the reactor must be shut down during the removal procedure. In such cases, it is also wise to provide for an automatic shutdown of the reactor if coolant flow through the facility is accidentally stopped.

Although some amount of boiling of the water in a hydraulic tube may not harm either the capsule or the tube, it may not be acceptable as far as control of the reactor and constant power requirements of other experimenters is concerned.

b. Will the maximum temperature attained by any part of the capsule contents produce a hazard or objectionable condition?

Sublimation of some solids can result in their condensation on the inner walls of the capsule so that the heat loss rate is altered. This generally results in some reduction of the maximum temperature because of gap changes but could, in some cases, cause an increase if heat radiation is the principal method of dissipation.

Overheating of the central region of tightly packed capsules may result in enough expansion to cause the capsule wall to bulge so that removal from the facility becomes difficult or impossible.

When coolant flow past a capsule is through a small annulus, bulging due to gas pressure or material expansion will restrict the flow and worsen the condition.

In the case of specimens of fissionable materials, the temperature will have some bearing on the equilibrium amount of fission-product gases or vapors in gas gaps. Leakage from a high-temperature capsule will likely be a greater hazard than from a low-temperature one.

2.1.5. Reactivity Effects

Reactivity changes in a reactor may be caused by insertion or removal of neutron absorbers and moderators, insertion or removal of fissionable material, and by moderator or reflector displacement. The magnitude of the reactivity change due to a disturbance generally depends upon its proximity to the center of the reactor core and whether it is a widely dispersed phenomenon or is confined to a small volume. The reviewer must insure that the reactivity effects, which may be caused by the specimen being reviewed, in no way jeopardize the safety of the reactor.

a. Has the neutron absorption rate for the assembly been determined? Is the rate greater than that allowable for the facility?

One caution should be observed for high-cross-section materials. The actual neutron absorption rate may be greatly overestimated if calculated on a microscopic basis; i.e., number of atoms multiplied by the absorption cross section per atom. Actually, no specimen can absorb more neutrons than the number which impinge upon it; therefore, the maximum absorption cross section for a specimen is approximately equal to the projected area. As an example, the maximum absorption cross section for a sphere is approximately the area of a great circle of the sphere.

Unless the facility has been calibrated for reactivity effect versus neutron absorption rate, a calibration should be done

before any specimen with a high absorption rate is introduced. This may not be of great importance for those facilities where specimens can only be inserted and removed during reactor shutdown unless some credible accident can expel the specimens.

b. Is the volume of moderator or reflector material which will be displaced by the capsule sufficiently large to cause concern?

As with neutron absorbers, the volume effect requires calibration.

In considering the effect of displacement or replacement of moderator or reflector materials by specimen insertion and removal, the effect of collapse of the capsule should not be overlooked.

c. Is the rate of insertion and removal of the capsule sufficiently slow, and is the movement adequately controlled?

In the case of pneumatic and hydraulic tubes, the speed of insertion and removal of specimens usually cannot be varied very much. In other types of facilities, the speed may be varied sufficiently to allow the insertion and removal of specimens having large reactivity effects. Capsules or other assemblies must be moved into and out of irradiation facilities at speeds which allow the reactor controls to easily compensate the reactivity disturbance. Furthermore, in the case of large absorbers, this speed limit must be guaranteed by some mechanical arrangement rather than be done entirely manually. The mechanical speed-limiting devices must, of course, be just as reliable as those for control rods.

d. Will the capsule (or other assembly) be rigidly held in a fixed position during the irradiation?

Although no actual hazard can result unless a specimen moves an appreciable distance, annoying oscillatory disturbances of the reactor power can result from a specimen being vibrated or oscillated by a coolant flow or other cause. This is particularly true in small reactors where there are steep neutron flux gradients. (Such oscillations or vibrations can also cause holes to be worn through containment walls.)

e. If fissionable material is being irradiated, is the quantity sufficiently large to have an appreciable reactivity effect?

Unless the neutron production rate exceeds the neutron loss rate in the assembly, the reactivity effect on the reactor caused by introducing the specimen will be the same as for a nonfissionable material (negative or positive). Even though the net neutron contribution is positive, displacement of moderator or reflector material may still result in a negative effect.

f. Can a leak in the capsule have an appreciable reactivity effect?

A leak in the container may result in filling of a void in the capsule with moderator or reflector material to cause an increase in reactivity or may allow dispersion of a neutron-absorbing material from the capsule. Great care must be exercised to prevent leaks if soluble or finely powdered forms of materials having high absorption cross section are being irradiated in appreciable amounts. Unless leaks are large or pressure differences are high, a leak will generally produce only a slow change. The seriousness of a leak also depends, of course, on the type of irradiation facility being used, whether hydraulic or pneumatic and whether or not any material which leaks out will be confined in a secondary system or will be released into the reactor.

2.1.6. Radiation Control

Radiation control has been discussed to some extent under other subjects. In order to include all aspects of radiation control under one heading, some repetition of those considerations will be included here.

a. Will the total radioactivity generated in the assembly exceed the limits of the shielding and handling equipment provided?

The known upper limit of radiation intensity established for the facility must be known to the reviewer. Considerable time may be saved in planning and reviewing if such upper limits are clearly defined.

Some pneumatic and hydraulic facilities rely upon time of flight to prevent radiation exposures of personnel, so that some sections of the tubes may be completely unshielded. If there is a possibility that a capsule may stick in an unshielded portion, the radioactivity of capsules should either be low or short-lived to allow servicing to be done within a reasonable time.

Swift manual handling of radioactive specimens as a method of preventing high radiation exposures to personnel can be very disappointing if not thoroughly rehearsed with nonradioactive or slightly-radioactive specimens to insure that adequate equipment and procedures have been provided.

The reviewer should ascertain if the irradiation is to be done in an established facility where well proved techniques will be used or if the irradiation will involve new techniques or an untried facility. Any new or untried procedure or facility may also require a review.

b. What would be the consequences of a leak in the capsule or cladding?

The practice of playing statistical games with consequences which must be prevented at any cost is one that a reviewer must avoid. If the consequences of a leak are intolerable, the irradiation must be rejected. It is usually possible, however, to avoid intolerable consequences by proper choice of a well-contained irradiation facility or by reducing the quantity or changing the form of the material to be irradiated.

Multiple canning of a specimen without monitoring the annuli for leaks is not a guarantee against failure and should never be used as the sole method to prevent an intolerable leakage. In some cases, multiple canning can increase the risk of a leak by increasing the temperature of the specimen so that the inner can fails in such a way as to damage the outer can also.

Attention should be given to reducing the likelihood of a leak occurring only after the consequences of a leak have been reduced to the level of acceptable risk.

When the results of leakage will be serious, the review must extend beyond a simple inspection of the design drawings and written procedures. The actual fabrication, leak testing, and rehearsal of handling should be observed.

It should be remembered that a leaking capsule evolving radioactive gases will likely continue to leak after being removed from the irradiation facility.

A well fabricated container is not always a guarantee that a leak will not occur. Handling abuses, corrosion, and abrasion prior to, during, and following the irradiation must also be considered.

2.1.7. The Irradiation Facility and Associated Equipment

The success or failure of an irradiation depends not only on the capsule (or other assembly) but also on the condition of the irradiation facility and the condition and availability of handling tools and transfer shields.

a. What is the condition of the irradiation facility?

Because of accumulations of debris, presence of dents, etc., capsules may begin to stick in pneumatic and hydraulic tubes so that nonroutine procedures must be used to dislodge them. Obviously, specimens should not be put into such facilities if the irradiation time must be carefully limited to prevent a hazard.

If the reviewer is relying on the leaktightness of a facility to prevent serious consequences in the event of a leak in a capsule, he should ascertain that the facility is actually leaktight.

b. Are the handling tools and transfer shields adequate and in good repair?

These items should be checked before the irradiation is started. If the irradiation time might be shortened due to some failure, all tools and shields must be immediately available and usable.

c. Are storage facilities available for the specimen if it is not to be delivered immediately to the customer?

Storage facilities should provide protection for the specimen from corrosion, handling abuses, and other types of damage. It should also be possible to easily locate the specimen when it must be delivered to the customer.

2.2. Instrumented Capsules and Rigs

Instrumentation is provided on capsules and rigs for at least three different reasons:

a. Experimental data,

b. Environmental control, and

c. Safeguard.

Although it is true, to some extent, that instrumentation used for experimental data and environment control can double as safeguards, the mere presence of instrumentation should not imply that safety is enhanced. Conversely, the loss of some instrumentation during operation does not necessarily mean that safety is jeopardized.

The essential difference in reviewing instrumented capsules and rigs and those which are not instrumented is a consideration of whether or not the instrumentation is necessary for safety and, if so, whether or not it is reliable and ample. To better ascertain the need of safeguard instrumentation, the reviewer should first review the capsule or rig as though it were not to be instrumented. If he finds excessively high temperatures or pressures might exist, or that containment must be guaranteed, then safeguard instrumentation must be provided with adequate safety action to preclude any hazard.

2.2.1. Sensors

a. Are the sensors of a reliable type and are they adequate for their intended purpose?

If the reliability in the intended environment is not known, bench tests should be made.

b. Are the sensors properly located?

A thermocouple bead must be in contact with the object whose temperature it is monitoring unless there are no temperature gradients in the region.

It is not safe to place a thermocouple near a surface whose temperature is being safeguarded and to rely upon a calculation of temperature difference to supply the true temperature. This practice may be acceptable for obtaining experimental data but should not be used for a safeguard; the distance or thermal resistance may change during operation.

It is likewise a questionable practice to use the central temperature of a capsule as the only safeguard when the wall temperature is to be limited. It may be acceptable when the central temperature is not allowed to exceed the safe temperature of the capsule wall and when supplemental peripheral heating is not used. Otherwise, the part being safeguarded should be monitored directly.

It is obvious that the resistance-type monitor for water leaks will not function in a heated region where water cannot exist in liquid form.

c. Are there sufficient numbers of sensors so that failure of a relatively inexpensive sensor will mean loss of the entire capsule or rig?

There should be at least one more than the minimum number of required thermocouples since these are subject to failure. Other types of sensors, such as for pressure, are less easily duplicated but fortunately are less likely to fail.

2.2.2. Lead Wires, Piping, and Access Tubes

a. Has the introduction of thermocouple wires, minitubes, and other leads reduced the reliability of containment?

Experience has shown that glass seals around wire entrances are not reliable since they are subject to cracking due to thermal and mechanical stresses.

Metal-sheathed wires may leak along the wires if the insulating material is not well packed, particularly if the length of the lead is short.

b. Are the leads well supported, and is there enough slack to allow for expansion and contraction due to temperature and pressure changes?

The adequacy of support and other protection for the leads must be investigated for their full length. The conduit or access tube through which the leads penetrate to the outside of the reactor is of particular concern since, in some cases, it must be sufficiently strong and well mounted to withstand severe hydraulic or pneumatic forces. Some troubles which have been encountered with access tubes are:

1. Ejection from the reactor tank by a water-pressure surge.
2. Leakage of water due to a hole caused by vibration against an adjacent surface.
3. Weld failures due apparently to thermal or mechanical stress.
4. Binding of reactor core components due to side pressure exerted by the conduit.
5. Impossibility of installation due to being of the wrong size or shape.
6. "Streaming" of radiation through straight, gas-filled tubes.

c. Does the use of minitubes for pressure monitoring violate containment requirements?

A minitube which is used to monitor the pressure in a primary containment extends the primary containment to the pressure sensor. In such cases, and when secondary containment is required, the minitube should be enclosed in secondary containment for its full length. It may also be necessary to enclose the sensor.

d. Are the lead wires and tubes of suitable materials for their environment?

Some trouble has been encountered when a transition was made from metal-sheathed or ceramic-insulated wires to wires insulated with organic materials too close to the reactor so that gamma-induced damage occurred. If the lead wires pass another radiation source than the reactor, such as a spent-fuel storage rack, this must also be considered.

The access tube must be considered in this respect also.

2.2.3. Instruments and Controls

a. Are the instruments of a well tried, reliable type?

New types of instrumentation should be bench tested, both to determine their reliability and to familiarize personnel with them. Of particular importance is the immediate availability of spare parts or even spare instruments.

b. Is there adequate duplication or redundancy of instruments?

Because of a history of instrument failures of various types and frequencies, it is customary to provide duplication and even triplication of safeguard instruments when the hazard being safeguarded against is sufficiently serious. The philosophy originally was that having two instruments would more nearly insure safety action. Having the two instruments also may allow an orderly shutdown of the reactor after a failure of one which does not cause a shutdown. (Such a shutdown would be required if a sensor failed and there were no spares.) If the failure is in the instrument, repair without requiring a shutdown may be possible. If, however, the hazard safeguarded is sufficiently serious, some organizations require triplication of such instruments so that two are always still functioning to guarantee a shutdown while the third is under repair.

If containment is guaranteed, more liberty may be taken with the reliability of instrumentation as far as ultimate safety is concerned. This, of course, involves the risk of contaminating the containment system. When dangerous experiments or tests are being performed which may, upon failure, release large amounts of radioactive gases or other materials, a safe philosophy is that containment must be provided for any credible event and that instrumentation and controls are provided as a first and perhaps second line of defense to avoid having to use the containment.

In the opinion of the author, the use of the two-out-of-three response system to cause safety action should be avoided when the hazard being safeguarded is serious. A completely guaranteed

monitoring system for such usage of instrumentation has not been developed; and, furthermore, its use tends to reduce the importance of good instrument maintenance by reducing the importance of instrument failure. Experience has shown that a good instrument maintenance program keeps the failure rate sufficiently low that the additional investment in instruments (and additional maintenance) for two-out-of-three systems cannot be justified.

c. Are the instruments located in an arrangement which makes both use and maintenance easy?

Instruments which must be observed simultaneously by the operator should be close together.

A readout instrument for any property must be located close to the controls for that property (rheostat, throttling valve, etc.) so the operator can immediately see the results of adjustments. When this is not possible, communication must be provided between the two stations for use by two operators.

For the benefit of maintenance personnel, both the front and back of instrument panels should be readily accessible.

Frequently observed instruments should be placed at eye level for a standing person (unless a desk-type console is provided) and less important or less observed instruments located in the high and low positions.

When instrument racks must be located near a thoroughfare, critical adjustment handles, such as for throttling valves, heater controls, etc., may need some safeguard to prevent their being bumped or otherwise tampered with.

Wiring or piping to instrument racks must be routed so as not to be endangered by personnel traffic, janitorial work, or other such activities.

d. Are environment controls adequately limited?

In the event of malfunction of controls, there must be some safeguard against exceeding safe limits. For instance, the power supply for heaters should be limited to the maximum that is safe

for the system. Also when the rig or capsule atmosphere is being supplied from a source whose pressure exceeds that which the system can withstand, a pressure relief should be supplied if a failure or misoperation of the pressure-reducing controls can subject the system to the full pressure. When the access tube is protected from this overpressure by a pop-off valve or rupture disc, protection against the "waterlogging accident" is also afforded. (It is considered possible that some systems may become overpressured if an inward water leak occurs and some of the water flashes to steam. This may occur when a fast startup of a reactor is made when water is present in a system which has a high fission-heat generation rate.)

e. If dual-purpose instruments are used (combined safeguard and data or control functions) is the safeguard function in any way restricted or jeopardized by the other function?

   If a temperature controller is also used to cause a reactor-power reduction, an open thermocouple will cause not only a failure of the safety function but also an increase in the heater power.

   If data taking requires special adjustments, calibrations, or other action that temporarily blocks a safeguard action of an instrument, then the two functions must not be combined in a single instrument.

f. Are the intended instrumentation-and-controls, maintenance, and checkout procedures and schedules adequate?

2.2.4. Safeguard Action

a. Is the intended safeguard action appropriate for the condition it must correct or control?

   If the operating time of a reactor is of great value, if the reactor is used for a large number of consecutive programs, or if refueling may be required in the event of a power reduction, the reactor should not be used as a temperature controller for an experiment or test. A reactor-power reduction should be required only as a last resort to avert or minimize a serious hazard or to prevent loss of expensive equipment when the loss

will exceed the cost of a shutdown. Small power reudctions may be of less consequence but can greatly interfere with other programs if they occur frequently.

The controls should cause a reduction of heater power, increase of coolant flow, or even retraction of a capsule from the reactor before requesting a reactor-power reduction.

The ultimate pressure control is a pressure-relief system.

b. Can the safeguard action itself be the cause of a hazard?

In one test apparatus, the surge of extra coolant, supplied to suppress a high temperature, increased the system pressure so much that a seal was broken and a large quantity of radioactive gas was discharged to the environment.

When an emergency discharge system on a high-pressure irradiation device was activated, a rubber hose in the discharge line was blown off and caused the release of a large quantity of radioactive gas into a reactor building.

If specimen retraction is used as a safeguard action, the reactivity effect must be within the controllable limits for the reactor with respect to both the rate and the total.

Too rapid a reduction of temperature may produce thermal stresses which may endanger specimens or containment.

c. Will the controls automatically assume a safe condition if electrical power or pneumatic pressure is lost?

Loss of control power must produce the maximum safeguard action, such as a reactor scram or power reduction. Pneumatically or electrically operated valves must automatically assume the maximum safety position (open, closed, or mid-position) when control power is lost. Where these types of valves are used to seal off dangerous gases or liquids, they should be backed up by hand-operated valves. (See 2.3.3.3.b.)

2.3. Loops

No attempt will be made to go through a complete routine of asking all the questions necessary in the full review of a complex loop. Only some of the major considerations are treated. With only minor modifications a majority of the questions which must be considered for noninstrumented and instrumented capsules and irradiation rigs can also be applied to loops.

Loops are usually installed in reactors for one or more of the following reasons:

a. To provide containment for a hazardous material,

b. To provide a special environment for an irradiation specimen,

c. To supply additional cooling,

d. To circulate a liquid or gas through the reactor, and

e. To provide a means of inserting and removing irradiation specimens (pneumatic and hydraulic tubes).

The degree of complexity will vary both with the number of purposes of the loop and with the amount and types of data required by the experimenter. The hazards which must be safeguarded against will be of various degrees, of various types, and of various origins. To discover them or to know that adequate safeguards are provided, the reviewer must not overlook any part of the loop or its auxiliaries. All hazards are not necessarily generated by the loop itself. During the review of one loop, it was noticed that no continuous water drains were provided in the floor of a well sealed large equipment cell although it contained several sources of water leaks. If a leak should have occurred and gone undetected, as during a shutdown period or building evacuation, the weight of the water filling the cell would have broken the floor so that both the loop and a part of the reactor shield could have been destroyed.

Only the final review of the loop will be treated here, but from this the day-to-day design-progress reviewer will be able to judge if the necessary requirements are being met. In addition to the review of the loop as a whole, each component must be examined for its own merits and for its effects on all other components.

2.3.1. The Total Loop

a. Is the total loop concept well proved by experience or bench tests?

Most of the possible types of loops have now been operated in reactors, but it is not impossible that some new type of system can be devised. The reviewer should acquaint himself with the history of the type of loop he is reviewing before proceeding.

One great caution must be exercised in comparing a loop (or other experiment) to other similar loops. The safety requirements of the two locations may not be the same. For instance, in some remote locations, the safeguard systems may allow the discharge of a large amount of radioactive gases to the environment. In more populated areas, this cannot be done and the safeguards must be more elaborate and restrictive.

The reactor should not be used for making checks of a system that can more safely and just as well be done outside the reactor. Such effects include corrosion (except for the effects of irradiation on corrosion), pressure surges due to water inleakage producing steam, determination of burnout heat fluxes, etc.

b. Has the most hazardous work foreseen for the loop been clearly defined?

Limits should be set for the specimens and environments for which the loop is being reviewed. It sometimes happens that a loop designed for one purpose is converted to other uses. When this happens, a new review should be required. An example is the use of a simple hydraulic tube for irradiating fissionable materials when the tube was designed for materials have a low heat-production rate. Although the water flow may provide ample cooling during the irradiation, the flow direction must be changed to expel the capsule. Burnout may occur during the short time when the flow rate is zero. To perform the irradiation, provisions would have to be made to automatically scram the reactor if the water flow is lost; and it may be necessary to provide for the disposal of fission-product gases if the capsule should leak during the irradiation. The capsule should be expelled only during a reactor shutdown.

c. Has the necessary degree of containment for the loop been determined and provided for all components?

If any direct leak from the primary containment will not be hazardous, then secondary containment is not justified. If such a leak would be a moderate hazard, then it may be justified to provide secondary containment only for those parts most likely to leak. If, however, any leakage is defined as intolerable, reliable secondary containment must be provided and maintained for all parts and all piping of the primary system.

The cladding of a test specimen or capsule is primary containment only if it is unlikely to fail and operation is immediately discontinued when any failure occurs. It should be kept in mind that a system for irradiating fissionable material in capsules or other cladding may become sufficiently contaminated with fissionable material after a specimen failure that it must thereafter be considered primary containment. It will then be necessary to dispose of the system, decontaminate it, provide secondary containment, or lower containment standards. When the contaminating event is very likely to occur, it is sometimes more economical, and certainly safer, to provide a secondary containment for the loop itself as part of the original design to allow for operation with some degree of contamination. The reviewer should be certain that safe provisions are made to remove specimens from the loop under contaminated conditions. It is also necessary to know that a contaminated loop can be either decontaminated or safely removed and disposed of.

Every sampling tap and other penetration of the containment walls must be carefully checked. Of especial importance is whether sealing techniques will withstand the expected pressures and temperatures and whether the method of support allows for thermal expansion and contraction without breaking off the taps.

The support and clearances for all loop parts must also be checked for allowance of thermal expansion and contraction. Both external and internal piping must be checked in this respect. Also, bolted

flanges are especially likely to leak due to thermal effects which may not only damage gaskets but the bolts as well. Any flanged connection in the primary system must be continuously monitored if containment must be assured.

Any containment which must be guaranteed continuously leak-free must be continuously monitored.

Two types of "containment" are possible--"dynamic" and "static" or "absolute". Their usage may be dictated to some extent by the physical arrangement of equipment but to a greater extent by the reliability of the available off-gas systems and the allowable rate of discharge of radioactive gases to the environment through the off-gas systems. As the name implies, dynamic containment consists of simply discharging all gases from a containment volume to a guaranteed off-gas system which is always maintained at a negative pressure. In this case, the containment shell may not need to be leak-tight (except under water) since all leakages will be inward. Also, shielding requirements are low since the residence time of a radioactive gas will be short. Static or absolute containment is the complete retention in the secondary containment volume of anything that leaks from the primary containment. This requires leak-tight secondary containment walls which must sometimes withstand high pressures as well as provide adequate shielding for the material contained. Dynamic containment is far more easily used, is more reliable, and is more economical than absolute containment. The reviewer will, therefore, find that there will be attempts to use dynamic containment when absolute containment is necessary. If leakage from a primary containment will release amounts of radioactive gases which exceed the upper limit of the off-gas system, absolute containment must be used. (See 2.3.5.)

Absolute containment generally results in lengthy shutdowns of the reactor since the removal of contaminated equipment must await the decay of radioactive gases. It may be possible to partly dispose of trapped gases into shielded evacuated containers if provisions have been made to connect them to the containment

system. There is always then the risk of a leak occurring during the connecting and disconnecting procedures so that such methods must be carefully reviewed.

Dynamic containment may be used to some extent even when the off-gas limits are severe if an adequate gas cleanup system is installed with the experiment. The use of cold traps in such cleanup systems must be reviewed carefully since the refrigerant may become depleted during any time of inattention, such as during a building evacuation so that the retained gases are released in high concentration. In any case, if there is the possibility of releasing large amounts of radioactive dusts, a dynamic system may require the use of filters to prevent distributing the dust through unshielded pipes.

It should be further insured that containment is maintained throughout specimen removal procedures if the specimens are likely to release radioactive gases when damaged. A large percentage of gas release incidents have occurred during specimen-removal and subsequent handling procedures.

Containment may be necessary for purposes other than to prevent releases of radioactive materials. A secondary containment should be required when the failure of a container will subject the reactor to destructive pressures, release highly reactive materials into the reactor, or release toxic materials into personnel areas. In these cases, primary containment may not be the same as that for radioactivity containment.

d. Is the equipment arrangement such that it can safely and efficiently be operated by the minimum number of people?

Operators must not be required to enter containment cubicles to make valve adjustments or do other work during times when a release of dangerous amounts of radioactive material into the containment is possible.

The comments on the instrumentation arrangement for instrumented capsules also apply to loops.

All pumps and other components which require servicing or replacement should be easily accessible.

e. Is the proposed routing of piping and placement of equipment such that other installations and access to the reactor for servicing are not blocked or otherwise unnecessarily inconvenienced? Further, is there assurance that the required routing paths will be available and unrestricted at the time the loop is installed?

Because of the large number of activities and continuous alterations that occur at large research reactors, there have been many conflicts in routing paths when insured space reservations are not made with the proper personnel. When such problems are encountered during the installation, "last-minute" field changes may have to be made so there may be poor welds, improper clearances, and mechanical stresses which not only may cause containment failures but also exert undesirable forces on the reactor components.

2.3.2. Cooling

a. How dependable are the provisions for coolant flow in the loop?

If coolant flow must be guaranteed at all times, spare pumps or blowers must be provided with guaranteed emergency electrical power or other power source. (An emergency pump or blower may be operated by steam or compressed air.) Since some lack of dependability has been experienced with start-on-demand systems, the best guarantee of continuous cooling is to provide at least two continuously operating pumps, either of which will supply ample cooling, with provisions for shutting down loop operation (and the reactor) if one pump should fail.

In order to know that ample coolant flow exists, it is not always adequate to monitor only if a pump is operating or if flow is passing through some orifice or other monitor which is remote from the object being cooled. To avoid the possibility that bypasses are open or that some flow path is blocked (particularly where parallel paths are provided), the surfaces to be cooled should be monitored. When surface temperatures cannot be monitored, the use of parallel paths should be carefully controlled with some

guarantee provided to prevent debris from plugging one or more flow paths. When flow must be relied upon as a guarantee of cooling, the flow monitor should be downstream from the surface being cooled.

Where closed volumes of recirculating coolant are used, some reserve volume needs to be supplied with provisions for thermal expansion and contraction. When liquids are used in radiation, provisions must be made for disposal or recombination of radiolytic or decomposition gases.

Water-cooled systems in which the water passes through high-intensity radiation must be free of gas traps such as closed vertical pipe sections where appreciable amounts of radiolytic gases may collect and produce an explosion hazard. Where such vertical pipes must be present, some provision should be made to prevent gas accumulation.

When heat exchangers are used and the primary coolant is radioactive, or likely to become radioactive, the secondary coolant discharge should be monitored for possible leaks in the heat exchanger.

If a closed cooling system is used, the provision of an emergency coolant supply which discharges to the environment should be avoided unless a failure cannot contaminate the coolant. If the discharge of a contaminated coolant is less a hazard than failing to provide cooling, then the discharge may be justified; however, allowing such a need to ever exist is questionable.

Attention must be given to preventing large gas bubbles from passing through the in-pile sections of water-cooled systems. Such bubbles not only interfere with the control of the reactor but may cause damage to the specimens being cooled.

2.3.3. Components

It must always be kept in mind that in a reactor loop a component not specially designed and built may be in an environment different from that for which it was originally intended. Also, the acceptability may not be

the same as for other purposes where shutdowns and repairs are easily arranged and access is no problem.

2.3.3.1. Piping.

a. Are all sections of pipe of an acceptable material, dimension, and strength for the intended use and environment?

The choice of the material and strength must be based on both the internal and external environments. Frequently, a pipe's required strength may depend upon whether or not it may be stepped on or otherwise abused by personnel.

Whether or not all welds can be properly dressed and treated to prevent corrosion may dictate the choice of material.

The method of joining dissimilar materials must be such that differences in thermal expansion or contraction will not damage the connection.

2.3.3.2. Pumps. - The questions of the required number of pumps and their accessibility for servicing have been discussed in other sections. There are yet some questions which are more specific.

a. Are all parts of the pump compatible with the loop environment?

Standard "off-the-shelf" pumps may contain parts made of unacceptable materials. A brass or bronze impeller would not be desirable if aluminum piping is used. Nonstainless steels and cast iron will contribute to fouling water, particularly in recirculating systems.

b. Are the operating characteristics and limitations well known? Has performance reliability been well checked?

Any pump used for a critical purpose must, of course, be highly reliable. Unless the type of pump to be used has a well established history of reliable service for the intended usage, thorough pretesting should be required.

A positive-discplacement-type pump may form an undersirable barrier to natural convection if stopped. In some cases, such a barrier may, however, be desirable.

The upper operating temperature for the pump should be known and some guarantee provided to insure that it is not exceeded. If a separate coolant for the pump or pump-motor bearings is required, the coolant flow or the bearing temperatures should be continuously monitored.

c. Will the pumps be firmly mounted and provisions made to prevent objectionable vibrations of the piping?

d. Are the shaft bearing seals suitable?

If only moderate radioactive contamination of the fluid is possible and an adequate disposal system is available, some leakage may be tolerated. If leakage cannot be allowed, a canned-rotor pump may be required.

Some types of pumps may allow some inleakage of air through the seals to prevent an outward fluid leakage. These should be avoided for most applications since they may saturate the water with dissolved air which may not only interfere with cooling but may be a source of radioargon. The dissolved air will also be a source of nitrous and nitric acids in radiation.

e. What type of lubrication is required for the bearings? Can this contaminate the fluid with any objectionable material? Can the lubricant be replenished as often as required without violating containment requirements?

f. Are the pump controls and necessary valves arranged so that they can always be operated without exposure of personnel to radiation?

g. Is there need for visual observation of the pump during operation? If so, is such observation blocked by containment requirements or by other equipment?

It may be desirable to provide an observation window in the containment wall and lights within the containment.

2.3.3.3. Valves. - Valves are a frequent source of trouble. The reviewer must be satisfied not only that valves are located in proper places but also that each valve is as reliable as its function requires.

a. Are all the materials of the valves suitable for their intended environment?

"Stainless-steel" valves have sometimes been found to have other materials used for seating rings, stem bearings, etc., when received from the manufacturer since stainless steel was substituted only for other steel parts.

Stem-packing and gasket materials must have been proved suitable for the intended fluid, pressure, and temperature. Tests should also include opening and closing the valve a sufficient number of times to know how frequently servicing may be required.

In some applications the valve-stem packing may require special cooling. This is especially likely in high-temperature systems where pipes must be insulated.

b. How important is it that there be no leakage through the valve when it is closed? Can leakage be checked?

When such leakage is intolerable, it may be necessary to have two valves in series to better guarantee total closure. A further guarantee is to provide a safe drain for the volume between the two valves.

Automatic or remote-controlled electrically or pneumatically operated valves may need manually operated valves as a backup. Since only a limited force is available for closing them, a small piece of debris, which could be crushed in a manually operated valve, may keep a pneumatically or electrically operated valve from completely closing.

The use of check valves as the only seal against the leakage of radioactive gases or liquids is a questionable practice. In many applications, their reliability cannot be readily and frequently tested and leakages due to debris and corrosion are likely. They can, however, prevent massive leaks so they have their applications; but they should be supplemented by other types of valves if back leakages cannot be tolerated.

c. What would be the consequences of a leak along the valve stem or through the bonnet seal?

If a leak from any part of the valve to the environment would be serious, the valve should be enclosed in a secondary containment such as an equipment cell or glove box. If a liquid is involved, provisions for safe drainage or storage should be considered. If radioactive or noxious gases are involved, adequate off-gas provisions must be made.

d. Is each valve to be located where it can be operated under all necessary conditions without exposing personnel to radiation or other hazards?

Valves which must be frequently adjusted must, of course, be located as conveniently as possible. Those inside shields or equipment cells may require extension handles through the walls. Such extensions must not violate containment requirements.

Judicious placement of valves may also reduce the possibility of burns and discomfort of personnel in the case of loops and equipment which operate at elevated temperatures.

Any isolation valves provided for containment purposes must be accessible during the worst emergency condition.

e. Are all important valves replaceable under the conditions that will exist after the loop has been operated?

Although the replacement of some valves will be difficult and acceptably so due to normally expected infrequency of failure, the difficulties must be carefully considered. If the difficulties are such that an extensive shutdown of the reactor may be required, it may be desirable to provide two valves in series just to prolong the time between repairs. Where leaks past valves are serious, this should be a requirement. It should also be required that when one of these valves leaks, it must be replaced as soon as a shutdown can be arranged.

f. Are the valves to be very clearly labeled so that misoperation will be avoided?

Clear labeling, color coding of handles, painted flow diagrams on valve panels, or other methods may be used; but it should always be clear what the function of each valve is. It should be kept in mind that under emergency conditions the valves may have to be operated by someone other than the regular operator.

When self-sealing, quick-disconnect hoses are used in lieu of valves, clear labeling is also important. In one case with an air-cooled loop, the exhaust line which was being connected first was accidentally connected to the air supply instead. The air blew through the loop and exhausted through the still-open inlet pipe carrying radioactive dust so that personnel and the entire experiment room had to be decontaminated.

In addition to clear labeling, it may be desirable to require that those valves which must not be accidentally opened or closed must be kept locked or have their handles removed between the times of necessary operation.

2.3.3.4. Flow Monitors and Controls. - Any flow which must be guaranteed must certainly be monitored in some way. This can be done by direct flow measurements or by monitoring the temperature of the specimen which is being cooled. Flow monitors of the pressure-difference type have been found most reliable for most fluids but may not be sensitive enough for very low flow rates.

a. If an orifice or venturi type of flow monitor is used, do the ΔP transmission lines violate containment requirements?

   If the flow being monitored is in a primary system and secondary containment is required, the pressure transmission lines must not extend beyond the secondary containment.

   If the flow being monitored is in a primary or secondary system which is likely to become contaminated, the pressure lines should not extend to any personnel area which is not continuously monitored for radiation.

b. Can failure of the flow monitor or controller cause a hazard?

In most cases a flow controller should always allow some minimum flow to exist. If a failure of the controller, the monitor, or the power supply to the controller can result in complete closure of the control valve, provisions must be made to guarantee that the flow is not stopped. This may be done by mechanically limiting the stroke of the control valve or by providing an always-open bypass so that the controller only operates on some fraction of the total flow.

Flow controllers must also be limited so that they cannot allow too high a flow which might damage some portion of the loop or the specimens. (See Section 2.2.4.b.)

2.3.3.5. Strainers, Filters, and Traps. - Strainers or filters may be required in a loop for protecting delicate equipment, purifying a recirculating liquid or gas, or for cleaning a liquid or gas before it is discharged.

a. Has any need for a strainer or filter been overlooked?

Pumps or blowers should be preceded by a strainer if the loop may contain debris which can damage them.

Gases which may carry radioactive particles must be filtered before being discharged to the environment. Although off-gas systems usually contain filters, there is sometimes a requirement that the gas be filtered before it is discharged into the off-gas system. This prevents distributing radioactive particles through the off-gas piping which may not be well shielded and also reserves the off-gas filters as a second line of defense for the environment.

Liquid-waste drains should always be equipped with simple strainers to prevent large objects from entering the pipe. There may also be a necessity of removing from the waste stream any radioactive particles which are too heavy to be easily swept through all the piping by the flowing liquid. Such particles may collect in parts of the piping so that shielding problems arise. A particle trap may be more desirable than a fine-mesh strainer since it will be

less likely to become clogged. Particles of radioactive metals such as cobalt, tantalum, and silver are of particular concern because of their long half lives and because they may be difficult to remove from crevices and other traps in the piping.

When an aqueous system is equipped with a demineralizer, fine particles of the resin may be expected to be swept into the system unless a fine-mesh filter is installed downstream from the resin bed.

b. Can the failure of any filter or trap cause a hazard? If so, how is its integrity guaranteed?

Some types of filters require very careful handling during installation to prevent their being damaged. When a filter is relied upon as a barrier against severe contamination from radioactive particles, its integrity must be guaranteed by a very careful inspection or test after installation and at adequate intervals later. When the consequence of a failure of a filter is serious, continuous monitoring for radioactive particles downstream from the filter may be necessary.

When the dust load in any gas stream may be high, "absolute" filters should be preceded by a "rough" filter. In such systems, the filter area should be chosen not only on the basis of the initial pressure drop but also with some attention to the expected dust accumulation rate.

If there is a possibility of a fire occurring in or near any equipment cell whose ventilation must pass through filters, the filters may be expected to become rapidly clogged with soot and smoke particles. If ventilation is to be relied upon to prevent the accumulation of explosive gas mixtures or other hazards, a serious situation can result. In such a situation it may be a lesser hazard to provide for automatically bypassing the filters or flooding the cell with nitrogen or carbon dioxide.

When refrigerated traps are used to remove radioactive noble gases and halogens from gas streams, a hazardous condition can

result if the refrigeration is lost. Trapped gases can be released as a burst and, if the trap should be isolated by valves at such time, an explosion can result from pressure buildup. A further hazard may result from traps cooled with liquid nitrogen (or kept at a lower temperature)--any oxygen in the gas stream will condense inside the trap and may react with other materials to cause an explosion even at the low temperature. The possibility of such a reaction is enhanced by radiation which produces ozone.

c. Are all parts of the filter or trap compatible with its intended environment?

If a commercially-available filter is to be used, it, like all other parts of the loop, must be checked to be certain that no objectionable metals or other materials are used.

In aqueous systems where the water circulates through high radiation, cellulose fiber filters will have a finite life after which they disintegrate. Until this period of time has been established for the system, inspections at not less than one-month intervals would be advisable. Such a disintegrating filter may suddenly pollute the entire system with small bits of fiber.

Air filters must be checked to know that they will withstand any chemical fumes which may be expected in the gas stream. They must also, of course, withstand the maximum gas temperature and maximum ambient temperature. In this respect, not only the filter media but also the mounting frame, gaskets, and other parts must be checked.

d. Are all filters, strainers, and traps well located for easy servicing?

If the filter, strainer, or trap will become radioactive and require removal in a portable shield, ample handling room must be available. This is sometimes not well provided since the shield is not required for installing the filter and, unless a trial removal is made, may not be proved until a radioactive filter must be removed.

e. Has ample shielding been provided?

Since these components are installed to collect various types of impurities, they may be expected to become more radioactive than the average loop piping and must be shielded accordingly. The actual thickness of shielding should be based upon the maximum radioactivity which can result due to a failure of a test specimen. Although the component may be located within a shielded equipment cell, additional shielding may be required to allow servicing of other components in the cell.

2.3.3.6. Degasifiers and Recombiners. - It is so well known that aqueous and organic recirculating systems will need some provision for disposing of radiolytic or decomposition gases that such provision will likely be made. The reviewer must, however, check that certain details are acceptable.

a. Will explosive mixtures of gases collect in any portion of the loop which is not vented to the disposal system?

This has already been mentioned in Section 2.3.2.a. If a vacuum-type degasifier is used continuously, the gas concentration in the liquid may be kept low enough that gas pockets will not form in other parts of the loop which are kept under pressure. However, nearly continuous operation of the degasifier will be necessary. If only a gas sweep through the gas volume in a tank is used to purge the radiolytic gases, some provision must be made to connect any potential gas pocket volumes to the purge tank.

A recombiner must be operated in such a manner that it cannot subject the system to pressure surges, either positive or negative. To do this, it must either operate continuously or be a part of a side-stream degasifying system beyond a let-down valve.

If organic vapors or radiolytic gases are purged to an off-gas line, there must also be a provision to prevent the accumulation of explosive mixtures in the off-gas system. This can be accomplished by providing a gas sweep through the off-gas line either by admitting air or by supplying a source of carbon dioxide or nitrogen.

b. Has ample shielding been provided?

A degasifier may be expected to become one of the more radioactive parts of a loop in the event of a release of radioactive gases into the system. (See section 2.3.4.)

c. Will the degasifier or gas sweep violate containment requirements in the event of a specimen failure?

If the maximum amount of radioactive gases which may be released into the loop when a specimen fails cannot be discharged into the off-gas system, there should be a reliable, continuously operating gas cleanup or retention system preceding the off-gas connection.

2.3.3.7. Demineralizers

a. If a demineralizer is installed in the loop system, have provisions been made to maintain the proper environment for the resins?

Water from the loop may have to be cooled before it enters the demineralizer. Also, if a commercially available demineralizer is used, the water pressure may have to be reduced. Under these conditions care must be exercised to be sure that the demineralizer tank does not accumulate a pocket of explosive gases.

b. How is the demineralizer to be regenerated?

The safest procedure is to change the resin bed when it is depleted. This may be done by removing the demineralizer tank or by flushing out the resin and filling with regenerated resin. Either of these methods may require using a portable shield unless the liquid-waste disposal system can accept the resin directly.

If the resin is to be regenerated in place, there must be assurance that the regenerating solutions cannot be accidentally injected into the loop either through a leaking valve or by misoperation. The best way to insure this is to require that the demineralizer be completely disconnected from the loop by removing pipe sections for the duration of the regeneration.

c. Is adequate shielding or isolation provided?

If the demineralizer is not separately shielded, its radiation may greatly interfere with other work in an equipment cell. (See section 2.3.4.)

d. Will the instrumentation or sampling taps violate containment requirements?

Water monitoring probes are usually installed to be replaceable so they must be gasketed. They should, if possible, be located in the low-pressure, low-temperature system provided for the demineralizer; otherwise, the type of seal should have been proved reliable for the intended environment. This is also true for the insulating seals around the electrical wires for the probe. (See also section 2.3.3.9.)

2.3.3.8. Makeup Systems. - A closed recirculating system, whether liquid or gaseous, will generally require some type of makeup system because of leaks, sampling, decomposition, etc. Such systems must be carefully checked by the reviewer since some types can be hazardous.

a. Can the loop be overpressurized by the system?

Probably one of the safest methods of injecting a makeup gas or liquid into a closed loop is to use a small compressor or pump in order to best control the injection rate and pressure.

If pressurized gas is used to inject either the gas itself or a liquid into a system which cannot withstand the full pressure of the pressurizing source, an intermediate pressure tank should be used to limit the possible volume of gas directly connected to the system.

The use of such a tank also prevents having primary containment extended outside a containment cell when pressurized-gas cylinders may not be installed in the cell.

A single reducing valve should not be considered a safeguard against overpressurizing if a failure or misoperation of the valve can result in overpressure. If a direct connection must be made between a loop and a gas supply being reduced from a high pressure, the connecting line should be equipped with a pressure-relief valve or rupture disc located between the reducing valve and the loop. There must, of course, then be an isolation valve between the pressure-relief system and the loop. This arrangement

should also be used where containment volumes associated with the loop must be maintained at some particular overpressure.

b. Does the makeup system violate containment requirements?

During the injection procedure, the makeup system becomes a part of the primary loop (or other system being filled); therefore it should, at least in part, have the same containment requirements as the system it services.

c. Are all parts of the system made of acceptable materials?

Injection pumps, pipes, valves, gaskets, etc., must, like other parts of the loop, be examined for acceptability of materials.

2.3.3.9. Sampling Systems

a. Does the sampling station violate containment requirements or good radiation-control practices?

Liquid or gas sampling taps usually are extended outside the main equipment cells. These, then, may violate containment requirements by causing leaks at the place where they penetrate the cell wall and by extending primary containment outside the cell. If the liquid or gas being sampled may be radioactive or toxic, ample disposal and containment provisions must be made for the sampling station. These would include a drain for radioactive liquids and a hood or glove box with an off-gas connection for disposal of radioactive gases.

If radioactive specimens of varying intensities are taken frequently or if the radioactivity of samples may increase unexpectedly due to a failure or misoperation, a permanently installed radiation monitor at the station may be advisable.

Sample containers must be amply shielded. If they may evolve radioactive gases, they must also be sealed before they are removed from the glove box or hood. The use of glass as a container for radioactive specimens, especially gases, should be allowed only if the glassware is completely sealed in a secondary container of metal or durable plastic during transport and when stored outside a containment cell.

If a demineralizer contains fission products, the effluent may have a higher concentration of xenon than the average water in the loop due to the decay of radioiodine trapped in the anion column. Although the quantity of gas from a water sample may not be hazardous, it should be known that the gas evolving from a water sample may cause some increase in the background in a counter room.

b. Can any single valve failure produce a hazard at the sampling station?

Any sampling tap from a pressurized radioactive system should be at least double valved with two valves accessible at the sampling station. If the sampling line is long, an additional valve near the loop may be advisable. Failure of a valve may result in severe contamination if a backup valve is not provided and immediately available. This is especially important if the flow from a sampling tap may exceed the off-gas or drain capacity.

c. Is the sampling station to be well labeled and otherwise guarded from tampering and environmental abuse?

The sampling station should be labeled with a sign which tells what it is and lists any necessary precautions. Also each valve should be labeled as to purpose. The use of only a numbering system may not be adequate during emergency situations. All pipes must be well supported. In the case of high-pressure systems, valves should be of a type which can be mounted on a support to prevent the force of opening and closing the valve from being exerted on the piping if the pipe diameter is small.

2.3.3.10. Dump and Drain Systems. - The contents of any liquid-filled loop must, of course, be disposed of at some time. Provisions for this disposal must be made before the loop is filled and must be designed for the most severe condition which can result from any failure within the loop. Disposal may be final if an adequate waste disposal system is available or temporary storage of the liquid near the loop may be required if one is not. Such storage containers, may be portable. It may also be possible to remove the still filled loop from the reactor in some cases.

a. If an existing liquid-waste drain is to be used, is it adequate for the worst condition that the loop can produce?

If fission products are to be discharged to the drain, it should be a closed type of drain system or must be kept under negative pressure to prevent fission gases from being released from the drain openings. If the drain discharges to an open pit or tank outside of containment, the gases will be released to the environment.

The total drain system must either be shielded or isolated from personnel during the draining of very radioactive systems. Shielding for any traps or low-flow sections of the system may require special attention due to the possibility of particle retention. It should also be possible to flush the drain with clean water after the discharge.

It should be ascertained that the intended discharge rate will not cause an overflow from other openings in the drain system. This should be checked by actually discharging an equivalent volume of clean water. Even though the pipes may be more than adequate in size, they may be partially plugged with debris, improperly vented, or may have too little elevation change per unit length.

It should be ascertained that any fluid to be discharged to the drain can be handled by the disposal system. Large discharges of oil, carbon tetrachloride, mercury, or other nonaqueous fluids may be objectionable.

b. If either stationary or portable dump tanks are to be used, are they of adequate size and properly equipped?

The dump tank or tanks should be capable of containing considerably more than the loop volume if decontamination of the loop may be required.

If fission products are to be discharged into a dump tank, it should be vented to an appropriate off-gas system unless it is first evacuated of air.

Shielding for dump tanks should be designed for the highest possible amount of radioactivity the loop may contain at the time of draining. It should be kept in mind that some types of failure of a loop may require immediate draining without recourse to a long decay period.

c. If a dump tank is to be used, how will it later be emptied? How soon must it be emptied?

It should be planned to always have an adequate dump volume for the loop contents and cleanup rinses before the loop is filled each time. This may require a large dump tank or frequent emptying.

Emptying may be accomplished by simple gravity draining, pressurizing, or by use of a jet or pump. Simple gravity draining or use of a pump are less likely to cause troubles resulting in contamination. Some of the precautions which must be observed in pressurizing a tank are discussed in section 2.3.3.8. In pressurizing a tank connected to a closed liquid waste drain, the consequences of pressurizing the drain system must be considered. Also, a minor leak in the storage tank may become a major problem when pressure is applied. Such a leak may result from corrosion during a long storage period. A jet must have a source of steam, air, or water. Unless these are completely disconnected or the valves are kept in good repair, there is a danger of flooding from a water or steam leak into the tank. A gas-operated jet may cause expulsion of radioactive gases and particles during storage or even during draining if there are valve leaks. The use of either gas pressurization or a gas-operated jet will result in gas being discharged into the drain system so that, if the drain is not vented to an off-gas system, the gas will emerge from other drain openings.

The materials of the dump tank must be such that it will not be severely corroded by the materials it must hold. Before each usage, the tank should be checked for integrity if it must hold a hazardous material. This is of particular importance for portable tanks which are used frequently and which are subject to being damaged by handling abuses.

2.3.3.11. Pressurizers and Controls. - An overpressure in a liquid system is generally maintained by applying either gas or steam pressure to a head tank connected to the loop. The gas supply is usually cylinders of compressed gas; and if steam pressure is used, it will be generated by heating the fluid in the headtank.

An overpressure in a gas-filled loop is maintained by supplying gas at the desired pressure from cylinders or a compressor.

The method of controlling the pressure in a gas-filled loop or in a gas-pressurized fluid loop is to add or bleed off gas. Steam overpressure is controlled by controlling the heaters or by bleeding off or condensing steam.

a. Is the pressurizer capable of overpressurizing the system?

If a failure of the pressure regulating system can exert a dangerous overpressure, some type of pressure relief should be provided for the pressurizer tank or for the loop system itself. If an overpressure must be maintained to prevent failure of capsules or flashing of a water to steam, a complete loss of overpressure as by a rupture disc may be serious but not as serious as rupture of the loop piping or other component. A spring-loaded relief valve may not always reseat properly after use but may be useful to prevent total loss of overpressure. A rupture disc is sometimes backed up by a spring-loaded valve to prevent any leakage prior to disc rupture and yet prevent total loss of the overpressure suddenly.

If the gas or vapor discharged through a pressure relief system may contain fission products or other radioactive materials, it should go to a containment volume or to an off-gas system. It should be remembered that loss of pressure may cause failure of fuel specimens in the loop and severely contaminate the system.

b. Can the pressurizer tank collect an explosive gas mixture in the gas phase due to the radiolytic gases in the system?

Provisions must be made for periodic or continuous venting of the gas phase to preclude the possibility of accumulating explosive gases.

This is especially important for steam-pressurized systems since the steam will condense during shutdown periods, leaving only radiolytic gases unless some volume of inert gas has also been provided in the pressurizer.

If a recombiner is to be used, there should be sufficiently frequent checks of the gas constituents to insure that the recombiner is functioning.

c. What will be the consequence of failure of the pressure-regulating system?

This has been discussed to some extent under section 2.3.3.11.a. with respect to the need for overpressure protection. The consequences of underpressure must also be evaluated. The rapidity of loss of overpressure following a loss of electrical power to the heaters in a steam-pressurized system will depend upon a number of factors including insulation and whether or not some of the pressure is provided by a compressed gas. It should be required that the pressure loss versus time be determined experimentally for the installed loop to know what the minimum safety action should be, such as reactor-power reduction or reactor scram. Until that is done, loss of the heater power should require the maximum safety action necessary for total overpressure loss.

Loss of overpressure maintained by a compressed gas or by steam, if the heater power is not lost, should be ascribed to a leak of undetermined size and the maximum safety action should be required.

If the consequences of a pressure increase or decrease will be serious, the pressure-regulating system should not be the only protection against these changes. A regulating system can fail or be mis-set in such a way as to try to maintain an undesirable pressure, either too high or too low. An independent pressure monitor for safeguard purposes only may be used to increase the reliability of the system. The ultimate safeguard from overpressure should be a pressure relief system and/or secondary containment. Additional safety against the consequences of under-

pressure may be had by monitoring the temperatures of the specimens which are being irradiated in the loop and using these to initiate safety action.

2.3.3.12. Heat Exchangers and Controls. - The reviewer will encounter a variety of heat-exchanger types and methods of use. In addition to the usual questions of material strength and compatibility applicable to all components, there are questions unique to heat exchangers. Due to the complexity of their structure and the tendency to use minimum thicknesses of piping, they are more likely to develop leaks than most other components and yet are more likely to violate containment requirements due to the necessity of disposing of the secondary coolant.

The term "heat exchanger" as used here includes any device for removing heat from any part of the primary system by a secondary coolant. This, therefore, includes cooling coils or blowers used to cool valve packings, seals, etc.

a. What would be the consequences of a leak from the loop primary system to the secondary coolant system?

The answer to this question will depend upon whether or not the primary system fluid contains an appreciable amount of radioactive material, either normally or following a failure, and whether or not the secondary coolant is discharged to a radioactive-waste disposal system.

If leakage from the primary system to the secondary coolant cannot be tolerated, an intermediate stage may have to be installed with the pressures of the three systems adjusted so that only leakage into the intermediate system from either of the other two is possible.

If some leakage from the primary to the secondary system can be tolerated, it may suffice to install a radiation detector on the secondary effluent line. Since such a detector may only detect large leaks which may also be observed as a loss of fluid (or gas) from the primary system, it may only be useful to aid in locating a known leak. Small leaks may be detected by comparing the radioactivity of samples of water taken from the secondary inlet and

outlet lines. This should be done in a low-background laboratory for maximum sensitivity.

b. What would be the consequences of a loss of the secondary coolant supply to the heat exchanger?

In addition to simply removing heat from a loop to maintain the desired temperature of specimens or the fluid itself, heat exchangers may be necessary to protect certain temperature-sensitive components from damage. These may be the pumps, demineralizer resin, monitoring devices, or others. In these cases, loss of secondary coolant can lead to serious consequences. The necessary type of safeguard will then depend on the time behavior of the temperatures following coolant loss and whether or not the component being protected can be isolated. Isolation may be possible in the case of a demineralizer but most likely cannot be used in the case of the main pumps. If immediate shutoff of all heat sources, such as the reactor and supplementary electrical heaters, cannot protect the pumps, it may be necessary to supply emergency cooling from a head tank or another source. These, of course, cannot overcome downstream blockage so it is important for such heat exchangers that downstream blockage of the secondary coolant is not credible.

c. Will any pretreatment of the secondary coolant be desirable?

Although fouling of the secondary system may not cause any precipitous failure or emergency, cleaning operations may involve operational delays, contamination spread, or radiation exposure of personnel. If the secondary supply is known not to be reasonably clean, it may be desirable to supply a strainer ahead of the heat exchanger, especially when the pipe sizes are small and the supply lines are large. Water-to-air or air-to-air heat exchangers (radiators) are likely to become dust laden if not preceded by a dust filter.

It is best to choose heat exchanger materials which do not require chemical pretreatment of water to prevent excessive corrosion on the secondary side with the least effort.

d. If the heat exchanger for the main system is installed in a bypass arrangement with variable flow, can failure of the controls or throttling valve produce a hazard?

If total loss of flow through the heat exchanger cannot always be tolerated, these should be a guarantee of the minimum allowable flow either by a mechanical stop on the throttling valve or by an always open bypass around it. If there are times when any heat loss to the heat exchanger is undesirable (during startups) and yet there must be heat removal at all times after startup, it may be necessary to install supplemental heating to the system during startups rather than compromise the safeguard requirements for the heat exchanger. It is also possible to supply an automatically opening bypass around the control valve for emergency conditions although this is a less reliable solution. If this type of action is used, it must be known that opening or closing of the bypass cannot produce a sudden pressure change that can damage any part of the loop.

It should be noted by the reviewer that rather than giving a great deal of attention to preventing failure of the control system, the recommended approach is first to make such a failure harmless. This, of course, should not imply that a reliable control system is not important. It is important for the operability of the loop and economy of operating time that the controls be reliable. The safeguard aspects, however, should be of first importance to the reviewer.

2.3.3.13. Heaters and Controls. - Heaters, usually electrical, may be used for miscellaneous purposes such as direct heating of specimens, heating of the loop fluid, or maintaining a steam overpressure. They are subject to such obvious failures as open circuits, short circuits, and overheating; so they must be carefully examined with respect to their influence, if any, on safety.

a. Is the heater required in order to maintain safe operating conditions?

Heaters used to enhance recombination of radiolytic gases or to maintain a steam overpressure may be required for safety. Whether

or not spare heaters are desirable should depend upon the ease and expense of replacement, expected likelihood of failure, and the length of time available for safeguard action following a failure of the heater.

If the heater is required for safety, then there must be safeguard action if function of the heater is lost. This will likely involve a power reduction or scram of the reactor. Attention must also be given to seeing that such heaters are not likely to fail. This would include ample pretesting, good installation techniques, supplying reliable electrical power, use of a minimum of fuses (or even no fuses), direct wiring to terminal strips (not simply plugging into a receptacle unless it is a type that cannot be easily unplugged), enclosing all wiring in conduits, etc. Loss of the heater should not be allowed to create an intolerable condition, however. This should be averted by use of pressure protection, containment, etc.

b. What are the consequences of overheating?

Overheating will usually result in physical damage to test specimens, to the heater assembly itself, or to the total loop by increasing pressure. Perhaps the best insurance against overheating is limiting the power to the heater. If an automatic control is used to prevent overheating, then the consequences of overheating should be reduced to a tolerable level by providing other safeguards such as overpressure protection, containment for damaged specimens, etc. This may be necessary when fast response of the heater is required to maintain an even temperature, but in no case should a heater have enough available power to destroy itself. To provide such a limit it may be necessary to require that mechanical stops be installed on variacs. The use of fuses should usually be limited to protecting the power supply from gross damage only unless loss of heater power will not create a hazard.

c. If automatic control of the heater is required, will the relative location of the heater and the temperature sensor cause safety or operational difficulties?

The thermal-path distance between the heater and the sensor should be minimized for good control, especially when fast response is desirable. If heat transport by a flowing fluid is required between the heater and sensor, loss of flow should not be allowed to result in overheating. The heater power should be automatically shut off if flow is lost.

d. Are all regions or materials which the heater must not heat sufficiently insulated or isolated from it?

Special attention must be given to insure that overheating of reactor coolant, entry tubes, and shielding does not occur. This can usually be prevented by the use of insulation or by providing ample coolant flow outside the heated section. When the arrangement is questionable, appropriately located temperature sensors and adequate protective action should be required.

2.3.4. Shielding

Most loops require an extensive use of shielding. This may be supplied by the facility arrangement at the reactor or may have to be furnished as part of the loop equipment. Almost any solid material which is of sufficient mass and is not hazardous to personnel or to the reactor system may be freely used for shielding if it is compatible with the environment. The use of liquids for shielding should require certain safeguards.

a. Are all parts of the loop supplied with an ample shielding thickness for both normal and emergency operation?

Although isolation while waiting for the decay of radioactivity may be used in lieu of shielding, some parts of the loop may have to be approached by personnel to cope with the emergency before decay has taken place. A careful examination of the procedures which are to be followed during any credible emergency must be made to determine those parts of the loop which must be shielded to allow the emergency procedures to be used. (See section 2.3.5.e.)

Every part of the loop must be considered including sampling lines, drains, ventilation ducts, off-gas lines, demineralizers, charcoal traps, filters, etc., which may normally be radioactive or may become very radioactive due to specimen or loop failure.

b. Is undue advantage being taken of the already installed shielding of other experiments or of the reactor itself?

The use of common shielding walls or compartments for two or more experiments may introduce undesirable problems such as failure or maintenance activities of one experiment endangering the other experiments.

If the loop extends through the water shielding provided for a pool-type reactor, the radioactivity from the loop may prevent the pool-water level from being lowered for servicing the reactor. When it is necessary to lower the pool water in order to remove such a loop from the reactor (for disconnecting flanges, etc.), the problem may only be solved by a lengthy shutdown of the reactor to allow decay of radioactivity or decontamination of the loop. To avoid such difficulties, it will usually be necessary to require that the loop piping can be disconnected and removed without lowering the pool water or that it be adequately shielded to allow lowering of the water even under loop-failure conditions.

c. Is the shielding to be adequately supported? Can any credible mishap cause a loss of the shielding?

The support structures and the floor must, of course, be strong enough to support the shielding as well as to also support the weight of servicing machines or portable shields which may be required for the area. Reference must not be confined only to blueprints or reports of what the floor may support; a survey must also be made of what the floor is already supporting and of what other weights may be added while the shielding is in place.

Shielding walls made up of stacked blocks of any material must have a type of support which prevents dislodging of blocks by bumping or by forces that may be generated within the shield. This may be done by support frames, by use of interlocking blocks, by welding of metal blocks together, by mortaring concrete blocks, etc. This is important not only from the standpoint of loss of shielding but also to protect personnel and equipment from falling shielding blocks.

When tanks of water or other liquids are used as shields for personnel protection, there must be some guarantee that the liquid will not be lost due to puncture of the container or other cause. The use of liquid-level monitors, continuous overflow, etc., should be supplemented by routine visual inspection.

2.3.5. Equipment Cells

Equipment cells may be provided for a number of reasons which include: secondary containment for radioactive gases, liquids, or dusts; shielding against direct radiation; suppression of noise from pumps, compressors, etc; protection of equipment from environmental abuse; containment of a possible explosion or violent rupture of high-pressure equipment; protection of personnel from electrical hazards; confinement of noxious or explosive fumes; and provision of special conditions such as air-conditioning or heating.

Therefore, the reviewer should not assume that the mere existence of an equipment cell will satisfy all the requirements that may be necessary for the loop. Also, since several or all foregoing reasons for any equipment cell may exist for a single cell, it should be ascertained that the cell is adequate for all hazardous events and that one of these events will not destroy the cell's effectiveness for other safety requirements.

a. In providing the equipment cell, have the designers foreseen all the purposes it must satisfy?

It would be well to first establish the intended purpose of the cell before proceding to a review of whether or not it meets all the requirements for the loop. This should aid in locating inadequacies with respect to other purposes which the reviewer may find that the cell must serve.

This question should be reconsidered after other aspects of the cell and its contents have been reviewed.

b. Should the equipment cell act as a secondary containment for releases of radioactive materials? If so, what type of containment is required? (See 2.3.1.6.)

If the cell houses primary loop equipment which contains a liquid or gas which is, or may be, expected to become radioactive due to a

failure, it must provide some degree of containment. If the amount of radioactivity is minor and cannot become airborne, the cell need only be a barricade against entry by unauthorized personnel. If the amount of radioactivity is not trivial and may become airborne due to leaks in the equipment, containment by the cell will be necessary.

If there is a guaranteed off-gas system with adequate cleanup for any discharge from the cell, the containment provisions need only guarantee that the airborne radioactivity be delivered to the off-gas system. For this to be done, all leakage through cell openings must be inward even under the worst failure conditions of the equipment in the cell such as rupture of a high-pressure system. This can be guaranteed by a sufficiently great underpressure in the cell or by total sealing of the cell. If sealing is used, then, of course, the cell walls must be able to withstand the maximum possible internal pressure that an equipment failure might generate.

If an off-gas system is not provided or if the off-gas system cannot be allowed to receive the full amount of radioactivity that can result from a failure, then total sealing of the cell is the only form of containment acceptable.

Total sealing, or static containment, introduces a group of problems for the designer and experimenter and is more expensive than dynamic, or continuously vented, containment. Its use should be avoided when it is possible and safe to do so. Some of the problems of total sealing are:

(1) The cell atmosphere may have to be air-conditioned to remove heat generated by pumps, lights, etc.

(2) There must be some monitor to detect any accumulation of oil vapors or gases from heated equipment to prevent an explosive atmosphere in the cell unless it is filled with an inert gas.

(3) If there are water lines in the cell which may leak, well trapped drains must be provided unless accidental filling of the cell with water is not hazardous.

(4) Direct personnel entry into the cell should be prohibited when the loop is in operation and contains radioactive materials. If a person enters such a cell under these conditions, he should be considered in jeopardy.

(5) All penetrations for wiring, piping, valve stems, etc., must be well sealed and well maintained.

(6) In case of a failure and release of radioactive material into the cell, a lengthy shutdown of the reactor will be required to await decay and/or cleanup of the airborne radioactivity before any work can be started toward repairing or removing the loop from the reactor.

(7) It may be necessary to provide the cell with remote handling equipment for performing some operations.

The containment requirements which must be met must be those for the site where the loop is to be operated. Although it may be allowed at some sites to have no secondary containment or only dynamic containment, the site in question may have to require static containment for the same type of loop. It is very important that this point receives thorough attention especially at those sites equipped with gaseous-waste disposal systems which automatically shut down when some upper limit of radioactivity of the discharged gases is reached.

c. Can all equipment, especially that required for coping with a failure or other emergency, be operated without jeopardizing personnel?

If a cell cannot be entered under emergency condition, it is obvious that all valves or other equipment which must be operated then must be equipped to be operated from outside the cell. The use of only electrically or pneumatically operated valves for this purpose is questionable since the emergency may include or even be caused by loss of electric or pneumatic power.

d. Will all the loop primary components which might leak be located in the cell or in other adequate containment?

e. Is the cell adequately shielded for both normal and emergency operation?

If the cell is located in a region which must be frequented by personnel even in an emergency situation, it should be shielded for the worst credible case of discharge of radioactive materials into it. Since such shielding will likely be required for large wall areas some economy can be realized by keeping in mind that it is for emergency purposes and may not need to reduce the radiation to the eight-hour-per-day allowable level.

If the cell must be shielded for either emergency or normal operation, this shielding should not necessarily be considered adequate for all conditions. In order to allow personnel entry into the cell for maintenance between operating periods, certain components such as filters, demineralizers, and charcoal traps may require individual shielding even though they are within the shielded cell.

2.3.6. Instrumentation and Controls

As with instrumented capsules, loops are equipped with instrumentation to provide:

a. Experimental data,
b. Environmental control, and
c. Safeguards.

Therefore, as with capsules, the reviewer must not assume that the mere presence of instrumentation enchances safety. For the most part, the questions and comments regarding instrumented capsules also apply to loops. Comments which are specific to loops have been included in the discussions of individual components of the loop.

2.3.7. Fabrication and Assembly

The reviewer must be assured that the loop, as built, will satisfy the approved specifications of the designer as well as those required by the reviewer himself.

a. Will the fabrication and assembly controls specified by the designer be adequate?

The following are some of the requirements which must be insured by an interested and competent inspector who keeps close control of the fabrication and assembly:

(1) There must be no unauthorized substitution of materials or components for those specified by the designer and approved by the reviewer. This includes not only all major parts but also all small parts such as welding rods, bolts, nuts, washers, gaskets, valve packings, cotter pins, etc. Substitutions should be allowed only by approval of both the designer and reviewer.

(2) All dimensions must be as specified. Any deviations must be specifically approved by authorized personnel.

(3) All welds required for support or for containment must be checked by standard approved techniques to guarantee their integrity. Some types may need only visual inspection, while others require the use of dye penetrant and/or x-ray techniques. Such specifications are available in existing standard codes.

(4) Piping must not be installed in such a manner that it is under severe mechanical tension. Pipe supports and clearances must also be arranged to allow for thermal contraction and expansion of the pipe.

(5) All piping and other components of the loop must be cleaned of grease, dirt, welding scale, etc. Stainless steel must be protected from chloride contamination and aluminum piping from various materials such as graphite, copper, and mercury which may enhance corrosion in aqueous systems.

(6) The bolts in critical flanges should not be tightened too much. This is especially important for those which will be subjected to severe thermal cycling. A torque wrench should be used.

(7) All components and the assembled systems which will be operated under pressure must be pressure checked. The overpressure of the check above the intended operating pressure will be dictated by the applicable code and will depend to some extent on the intended operating temperature. A minimum overpressure of fifty percent is advisable.

(8) Any difficulty encountered during the fabrication and assembly which jeopardizes the desired quality of the installation,

or any part, should be reported; and, perhaps, a revised design can resolve the difficulty. This would be illustrated by the impossibility of inspecting a weld because of lack of accessibility.

2.3.8. Installation and Removal

The only acceptable answer to the following questions (a), (b), and (c) for the reviewer is that some knowledgeable person or persons familiar with both the loop and the reactor will directly supervise every detail of the planning, scheduling, and installation work performed whether during a reactor shutdown or during reactor operation.

a. Has the installation of the loop been planned in such a manner that it can be done during the time normally available between reactor cycles?

If the total installation cannot conveniently be done during the time available during a single shutdown of the reactor, prescheduled increments of the installation work should be planned for two or more shutdown periods. Although it may be possible to prolong a reactor shutdown for the installation, it should be specifically determined that this is possible for the particular loop. A poorly planned partial installation may result in hazards to personnel, to the reactor, or to the loop components. Some points to be checked are:

(1) The use of temporary shielding,

(2) The use of temporary coolant supplies for components installed in the reactor,

(3) The use of temporary support structures for shielding, loop components, etc.

b. What installation work will be done while the reactor is in operation? Can this jeopardize personnel or the reactor?

Work which may cause some item to be dropped into a pool-type reactor or upon existing operating equipment should be avoided or very carefully controlled. Equipment installation work is frequently done by personnel who are not very familiar with radiation hazards and do not know the dangers which might arise

from abuse of existing equipment such as pipes, electrical wires, stacks of shielding blocks, etc. When climbing must be done by the workmen, ladders or platforms should be provided to prevent their using piping, conduits, etc. The work area must be carefully inspected and the workmen instructed as to what they must not touch, bump, step on, or move.

c. Can the planned method of installation damage the reactor or other existing equipment?

Activities which create dust such as chipping or drilling concrete, grinding pipes or welds, sawing wood, etc., may plug air filters, harm delicate equipment, or dirty the water in pool-type reactors. Such activities should be done in properly ventilated enclosures, or wetting-down techniques should be used. Otherwise, equipment subject to damage or fouling by dust should be covered.

Items to be inserted into the reactor must be handled carefully and there should be a last-minute examination to determine if dimensions are correct, surfaces are clean and free from scratches, there are no burns on the surfaces due to welding, and there is no warpage of items which must be straight. Those items which may damage the reactor if inserted too far, such as beam-hole plugs, must be equipped with sturdy mechanical stops to prevent their being accidentally inserted too far. No reliance should be put on the promise of the person doing the work to refrain from inserting the piece too far.

Careful preparations may have to be made for connecting into existing water lines and electrical supplies, especially when this involves a shutdown of the service. All users of the service must be warned in advance of the shutdown so they can prepare for it.

The use of a hoist to insert heavy items into a reactor must be very carefully controlled. This is especially true for lifting operations. If upward forces must be limited, the use of some device to measure the lifting force is advisable.

d. If the installed loop is not to be regarded as a permanent facility, will the intended method for its installation and removal leave the reactor facility undamaged for future use?

It should be known that all alterations to existing structures are reversible or that they are an improvement to the facility. It should certainly be assured that any alterations will not make the facility useless after removal of the loop. It should also be known that all parts of the loop will be removable and not require long delay times such as may happen in the case of dump tanks or filters which are not accessible for removal in portable shields.

e. Is a standard well proved procedure being used for the installation of parts in the reactor and for their removal?

If portable shielding or special handling tools will be required for removal of loop components from the reactor, these should be on hand before the installation is begun. Otherwise an early failure of the loop may involve a lengthy shutdown of the reactor while the necessary tools and shields are being built.

If new techniques or new types of complex tools are to be used for the installation and removal, a trial insertion and removal of the system should be done in a mock-up of the facility if possible. This is especially important when the actual installation will involve some radiation exposure of personnel and the work must be done smoothly and swiftly. If underwater manipulations must be done which require some precision, these also should be tried first in a mock-up. This is particularly important for removal operations which must be done on a component which is so radioactive that the water level cannot be lowered.

The technique for removal of the loop must, of course, be adequate for its removal after experiencing the worst credible failure of an irradiation specimen or of the loop itself.

f. What disposal is planned for the nonreusable parts of the loop when it is removed?

This decision should not be put off until the loop is installed. Since the loop may fail and have to be removed early, its final disposal should be included in the original planning.

2.3.9. Specimen Insertion and Removal

This discussion is concerned with specimens which have already been approved for insertion into the loop. It is assumed that they have been reviewed as either instrumented or noninstrumented capsules or rigs and are acceptable for the loop environment.

a. Is the method of insertion and removal likely to damage the specimen or the loop?

Almost any insertion and removal technique is likely to cause damage to the specimen unless very carefully done. The best assurance against damage is for the specimen to either be difficult to damage or be mounted in some type of rugged package which protects it.

Insertion and removal tools, if possible, should be manually operated to detect unexpected obstructions and to better control the forces being applied.

If the specimens are expensive, the insertion and removal techniques should be proved by use of dummy specimens. (This would likely be requested by the reviewer only if damage to the specimen will result in a hazard or loss of reactor operating time.)

b. If the irradiated specimens are to be removed into a portable shield, will the shielding thickness be adequate for the most radioactive specimens foreseen for the loop?

New shields should be checked with sources to be certain that the walls do not contain voids, especially if they are made by pouring lead or concrete into a cladding shell.

c. If the specimen should be damaged during insertion or removal, what hazard, if any, may result?

If damage to the specimen will result in the release of an appreciable amount of radioactive gases, there should either be provisions for containing or disposing of the released gases or the operators should wear appropriate gas masks.

d. During the removal operation, is it possible to pull the specimen too far (through a shield or above water) so that personnel may receive excessive exposure to radiation?

Good intentions have not always prevented radiation exposure of personnel from this cause. The use of mechanical stops should be required. Specimens have been pulled all the way through removal shields and too high in water. Some shields have been too short so that radioactive wires and tubes extended through the tops of the shields when specimens were drawn into them.

e. Have provisions been made for removing damaged specimens?

Unless a long decay time and/or a very thorough cleanup of the loop can be accomplished, the removal of damaged specimens containing fissionable materials may be expected to involve a release of some fission-product gases. If the removal technique allows mixing of water from the loop with the water in pool-type or tank-type reactors, the problem of cleaning the pool or reactor water must be considered. Radioactive gases may be evolved from the pool surface for several hours after it is contaminated with fission products.

Unless careful planning has been done, it may be found that the parts of the loop which must be approached by personnel to effect the specimen or loop removal will be too radioactive to allow the work to be done. Long delays have been caused when the reactor pool water was the only shielding and, because of radiation, could not be lowered to allow access to flanges or other devices which had to be disconnected to remove either a specimen or the in-reactor part of a loop.

Specimens which are dry when removed from a loop or other facility may evolve radioactive gases or release radioactive particles. Particles may be shaken loose even from an intact dry specimen. Direct withdrawal into a shield which is ventilated to an off-gas system or to an efficient vacuum cleaner should eliminate most radioactive dust problems.

2.3.10. Handling Tools and Shields

For economy of both money and storage space, new experimental rigs should be designed to make use of existing handling tools and portable shields if this is possible. One of the most trying problems for reactor operators is to provide adequate storage space for an ever growing number and variety of long-handled special tools which are usually somewhat contaminated. A similar problem exists for portable shields although these can usually be stored a greater distance from the reactor. If, however, existing tools and/or shields are not adequate or if the designers can provide truly superior tools or shields for safer or more efficient handling techniques, then the new items should be supplied.

a. If existing tools and/or shields are to be used, are they adequate in all respects?

   Following are some of the points which should be checked:

   (1) The strength of the tool must be adequate for the weights it must support.

   (2) There must be a sufficient number of tools. If two must be used simultaneously, then there must be two. (Sometimes a common long handle is used for a variety of tool heads so only one tool at a time may actually exist.)

   (3) The existing tool may have been provided for a different environment. Some tools which may be acceptable for use in a dry facility may not be acceptable for use in water.

   (4) Portable shields must be of adequate size, have sufficient shielding thickness, and provide the necessary degree of containment. As with tools, a shield designed for dry usage may not be appropriate for underwater usage.

b. If new tools and/or shields are to be provided, will they be suitable and dependable?

   Some of the comments under question (a) apply here also. The best proof of the suitability of handling tools is to test them in a mock-up of the facility or in the facility itself using nonradioactive or slightly radioactive specimens. It is of extreme importance that any shortcomings be discovered prior to actual use with very radioactive materials.

Any new tools or shields which must be provided for specimen or loop removal should be on hand and pretested prior to installation of the specimen or loop.

Following are some of the points which should be checked for new tools and portable shields:

(1) Small items such as locking pins, nuts, or bolts which must be attached or detached while the tool or shield is over the reactor core should be attached to swivels on chains which, in turn, are attached to the tool or shield body to prevent their being accidentally dropped into the reactor.

(2) There must be some assurance that no part of the tool or shield such as nuts, bolts, washers, springs, etc., can work loose or break and fall into the reactor.

(3) If the tool or shield is to be used in reactor water or storage-pool water, it should not contaminate the water with any objectionable material such as a lubricant or types of metal ions which cannot be tolerated.

(4) If a tool or shield must be used in a radioactive fluid, it should have no compartments from which the fluid does not automatically drain as the tool is withdrawn unless the fluid is to be intentionally retained.

(5) If a beam of radiation will exist during the removal procedure, as from an unshielded beam hole, the tool or shield must be designed so that it can be handled by personnel standing out of the beam path or behind shielding.

(6) When extremely radioactive materials must be handled under water by use of a tool attached to a hoist, accidental withdrawal of the material above the water can be prevented by making the tool sufficiently long.

(7) New portable shields not only should be checked for adequate thickness of shielding but also to discover if any voids or other radiation leakage paths exist in the assembled shield.

(8) Portable shields must not be too heavy for the floors, hoists, and handling tools.

(9) Handling tools and shields must be made of or clad with materials which will not deteriorate under the expected conditions of use, decontamination, and storage.

(10) Any shield or piece of handling equipment which must provide positive containment must be capable of being tested for leaks prior to usage unless it is of such simple design that visual inspection is adequate.

(11) A plastic envelope around a portable shield or other equipment is not a guarantee against leakage of radioactive gases unless the envelope is continuously vented to an off-gas system which is kept under negative pressure, and there is some means of protecting the envelope from damage. If there is no air sweep through the envelope, any leaking gases will accumulate and produce a direct radiation problem. Plastic envelopes are, however, helpful in preventing the spread of contamination from surfaces. (Plastic-wrapped contaminated objects must, of course, be handled carefully to avoid damage to the plastic.)

(12) It is important that the tools and shields supplied for a special purpose are stored in such a manner that they are immediately available and in good condition when needed. They must be protected from damage, deterioration, and being subverted to other uses.

2.3.11. Operating Procedures

The reviewer must not be content with checking only the hardware and instrumentation of the loop. He must know that the actual usage and operation will be consistent with the usage and operation which is approved. To guarantee this, the various tasks which are associated with operating the loop should be described in detail in writing, and deviations should require new approval. Errors made by the operating personnel have caused a high percentage of the cases of contamination spread and radioactive gas releases from loops.

a. Have written procedures been prepared for all important tasks associated with operation of the loop, and are these in sufficient detail?

A written procedure is not only a description of how an operation is to be performed, it should also include the following:

(1) A description of what is to be accomplished;

(2) A list of special tools, equipment, checklists, etc., which are necessary for performing the task;

(3) The personnel requirements for the task;

(4) Any preparations which must be made;

(5) A step-by-step description of the task itself together with any precautions which must be observed;

(6) Any follow-up operation which must be done such as checking for contamination, locking valves, disposing of materials, cleaning of tools, etc.; and

(7) Reporting the results of the operation if this is required.

b. Are the procedures acceptable for safe operation of the loop and for the accompanying tasks of specimen insertion and removal, prestartup tests, sampling, radiation and contamination control, etc.?

Each procedure should be reviewed in detail; checking that a written procedure exists is not sufficient. If any procedure is questionable, it should be proved by a test run before any hazard is involved.

For complex tasks which involve several steps, such as valve manipulations, a checklist type of procedure should be used. This is particularly important if there might be a change of personnel during performance of the task.

c. Have procedures been prepared for coping with all foreseeable emergency situations?

Adequate emergency procedures will dictate what emergency equipment must be supplied. Such preparations can greatly lessen the exposure of personnel to radiation and save reactor operating time. A great deal of time can be lost if special equipment and tools have to be built after an emergency situation develops. It may not be possible to write some of the details of all emergency procedures; but it is possible to list the personnel who are

to be notified, to describe the method for shutting down the loop, to list any precautions about firefighting, etc. It should be kept in mind that the regular loop operators may not be always available to cope with the emergency. It is, therefore, of great importance to describe how to recognize that an emergency condition exists if it might not be immediately obvious.

d. Where will copies of the written procedures be kept? What are the guarantees that they will be followed?

Copies of the procedures must always, of course, be available to the loop operators. They must be trained in the use of the procedures and cautioned against deviations from them without due authorization. The reviewer, however, should not burden himself or the loop operators' supervision with obtaining lengthy approvals for deviations which are not hazardous. The procedures should be carefully examined and only those parts which might produce a hazard if unwisely changed should require new approval by the reviewer. Any deviation from any standard procedure should, however, require approval of the loop operators' supervision. It is not good practice to allow arbitrary deviations from the written procedures by the operators; if this is allowed, the written procedures will lose their importance and deviations which will be hazardous will also occur. Any procedure which needs to be changed must be rewritten and properly approved.

It is important that operating loops be periodically reviewed to see that the written procedures are being followed.

2.3.12. Personnel Requirements

The number of personnel required for operating a loop will depend upon its complexity and upon the requirements of immediate attention to maintain the proper and/or safe operating conditions.

a. Is the loop supervisor's estimate of personnel requirements realistic?

It should be determined whether constant or only periodic attention to the loop is required. If constant manning is required, one man per shift is not enough. Consideration must be given to rest periods and lunch time.

b. What variations may the personnel requirements have?

It may be necessary to require higher technical supervision during startups, shutdowns, and times when there are operating difficulties although a technician may be sufficient for manning the loop routinely.

c. Will the required personnel be available and well trained at the time the loop is initially started up?

A trained operator should have a knowledge of all the loop components, the written procedures for operation and for coping with emergencies, and all safeguard requirements. He must also have instruction about what he may not do, such as disarming of safeguard instrumentation, deviating from the prescribed procedures, making decisions about matters in which he is not competent, etc.

d. Are there considerations other than attention to the loop controls which determine a minimum number of personnel?

Even when the presence of personnel is not required constantly, there may need to be a minimum of two people present for making checks and adjustments. This is especially important when the loop components are remote from constantly manned personnel locations and there are hazards from steam, electricity, acids, etc.

2.3.13. Minimum Safeguard Requirements

The degree to which a loop is safeguarded will depend to some extent on the cost of a failure in loss of data, loss of loop equipment, and loss of reactor operating time as well as on actual hazards to personnel and to the reactor. There will likely be a further dependence on whether or not the loop is constantly manned.

a. What safeguards may be replaced by constant attention from an operator?

An operating temperature or pressure controller may be replaced by an operator who keeps a coolant flow, heater, throttling valve, etc., correctly adjusted; exceeding of an upper safe limit of temperature or pressure, however, should not be safeguarded against by only operator action.

b. Which safeguards are required for actual safety of personnel and the reactor? What is the minimum number of each that should be allowed?

Important safeguards are often supplied in more than the minimum number to allow continued safe operation if one or more of the safeguards is lost. The reviewer should prescribe the minimum number of these safeguards (which should exceed one) and require that the loop operation be immediately terminated when less than the minimum safeguards exist if actual safety may be affected.

c. What single safeguards require immediate termination of the loop operation if lost?

Loss of secondary containment may be a cuase for immediate shutdown of a loop. For dynamic containment, this would result if the ventilating system stops functioning. For static containment, a leak in the containment wall would constitute loss of secondary containment. In either case, if a leak occurs in the primary containment, the secondary containment system then becomes a primary containment; and immediate shutdown should be required. Other single safeguards whose loss may require immediate shutdown include emergency electrical and coolant-supply systems.

d. Under what conditions can the minimum number of safeguards be reduced beyond those originally specified?

When a loop is being designed, it may be necessary to require some safeguards because of lack of knowledge of what the actual performance will be. After initial operation and tests, it may be found that these can be removed. The reviewer should approve such removals only upon being supplied with sufficient evidence that the safeguards are not required. (Conversely, the initial operation may indicate a need for additional safeguards.)

2.3.14. Maintenance

Good maintenance is required to keep a loop and its components in safe operating condition. The reviewer should require that an appropriate maintenance procedure be established and followed.

a. Has the experimenter devised a thorough maintenance program which will insure a safe and operable condition for the loop and all its components?

A good maintenance program should attempt to prevent failures of equipment rather than to simply replace or repair parts which fail. In order for this to be done, a maintenance schedule must be prepared to insure that servicing and replacement of parts are done at sufficiently frequent intervals to prevent failure. Some of the items which must be included in the schedule are:

(1) Lubrication of all components, which require it, on a schedule recommended by the manufacturers and for the particular operating environments.

(2) Replacing filter media and cleaning of strainers at frequent enough intervals to prevent their becoming plugged or deteriorating.

(3) Replacing of parts subject to radiation damage or wear before they fail. Some items to be considered are: brushes on electric motors, valve packings, gaskets, demineralizer resins, filter media, bearings, and all in-pile parts.

(4) Keeping all parts clean of any dirt or other material which will impair their functioning.

b. Are the intended checkout procedures to be performed frequently enough?

The frequency of performing checkout procedures will depend on the expected life of components, the available time, whether some alteration has been made, and whether or not some malfunction exists. It is of particular importance to require that emergency systems and safeguard instrumentation be thoroughly checked for performance at least before each startup of the loop. If the loop operating time is long, checkouts should also be arranged at other intermediate times such as at the end of reactor cycles.

To guarantee that all checkouts are done thoroughly and on schedule, the use of checklists should be required at least for complex systems.

c. Will the maintenance and checkout procedures be performed by established, experienced groups?

If such groups do not exist, the reviewer should have some assurance that personnel will be made available and trained before the loop is operated.

If such groups already exist, the reviewer should have assurance that they will be supplied with ample information and opportunity to maintain the loop and its components. Such information should include design drawings, instrument and piping flow sheets, manufacturers' servicing specifications for all equipment, wiring diagrams, etc.

d. Are ample spare parts and materials to be provided?

From a study of the maintenance requirements, a list of necessary spare parts should be prepared. It will probably not be necessary to have a spare for every part, but spares for some items should be required. These would include:

(1) Any item which must be replaced routinely,
(2) All electronic tubes for instruments required for safe operation,
(3) All important electrical relays and switches,
(4) Main coolant pumps or sufficient parts to rebuild one if it can be done in a short time,
(5) Valves or valve parts, and
(6) Any other component required for safety or to prevent a long reactor shutdown.

Spare parts and materials must be kept in a place where they can be easily found and where they will be protected from damage. An inventory should be made at properly spaced times to insure that an adequate supply is always on hand.

2.3.15. Emergencies

Handling of emergencies has been discussed in part in other sections. The reviewer should consider the behavior of the loop and each component under emergency conditions as he reviews them, but a resumé of preparations for emergency conditions should also be made.

a. Will the loop operators always know when an emergency condition exists? Is it possible from instrument indications to foresee and to preclude a hazardous emergency by corrective action?

An analysis of instrument responses to various abnormal conditions should be made to aid the operators in making fast decisions. Corrective actions for predictable abnormal situations should also be prescribed.

b. Will any emergency procedure be of such importance and complexity that it should be rehearsed?

The use of all handling equipment and procedures for removing damaged specimens should be demonstrated; this is particularly important if the removal procedure requires containment of radioactive gases or other easily spread types of radioactive materials.

Emergency supply systems for electricity, compressed gases, coolant, etc., should be tested under simulated emergency conditions at sufficient intervals to demonstrate their reliability. Any emergency system which cannot be routinely checked in this manner cannot be considered reliable.

c. Are all emergency tools and equipment stored so they are immediately available? Will they be in working condition when needed?

If emergency situations do not occur frequently, the emergency tools and equipment may be allowed to deteriorate or be subverted to other uses. The reviewer should have positive assurance that this will not occur.

d. What groups other than the loop operators will be involved in coping with emergencies?

Other groups such as the reactor operators, other experiment operators, firefighters, and radiation control groups will likely become involved in controlling some or all emergencies. It is important that they be furnished with ample information and any training that may be required for their participation.

e. Who should be notified about the existence of an emergency situation?

If the loop is continuously manned, the operators should be furnished with a list of the various personnel who must be notified for the several types of emergencies that might occur. If the loop is not continuously manned, this information must be supplied to the groups who will likely discover that an emergency situation exists. It may be necessary to furnish this information on a sign posted at one or more places where loop components are located.

2.4. Beam Experiments

Most of the equipment associated with beam experiments is external to the reactor and can be repaired or replaced without requiring a reactor shutdown if a beam shutter is provided. The reviewer, then, usually need not concern himself with the reliability of this external portion of the equipment unless failure can produce some physical hazard to personnel.

2.4.1. Collimating Plugs

a. Is the material of the collimating plug compatible with the material of the beamhole liner?

If the space between the plug and the beamhole liner is to be kept dry, materials compatibility is not a great problem with respect to corrosion. If, however, the space must be flooded with water for cooling or shielding purposes, the plug must be clad with a material which is compatible with that of the beamhole liner. This is particularly true if the plug material is concrete or graphite and the beamhole liner is aluminum.

If the space between the plug and the liner must be kept dry, neither the plug nor the liner should be cooled sufficiently to cause moisture to condense on the surfaces. If either must be kept at a low temperature, a dry atmosphere should be provided in the space between them.

A great deal of trouble with galling has been encountered when aluminum-clad plugs were used in aluminum-lined beamholes and when stainless-steel-clad plugs were used in stainless-steel-lined beamholes. If the beamholes are lined with aluminum, the plugs should be clad with stainless steel and vice versa. This

is of particular importance when clearances are small. The use of dissimilar alloys of the same type of material may also be possible if tested for tendency to gall prior to use.

b. Are the outside dimensions of the plug acceptable?

The length of the collimating plug should be such that it is not possible for it to be accidentally jammed against the inner end of the beamhole if it is of the thimble type.

The outside diameter(s) of the plug must be such as to minimize radiation streaming along the plug and yet leave enough clearance to allow easy insertion and removal. The clearance should be as large as can be tolerated. Since most beamholes are equipped with steps to minimize streaming, clearances of as much as 1/8 in. or more on the diameter are possible for most reactors. If the plugs are to be machined so that the dimensions, roundness, and straightness are carefully controlled, minimum clearances may be used; if not, maximum clearances should be required.

c. If the plug is to be water-cooled, is such cooling really necessary; and can any hazard result from a leak in the water system?

When possible, water cooling should be avoided. It may be found that, if the plug extends only the minimum necessary distance into the beamhole, special cooling of the inner end may not be required.

If water cooling is necessary for the plug or for any special moderating material in the beamhole, the system must receive very special attention to insure that it will remain leakfree during the expected lifetime of the experiment. Since collimator plugs frequently must continue in service for a number of years, the cooling system should be expected to withstand the resulting amount of corrosion without leaking.

A water leak into a beamhole may have several objectionable effects. It may:

(1) Wash radioactive particles from the beamhole to cause a severe contamination problem;

(2) Increase or decrease the reactivity of the reactor if the water is impounded in the inner end of the beamhole. (In water-moderated reactors, the reactivity change is usually positive.); and

(3) Drastically change the output of any ionization chambers located near the inner end of the beamhole if the water is impounded there. (Changes of more than 50% have been observed and, if these are reactor power-level control chambers, the results may be serious.)

When the plug must be water-cooled, it is far safer to install a constantly open drain to dispose of the water from any leak which may occur than to simply rely on the integrity of the cooling system regardless of the care that is used in the design and fabrication.

If water or gas cooling of the collimating plug is necessary to protect any part of the reactor system or to avoid a personnel hazard, the reviewer must require that it be guaranteed with appropriate instrumentation and that a reactor power reduction occur automatically if cooling is lost. As with other systems requiring cooling, the region being cooled should be monitored directly with thermocouples or the coolant flow downstream from the plug should be monitored.

If the water passes through a region having an appreciable fast neutron flux, the exit water line may require shielding due to the presence of nitrogen-16. If the water contains dissolved solids, objectionable concentrations of other radioactive materials may also be generated. This will, of course, depend upon the time the water remains in the neutron flux.

d. Can standard handling tools, shields, and procedures be used for installing and removing the collimating plug?

If the proposed standard method has been found acceptable to the reactor operating personnel, then it should be required unless it cannot be used for the necessary requirements of the experiment. If only the design need be altered to accommodate standard

procedures, the alterations should be required. When the proposed standard method (usually for new reactors) has not been found acceptable, revisions may be required. The reviewer should consult the operating personnel about this point.

In some locations, operating groups may prefer that the collimating plug be installed in the form of interlocking segments which can be inserted into the beamhole piece by piece. This may be due to ease of handling, working space, available shields, storage facility design, or other reasons. The use of a single integral plug, however, enchances proper alignment and the integrity of cooling systems.

2.4.2. External Shielding

The amounts, types, and placements of external shields for beam experiments vary greatly. The details will, of course, have to be worked out for the type of experiment being conducted and for the available space for installing it. The reviewer must be concerned with insuring that, under all conditions, objectionable amounts of radiation do not penetrate beyond the immediate working space assigned to the experimenter and with seeing that the experimenter provides himself with means of protecting himself from radiation at all times when working in the beamhole vicinity.

a. Will the experimenter be working with the primary beam from the reactor or with a secondary beam scattered from the primary beam?

The primary beam consists of neutrons and gamma rays of a wide range of energies and so must be shielded by a combination shield consisting of a neutron moderator, neutron absorber, and gamma attenuator. If there is to be a neutron scatterer to provide a secondary beam, it must be surrounded by such a shield with a lesser shield for final disposal of the secondary beam. If the work is to be done with the primary beam, then much of the apparatus may have to be surrounded with a massive shield. The reviewer should ascertain that a study of past experience with beamhole shielding has been made by the experimenter and designer and that acceptable techniques are to be used (see section 2.3.4.).

Because of the nature of beam experiments, it may be expected that a radiation survey of the working area will have to be made after installation of the equipment to determine where additional shielding is necessary, both to protect personnel and to prevent an increase in the background at adjacent experiment locations.

2.4.3. Beam Shutters

If the reactor power cannot conveniently be reduced at any time the experimenter must make alterations to the equipment, a shutter for the primary beam should be provided. It is also convenient to have shutters for secondary beams if the primary beam shutter is cumbersome to operate.

a. Can the primary beam shutter be operated without hazard to the reactor? Is it adequate for its purpose? Is there a positive indication of whether it is open or closed?

One method of shutting off the primary beam is to flood the collimating tube with water. If this method is used, the water-filled volume must not be close enough to the inner end of the beam tube to appreciably influence the reactivity of the reactor or the signals from any nearby ionization chambers used for reactor control.

A primary-beam shutter located outside the reactor shield must be roughly equivalent to the massive shielding that must be used around a monochromator crystal. Unless such external shielding exists in part in the structure for the experiment, the shutter should be in the beam tube to take advantage of the collimating plug and reactor shield. The collimating tube may be shut by being plugged with a rod or bar of shielding material, by being filled with water for an appropriate length, by rotating plug segments to misalign segments of the beam collimator, or some variation of these.

There must be some method of easily determining whether a shutter is open or closed. If the shutter is visible, no indicator may be needed. If its position is not clearly visible, there should be some indication of whether or not a beam of radiation exists. Since valves may leak or be misoperated, sliding gates or plugs

may stick, and other mechanisms for shutting off the beam may also fail, the most reliable technique is to check with a reliable radiation monitor to know whether or not the beam has been stopped by the shutter-closing procedure. Although this may be done by portable instruments or by a permanently installed monitor, the latter is a better guarantee that a radiation check will always be made.

2.4.4. Instrumentation

Usually the instrumentation of concern to the reviewer will be that for guaranteeing coolant for the collimating plug and for warning of high radiation. Breakdown of most other beam-experiment instrumentation cannot cause harm to the reactor, loss of reactor operating time, or danger to personnel. (See sections 2.2.1, 2.2.3, and 2.2.4.)

2.4.5. Miscellaneous

Some of the considerations for other types of experiments may also be applied to the review of beam experiments. This is particularly true of the discussions in sections 2.3.4, 2.3.7, 2.3.8, 2.3.10, 2.3.11, 2.3.13, 2.3.14, 2.3.15, and 3.

2.5. Industrial Hazards

If the organization which operates the research reactor has a special safety group devoted to detecting and controlling "industrial" hazards, the experiment reviewer should be alert for such hazards also and bring these to the attention of the safety group. If such a safety group does not exist, the reviewer himself should see that control measures are devised.

Following is a partial list of the more common industrial hazards which may be associated with reactor experiments together with a few typical comments. Some of these have already been discussed in other sections.

2.5.1. Electrical

Electrical wiring should be in conduits in areas where it is likely to be damaged by environmental abuse. Circuit disconnects should be installed near the area where the electrically operated equipment is located. High-voltage systems should be clearly labeled; and, if the power source is of high enough capacity to cause death, the high-voltage

system should be behind an interlocked barricade which automatically shuts off and grounds the system when it is opened.

2.5.2. Harmful Chemicals

The various solvents and decontaminating agents frequently used around experiment installations may be toxic to personnel or may produce fire and explosion hazards when imporperly used. A high concentration of carbon tetrachloride fumes can be deadly. Also, this material should never be used as a fire-extinguishing agent in poorly ventilated areas since phosgene gas may be produced.

The vapors of acetone and similar volatile combustible solvents form explosive mixtures with air. The quantities of such materials which may be brought into containment shells should be carefully controlled. Also, the use of breakable containers for these materials is questionable.

When appreciable quantities of acids and caustics must be handled, as for regenerating demineralizers, proper safeguard clothing should be worn. Safety showers should also be available.

The alternating use of acids and organic materials for loop or other system decontamination must be carefully done with full knowledge of what products may be formed from any chemical reactions between the acid and organic material or other materials which might be involved. Such a procedure being used in chemical equipment in a hot cell produced an explosive compound which detonated and severely damaged the cell.

2.5.3. Explosive Gas Mixtures

Explosive gas mixtures resulting from the use of combustible solvents have already been mentioned. They may also result from an improper use of hydrogen, methane, acetylene, butane, natural gas, and other common combustible gases. One of the more common hazards results from experimenters' use of hydrogen as a refrigerant and as an atmosphere for irradiation targets. Other sources of explosive mixtures of hydrogen and oxygen are radiolytic gases from water and the electrolytic gases evolved from wet-cell batteries while they are being charged.

2.5.4. Inert Gases

A person entering a room filled with an inert gas, nitrogen, or carbon dioxide may be expected to collapse within seconds and die within minutes. Poorly ventilated rooms or other enclosures where sources of such gases

exist should always be suspect. Recently a man died when he entered a valve pit which had become filled with argon gas leaking from a pipe which was being pressure tested. Another incident involved a man who barely escaped a nitrogen-filled room before collapsing; the source of this nitrogen was a large liquid-nitrogen-filled flask being used as a source of coolant for a cold trap. Carbon-dioxide ice is another refrigerant which can produce the same type of hazard.

Any large enclosure which is intentionally kept flooded with an inert gas must be clearly labeled and barricaded against entry by unauthorized personnel. If any enclosure capable of being entered by personnel contains appreciable sources of inert gas, it must be well ventilated or equipped with a detector and alarm system.

2.5.5. Compressed-Gas Cylinders and Supply Pipes

If a cylinder of compressed gas falls over, the top valve may break off. This is especially likely to happen if a pressure-reducer assembly is attached to the valve. When this happens, the gas cylinder suddenly becomes a deadly, highly destructive jet-propelled missle. Gas cylinders should always be firmly fixed to some substantial structure when the protective end cap is off the valve. If the cylinder is kept in an upright position, it need only be chained to prevent its falling sidewise since, in this position, the force exerted on the cylinder by gas escaping from a broken top will be harmlessly spent against the floor. If the escaping gas is combustible, a serious explosion hazard may result. If it is pure oxygen, any combustion hazards in the vicinity will be temporarily greatly magnified.

Pipes and tubes containing high-pressure gases may be a source of several types of hazards. A jet of high-pressure gas can penetrate skin and produce painful damage or even death. A jet of high-pressure hydrogen may ignite spontaneously and cause an explosion from the gas which escaped prior to ignition. An explosion which occurred in this way once severely damaged a section of a reactor building and injured four people. The leak was caused when a carpenter accidentally drove a nail into a hydrogen-gas supply pipe which was hidden under structural material. Tubes and capillaries which contain high-pressure gases should, if possible, be inclosed in steel conduits particularly in areas where they might be subjected to

abuse. Direct handling of pressurized capillaries should be considered hazardous.

2.5.6. Dust, Smoke, and Vapors

Dust and smoke will foul many types of delicate instruments and other equipment used in reactor experiments. They will also rapidly plug absolute air filters and impair other filter systems.

Corrosive vapors from acids and some other types of chemicals can damage many types of equipment as well as be dangerous to personnel.

2.5.7. Overloading of Floors and Other Structures

This was discussed in Section 2.3.4.c.

2.5.8. Fire Hazards

In most cases, these should be obvious. The reviewer should know that ample fire-fighting equipment will be available near any fire hazard. This equipment must be appropriate for the type of fire which might be expected.

2.5.9. Falling and Tripping

Elevated working platforms and balconies should be surrounded by handrails and kickplates. Personnel thoroughfares must be kept free of pipes, electrical wires, etc., which might cause people to trip and fall. Any equipment which may leak oil should be placed in or over a catch pan to prevent the oil from producing a slipping hazard on the floor.

2.5.10. Vibration

Besides producing objectionable noises, vibration may damage equipment. Proper design and support of equipment should minimize vibration or limit its transmission to vulnerable components.

2.5.11. Noise

A high noise level may not only annoy personnel but will greatly reduce their efficiency. It may also mask audible alarms and will interfere with announcements over public address systems.

2.5.12. Low Clearances

Head injuries occur frequently around reactor experiment installations due to suspended shields, low-clearance thoroughfares, etc. Clearly marking or cushioning the offending objects with foam-rubber padding greatly reduces the injury rate.

3. FOLLOW-UP REVIEWS

The initial approval for the operation of an experiment should be for some specific period of time after which a new review should be requested.

a. What should the frequency of follow-up reviews be?

As soon as operating data is available, a short review of the adequacy or over-adequacy of safeguards should be made. Over-adequacy may be of no real importance if the experiment is to be operated only a short time. If, however, the experiment is to be operated for a long time, the experimenter should not be required to maintain unnecessary safeguards. (See section 2.3.13.d.) Other reviews should be planned on such a schedule that the reviewer keeps informed of difficulties. This is important not only to improve review techniques but also to demonstrate that the experiment and its operation are under surveillance.

b. What should be checked in the course of follow-up reviews?

The reviewer should check that the system is operating as predicted, that any difficulties have been safely corrected, and that all components are in good condition. Attention should be given to the following items:

(1) All changes which have been made in the components.
(2) All changes which have been made in operating limits.
(3) All changes which have been made in operating procedures.
(4) The adequacy of maintenance practices.
(5) All operation difficulties.
(6) The cause and correction of any emergency situations.
(7) The proved reliability or unreliability of all components.
(8) The adequacy of shielding.

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