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Manual for the Operation of Research Reactors

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1965

MANUAL FOR THE OPERATION OF RESEARCH REACTORS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

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FOREWORD

In view of the very large number of research reactors that are or soon will be in operation throughout the world, the IAEA has devoted special attention to the problems associated with their operation and efficient utilization. This interest has resulted in the publication by the IAEA in 1960 of a small manual on the "Safe Operation of Critical Assemblies and Research Reactors".

The great majority of the research reactors in newly established centres are light-water cooled and are often also light-water moderated. Consequently, the IAEA has decided to publish in its Technical Reports Series a manual dealing with the technical and practical problems associated with the safe and efficient operation of this type of reactor. The manual has been written by J. A. Cox of the Oak Ridge National Laboratory with the assistance of R. Skjoeldebrand, Division of Reactors, IAEA, and C. N. Welsh, Division of Scientific and Technical Information, IAEA.

Even though this manual is limited to light-water reactors in its direct application and presents the practices and experience at one specific reactor centre, it may also be useful for other reactor types because of the general relevance of the problems discussed and the long experience upon which it is based. It has, naturally, no regulatory character but it is hoped that it will be found helpful by staff occupied in all phases of the practical operation of research reactors, and also by those responsible for planning their experimental use.

CONTENTS

INTRODUCTION

This manual is meant to provide general information on the safety, operation and functional requirements of a number of systems pertaining to reactor operation. Because different facilities vary widely in design, it is not practical to be too specific concerning criteria or design details. Therefore an attempt has been made to limit the criteria to the functions which the systems must perform and to general problems of safety.

A number of examples are given of specific systems or situations generally associated with light-water moderated and cooled reactors. It is hoped that the various safety and operating problems described will enable the operating staff to visualize not only similar situations but entirely different ones which have not been foreseen.

One of the most useful messages which this manual can convey is that, since every situation cannot always be foreseen in the design and in the procedures initially developed, the operating staff must be constantly vigilant for new problems brought on by changes in fuel loading, fission-product build-up, changes in flux pattern, changes in experiments, or a multitude of other factors, any of which may unexpectedly confront the operator with a new, and sometimes unpleasant, situation.

While a number of desirable design features are listed for a reactor and its various systems, it should be pointed out that probably no reactor in existence includes all the features discussed. It is always possible to suggest improvements in the design of any reactor and the reactor manager should not necessarily change his reactor to conform with all the features listed since most reactors are successfully operated without many of these. It is hoped, however, that this manual, in pointing out desirable features, will cause the reactor manager and supervisors to appreciate wherein their reactor is superior or inferior and to provide effective safeguards against any deficiency in design or equipment by increasing administrative control, if necessary at the expense of some limitation on operations.

In considering the necessity of making changes in a reactor which has already been built, the reactor manager should consider whether administrative control can make up for any deficiency of design. It is probably true that a well-managed, poorly-designed reactor can be operated much more safely than a well-designed, poorly-managed reactor.

It is not claimed that the criteria given are perfect, but every reactor manager should be convinced that his reactor either meets these standards through inherent safety, designed safety, and administrative procedures or that the standard is incorrect or more rigorous than necessary.

Scope

This manual is directed mainly toward research and testing reactors with emphasis on those that are light-water moderated and cooled. An attempt has been made to include most of the fields encountered in reactor operations, together with comments on design, the start-up of new reactors, problems with experiments, procedures (both normal and emergency) and the training and qualification of personnel.

No attempt is made to consider all items which are normally considered in design, nor is this manual intended to outline a safety analysis of the type normally performed on a new reactor. The approach to the subject has been from the operational aspect, to make available to operators some experience of shortcomings in design that have not been obvious until after extended operation.

Limitation

The procedures and criteria outlined in this manual should not be regarded as binding; instead, they should be treated as recommendations to be considered and accepted or rejected, part by part, according to whether they pertain to the system in question or whether the probability of any particular accident occurring in the subject system is high enough to warrant consideration.

Since research reactors have so many different designs and are subject to the influence of widely different technical backgrounds, it would be presumptuous to attempt to discuss in detail the safety considerations of all the various types, even if the author were sufficiently familiar with them. However, many problems are common to all reactors and reactor staffs should attempt to project the examples given in this manual to their system, even though the examples may not apply directly because of the difference in design.

PART I. OPERATION

1. BASIC CONSIDERATIONS

The basic mission of the operating staff of a nuclear research reactor is, of course, to operate the reactor safely and efficiently and to provide experiment facilities for various research programmes. In achieving this rather simple objective, a skilled staff and much planning and hard work are required. The manager must train and qualify his staff, prepare procedures, plan for initial and routine operation and above all ensure the overall safety during all the various conditions likely to be encountered in operation, shut-down, start-up, maintenance, or any other normal or emergency situation.

While technical skills are generally considered to be the most important attribute of the operating staff, organizational skills are also very necessary. The training of the staff must not be too concentrated in theory, but must be heavily supplemented with practical experience. Standards for qualifying the staff for each position should be established and the operating staff organization should define the extent of each person's responsibility for decisions so that the proper level of technical competence may be brought to bear on a problem.

The specific hazards of reactor operation, i.e. criticality, radiation and contamination, are not encountered in other fields and must be carefully considered. Where necessary, administrative safety in the form of training, procedures, rules, check lists etc. should be added to the normal safety devices designed as part of the reactor. In specifying these, consideration should be given to the safety of the public at large as well as that of the staff and the reactor itself. Each hazard must be clearly set forth and emphasized in the training programme so that the staff understands the reason for the safety devices and administrative controls.

Since safety devices play such an important role in reactors and in some types of experiments, careful procedures must be followed for establishing the reliability of these at appropriate intervals. Safety devices cannot provide protection in every conceivable situation and these situations must be clearly recognized so that additional administrative safety may be provided.

Because it is usually necessary to change or supplement the procedures adopted with a new reactor, care must be exercised to ensure that the procedures are complete, properly authorized and readily accessible to the staff. If a rigid system is not followed when changing procedures, it may eventually be difficult to determine what the approved procedures actually are.

During the initial start-up a long series of tests must be performed which are designed to provide information for the subsequent safe operation of the reactor and experiments. Test procedures for the reactor and its auxiliary systems must be developed and operating and maintenance procedures and check lists must be formulated. After the initial start-up and testing period, the emphasis usually shifts to the task of keeping the reactor operating safely and efficiently. While it is sometimes assumed that routine operation of a reactor is very simple, this is by no means the case. Procedures must be changed as experience indicates flaws in the original ones or as equipment is changed. The qualification and training of the operating staff must be maintained, changes in the reactor and new experiments require safety evaluations, functional tests must be carried out at regular intervals to guarantee the safety of the facility and a myriad of other problems must be solved.

The manager of a routinely operating reactor must become familiar with the problems of the experimenters and other groups utilizing the reactor in order to increase the usefulness of his facility. He can do this in many ways, such as establishing standards for the design of experiments; providing consultation for groups wishing to do experiments in the reactor; and maintaining services which foster utilization. Such services include radioisotope production and assay, consultation on usage of radioisotopes and design of experiments, and dosimetry measurements which provide experimenters with the value of fast and thermal neutron fluxes and gamma heating in many locations in the reactor.

This list is by no means complete and the various problems involved in reactor operation will be discussed further in the following section.

2. STAFF ORGANIZATION

2.1. *Typical organization chart*

A typical organization chart is shown (Fig. 1), based upon a small reactor operating continuously and having a fairly complete and independent organization. No organization of experimenters is shown; it is assumed that this would be separate from the operating group.

2.2. *Size of staff*

The size of the staff depends upon a number of factors having to do with the size of the reactor and the research programme:

(1) Some small reactors operating only on day shift have an operating crew of only five or six people, whereas larger reactors operating continuously may require upwards of 50 people.

(2) The amount of service from other sections has a considerable bearing on the size of staff required. If established radiochemical, activation analysis and neutron dosimetry groups are already available, the added service required by the reactor can be handled with a small increase in staff. If, however, these groups must be provided for at the reactor, between five and six highly-trained staff members will be needed. These particular groups are among the most important for the successful utilization of the reactor. For instance, activation analysis and production and measurement of radioisotopes all depend upon a skilled radiochemical group. The dosimetry group is essential for the measurement of fast and thermal neutron fluxes and for determining gamma dosage received by experiments. All these functions might be in a single group or, in a very large laboratory, might each be in separate groups.

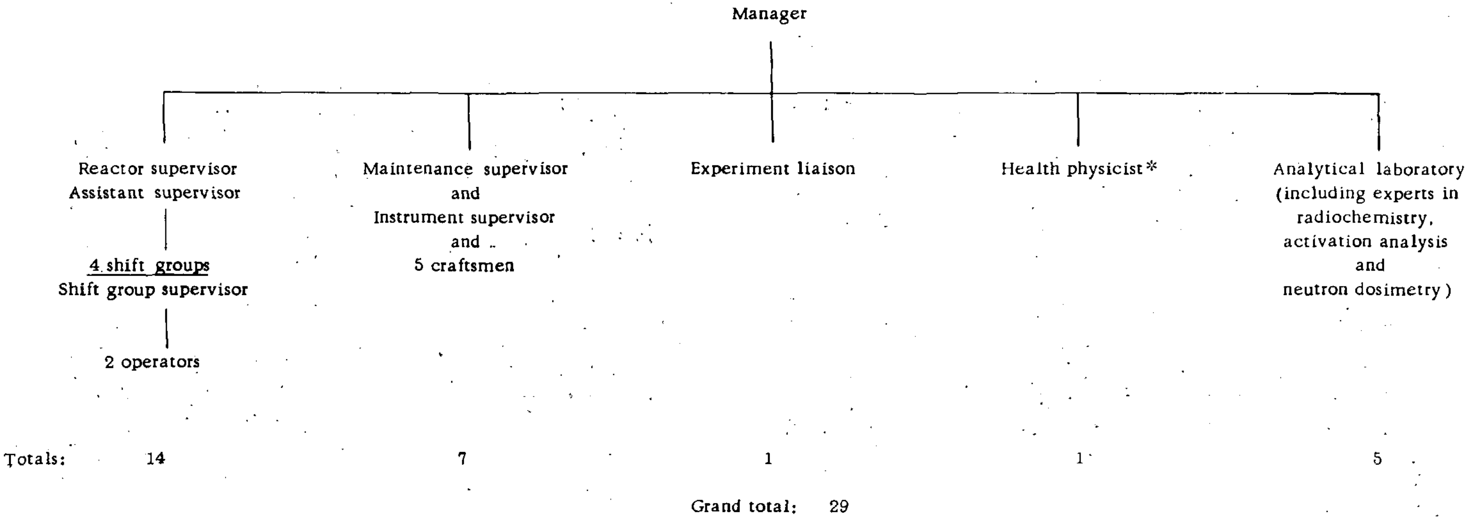

Fig. 1

Typical organization chart

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[*] The health physicist is often independent of the reactor manager but administratively attached to the reactor.

(3) A maintenance group must also be provided. If the reactor is attached to a large organization the existing maintenance group could probably handle the additional work at the reactor, whereas, if a special group has to be formed, perhaps four to ten people would be required for a small reactor. The size of the group would also depend upon how much of the maintenance work could be done by the operating staff and how much work was required for constructing experiments.

(4) An important part of the operating staff is in the liaison with experimenters. At least one person should be well trained in the problems of design and safety of experiments so that he can assist experimenters in preparing the experiments. This function is most important and without it the reactor is liable not to be well utilized.

(5) The staff conducting the experiments may be organizationally separate from the group operating the reactor, although some organizations include both these functions. The size of the experiment group will obviously vary over wide limits.

2.3. Responsibility

The ultimate responsibility for reactor safety should rest entirely with the reactor manager who may delegate it, in part, to his staff. One person should be delegated to be responsible at all times when the manager is absent so that, in case of need, the supervisor on duty always knows whom to call for assistance.

2.4. Duties of personnel

A suggested list of duties is given below for the reactor manager, the reactor supervisor and assistant supervisors, the radiochemist, the instrument and mechanical engineers and the health physicist. The duties of each of these are listed separately; however, there is no reason why several of the positions could not be combined, if the work load is not too great. For example, it might be possible to combine the positions of health physicist and radiochemist or instrument engineer and mechanical engineer.

2.4.1. Reactor manager

The manager should be generally familiar with nuclear physics, reactor physics, instrumentation, shielding, and hazards analysis including some meteorology and should have a basic scientific or engineering education. Technical specialists should be available for each of these fields, possibly also acting as senior supervisors at the reactor. The manager should, of course, have had considerable experience in reactor operation. His duties should include:

(1) Supervising the different groups in the operating organization;
(2) Approving all procedures and changes of procedures;
(3) Being responsible for setting up new procedures and check lists for maintenance and operation as required;
(4) Making periodic safety inspections of the equipment and the operation;

(5) Procuring equipment and supplies with the aid of the administrative staff;
(6) Hiring and promoting personnel as required;
(7) Appointing a training co-ordinator and ensuring that the proper training is conducted, that the staff is properly qualified and that training records are maintained;
(8) Ensuring that the various groups maintain proper records of operation and maintained;
(9) Preparing reports on reactor operation as an aid in safety reviews;
(10) Approving all physical changes in the reactor core, safety instruments or other facilities which may affect safety;
(11) Conducting surveys to determine that no criticality hazards exist in fuel storage;
(12) Investigating all unusual incidents to determine whether these were due to poor equipment, faulty maintenance, or misoperation by personnel and taking the indicated remedial action;
(13) Recognizing occasions when additional technical assistance should be obtained (this is one of the most important attributes of the reactor manager);
(14) Reviewing experiments proposed for the reactor and approving experiments for safety (if he feels that it would be valuable, he might refer the experiments to a safety committee);
(15) Taking part in the designing of experiments for the reactor to ensure that they will be operable, safe and will not interfere with the operation of the reactor;
(16) Supervising the safety procedures of the reactors, including radiation safety and control of the release of radioactivity to the environment; and
(17) Studying records of incidents, operating troubles and malfunctions of equipment to determine if there is a pattern suggesting poor design, poor maintenance or lack of training and whether some action is indicated.

2.4.2. Reactor supervisor

The reactor supervisor should have the equivalent of a B.Sc. degree in science or engineering and experience in reactor operation. The duties of the reactor supervisor are:
(1) Supervising all operations of the reactor under the direction of the reactor manager;
(2) Maintaining a record system on reactor operations including a log book;
(3) Preparing reports on reactor operation;
(4) Making sure that all incidents are properly recorded for later evaluation of cause and remedies;
(5) Maintaining control over radiation exposures of personnel in co-operation with the health physicist and supervising all radiation and contamination work;
(6) Submitting all proposed changes to the reactor, instrumentation or

other safety equipment to the reactor manager for approval along with recommendations;

(7) Conducting a training programme for all subordinates;

(8) Ensuring that the reactor components are properly maintained in co-operation with the instrument and mechanical engineers;

(9) Developing special procedures and tools as required to improve safety and efficiency;

(10) Ensuring that all changes in the reactor or instruments are properly reflected by changes in the reactor drawings, descriptions and procedures;

(11) Ensuring that safety devices and systems are checked according to written procedures at prescribed intervals;

(12) Developing new procedures as required to reflect changes in equipment or to prevent recurrence of equipment failures or misoperation by personnel;

(13) Preparing shut-down procedures, including the non-routine and routine operations to be performed during each major shut-down when maintenance or changes of the facility are to be done, and submitting these to the manager for his approval;

(14) Supervising operation of all auxiliary services, including utilities, water disposal, etc.;

(15) Studying operations and equipment for possible hazards and taking appropriate action;

(16) Assisting experimenters in designing experiments; and

(17) Supervising the installation and removal of experiments.

2.4.3. Assistant reactor supervisor

The training and duties of the assistant supervisor are essentially the same as those of the supervisor. He should assume the duties of the supervisor in his absence.

2.4.4. Reactor shift supervisors

If the reactor is operated continuously, it is usually necessary to have four shift supervisors so that one is always present. The duties and training of the shift supervisor are essentially the same as those of the supervisor and assistant supervisor except that he is usually a more junior person and has less experience. He is, of course, responsible to the reactor supervisor and must assume all of the duties and responsibilities of the reactor supervisor during shift operation when no other supervisors are present.

2.4.5. Operators

Operators should have the equivalent of a secondary school education, should be intelligent, alert and have good mechanical aptitude. Their duties include:

(1) Operating the reactor console and keeping records of all important events;

(2) Starting up the reactor, but only under supervision;

(3) Taking readings of various recorders and instruments and recording these on appropriate forms;
(4) Notifying the supervisor of any unusual occurrences;
(5) Shutting down the reactor immediately if any abnormal condition develops which appears unsafe and notifying the supervisor as soon as possible;
(6) Recognizing situations which require supervision and requesting supervision for any unusual jobs not normally done independently including all non-routine work involving contamination and radiation;
(7) Assisting with the insertion and removal of experiments under the supervision of the reactor supervisor or assistant supervisor;
(8) Operating all auxiliary equipment such as pneumatic tubes, pumps, water systems, etc.;
(9) Making routine radiation surveys in co-operation with the health physicist;
(10) Decontaminating tools, equipment, etc., as required;
(11) Aiding technical personnel as required, and
(12) Doing all miscellaneous work as required by the supervisor, including loading or unloading the reactor fuel.

2.4.6. Instrument engineer

The instrument engineer should have the equivalent of a B.Sc. degree in electrical or electronic engineering. Preferably he should have been trained in reactor instrumentation or have worked at another installation to become familiar with reactor instruments. His duties include:

(1) Diagnosing troubles in the reactor instruments and performing necessary repairs;
(2) Performing checks of safety instruments and developing check lists as required;
(3) Repairing the electrical distribution system as required;
(4) Establishing a maintenance programme on all instrumentation, including all safety instruments;
(5) Keeping records of maintenance and changes in equipment;
(6) Making individual instrument checks and functional checks of all instrument systems at regular intervals;
(7) Examining operating records for instrument failures and investigating all instrument malfunctions;
(8) Preventing any changes in the instrumentation which may prejudice safety;
(9) Maintaining spare instruments ready to replace instruments which have become defective; and
(10) Training other supervisors and operators in normal and abnormal behaviour of instruments and in operation of instrumentation.

2.4.7. Health physicist

The chief health physicist should have the equivalent of a B.Sc. degree in science and either practical experience or special training in health-physics monitoring. His duties include:

(1) Making regular surveys of the reactor and adjacent areas for radiation and contamination or seeing that this is done by other persons such as operators;
(2) Making independent monitoring checks to ensure the adequacy of routine surveying done by others;
(3) Ensuring that monitoring instruments are adequate and are recalibrated on a regular schedule;
(4) Training all other reactor personnel in health-physics monitoring so that they can be more useful in routine radiation control and in emergencies;
(5) Making, or having made, daily measurements of the radiation exposure of each person considered likely to receive radiation and keeping a cumulative record so that each worker knows how close his exposure is to the maximum permissible;
(6) Making monthly or quarterly measurements of film badges to determine the accumulated dose received by individuals and checking this against the accumulated daily doses;
(7) Maintaining permanent records of exposures of all individuals; and
(8) Assisting in the investigation of any radiation incidents to determine possible exposures to personnel and remedial action required.

2.4.8. Radiochemist

The radiochemist should have the equivalent of a B.Sc. degree in chemistry with special training in radiochemistry. His duties include:

(1) Identifying different radionuclides and performing separations of mixtures of radioisotopes;
(2) Performing routine chemical analyses;
(3) Making activation analyses and performing radioassays;
(4) Measuring fast and thermal neutron fluxes and gamma intensity and determining doses received by samples and experiments in the reactor, and
(5) Conducting investigations of any corrosion or other chemical problems which may arise.

2.4.9. Mechanical engineer

The mechanical engineer should have the equivalent of a B. Sc. degree in engineering and, preferably, experience in designing and fabricating equipment. His duties include:

(1) Developing maintenance procedures on all equipment at the reactor and keeping records of maintenance;
(2) Investigating any malfunction of equipment and taking remedial action;
(3) Supervising all mechanical fabrication, repair, and design; and
(4) Designing special equipment required for the reactor or experiments.

3. TRAINING

3.1. *Training required by the operating staff*

It is convenient, for training purposes to divide the staff into senior supervisors, technical specialists, junior supervisors and operators.

Training of the senior supervisors who are charged with the responsibility for operating the reactor is one of the important duties of the reactor manager and it is essential that training should include operating experience in addition to classroom training. A few technical specialists should be available for work in reactor physics, heat transfer and instrumentation. The junior supervisors do not require such a high degree of academic training and the operators require even less. The degree of training required by any one group in a particular field is less if another group is very experienced in that field and a careful evaluation is required to determine the proper level of proficiency for each group.

Many licensing and qualification criteria specify only minimum requirements, but it is essential that the senior supervisors be much better trained than this. These supervisors, who have the major responsibility for operation, must determine how much responsibility should be delegated to each of the other groups and to do this they must be both experienced and extremely well trained.

One supervisor must co-ordinate training, either full time or part time, to ensure that the staff receives the proper training, that standards for qualifications are uniform, that retraining is done regularly and that records are kept of the training status of each man.

3.2. *Academic training*

A certain amount of academic training should be given to all personnel including supervisors and technicians. The subjects should include such material as radiation safety, reactor physics, instrumentation, nuclear physics, heat transfer and fluid flow with special application to the reactor. An outline of such a course is appended (Appendix I). The supervisors should be given additional training over the technicians, and specialists (perhaps only one person for small organizations) in each of the above fields should be trained to provide assistance to the staff when required.

3.3. *Balance between academic and operational training*

A balance is necessary between the ratio of academic training to practical training for each class of personnel — technicians, supervisors and technical specialists.

A mistake which is frequently made is in concentrating the training of the operating group, especially the supervisors, on reactor theory and similar academic-type subjects with the result that the operating group is much stronger in the skills required to design a reactor rather than to operate it. It may be argued that more problems of a design nature arise in the operation of a reactor than of a conventional plant due to the possibility of changing the core, effects on heat transfer of small changes in experiments, etc., and it is true that some training in these fields is necessary. However, such problems are no more important than problems of operation and maintenance which must be solved daily in order to keep the reactor operating safely and efficiently.

The question naturally arises as to how intensively operating supervisors should be trained in reactor design problems. It is believed that a balance should be struck in which more emphasis is placed on operational training. Design problems do not generally occupy the major portion of the supervisor's time and if they did, it is possible that problems of operation and maintenance might be neglected. All supervisors should, of course, have enough training in design to recognize the situations which require further study, but a large fraction of their training should be concentrated in actual on-the-job operation in which they have to solve the problems to be faced in practice. The design-type problems which arise should be handled by a small staff (perhaps only one person) in a small organization with specialized training in this field.

Institutions such as universities sometimes use many people with a theoretical background, such as graduate students, as reactor supervisors and encourage them to do research in their spare time. While such an arrangement may be perfectly safe, there are several points which should be carefully watched. Among the most important is that supervisors of this background are usually not satisfied with this sort of work for a very long period, and a high turnover of personnel is likely to occur. Similarly, if supervisors become too deeply involved in research, they may not have time to perform the work of a supervisor adequately and may neglect important functions.

3.4. Decision making

Not the least important facet of training is in bringing all personnel to the stage at which they recognize situations not covered by procedures and which require additional technical assistance or direct supervision by one of the senior staff. The training should convince both operators and supervisors that they must not make decisions independently unless they are thoroughly familiar with the problem. A great many reactor accidents are caused by lack of knowledge of the problem and an unwillingness to ask for advice. Examples of incidents caused by ignorance or improper evaluation of a situation may also be helpful in emphasizing this point.

3.5. Training of replacements

In one sense, it is easier to train the crew for a new reactor than to train replacements. A great deal of effort can be put into the initial training. An extensive series of lectures can be organized and the check-out and initial start-up period provide the staff with an opportunity to become familiar with the equipment.

The problem becomes quite different in training replacements. It is a great deal of trouble to set up a long series of lectures to train individual operators or supervisors and it is difficult to ensure that this training is equivalent to that given initially. A well-conceived training programme provides some uniform means of qualification and ensures that a person trained at one time possesses approximately the same skill as those trained at other times.

An outline of the training course and appropriate references, texts, sketches and other information are also helpful. The more written training material available, the fewer lectures are necessary and, if the training course is sufficiently well outlined and detailed, it should be possible for replacements to be trained largely by self study together with on-the-job training. Some assistance is, of course, necessary during the course of an individual's training to ensure that he grasps the important points and understands the material.

3.6. Training check lists

Practical training can be best controlled by use of check lists which specify every system and every major component. A training check list should be made including all phases of operation and procedures. It should cover the hazards of operation and should stress familiarity not only with the design of the reactor but with the control system and auxiliary systems as well. As the trainee learns each item, this should be noted by his supervisor on the check list and, at the completion of his training, he should be examined and the results noted. This check list should be a permanent part of the training record.

3.7. Training materials

The design report, safety analysis report, operating procedures and drawings furnish most of the background material necessary for the trainee in learning the design, operation and possible hazards of each system.

3.8. Training for emergencies

Training for emergencies is most important in order to give reasonable assurance that the personnel will react properly during different types of incidents. Since actual emergencies usually arise very infrequently, some sort of training is necessary to give the supervisors a background and an appreciation for emergency situations. While it is difficult to develop realistic training procedures for all situations, several types have been used.

Simulating emergencies, such as the evacuation of a building, is very beneficial practice. When the situation is too difficult or expensive to simulate, some other means must be developed if any effective training is to be achieved. For example, in the situation where radioactivity is released into the reactor coolant stream, it is difficult to simulate all of the different alarms and instrument readings which might occur in an actual event. Some success has been achieved in developing such situations in the form of written questions. The various alarms and actions of instrumentation are described in some detail and the trainee is allowed only a limited time to analyse the situation.

3.9. Study of incidents

Supervisors should study, as a part of their training, a number of safety incidents and make an estimate of the factors responsible for each incident. Accident reports should be analysed in this fashion regularly, since, by a systematic study of incidents, supervisors can be taught to appreciate many important safety factors.

3.10. Retraining

A definite policy should be established for retraining in order to maintain and check the proficiency of the operating staff. Periodic training exercises should be held along with reviews of operating procedures and training in all changes which take place in operating procedures or equipment. A retraining check list should be kept on all individuals so that all important operations and systems are covered at regular intervals.

3.11. Qualifying examinations

In order to ensure that uniform standards are used for qualifying reactor supervisors and operators, it has become a custom at many reactors to give a qualifying examination on both academic and practical subjects. Some countries give such examinations as part of a national licensing procedure.

4. PREPARATION FOR INITIAL OPERATION

Preparation for operation offers an excellent opportunity for the staff to learn the details of the reactor through participating in the procedure writing, the final stages of construction and the testing of the various systems and components. The reactor manager often takes an active part in the work and is responsible for a number of decisions during this period. One of the first is to determine what jobs must be completed and whether adequate personnel are on hand to complete them.

A distinct list of the different tasks which must be completed by the operating staff should be made at the time preparation begins for the start-up of a new reactor. The following are examples of such jobs and typical decisions for which the reactor manager is responsible.

4.1. Schedule

In planning the start-up of a new reactor, adequate time must be provided for pre-operational testing and completion of all the details which often delay a large construction project. Unless the staff is very experienced, the time required for this is easily underestimated. Schedules are necessary not only for precritical and critical tests, but for the power tests required to demonstrate that the reactor is ready for operation.

4.2. Design report

A design report is most useful in preparing for operation, both for staff training and for developing tests of equipment. The report should explain why the reactor was designed as it was and it should give the limitations of the various systems. It is also needed particularly after those who were associated with the design have left and personnel who are not familiar with the basis for the design have joined the staff. Failure to provide adequate information to the operating group has contributed to serious accidents [1].

4.3. Safety analysis report

In preparing to start a new reactor, the supervisory personnel should study the safety analysis report to obtain an appreciation of the limitations and the need for administrative controls. Appropriate portions of the safety analysis report should also be taught to the operators.

4.4. Preliminary operation of systems

As soon as possible all the various auxiliary systems, such as the primary and secondary water systems, should be put into service and operated more or less continuously for a considerable period of time to find any flaws in the equipment or procedures and to accustom the crew to the systems. All the non-nuclear equipment and systems should be operated, including remote-handling equipment for loading fuel. All operations should be practised, including assembling and dismantling parts of the reactor and performing all operations in the water system or other coolant systems. If this is done, much time can be saved which might otherwise be lost in remedying faults after the reactor actually begins operation.

4.5. Testing

Along with the other systems, the instrumentation should also be put into service and operated continuously insofar as possible before the reactor begins operation. If the control rods can be operated during this preliminary testing, any difficulties with the safety instrumentation or scram mechanisms which would cause spurious scrams or other malfunctions may be found and remedied.

In addition to testing by complete systems, the equipment should be tested piece by piece. Test procedures based upon the manufacturers' ratings should have been previously developed. Writing these test procedures is very good training for the operating staff.

If a mock-up of the reactor is available, some of the remote handling and other tests may be performed there when the reactor itself is not available.

4.6. Final qualification of staff

Using the training check list, the reactor manager should give tests to the supervisors to make certain that they are familiar with the reactor, with the procedures of operation and with safety devices and safety requirements. A less comprehensive training check list may be used to evaluate the training of the operators and, since they will rarely be assigned any responsibility until after routine operation has begun, their training may be continued for some time after the supervisors have qualified.

4.7. *Independent review*

When all the above preparations have been completed, the reactor manager should secure the assistance of an independent review group consisting of senior personnel not directly associated with the operation of this particular reactor. This group should review the procedures, training of personnel, and other plans for start-up to ensure that all necessary preparations have been made. Such a review places a certain formality on the proceedings and forces the staff to actually complete all preparations. While a little extra time might be required, the subsequent operations should proceed much more smoothly than if a hurried, less well-planned start-up were made.

Such a review is required in many countries where formal review and/or inspection bodies have been established.

5. INITIAL START-UP

5.1. *General considerations*

In starting up a new reactor, plans should be prepared well in advance for the critical and power tests to be made, the lattice arrangement or arrangements to be tested, the information to be obtained for experiments such as the effects of different experiments on reactivity and flux distribution and all the other tests needed to provide information necessary for the operation of the reactor and the design and operation of experiments. Considerable time should be available for planning these tests if the maximum benefit is to be obtained from the critical and low-power testing, since these tests require careful preparation and it may be very difficult to perform a new set of tests at a later date, because of interrupting operations and thereby delaying experiments and other work.

First, the tests should be related as closely as possible to the reactor as it is expected to be when it is operated with experiments. Although the data obtained on flux distribution, control-rod worth and reactivity effects will all change as the experiments are added and after burn-up reaches an equilibrium level in the fuel, much more useful data will be obtained from a core which is arranged like that expected with experiments than data obtained from one of a different arrangement. If the final arrangement of the core cannot be foreseen, it may be desirable to make certain tests on two or more core arrangements to obtain information on the effects of core changes.

5.2. Precision of tests

As stated above, the flux distribution, control-rod worth and other core values will be somewhat different after operation begins. Therefore the reactor manager should consider what precision is required for these tests and whether more than moderate precision is justified. On the other hand, it may be decided that the initial tests should be rather elaborate to give the operating personnel experience, thus justifying the added time and cost involved in making very precise measurements.

5.3. Hydraulic tests

Hydraulic tests should be performed before the fuel becomes radioactive so that access to the core will not be restricted. The tests may be very elaborate for a high-power reactor or they may be omitted entirely for a low-power reactor without forced circulation. In case a high coolant velocity through the core and consequently a high pressure drop occurs, information should be obtained on such matters as the velocity between the plates, especially as to whether this is equal between all plates. For example, it is sometimes found that the fittings on the ends of the fuel elements (end boxes) cause the flow to vary in different sections of a fuel element. The difference in pressure inside a fuel element and outside the element at various points along the length should also be measured at full flow to determine if a large imbalance of pressure exists.

High-velocity cooling systems should be operated for some time, after which the core components should be carefully inspected to determine if any failures or weaknesses have developed.

5.4. Core arrangement

The arrangement of the fuel has a considerable bearing on the neutron flux in the experiments and on the number of experiments which can be put into the reactor. In some reactors this is strictly limited to some symmetrical shape and experiments must accept whatever neutron flux is available. In other reactors a policy is followed of adapting the lattice, to some degree, to provide the greatest possible utilization. Both policies have advantages and disadvantages. The first offers fewer problems to the reactor manager at the expense of some flexibility in providing experiment facilities while the second requires more work in remeasuring flux distribution to establish new burn-up factors whenever the fuel arrangement is changed. The second also causes some problems from the experiment standpoint in that moving a fuel element from one position to another position may increase the flux in some experiments but decrease it in others.

It should be possible in many cases to predict approximately what experiments will be in the reactor and it may even be possible to plan some of the low-power tests with mock-ups of the experiments in the core to obtain some information on their effects.

Whether the initial tests are made with a fixed symmetrical core, or an unsymmetrical one which can be changed from time to time to adapt to the requirements of experiments, does not prevent the policy on core arrangement from being changed at some later date, although more tests would probably be necessary to provide the reactor manager with the necessary information. By careful evaluation of the eventual use of the reactor and the final core arrangement, however, it may be possible to make the initial tests of the core more useful and reduce the need for performing more tests at some later date.

If there are any plans for operating experiments inside the fuel region, (i.e. surrounded on three or more sides by fuel) careful tests should be made of the reactivity effects induced by any conceivable failure. In general, such experiments are liable to have high reactivity worths and their failure may be extremely dangerous. Usually, experiments should be located outside the fuel where they have much less reactivity effect. In general, no experiment should have a higher reactivity worth than about 0.5% $\Delta k/k$ since this would raise the possibility of very serious accidents. If larger worths are entrusted to an experiment, very careful design and safety reviews are necessary.

The various experiments on the flux distribution should be evaluated to ensure that the safety and control instrumentation is not adversely affected. Experiments should also be planned to provide data for safety analysis of the effects of the formation and collapse of voids in the core.

Boiling can occur or experiments might leak compressed gas into the core, and the effect of this on the safety of the reactor and on the instrumentation should be known. If the cooling water is saturated with air or other gas, bubbles may form as the water is heated in the core and, under certain conditions, a pump may suck in enough air to produce an appreciable disturbance of the power-level control system because of the passage of bubbles through the core. Consequently, an attempt should be made to give the operator some criteria for recognizing gas or boiling before burn-out occurs.

In general, the measurements made at this time should provide the reactor manager with information about any necessary limitation on experiments and with approximate flux values and reactivity worths which can be used in designing experiments.

5.5. *Control rods*

The location of the control rods is usually fixed by the mechanical design of the reactor, but provision may be made for adding rods or moving them from place to place. The lattice pattern adopted must, of course, be such that no section of the fuel lattice has any possibility of going critical independently of the influence of a control rod. Where the lattice arrangement is flexible, the maximum number of fuel elements which can be loaded outside the control rods must be determined.

A critical assembly could not be formed outside a control rod's influence during the initial start-up when fuel is loaded in small increments. Such a hazard might occur, however, at a later date when a large number of elements are loaded during refuelling. If elements of various weights are present and, through error, a group of heavy elements were loaded instead of light elements, a critical assembly might be formed. For this reason and for determining the possible fuel arrangement for the benefit of experiments, it is desirable to obtain data on the minimum fuel loading which can be made critical in the reactor.

The reactor manager must be certain that control rods contain cadmium or other neutron poison before critical testing begins. This is especially important at initial criticality when there is a possibility of all rods being faulty. After operation has begun, the control rods would normally be replaced one at a time and any fault would be discovered before a hazardous situation could develop.

The control rods must be calibrated and plans should be made to obtain that information which will be of the greatest possible use during later operation. As in the measurements of the flux pattern, it should be realized that the calibrations of the control rods will change as the experiment load in the reactor increases, as the fuel burn-up increases and as the rods themselves are burned up, especially if they contain fuel sections. Accordingly, very precise measurements may be made for the purpose of obtaining experience but the results should not be expected to remain unchanged.

Some means of calibrating the control rods over their entire length is desirable but, since this usually requires the use of a distributed poison in the core, it is not well adapted for regular checks after operation has begun. A second measurement technique, such as a period measurement of the worth of the portion of each control rod normally used in operation, is very useful, since this can be used to establish the worth of the most important section of the rod and can be repeated easily after operation has begun in order to follow any change in worth of the rods. Furthermore, since the distributed-poison method of calibration gives a calculated value of $\Delta k/k$ per unit length of rod, it is advisable to check this value by at least one period calibration of a small section of rod to ensure that the correct values of parameters were used in the calculation.

5.6. *Source*

A neutron source must be obtained which supplies enough neutrons to be measured by the low-level instrumentation and it must be so placed in the core that neutrons measured by the instruments come through a portion of the fuel rather than directly from the source.

5.7. *Final check of safety systems*

All the instrumentation tests planned for normal start-up to ensure that the low-level instruments are counting neutrons, that the mechanical controls operate properly and that nuclear systems are operable should be made before initial criticality. If necessary, auxiliary, low-level instrument channels to provide greater sensitivity or increased coverage of the region around the core should be added.

During the period of critical and low-power testing, the safety channels should be set to scram at a low power so that there will be less chance of the power being inadvertently raised so high as to produce large amounts of radioactivity in the fuel and core structure before tests have demonstrated that the reactor is ready for power operation.

The core and any assembly which is planned for installation near the core should be inspected to make certain that no part can be accidentally moved by any operation or mistake in such a manner as to add reactivity to the core.

5.8. Loading of fuel

Loading should start around the control rods and, after each insertion, the rods should be raised and the curve of the inverse counting rate plotted against the fuel mass and extrapolated to predict the critical loading with increasing accuracy. If a removable reflector is used, it should be loaded around the fuel and a reflector piece replaced by a fuel element each time an element is added. The reflector should be kept around the core as this is expanded so that the maximum effect of the reflector is obtained, and the core should be expanded symmetrically about the control rods so that the reactivity worth of added fuel elements decreases as criticality is approached.

As discussed in the section on fuel, it may be desirable to load elements of different weights to simulate the effect of a partially burned core and to permit the core to be expanded to the equilibrium size expected after operation begins.

After the core has been made just critical, the control rods will probably be completely, or almost completely, withdrawn. Fuel should then be added in small increments of one or two elements at a time and the critical rod position determined after each addition until the full-size core is reached or until the maximum permissible excess reactivity is indicated by the position of the control rods. With many research reactors this maximum excess reactivity condition is represented by the reactor being critical with the rods withdrawn to about one-half their total worth. Since the control rods will not have been calibrated at this time, the maximum excess reactivity should be limited to a control-rod withdrawal of approximately one-half their travel, provided the control-rod worth curves are estimated to be symmetrical.

5.9. Excess reactivity

Several different practices are used in specifying the maximum permissible excess reactivity of the core. Among these are the following:

(1) The excess reactivity of the cold operating core should not exceed 50% of the worth of the control rods available for shut-down. (Note that cold operating core is specified.) This refers to the core with the experiments in place and with the equilibrium burn-up in the fuel.

(2) The reactivity worth of the control rods should be 50% greater than the total excess reactivity available at the time within the core. This total excess reactivity includes that due to removal of all experiments, flooding of beam tubes and changes in temperature.

In the first, the shim rods must control twice the excess reactivity in the operating core, while in the second the rods must be worth 1.5 times the value of the experiments and beam holes plus any excess reactivity needed for operation. The first is more conservative if no experiments are added, since the rods must always control twice the amount of excess reactivity in the core — also this specification is very easy to administer. In the second, if no experiments were loaded and beam holes were flooded, the rods need only be worth 50% more than the total excess reactivity. If the total worth of experiments were great enough, then the second would become the more conservative. There may also be a problem in administering the second, since a definition of reactivity worth would have to be made as to whether this should be that in a cold clean core or that in the operating core.

One commonly-used criterion is that it should not be possible to make the reactor critical with only one single rod out of the core. This takes into account cores where there are large differences in the values of the control rods.

If, by any chance, the core cannot be loaded to the size desired because the weight of uranium in the fuel elements is too great, it will be necessary either to obtain fuel elements containing less uranium, to operate with a core of reduced size until enough burn-up has been obtained to permit the core to be expanded to the desired size, or to load solid aluminium or beryllium reflector pieces within the fuel region. This would make it possible to operate the reactor from the very start with the configuration desired for normal operation, even though one or more of the element would have to be replaced with a beryllium or aluminium piece. There might be some slight disadvantage in this, however, in that the flux pattern would probably be somewhat different than that in a core composed completely of fuel and the worth of the control rods might be affected slightly. However, in most cases this should not be a very serious effect and it would have the advantage that the core could be expanded to the desired size.

5.10. Low-power testing

All the tests referred to should be made, including measurements of reactivity effects caused by moving the fuel and experiments, flux distribution, flux in experiment facilities, temperature coefficients, and void coefficients. In general, the tests should be made in an order determined by the increasing power needed. It is desirable to keep the fuel radioactivity low as long as possible, in case some work should have to be done in the core structure or on the fuel elements. Temperature coefficients may be measured by heating the water by some non-nuclear means such as by the operation of a pump but, if this should not be sufficient, the test should be postponed until power tests begin. In heating the coolant the temperatures of the fuel, coolant and reflector are raised at the same rate, and consequently the isothermal coefficient thus obtained may be different from that observed during power operation.

The effect of voids should be especially studied in locations where experiments are expected to be made. This is necessary in order to determine whether the void coefficient varies greatly from one location to another. If an experiment is planned to be held inside the fuel region, a void coefficient measurement should be made extremely carefully, since the collapse or formation of a void in a central core position might increase the reactivity by a dangerous amount.

5.11. Power tests

After completing all the tests which can be made at low power, the safety trips should be raised to a point estimated to be a fraction of full power, such as one-tenth, and the reactor power brought to this level. A radiation survey should be made immediately to ensure that there are no high radiation fields in areas normally accessible to personnel. The power may then be raised in steps until full power is reached. After each step, a heat-power determination should be made and the power instruments set by this.

During the period when the power is being raised, measurements of power coefficient, afterheat cooling, and other measurements of high-power characteristics should be completed at appropriate power levels.

It may be desirable to obtain some experience with the effect of xenon poisoning during the early part of power operation. A simple test may be made by decreasing the power by a factor of 100 (after a period of full-power operation long enough to allow the xenon to reach equilibrium) and then keeping the reactor critical for several days to observe the growth and decay of xenon poisoning in the fuel. If the power is much higher than 5 MW, however, it may not be feasible to carry enough excess reactivity to keep the reactor critical; during part of this time the reactor would be completely poisoned. After the xenon had decayed sufficiently, the reactor could once again be made critical and the further decay could be observed by the changing position of the control rods.

The reactor manager should review the information that has been gained from the measurement programme after the initial start-up with relation to reactivity effects, cooling capacity and a possible need for shut-down cooling of the core.

6. NORMAL START-UP

Normal start-ups are defined as those following a planned shut-down during which experiments were changed or maintenance work was done on the reactor, experiments, auxiliary systems or some combination of these. The following discussion specifically excludes start-ups following short shut-downs caused by spurious scrams or other failures in which the work done on the reactor or on the experiment does not justify repeating all the safety system checks performed before a normal start-up.

6.1. Purpose of start-up procedure

The purpose of a normal start-up procedure is to define all the system and safety checks needed to ensure that the reactor auxiliary systems and experiments are ready for operation and that all safety systems are operating properly. The procedure should be outlined in the form of check lists (Appendices II, III) which will be filled out and signed by the responsible supervisor each time the reactor goes critical after a shut-down as described above.

6.2. Responsible person

One of the supervisors must be present in the control room during the start-up. It may be permissible for one of the operators to sit at the control desk and to do the manipulation of switches but only under the close direction of a supervisor.

6.3. Trip points

The trip points of all safety devices should be checked and functional tests should be made of the whole reactor system as far as possible. The operation of the mechanical portion of the safety system should be carefully checked to detect any abnormality. For example, the time required for the control rods to fall gives an indication of any misalignment, galling, etc. which might prevent the proper action of the rods. Permissible performance limits for such action should be clearly prescribed so that the decision can easily be made as to whether to operate with a given condition.

6.4. Low-level instrumentation

The low-level instrumentation must detect neutrons, and some suitable test procedure should be provided to ensure that the counting rate measured is due to neutrons.

Most of the neutrons detected should originate in the core and not from (γ, n) or some other reaction in the moderator, reflector, or structural materials. The neutron source should be located so that neutrons from it must pass through fuel to reach the detector.

6.5. Prediction of critical position of rods

The critical position of the control rods should be predicted before start-up, based upon changes of fuel, experiments or other factors affecting reactivity, including the estimated amount of xenon in the fuel.

6.6. Withdrawal of rods

The control rods should be withdrawn while observing that the low-level instrumentation reacts normally. If the instruments do not show the increase normally expected from a control-rod movement, the withdrawal of the control rods should be stopped and an investigation made to determine the cause. In reactors which have a high xenon concentration in the fuel the reaction of the low-level instrumentation during start-up may be difficult to predict until some experience has been obtained.

6.7. Poisoning and reactivity balance

The xenon concentration in the core of a reactor at any time after shutdown from full-power operation should be known so that the supervisor will be able to estimate the position of the shim rods when he starts up the reactor. In a 3-MW enriched-fuel, pool-type reactor, for example, the xenon poisoning increases after shut-down to a maximum of about 3% $\Delta k/k$ above the equilibrium xenon poisoning level during steady operation.

6.8. Action if criticality is not achieved

If, at the time the rods reach the predicted critical position, the reactor is not critical or nearly critical within the normal error of estimation of criticality, the start-up should be stopped and an investigation made to determine the reason for the discrepancy. This procedure is designed to detect some change of fuel or absorber in the core which has occurred unknown to the supervisor and which might suddenly be reversed so as to add a large amount of reactivity. For example, if a fuel element should be moved by the action of an adjacent control rod or by an experiment, this might cause the control rods to be withdrawn farther than normally required for criticality. Later if the element should fall back into the core, it might increase the reactivity by a considerable amount.

6.9. Operating excess reactivity

The total excess reactivity should be limited to that needed for operation even though more excess reactivity is permitted by other regulations.

6.10. Maximum excess reactivity

The criteria for maximum excess reactivity and rod worths must be fulfilled at every start-up. Depending upon the criteria used this could for instance mean that the reactor should neither go critical with any single rod withdrawn and the other rods inserted, nor should it go critical with less than half of the rods' worth out of the core.

6.11. Power operation

After criticality has been reached, the reactor power should be raised in steps. This procedure is recommended because it is sometimes possible to detect a malfunction at lower power which might become serious if the power were raised quickly. For example, if an experiment temperature is too high, it may be possible to make adjustments at one-third or two-thirds full power, whereas, if the power were raised quickly, a scram might be produced by the high temperature in the experiment. A further reason for raising the power slowly is to calibrate the heat power of the reactor against the power shown by the instrumentation. If the power is raised quickly to the full value according to the instrumentation, it may be higher or lower than the desired value. This is because changes in the core during a shut-down, such as insertion or removal of experiments, changes in fuel, position of control rods, etc., may all affect the calibration of the neutron chambers. It is therefore necessary to allow time for the heat power to be calculated from flow-temperature data at some safe intermediate level such as two-thirds or three-fourths full power to determine whether the instrumentation should be adjusted.

If new experiments have been installed or other changes made, it may be desirable to make radiation surveys at each step in power.

6.12. Checks for abnormalities

After each step rise in the power, such as at 25%, 50% and 75% full power, the reactor supervisor should carefully observe all the instruments to detect abnormalities, since these often signal trouble which may become serious at higher power. Usually this requires only a few minutes but it is a most important procedure and should always be observed during a normal start-up.

As soon as the reactor has reached about 25% full power, the supervisor should make a careful visual inspection of the core (if visible) for any abnormalities. This type of check may prove very useful. For example, objects which had partially plugged the fuel elements would be visible in the Cerenkov light. Boiling in fuel elements in which the cooling passages have become restricted is sometimes observable as increased noise on the instrumentation. While such fuel might not melt at one-third power, it might well melt at full power.

6.13. Checks post start-up

As soon as full power is reached, a radiation survey should be made to determine if any change during the shut-down has resulted in high radiation areas around the reactor or experiment systems. The period just after start-up is a time when incipient troubles are likely to be observed and it is necessary for the supervisor to be alert to detect them as soon as possible. Also the heat power previously adjusted at a fraction of full power during start-up may be found to be in error by a small amount when temperature equilibrium in the system is achieved and this may require a further small adjustment.

6.14. Power increases

The supervisor must be present for power increases of more than a few per cent. For example, if the power of the reactor should be automatically decreased by some safety action or by an unknown cause, the operator should not bring the reactor back to full power but should call the reactor supervisor instead to decide whether the reactor power should be increased or whether an investigation is necessary. In one reactor accident which involved the melting of a fuel element, the power of the reactor dropped sharply when the first melting occurred. Unfortunately, however, the power was raised back to the original value by pulling the control rods, causing more fuel to melt.

6.15. Changes in start-up procedures

The start-up procedure prepared when the reactor first begins operation cannot be expected to include all the procedures later found desirable or necessary after the manager and supervisors gain experience with the reactor. As new checks and procedures or changes of old procedures are found necessary, the manager should not hesitate to adopt these and include them with the original procedures after they have received the same careful safety surveillance given any new procedure.

7. START-UP FOLLOWING AN UNSCHEDULED SHUT-DOWN

When an unscheduled shut-down occurs, the supervisor is faced with the questions of what caused the shut-down, what to do about the conditions causing the shut-down, and whether to start up the reactor immediately. As soon as a shut-down occurs the supervisor should act as follows:

(1) He must attempt to determine the cause of the shut-down, whether it was produced by the experiment or reactor safety systems or by some malfunction.

(2) If the shut-down was necessary (i.e. due to some cause which required safety action), the supervisor must determine what must be done to eliminate the unsafe condition. For example, if the safety action were caused by the temperature of a loop which increased to a trip-point value, it may be possible to increase the coolant flow through the loop to decrease the temperature. Some experiments may be designed so that they may be moved to a lower flux position and this feature may be used to adjust temperatures. If such actions are impossible, the reactor must, of course, be left shut-down until the unsafe condition has been remedied.

(3) If it is found that the shut-down was spurious (i.e. not required for safety), the reactor may be started up immediately, provided tests of the safety system are not required on such occasions. At most reactors, safety checks are not usually required at this time, these being done on the regular schedule when complete tests are made. A definite procedure must be adopted, however, as to whether to make a few safety tests or none at all on such occasions.

8. NORMAL OPERATION

Normal operation is usually very uneventful, but the supervisor and operator must remain alert for unforeseen events and especially for unusual behaviour of instrumentation or other systems which often signals an approaching failure. After a failure has occurred, close examination of records, charts and other data often shows that some indication was given but was not interpreted correctly. Supervisors and operators should regard one of their major functions to be the anticipation of failures rather than to recognize them after they have occurred.

8.1. Routine records

It is necessary to make a number of checks and records of many of the characteristics of the system during the routine operation of the reactor. If there are auxiliary systems such as water purification systems, secondary water cooling systems, emergency power systems, etc., a number of tests and checks must be made on a regular schedule. These, of course, should be indicated on a check list and any troubles should be reported to the supervisor who can then be assured that he has been notified of any abnormalities. Appendices IV-XVI illustrate some records which have been found useful.

8.2. Abnormal behaviour

Occasionally some behaviour occurs which may not appear to be obviously hazardous but which is not usual in normal operation. In such cases the reactor supervisors should evaluate the condition carefully and, if in doubt, either shut down the reactor or refer the problem to higher supervision for technical assistance. In doubtful cases when the supervisor is not present, the control console operator should have full authority to shut down the reactor.

8.3. Degree of surveillance

The supervisor in charge of a shift should have, and should understand that he has, complete responsibility for the safe operation of the reactor. He should be alert for any unusual behaviour of the reactor or the reactor systems and should make sufficient regular personal inspections to ensure that the reactor, experiments and auxiliary systems are operating normally.

8.4. Unusual operations

A great many reactor incidents have occurred during some special non-routine operation. The standard or routine operations should be sharply distinguished from the special or non-standard ones and the latter must be reviewed carefully by the technical staff as well as by the operating supervisor before being performed. Reactor supervisors should be taught to recognize a special or non-standard procedure and to obtain technical advice when necessary.

8.5. Interpretation of abnormal behaviour

Abnormal behaviour is often attributed to equipment malfunction, especially of the instrumentation, because this is the most frequent cause. Supervisors must, however, be cautioned to assume always that the behaviour is real and that the reactor, rather than faulty instrumentation, is the cause until this can be disproved. In an example of such an occasion [2] it was assumed that increased reactor noise was due to faulty instrumentation. Instead, it was due to boiling in a fuel element in which the coolant flow was partially blocked.

8.6. Working rate

On some occasions there may be considerable pressure on the reactor supervisor to make last-minute changes or to complete some operation more rapidly than he thinks is safe. Supervisors should be cautioned not to prejudice the reactor safety in any such situation.

9. SHUT-DOWN OPERATIONS

9.1. General safety considerations

Most serious reactor accidents have been due to some operation which was being performed on a shut-down reactor, to a local coolant failure or to a general malfunction of the instrumentation during a start-up.

Accordingly, the safety of shut-down operations is very important and the reactor manager and supervisors should maintain very close control over these to ensure that reactivity worths are estimated, preferably on the basis of previous tests, to make certain that the total reactivity change is within safe limits. Very close administrative control must also be maintained over all maintenance operations to ensure that these do not cause large reactivity changes through some accident.

In order to ensure that the reactor is left in a safe condition after being shut-down, a check list should be used to eliminate errors from lapses in memory as far as possible. This should list any change required to put the reactor in a safe condition such as unloading fuel, removal of electric power to the control rods, cocking a control rod (if the "cocked-rod" procedure is used), checking the operation of the equipment for afterheat removal (if required), and any other operation necessary to guarantee safety of the reactor during the period while it is shut-down.

All shut-down operations must be scheduled with the reactor supervisor and certain classes of operation which might affect reactivity should be reviewed by at least one other competent person as well as the reactor supervisor. All operations should be described in written procedures and assembled into a complete "shut-down procedure" such as those shown in Appendices XVII and XVIII.

If it is necessary to make changes in procedures, these should be reviewed in the same manner and no change should be made in such a hurried manner that there is insufficient time to give adequate safety considerations.

As far as possible, all shut-down procedures should be prepared before the shut-down actually occurs. This allows more time to consider the effects of each operation on the reactor safety and on the other operations which must be done concurrently or consecutively.

9.2. Surveillance of a shut-down reactor

Different practices are followed concerning keeping an operator in the control room while the reactor is shut-down and no work is being done in the core. If not prescribed by some general code or regulation, the reactor manager must decide this on the basis of whether the reactor is safe in its shut-down condition or whether there is a possibility of the reactor being made critical through some error or the actions of unauthorized personnel. Some surveillance is definitely necessary during any shut-down period, even though no core work is being done, if fuel remains in the core so that the reactor could be started up. The reactor manager may be able to develop remote surveillance of the low-level instrumentation or some other procedure which is equally as safe as keeping an operator in the control room.

9.3. Position of control rods during shut-down

In order to keep the reactor safe during periods when it is shut-down and various changes are being made, two systems are in general use — the "inserted-rod" and the "cocked-rod" systems. In the first, all rods are fully inserted to give the maximum shut-down margin. The operations having potential effects on reactivity are reviewed and controlled to limit the total change to a small fraction of the shut-down margin. In addition, low-level instrumentation is kept in operation to warn of any close approach to criticality.

In the second, or "cocked-rod", system, the same controls are applied, but instead of leaving all rods fully inserted one or more are raised and arranged to be scrammed by the period and power-level safety channels.

A third method may be used in certain cases. This consists of unloading a large portion of the fuel during the period of shut-down. After the shut-down has been completed, the fuel is reloaded in small increments in an approach-to-criticality procedure.

Both the cocked-rod and the inserted rod systems have been used successfully and both have certain advantages. Both require careful control and supervision and a number of points must be considered before adopting one or the other.

For reactors in which mechanical drives or other portions of the control rods must be dismantled during shut-down, the only feasible practice is to use the inserted-rod procedure or to unload the core and reload as a critical test after all other changes have been completed.

9.4. Considerations of "inserted-rod" procedure

To keep the reactor safe while shut-down, it is the practice at many sites to keep all control rods fully inserted and to depend upon administrative control to limit all core changes affecting reactivity safely. This requires a large margin of shut-down reactivity above any positive effects which might be encountered and usually low-level instrumentation is provided to warn of any near approach to criticality whenever operations are being performed.

In cases where the effect of a core change may be large or when it is not known, an appreciable fraction of the fuel should be unloaded. An approach-to-criticality test should be made after the change has been completed so that the fuel is reloaded in small increments.

Apart from administrative control of core changes affecting reactivity, the low-level instrumentation provides the only safeguard against the inadvertent approach to criticality and great care must be exercised to ensure that the instrumentation is working properly. Any core changes which may make the low-level instrumentation inoperative or insensitive, such as water-filled lattice spaces between the neutron chamber and the rest of the core, must be investigated very carefully and, if it is not possible to keep the low-level instrumentation in operation, it may be necessary to unload a part of the fuel.

No maintenance work should be performed on the low-level instrumentation during periods when changes are being made which might affect reactivity. Since maintenance operations may affect adjacent systems, all maintenance must be carefully regulated to ensure that the low-level instrumentation is not jeopardized.

It must be possible to observe the low-level instrumentation during core changes either in the control room or on auxiliary instrumentation located near the operation. If observed in the control room, means of communication must be available to provide immediate warning of any large increase in reactivity.

9.5. Considerations of "cocked-rod" procedure

Some sites have the practice of keeping a certain number of control rods raised or cocked on a shut-down reactor so that they are ready to scram on impulse from the safety channels, if the reactor is inadvertently brought to or near criticality through some change which has a larger effect on reactivity than that foreseen. It is argued that the procedure provides a warning accompanied by the insertion of negative reactivity so that the operation which was responsible for the unexpectedly large increase in reactivity may be halted. Various sites have different practices as to the times during which a rod should be cocked. At some sites it is customary to cock one or more rods as soon as the reactor is shut down and to keep them cocked at all times. If a spurious scram should occur, they are immediately recocked. This, of course, may require a supervisor to be at the site at all times or that he be on call with some arrangement for him to be warned if a scram of a cocked rod should occur. At other sites, rods are cocked only when work is being done in the core which might affect reactivity and during times when large core reactivity changes, such as from the growth and decay of xenon, are taking place.

Many sites employing the practice cock only one rod having a small fraction of the total shut-down reactivity. The reasoning behind this is that the cocked rod, having a low reactivity worth, does not remove much of the shut-down reactivity but provides a warning of inadvertent criticality. The rate of inserting or removing fuel or experiments in the core should be slow so that, if the cocked rod should scram, there would be time to stop the operation before the value of the rod was exceeded by the further insertion of reactivity.

The cocked-rod system should have the same degree of reliability as that of the safety system of the reactor when it is operating. It would, thus, be recommended that at least two rods be cocked, since the probability of only one rod failing to drop is much greater than that of two failing at the same time.

The amount of reactivity to be entrusted to the cocked rods must be decided for each reactor. The reactivity value in the cocked rod, the remaining shut-down margin and the expected reactivity changes must be consistent. If only a small amount of reactivity is assigned to this system using a rod having a low worth, then there is little reserve to cancel out a reactivity change; and, if the change was of sufficient magnitude and occurred at a high rate, the small worth of the cocked rod might be overridden even if it should scram.

If a large worth is assigned to the cocked rods by cocking several rods having an aggregate worth amounting to a considerable fraction of the shut-down reactivity, then smaller changes in the core are required to make it critical and cause the cocked rod or rods to operate.

During some operations and with reactors of certain designs, it may be mechanically impossible to keep rods cocked and in these cases it would, of course, be necessary to revert to an "inserted-rod" procedure.

It is often necessary to perform maintenance work on the instrumentation and on various portions of the safety-rod systems during shut-down. This work must be strictly limited, if there is any possibility that it may interfere with the operation of the cocked rods. Maintenance operations are generally recognized as being difficult to perform on one section of a system without greatly increasing the probability of affecting other sections by some accident or through some unforeseen circumstance.

In order to keep the cocked rods operative and reliable, the effect of core changes on the response of the safety instrumentation must be considered in all changes of the core. For example, if the core changes should leave water-filled lattice positions (which had formerly been filled with water) on the side next to the neutron chamber, the sensitivity of the safety instrumentation might be seriously affected. This consideration applies not only to the low-level instrumentation but to the high-power safety channels.

Since the high-power-level safety channels are the primary safety channels in most instrumentation systems, the normal trip point is generally not satisfactory for the shut-down condition without cooling-water flow when a lower setting for the scram level is often necessary.

When a cocked-rod scrams, it may be assumed, as in many other cases of similar nature, that this was caused by faulty instrumentation or by electric power fluctuation. Supervisors must always make a careful investigation to assure themselves that the scram was not caused by high power or a fast period before recocking the rods.

Whether a cocked-rod procedure is used or not, the supervisor should never allow a change in fuel, experiment, or anything else to be made which might affect reactivity by an appreciable fraction of the shut-down reactivity. Instead, the core should be unloaded of most of the fuel and an approach-to-criticality procedure should be followed in reloading the fuel. If a cocked-rod procedure is used, it should be regarded only as a final safeguard in case predictions of reactivity effects are in error by a large amount. Providing a warning and inserting negative reactivity should give time to stop the operation responsible for the effect. However, it should be regarded as a last resort and warning should be provided of an approach-to-criticality by appropriate low-level instrumentation long before the power safety or the period channels cause the cocked rods to scram.

The cocked-rod practice does not relieve the reactor supervisor or manager of the responsibility of predicting the reactivity effect of changes in fuel or experiments. Any inadvertent increase in reactivity which causes the cocked rods to operate should be regarded as a serious failure of safety surveillance.

10. MAINTENANCE

The maintenance of reactor instrumentation and mechanical components is an extremely important factor in preventing spurious shut-downs and in preserving the reliability of the safety system. This is obvious, since only good and regular maintenance can give a reasonable assurance against failures that might jeopardize the safety of the reactor. Reactor incidents have occurred as the result of inefficient maintenance.

Good maintenance demands that responsibilities be defined and that a logical programme be adopted and followed. The reactor manager will normally have the over-all responsibility for this, but he may delegate this responsibility to a maintenance supervisor. Some aspects of the basic duties and requirements are given in the following sections.

10.1. General requirements

(1) A file of manufacturer's information should be kept on all equipment.

(2) A schedule of maintenance procedures required for each piece of equipment should be developed, and a system should be set up to ensure that the maintenance is performed as scheduled.

(3) Maintenance records should be kept on all major equipment listing the date and nature of maintenance, any unusual difficulties such as radiation, failure of parts, etc., as shown in Appendix XIX.

(4) Some logical criteria should be used to develop a list of spare parts and to determine which parts should be stocked.

10.2. Drawings

All drawings should be kept up to date and should be revised before alterations are made so that they give a true representation of the facility. While this may not be necessary as long as the original operating staff remains, new staff members may find it difficult to understand the reactor later.

10.3. Basic rules

(1) Maintenance personnel should be carefully supervised, since in most facilities they do not become as familiar with radiation or nuclear safety problems as do the operating staff.

(2) All maintenance operations should be under the general supervision of the operating staff.

(3) Maintenance operations involving the reactor or associated systems should be covered by written procedures; requirements for radiation or safety precautions should be clearly stated in writing.

(4) Maintenance personnel working on certain vital parts of the reactor, such as the control rods or lattice, should be warned of the possible consequences of careless workmanship to the safety of the entire reactor facility.

11. FUEL HANDLING AND FUELLING

The movement of fuel is a potentially dangerous operation, since it may result in high radiation if irradiated elements are inadvertently removed from shielding, or in unexpected criticality if the elements are stored in an unsafe manner. Accordingly, all fuel-handling practices should be governed by carefully prepared procedures. The movement of every fuel element should be strictly controlled at all times and written records should be kept as in Appendix XX. All movements of fuel should be under the direction of a trained supervisor.

Movement of any used fuel in a pool is also a possible hazard, since an inexperienced operator might raise it above the water or move it to a position where personnel might become irradiated. Such an accident has occurred in a pool-type reactor where a gamma-exposure chamber was built into the pool shield. A fuel element was moved inside the pool to the chamber while personnel were inside the chamber.

11.1. Loading fuel into the core

If the core under construction is not an exact duplicate of one with which experience is available, the fuel addition should be limited to one element at a time and a critical run made for each fresh element. If a large number of very small fuel elements are used, however, the reactivity of each element might be so small as to make it preferable to load several of these in each step. A certain number of elements may be added around the control rods, provided it is known that the number added will not be enough to reach criticality. For example, if 25 elements are required for criticality, 16 might be added before the approach-to-criticality procedure is begun. If fuel elements of different weights are used, even stricter control will be necessary.

11.2. Low-level instrumentation during fuel movement

Whenever fuel is being loaded, the nuclear instruments must be operating and, if the sensitivity is sufficient, the movement of each fuel element into, or out of, the core must be observed on the instrumentation to warn of any approach to criticality. For example, fission chambers must be inserted into their most sensitive position. An operator must remain in the control room to observe the instrumentation, or a remote instrument must be available near the person moving the fuel so that he can either observe or hear the response of the instrument.

11.3. Flux-trap loading

Conditions where a flux-trap loading might occur should be especially avoided. An example of this is a core with one fuel element omitted from the centre. If an element should be inserted into such an empty space in a light-water-moderated reactor, the reactivity might increase by 3 or 4% $\Delta k/k$ and, if the reactor were almost critical (for example, if the rods were partly withdrawn), this might make the reactor supercritical by several per cent. If the reactor is operated with an empty core position, a screen should be placed over this so that a fuel element or other object cannot be inserted.

11.4. Moving control rods

It should be a cardinal rule that a control rod should never be removed from a reactor during shut-down work until the fuel around the rod has been removed and stored. It is advisable to use written check lists for such work. Appendices XXI and XXII provide examples of these.

11.5. Use of hoist

Use of building hoists for handling radioactive experiments or fuel elements should be carefully regulated because, if a switch should stick, it might cause a fuel element to be lifted above the water level. Safeguards against such an occurrence are of several types. In cases where it is convenient, the tool holding the fuel element is made sufficiently long for it to be impossible to bring the fuel above the water level, even if the hoist raises the tool to its fullest extent. In other cases, the operator is warned to be ready to disconnect the power switch to the hoist should the 'raise' switch stick.

11.6. Safety of stored fuel

At a nuclear reactor there is always the necessity of storing the new unirradiated fuel and the fuel which has been irradiated. The latter must be stored in some shielded position until it is shipped for reprocessing or until it is returned to the reactor.

The requirements for storing the unirradiated fuel are adequate separation and/or use of neutron poisons to absolutely inhibit any possible nuclear criticality due to flooding or other incidents. In addition, fuel elements must be maintained in such a way that they will not corrode. With aluminium elements, this usually means that they should be kept dry and preferably sealed in plastic to prevent scratches or other damage. If there is any possibility that the fuel in the storage area might become critical, it is considered advisable to provide a neutron detector with an alarm to signal the approach of criticality.

The problem is considerably greater with irradiated fuel, since it must generally be stored under water to provide shielding and cooling. The need for cooling, of course, varies with the specific power of the fuel. With enriched uranium, water cooled and moderated reactors, it is unlikely that the elements could be removed so quickly from the reactor as to require water cooling if the reactor power is less than 2 to 3 MW. In higher power reactors, of course, it is absolutely necessary that the elements be kept under water for a considerable time. For example, fuel-plate temperature rose to approximately 500°F when an ORR fuel element was removed from the water and held vertically in a hot cell 19 h after the reactor had been shut down.

Irradiated fuel should be stored in racks so spaced as to prevent any possible criticality. This is generally done by placing the fuel in adequately spaced rows. It is possible, of course, to fabricate racks containing neutron poison in such a manner that the elements cannot become critical, even if stacked closely together. However, this generally causes considerable trouble to the operating staff, since it must be positively determined, from time to time, that the poison is still in the rack, whereas, if separation is relied on completely for safety, there is no need for this type of test.

It is obvious that stored fuel, either unirradiated or irradiated, must be kept clean and free of debris which might block cooling passages. It is often convenient to place screens over the elements when they are stored in the pool after having been in the reactor to exclude any debris which may fall through the water onto the elements. This is especially important if the elements are to be returned to the reactor.

12. ACCIDENTAL FUEL MELT-DOWNS

Large releases of fission products are most likely to be caused after a local blockage of one or more fuel elements causing a small amount of fuel to melt and release fission products into the coolant. The reactor manager should consider the consequences of such an accident and if it is credible in his reactor, he should formulate plans for the clean-up operation. If this is not done in advance, hasty and insufficiently planned procedures may be put into effect, leading to a possible great increase in the cost of clean-up and an unnecessarily long shut-down of the reactor.

12.1. General procedure

There may be a temptation to dispose of the highly contaminated water in the reactor as quickly as possible so that the local radiation problem will be somewhat reduced. However, if the contaminated water is released, it must be stored and the storage facilities are sometimes not as safe as the reactor system. It is nearly always safer and considerably less troublesome to keep the water in the reactor system and use a demineralizer and a degasifier to remove the fission products so that they can be discharged safely into the waste systems.

12.2. Clean-up

The first step which should be taken after an accidental fuel melt-down is to put the clean-up equipment, including filters, degasifiers and demineralizers, into operation, if they are not already operating. These should be operated at the maximum flow for which they were designed or even at a greater flow if this seems to produce desirable results.

The shielding of the equipment, especially of the demineralizers, becomes much more of a problem than during normal operation. However, if properly anticipated during design, enough shielding will have been provided to enable personnel to perform the necessary work in the vicinity of the equipment. After the resin becomes depleted, the demineralizers must either be regenerated or the resin must be replaced. If the latter method is used, shielded equipment for handling the resin will be required.

Fission-product gas in the water is one of the most troublesome problems following a fuel melt-down. If the reactor primary circuit is a tight system which has a degasifier, the gas may be contained and discharged to the gaseous waste system. However, if the primary system is not completely closed, some gas is likely to escape and force evacuation of the reactor building. If a melting failure occurs in a swimming pool reactor, for example, it would be almost impossible to prevent fission gas from diffusing from the pool into the air of the building, unless a ventilated cover could be placed over the pool quickly.

In order to follow the status of the radioactive nuclides in the water, it is necessary to have sampling stations, both before and after the demineralizers, in areas where the main water lines are shielded. If possible, the sampling points should be located in hoods so that the fission-product gas released when the water sample is taken will be contained. Sampling is required in order to measure the efficiency of the demineralizer in removing radioactive nuclides. As long as the removal efficiency is reasonably high and the pH and resistivity do not go too far out of normal range, it should be possible to postpone the regeneration or replacement of resin. (See also on demineralizers section 31.2.3.)

Filter media may, during a clean-up operation of this type, become too radioactive to be handled and, if provision has not been made to wash the filter with acid and caustic (this, of course, requires that the filter body and cartridge be made of stainless steel), it may not be possible to clean the filter. Circulation through the filter should be maintained as long as possible, however, to remove particles from the water. Since resin beds are rather good filters, the demineralizer would continue to act as the only filter if the regular filter has to be removed from service.

12.3. Surface contamination

By continuing to clean the water at the maximum rate with demineralizer, filter and degasifier, all contamination should eventually be removed except, of course, for that which has been absorbed into the surfaces of the water system. This, however, is not a great problem as long as it is in shielded areas of the system. Any unshielded equipment containing primary water may be quite radioactive but, since most fission products decay rapidly, the radiation should not remain a major problem for very long. In the case of equipment which must be opened for maintenance or other operation, it may be necessary to postpone such work until the radioactivity has decayed somewhat. However, if absolutely necessary, a considerable amount of decontamination could be done by flushing with decontaminating solutions [3].

12.4. Additional precautions

Another simple precaution is to provide flanges on the water lines at suitable places so that it would be possible to attach emergency decontamination equipment, such as an evaporator or additional demineralizer, in case the regular equipment should fail or could not be operated.

12.5. Gaseous contamination

Gaseous radioactivity is the most immediate problem following a meltdown, especially during the first few hours. A degasifier is especially valuable at this time, first, because it will remove the gaseous fission products and, secondly, if in continuous operation, it will have removed most of the normal dissolved gases from the water before the accident occurred. This is an advantage, because if the water is not already saturated with gas the fission gases will not escape so rapidly.

If the reactor system is closed (i.e. if the reactor is inside a pressure vessel), the water can be recirculated until the degasifier has removed most of the gas. If the system does not contain a degasifier, it is best to leave the system closed until the short-lived fission gases have decayed. Most closed systems have a surge tank or other expansion chamber in the system which can be put under negative pressure — even 20 or 30 in H_2O negative pressure would be helpful. The exhaust gas should, of course, go to a ventilation system with appropriate cleaning devices.

12.6. Some problems encountered during a fuel melting incident

A release of fission products from an overheated fuel element at the ORR [2] is described to illustrate some of the problems arising from even a minor incident of this type.

The failure was caused by the plugging of a fuel element by a piece of gasket material. It was not detected at the routine visual inspection through a window in the top of the tank when the reactor was at 20% of full power because the element involved was one of the few not visible through the window. The failure of one plate in the element, occurring at 80% of full power (24 MW), was signalled by a burst of radioactivity detected by the N^{16} monitor and other radiation instruments located near the primary water lines. Almost immediately after this the degasifier off-gas radioactivity recorder went off-scale and, within about 20 minutes, radioactivity was detected by air monitors located near the pool. Water from the reactor tank expanded into the pool through an open connection which made the pool the expansion chamber for the primary system.

At several points near the water lines the radiation level rose above 2 r/h and within about 30 minutes the diffusion from the primary system, noted above, had made the pool surface activity read ~60 mr/h. The air activity in the building had risen so that evacuation was necessary, however, the general radiation level in the building did not exceed a few mr/h during this period.

12.6.1. Immediate action

The building was evacuated and placed in the containment mode whereby all roof vents and ventilating air inlets were closed and all air leaving the building was exhausted through a caustic scrubber and filters. The scrubber was previously in continuous operation in all respects except that caustic was added to the circulating water in the containment mode.

Meanwhile, frequent radiation surveys were made by personnel wearing gas masks to measure the course of the radiation levels and check on the performance of the water-cleaning equipment — the degasifier, demineralizers and filters. Air-filter samples were also taken. No action was necessary to put the degasifier and demineralizers into operation since these were operating continuously.

A number of the problems encountered showed the desirability of design changes in the building or the water system.

The fission-product gas spread rapidly throughout the building. This illustrates the need for separating the different areas and ventilating them separately. Work on the water-cleaning equipment would have been made much easier if it had been in a separate compartment or building. Evacuation of the control room was also undesirable, since much information was available there. In such a situation it would be much better if the control room were located outside the main reactor building or ventilated separately so that it could be occupied during such an incident. Even if it is ventilated separately, an air monitor must be placed in the control room to ensure that the air contamination is not too high.

12.6.2. Early analysis

Within a few hours water and air samples had been analysed and it was found that the air contamination consisted of 18-min Rb^{88} and 32-min Cs^{138}, both decay products of fission gases. Analysis of the gamma spectrum of the water revealed the presence of most of the volatile short-lived fission products. Another sample was taken approximately ten hours after the accident and an attempt was made to compare the ratio of short-lived iodine to iodine of longer half-life to determine whether the element which failed was new or one with some burn-up. This appeared feasible, since the reactor had been operating only a short while before the incident occurred. No 8-d I^{131} could be found and comparisons of the shorter-lived isotopes indicated that the element was new. It was later found to have had approximately 14 grams of burn-up (out of 20 g) and to have been out of the reactor for approximately three months before reinsertion. If more sophisticated methods had been developed for the analyses in such a situation, more information could probably have been obtained from the ratios of other fission products. It would also have been helpful if each water sample had been checked for radioactive gas to measure the progress of gas removal by the degasifier and to show the effectiveness of the demineralizers in removing the non-gaseous fission products.

12.6.3. Clean-up of the water system

After approximately seven hours a second demineralizer, which had been out of service, was put into operation. Approximately 70 000 gallons in the primary system were now being cleaned by passing about 150 gal/min through demineralizers and 50 gal/min through a degasifier. The pool was likewise being cleaned by a 70-gal/min demineralizer and the unshielded anion column on this system now had a radiation level of 0.4 r/h. The demineralizer columns of the primary-system demineralizers were shielded except for a few places, and this made operations there somewhat difficult.

Gross gamma counts were taken frequently on the water passing through each column, and it was found that the contamination of the water passing through the anion column was greater than that entering. It was assumed that the column had become depleted, but it was realized later that this was probably due to Xe^{135} and other xenon isotopes resulting from the decay of the iodine absorbed on the anion resin. If the gaseous radioactivity had been routinely determined in the water samples, this problem would have been solved more quickly.

12.6.4. Reoccupation of the building

After 7.5 h, the air contamination had decreased sufficiently for the building to be reoccupied. All operations now became much easier. Radiation from the water system had, in most places, decreased to two or three times that experienced in normal operation.

After studies of the water analyses ten hours after the incident, it was decided that if the reactor tank were opened, gaseous contamination might still be released and require that the building be evacuated once more. It was decided to continue the cleaning for another ten hours to make certain that the radioactive gas could not present a problem. Further diffusion of radioactive gas from the reactor primary system into the pool was prevented by cooling the reactor water to approximately the same temperature as that of the pool.

The non-noble gaseous radioactivity released to the environment from the incident was measured in the exhaust stack to be approximately 150 millicuries of radioiodine. Practically all of this came from the degasifier through the off-gas system where the greater portion of it was removed by a caustic scrubber and filters (separate from the scrubber and filters on the building ventilation system) before entering the stack. Even that small amount of radioactivity would probably have been contained if the scrubber had had a higher efficiency. The efficiency of this scrubber had been estimated to be 90% for iodine removal.

No contamination outside the primary water system resulted from the incident, since the Rb^{88} and Cs^{138} had decayed away by the time the building was reoccupied.

After approximately 20 hours the primary water system was opened by personnel wearing gas masks as a precautionary measure. No increased gaseous radioactivity was experienced in the hall and operations proceeded normally.

In preparation for the core inspection, a sampling device was made to pump water from each element singly, so that samples could be obtained and analysed. On the assumption that it might be difficult to find the leaking element, plans were made for alternative procedures to be used, if no distinct differences were observed between elements. Two courses appeared feasible: either the reactor could be operated at low power with the tank open while the sampling was being done; or all the fuel could be replaced and the suspect elements, after cooling in the pool for some time, could be irradiated in a very low flux in the pool adjacent to the reactor, to generate enough fission products to be detected by the sampling-and-analysis procedure.

In fact no sampling was necessary. The gasket blocking the element was observed immediately after the tank had been opened and the element was removed from the reactor without difficulty. As a precautionary measure it was placed in a container, fitted with an off-gas connection at the top,in case fission gases were still being given off. The element was handled in the pool for approximately an hour; however, no fission gases were detected in the air above the pool.

The element was removed from the reactor approximately 21 hours after the incident, but about 19 additional hours were spent checking the water system for the source of the gasket. Altogether, the reactor was shut-down for about 40 hours. An increase in radioactivity of the water to nearly twice the normal level was observed after start-up; otherwise, operations were normal.

12.7. Lessons learned from the incident

Some of the obvious lessons may be summarized.

(1) It is desirable to ventilate each part of the building separately.

(2) The disadvantage of having the primary water system connected to the pool and through this to the building was demonstrated; they should always be separated if possible.

(3) The demineralizers and degasifier were very helpful in removing the contamination and discharging it into systems designed for this purpose.

(4) If analytical procedures had been planned for such an incident, a gas determination would have been made on every sample and a scheme would have been devised which would have permitted more information to be obtained as to which fuel element failed. Also a large sample would have been taken as soon as possible for use in a number of analyses. For example, comparison of samples taken after some clean-up had been done with an original sample would have given a measure of the effects of decay and clean-up.

(5) The N^{16} and degasifier off-gas radiation monitors were very good detectors of the event.

(6) Since the accident was caused by a gasket left in the system during a shut-down, the need for strict control of maintenance operations is obvious. Maintenance personnel should be instructed in the consequences of such accidents and all material used should be accounted for in operations where it might be left in the primary system. Appendix XXIII shows a check list developed as a result of this incident.

12.8. Relation to pool reactors

This incident, if it had occurred in an open pool reactor, would have undoubtedly released much more fission gas. The amounts released were a very small fraction of the total, since only a few hundred gallons of the primary water mixed with the pool. Accordingly, an open-pool reactor in which the water passing from the core eventually diffused to the top of the pool would, undoubtedly, release such large quantities of gas that the building would have to be evacuated for a longer period of time than was necessary at the ORR. Since most of these gases, however, have very short-lived daughters and since these decay without appreciable radioactive residue, it seems likely that, while the amounts reaching the building air at the time of the incident would be much greater, in a few days' time they would decay away entirely and it would be possible to re-enter the building. From the results at the ORR it does not seem likely that much of the iodines or the more dangerous radioisotopes would escape from the pool.

The proper procedure, of course, would be to begin taking smear samples from the building surfaces as soon as possible after the accident occurred. These samples should be taken over a period of time and their decay followed by counting after various times. It should soon be obvious whether any long-lived fission products have escaped and future action should be based on these results.

If the ion exchanger can be kept operating for a sufficient length of time, most of the fission products should be removed from the water. Greater precautions would, of course, be necessary if the ion exchanger were regenerated because of the radiation from the columns and the radioactivity of the regenerating solution discharged.

13. PROCEDURES FOR STORING AND TRANSFERRING RADIOACTIVE MATERIAL

Radioactive isotopes are produced in samples and various structural materials associated with experiments or in reactor components, which are removed from the core from time to time. Some of these components may be very radioactive and they may have to be stored for one reason or another. Consequently, a procedure is necessary to avoid a situation where radioactive material becomes scattered in so many places that no-one knows where it is or how much may be at any one place. Such a situation is likely to result in the identity of radioactive material being lost, so that after a time it may be encountered unexpectedly. This may cause serious contamination or exposure of personnel. (See also section 14.7.5.)

For these reasons it is necessary to establish, from the very beginning, a system for controlling and storing radioactive materials. First, a system should be developed for identifying the shield or container in which the material is stored. This should give information as to the nature of the radioactive nuclide, the approximate amount, the radiation at a distance or through a certain thickness of shielding, the date, the person for whom the material was irradiated, the shipper, form of the material (powder, metal, etc.), how it is encapsulated, how it should be removed and any precautions necessary. If the container is to be stored outdoors, the identification tag should be weatherproof. Secondly, all such material must be stored in recognized and well-identified areas, to reduce further the chance of its being mistaken for non-radioactive material. Thirdly, when radioactive material is shipped from one group to another, a standard shipping form should be attached to the container showing the name of the shipper and the consignee. The radiation information listed above should also be attached and the delivery should be made to a specified area which has been designated and marked to receive radioactive material. From time to time all such areas should be inventoried and material which is no longer needed should be discarded.

All personnel opening a carrier or container used to ship radioactive material should read the information concerning the nature and hazards of the material. If there is any doubt as to the safety of the operation, they should make further checks and proceed with the utmost caution. They should always measure the radiation as soon as the lid or door of the carrier is opened.

Capsules or solid specimens of radioactive materials may deteriorate or crumble after a time so that dust is scattered as soon as they are removed from the carrier. A procedure must be established which will permit early detection of this and control the spread of contamination.

The possibility of the escape of radioactive gas must also be considered. Some materials release gas during irradiation until considerable pressure is built up, if the container is gas tight. There is always the possibility of such materials releasing radioactive gas after they have been placed in a carrier or at some later time. On one occasion, for example, an experiment capsule containing fissionable material was removed from a reactor in a shielded carrier and brought into an adjacent building. Shortly after this, the air monitors in the building indicated air activity which was eventually traced to fission gases leaking from the carrier. It was necessary to wrap the carrier in plastic and suck air from the space between the plastic and the carrier by a hose connected to the off-gas system. As a result of this incident, carriers containing this type of sample are tested by sucking a sample of air from beneath a plastic cover or from the inner cavity of the carrier with a hose connected to an air monitor as soon as the sample is removed from the reactor. This illustrates a very practical use of the air monitor in locating leaks of gaseous activity. When used to detect suspected leaks, the hose must be moved slowly from place to place to allow for the transit time of air through the hose to the monitor.

14. SAFETY PROGRAMME

14.1. General

A definite safety programme should be established to ensure that all safety procedures and precautions are reviewed regularly. While the most important factor in safety is the operating staff [4] followed next in importance by the safety equipment, safety reviews are widely used as a means of maintaining a general surveillance over safety. Many reactors also make use of an outside safety committee as an extra means of surveillance.

The reactor operations staff should not, however, depend upon outside safety committees for all safety review and surveillance but should have an active safety programme in which each supervisor and operator has some part. A number of programmes have proved useful.

Regular safety meetings should be held in which supervisors and operators contribute suggestions. These meetings must be kept interesting by supplying information on accident reports from other sites or by other means designed to stimulate interest. Any local incident should likewise be discussed. Further regular meetings of supervisors should be held in which safety problems are discussed. Minutes should be prepared and distributed.

Members of the reactor supervisor's staff should be assigned different fields in which to review the literature for safety problems. These should report regularly on each field and attempt to relate each safety problem, which occurred at another site, to their reactor.

14.2. Safety committees

Safety committees should attempt to uncover deficiencies in the operating staff, equipment, or procedures and should assist the reactor staff in recognizing any shortcomings which may exist. The committee must, however, avoid diluting the responsibility and authority of the reactor manager. In cases where committees are very active, it may be difficult for the committee to avoid assuming some of the responsibility and making some of the decisions which should belong to line supervision.

By subjecting new experiments and changes in the reactor or operating procedures to a safety review by a group of experienced people, it is often possible to reveal errors or possible weaknesses in the design. This is especially necessary until the groups operating the reactor and designing experiments have built up considerable experience and have become completely familiar with the reactor, with the possible hazards and with the precautions necessary.

The safety committee should be constituted of people from the fields of reactor design, operation, instrumentation, or associated fields. The members should be actually working in their fields and not so senior as to be too busy with administrative duties to keep in close touch with operating problems.

14.3. Safety review of a new reactor

A safety review of a new reactor is useful, if several experienced people can discuss the plans for start-up, the testing of equipment, the state of readiness of the staff and any other factors affecting this stage of operation.

It is recommended that the manager of a new reactor obtain the advice of other experienced people, unless he is already very familiar with the design and operation of his type of reactor. More time is required here than in the usual hazards review and much can be learned if the review is thorough and is conducted by really experienced personnel who, preferably, should not have participated in the design.

Such a review might be difficult and time consuming and the reactor manager might not agree with all of the recommendations. After consideration, he might conclude that no action was justified or he might wish to improve the safety of certain operations by increasing the administrative or equipment safeguards.

The review should have the full attention of the operating group since this type of exercise is valuable in increasing their knowledge and competence. The safety of a reactor depends largely upon the skill and experience of the staff, particularly that of the upper supervision rather than upon committees or other safety groups. This does not imply that safety inspection is not desirable, but its chief purpose should be to increase the knowledge and skill of the operating group by discussion with other experts.

14.4. Assessment of changes

The manager must be prepared to review critically, or to assemble a group with the proper skills to review, changes in design or operation which may be desired from time to time. Many of these are seemingly unimportant but may, in fact, accumulate so that eventually a serious problem develops. Some examples are:

(1) Changes to the fuel element end-boxes, for example, might materially affect the pressure inside the element versus that outside the fuel element. In reactors having a high water flow, this might cause the fuel plates to be deflected inward or outward with the possibility of touching other fuel plates.

(2) The reactivity and heat-transfer effects of fuel changes in the core obviously have important safety considerations. When an element of high weight is placed near the centre of the core in a position of high flux, the heat flux may be higher than the safe maximum.

(3) A large water-filled volume in a core may cause flux peaking which extends into adjacent fuel elements and could increase the heat flux beyond the permissible amount in the fuel closest to the void.

(4) As a consequence of changing the configuration of fuel in the core, the worth of the control rods may be decreased so that the reactivity balance of the core is materially changed.

14.5. Safeguarding against tampering with equipment

An ever-present danger exists in the possibility of inadvertent or mischievous activation of switches, valves, or other equipment. A number of safeguards may help prevent accidents of these types by reducing the possibility of error: proper arrangement of switches, valves, etc.; clear identification of all such components; suitable guards; the locking of components when their improper use might be hazardous; and the exclusion of unauthorized people from areas where they might tamper with equipment to create hazards.

14.6. Radiation and contamination control

14.6.1. Personnel exposure

Control of personnel exposure under normal conditions is largely a matter of discipline. If an overexposure to radiation should occur, both the employee and his supervisor should be held responsible unless it can be shown that they exercised proper care.

If a task is expected to entail appreciable radiation doses for the workers involved, the cumulative records of the doses received by every person should be posted daily as shown in Appendix XXIV. This procedure makes exposure information readily available and any person whose dose approaches that permitted for the period may be removed from further work involving exposure. In addition to film badges, pocket electrometers or some similar instrument which can be read daily should be worn by each individual. The dosimeters of different types should be checked against each other and allowances for differences in calibration should be made.

Another extremely important factor in controlling personnel exposure lies in making sure that a radiation survey is made before any individual enters a radiation field to perform work. This is the responsibility of the supervisor who may make the survey himself or delegate someone else to make it. The responsibility of the supervisor extends throughout the job and he must maintain whatever surveillance is required to protect the individuals doing the work. Training has a great deal to do with this sort of safety and every person should be schooled in radiation safety, in the use of instruments and in the discipline required for radiation safety. A check list should be used to ensure that the proper surveys, authorizations and protective equipment are obtained. Appendix XXV shows a Radiation Work Permit used for this purpose.

14.6.2. Radiation monitoring instruments

A minimum number of portable radiation detection instruments is required around a reactor to ensure that any release of contamination or sudden increase in radioactivity will be promptly detected. A minimum complement of instruments which have been found to be most useful and necessary is given below.

(1) Two gamma- and neutron-sensitive instruments;
(2) Two air monitors;
(3) Background G-M counter and recorder;
(4) Counting-room equipment for counting smear samples;
(5) Portable survey meters:
  (a) Four ion-chamber-type survey meters and two G-M survey meters;
  (b) Scintillation counter or gas-proportional counter for alpha counting;
  (c) BF_3-counter for thermal neutrons;
  (d) A counter for fast neutrons;
  (e) Calibration sources for gamma, beta and alpha radiation;
  (f) Personnel monitors, such as pocket electrometers or quartz-fibre electroscopes; and
  (g) Film badges and equipment for developing films.

14.6.3. Radiation safety instrumentation

The number of each type of installed radiation-detection instruments should be established from the types of experiments being done in the reactor, the number of people in the building, the number of areas which must be monitored and other factors affecting safety. As a minimum, at least two air monitor instruments should be available to detect airborne contamination and three or more beta-gamma detecting monitors are needed. In addition, one or more hand-and-foot counters and sensitive survey monitors for hand use should be provided.

If there is a possibility of pure alpha-emitting isotopes being released without accompanying beta-gamma radiation, it may be necessary to provide a separate alpha air monitor. A small counting room should be available where portable radiation instruments may be stored and calibrated and where paper smear samples may be counted.

Some radiation safety instruments should usually be connected to the control room to give a remote alarm, while others may require only local alarms. If the reactor building is small enough for it to be possible to hear alarm bells from local instruments, the local alarms may be sufficient. However, if the building is so large that the operator might not hear the alarms, it is advisable to connect these to the control room through an annunciator. Emergency electric power should be supplied to the radiation monitoring instruments, if the safety analysis requires this. In very elaborate installations it may be desirable to connect radiation monitors from several buildings to a common control room, so that safety surveillance of the whole laboratory or plant can be exercised from a single point.

It is customary to have at least one instrument equipped with audible and visual alarms located so that any considerable increase in radiation above the reactor pool water will be detected. It is also desirable to have a second instrument available for use during special operations such as those performed at beam holes. Other monitoring instruments may be located as experience indicates.

14.6.4. Setting of alarm levels

Depending upon the procedure used, it may be desirable to set the alarm point of radiation monitoring instruments at a fairly high level during a short-term operation such as removal of beam-hole equipment. If the trip is set at a very low level, it may alarm so frequently that personnel tend to ignore it.

14.6.5. Checking monitoring instruments

All radiation monitoring instruments should be checked regularly to make certain that they are operating properly. Radioactive sources for checking instruments may be mounted in several places around the reactor area in small lead shields which can be opened for checking the instruments. Personnel should be warned of instruments which saturate in high radiation fields and give anomalous readings, e.g. G-M counters.

14.7. Contamination

Some examples of various types of work routinely performed at research reactors are given in Table I to illustrate the category normally expected.

14.7.1. Rules for working with radioactive materials

(1) Always wear a film badge.

(2) Wear pocket integrating electrometers if radiation exposure is possible.

(3) Wear a quartz-fibre, visually-readable, electroscope during jobs involving high radiation when it is possible to receive a day's dose in a short

TABLE I

RADIATION OR CONTAMINATION HAZARD OF VARIOUS ROUTINE OPERATIONS

Activity	Radiation	Contamination
Handling fuel elements under water	X	
Removing tools from the pool if the water or the objects they have contacted are contaminated		X
Removing experiments, samples, foils, or tools from the reactor or its immediate vicinity	X	X(possible)
Removing resin from demineralizer columns (if previously regenerated)		X
Changing filters in water systems	X	X
Removing or inserting experiments or collimators in beam holes	X	X

time. These should be checked frequently to ensure that any person does not receive too high exposure.

(4) If the job involves high radiation fields or contamination, make sure that a radiation survey has been completed and that precautions for working time, protective clothing and monitoring have been specified.

(5) Always check how radioactive an object is before picking it up. Remember that special instruments must be used in monitoring where there is a possibility of encountering some low-energy gamma or beta emitter free of higher energy betas and gammas.

(6) Use special care in monitoring high radiation fields with instruments which may saturate and give a false reading. False readings such as these have been responsible for large overexposures.

(7) Observe all rules, signs, barriers, etc., used in radiation protection. Radiation and contamination zone discipline is especially important.

(8) Make regular radiation surveys. Appendices XVI and XVII illustrate such surveys.

14.7.2. Eating in the reactor building

Some rules should be made concerning the places where eating is permitted. Certain rooms in or near the reactor building may be designated as eating places where food may be eaten and these should be checked frequently for contamination. Depending on the cleanliness of the reactor building, packaged food and drinks may or may not be eaten in other areas of the building.

14.7.3. Control of radioactive dust

Certain operations in almost any reactor are liable to result in the spread of radioactive dust or particles. For example, when a beam hole is opened, dust may be brought out of the beam hole along with the shield plugs, collimator or other apparatus. If allowed to spread over the working area, it can be quickly carried over the building on the shoes of the personnel. It is customary to arrange a suction device at the mouth of the beam hole to catch such dust before it escapes. This can readily be done with a vacuum cleaner (with filters) connected at the bottom lip of the hole or, if the reactor is provided with a good off-gas system, this could be used instead. It has also been found helpful to vacuum clean the surface of objects removed from the reactor, if they are dry and not too radioactive to approach. During an operation where objects are being removed from a beam hole, for example, it is also good practice to vacuum clean the work area frequently, if there is any reason to believe that dust may have escaped. If loose contaminated dust exists in a beam hole, it should be removed with a vacuum cleaner or with damp cloths, and for this a special tool with offset handles is necessary so that personnel will not have to work directly in the radiation beam.

14.7.4. Preventing inadvertent entry of personnel into dangerous radiation zones

Certain areas around a reactor may be accessible to personnel so that radiation exposure might result, unless inadvertent entry is prevented. For example, if very radioactive samples are stored in an inadequately shielded carrier or if an intense neutron beam is accessible, some warning or barrier is required. This can be supplied by the appropriate use of ropes or barriers with signs indicating the hazard or, in certain cases, by using locks. For example, a lock may fasten each beam-hole outer-shield plug. Keys to these locks must be removed after the shielding plug is installed and inserted into a special panel in the control room before the reactor can be started. Further precautions and procedures are given in section 13 above.

14.7.5. Protective clothing

Protective clothing used at reactors includes coveralls, neoprene and cotton gloves, rubber surgical gloves, shoe covers, wide adhesive paper tape (for taping openings in coveralls), caps and gas masks. Plastic suits with an independent air supply are sometimes needed for especially contaminated areas, such as hot cells.

14.7.6. Detection and control of contamination

While paper smears should be made regularly to detect contamination (Appendix XXVII), other indirect indications may give valuable information.

The cleaning tools may be monitored regularly, for example, to determine if radioactive contamination exists in the building which was not detected by other procedures.

Two things are important in controlling contamination – prompt detection and prompt clean-up. While the amount of contamination likely to be released around a low- or medium-power reactor is not very great, it can still be extremely troublesome if not controlled. For example, if an irradiated sample leaks so that its surface becomes contaminated with some material which is highly radioactive and if this is allowed to touch any surface outside the reactor, contamination will be transferred to the surface and is likely to be spread throughout the building. For this reason, frequent surveys of the floors and work areas around the reactor should be made with appropriate portable instruments. Paper smears should also be taken of the same areas since these are more sensitive in detecting contamination. Once contamination is found, the area should be promptly blocked off and cleaning begun. It is usually best to start at the outer edges and work inward, cleaning sections and checking smears to make sure that the contamination has been removed. If the whole building should become contaminated, it is advisable to have the people remain outside until a plan is devised as to how the cleaning should be done.

When work is performed, such as changing a beam-hole collimator, which may cause contamination to be released or when contaminated objects are being handled, a so-called "contamination-zone" procedure should be observed. It is important that one person should be in charge and be responsible for seeing that the following radiation safety procedures are followed:

(1) No radioactive dust should be carried away from the contaminated area or scattered from the operation (frequent cleaning with a vacuum cleaner and a radiation survey after each operation helps to prevent this).

(2) Personnel must not receive too high exposure to radiation. This is prevented by setting working times for each person and, if necessary, by making frequent readings of quartz-fibre electroscopes or other direct-reading instruments carried by each individual if high radiation fields exist.

(3) Contamination-area discipline must be maintained.

(a) Unauthorized personnel should be kept out of the area, and all personnel inside the area should wear the prescribed clothing.

(b) All personnel should remove outer coveralls, shoe covers etc., before leaving.

(c) All personnel should be monitored when leaving the area and should wash if necessary.

(d) All material should be checked for contamination before being removed from the area. If contaminated, the material must either be cleaned or wrapped in plastic and marked as contaminated or put into disposal cans for radioactive materials.

(4) The area should be checked with a sensitive survey meter after the operation has been completed and any radioactivity should be removed by vacuum cleaning or by washing.

(5) The area should then be checked again for low-level contamination by taking smear samples and counting the smears. Any contamination remaining should be cleaned by mopping or washing.

(6) The area should be checked by taking new smear samples after further cleaning, if the first smears showed contamination. This should be repeated until all smears show the area to be within acceptable limits.

14.7.7. Emergency decontamination equipment

A certain amount of decontaminating equipment should always be immediately available for emergency use. A small amount of equipment may be kept locked in a local storage cabinet where it is readily available for starting the decontamination operation. A list of such equipment is shown in Table II.

TABLE II

DECONTAMINATION EQUIPMENT STORED IN A TYPICAL EMERGENCY CABINET

12 pairs coveralls	2 mop buckets
6 laboratory coats	6 ten-litre pails
1 box shoe covers	100 plastic bags
6 pairs overshoes	2 boxes rags
6 dozen pairs neoprene gloves	2 boxes paper towels
6 flashlights	6 rolls waxed string
1 box flashlight batteries	2 hanks sash cord
6 mops	6 gas masks
	6 rolls adhesive paper tape

14.8. Radiation and contamination incidents

Every incident or near incident which results or nearly results in some damage or exposure to personnel should be recorded. By reviewing all such incidents over a period of time, it is often possible to observe patterns indicating the need for additional training, improvements to equipment or other action.

The incident reports should also be used to train new staff members to be alert for similar situations and to appreciate the need for safety procedures.

15. EMERGENCIES

15.1. Initial problems

When emergencies occur, the staff is suddenly faced with the necessity of making a number of decisions. Some of these can be foreseen in a general way and the staff can be given training and information to enable the decisions to be made more intelligently.

A procedure should be set up for issuing orders, so that all come from the proper authority and confusion is eliminated as far as possible. Personnel should be appointed to record the actions and decisions taken to provide a ready reference during and after the accident.

15.1.1. Recognition of an emergency

The most important aspects are the recognition of a state of emergency and the limiting of the area affected. The operating staff of a reactor should be trained to notify their supervisor immediately of any conditions which appear hazardous, especially the presence of high radiation or contamination. Likewise, the supervisor should be instructed to notify the person designated to take charge during emergencies and should act as temporary emergency director while the emergency director himself is being located.

15.1.2. Declaration of an emergency

As soon as the emergency director has determined that the event is serious enough to so warrant, he should declare an emergency and alert the available staff groups assigned to assist. These should include health physics, medical (if injuries are involved), engineering, maintenance and any other group which has been assigned particular responsibilities. As soon as the emergency director has had time to fully assess the situation, he should appoint or obtain the services of an advisory group of experts in the different fields involved. (For a discussion of emergency communications see section 35.5, below.)

15.2. Emergency procedures

Following the recognition of emergencies, the proper action is usually to evacuate the area or building and to take all action possible to reduce the release of radioactive contamination and protect the personnel involved, such as shutting down the reactor or process systems, starting emergency ventilation systems and any other procedures available.

15.2.1. Monitoring and assesment

The contamination and/or radiation exposure of individuals involved should be checked, if this appears to be necessary. The various checks may include developing film badges, making nasal smears, taking body-waste samples and any others which appear to be desirable.

As soon as possible, a radiation survey should be made to determine the extent of contamination and/or radiation and mark the areas appropriately to prevent the inadvertent entry of personnel. Since it is possible that the reactor building may be contaminated, many instruments may be useless and some spare radiation instruments should be available. The preferable arrangement would be, of course, to have the reactor building separate from the building containing the health-physics equipment or to have the health-physics equipment in a separately ventilated portion of the reactor building. Following the monitoring of the area, the emergency director should determine the working time, protective clothing and other working conditions required for working in the affected area.

15.2.2. Planning

Following an assessment of the incident, the course of action should be planned and a control centre should be established near the scene to permit the emergency director to keep close control of the work. If the reactor control room is separately shielded and/or ventilated, it would serve as an ideal control centre. Among the factors which influence the planning are the frequency of radiation and contamination surveys, the types and number of radiochemical analyses, the number of personnel available for damage control, repairs and decontamination work, and the difficulty of the work, taking into account the limitations of working time and the necessity of wearing protective clothing. Jobs should be separated into those which must be done immediately and those which can be deferred to take advantage of radioactive decay.

15.3. Personnel exposure

Personnel exposure may be a problem in some instances where the radiation is high and, since it may be permissible to give a quarterly dose in a short time, it may be decided to rotate all available personnel in the area, giving each only their maximum permissible quarterly dose. Careful records of personnel exposure must be kept, preferably by use of pocket electroscopes which can be read immediately in addition to the film badge. An instrument such as a quartz-fibre electroscope is valuable in determining what dose has been received at any time.

15.3.1. Problems

Typical problems which may be encountered during a decontamination operation are listed below.

(1) If the incident is very severe, personnel may become overtired by working long hours over a period of time and the emergency director must schedule his people so that they do not become too fatigued. If a month is required for decontamination, for example, it would be unwise to permit the staff to work too many overtime hours a day.

(2) The clothing requirements of a large crew may be a problem. Such things as coveralls, gas masks, radiation instruments, shoe covers, caps, and many other items are required in much greater quantities than normal. A clothes changing room may have to be set up near the scene of the incident, especially if the changing room in the reactor building has become contaminated.

(3) There may be a shortage of radiation monitoring personnel. It may be necessary to appoint surveyors from other groups to assist the health physicists.

(4) A good system of record keeping must be set up to record the analyses of samples and counts of smears which are taken to measure the progress of decontamination. All of this information should be kept at the emergency control centre.

(5) If alpha emitters are involved, it may be necessary to paint surfaces after they have been cleaned as much as possible, so that the remaining particles will be fixed by the paint.

(6) If gas masks must be worn, great care is necessary for safety in working on ladders and scaffolds.

(7) Increased problems in waste disposal may be encountered. Solid waste may be greatly increased due to the material used in decontamination. An increase in the liquid waste is also likely.

(8) If equipment has become contaminated, it may be decided to wrap it in plastic and move it to a decontamination facility rather than to decontaminate equipment in the area of the incident.

(9) Contamination may be spread by ventilating systems, especially where air is sucked through heating coils and discharged back into the building through ducts. Such ventilating equipment should have filters on the intakes but, if no filters are provided, one of the first actions during an emergency should be to shut off the recirculated ventilation.

(10) If the emergency should involve areas outside the site, a person in charge of the off-site area must be appointed. Whether this should be the site emergency director or some government official should be determined.

(11) The emergency director or other authority may have to decide whether it is necessary to make a press release. In some cases, it may be considered best to release information on the incident and/or the progress of the clean-up. If a press release is to be made, it is useful to make it through one person who is detailed to be solely responsible for all communications with news media.

16. PROCEDURES

16.1. *Written procedures*

In reactors with a small crew, it is often customary to rely on the memory of the supervisors for detailed procedures of operation. While this may be perfectly safe as long as the supervisors remain at the reactors, such a practice often fails to provide new supervisors with sufficient information and they may make mistakes which could be avoided with the aid of written procedures. For this reason, written procedures should be used whenever possible and each procedure should be approved by at least two senior supervisory staff members to ensure that it has been adequately reviewed.

16.2. *Changes*

Since it is often necessary or advantageous to make additions or changes to procedures, these changes should be documented in the same manner as the original procedure. Preferably the procedure should be rewritten so that all procedures are in a single manual. Records should be kept of all revisions and these should be approved by the same authority as the original procedures.

16.3. Standard method and format

The procedures provided originally often have to be supplemented as questions arise over such matters as water systems, loading of fuel, handling of experiments, changes in the control system, etc. A standard method of issuing new procedures and revising old ones should be followed from the very beginning, otherwise, records of changes may be lost and after several years a great deal of confusion may exist concerning the procedures actually being used. A format for such procedures should be established including the following sections: (1) references to other procedures; (2) drawings, reports, or other background material; (3) description of the system; (4) step-by-step procedures; and (5) a list of any possible hazards involved.

16.4. Temporary procedures

When it becomes necessary to perform non-routine experiments or operations with the reactor, such as calibration of control rods, etc., a temporary procedure should be written in advance and approved by the same staff members who approve procedure or design changes. During shut-downs many operations may be performed and a temporary or shut-down procedure should always be written in advance to ensure that no work is forgotten and that all the standard procedures, such as safety system tests, are performed before the reactor is started up.

16.5. List of necessary procedures

A list of procedures and operational information which should be provided is given below:

(1) Procedures should be provided for the operation and maintenance of auxiliary systems such as coolant systems, electrical services ventilation, utilities, and waste disposal including that of radioactive liquid, gaseous and solid wastes.

(2) A logic diagram of the instrumentation should be obtained or prepared, so that all supervisors and operators can refer easily to the various alarm, setback, or scram circuits which may be provided in the safety systems.

(3) The wiring diagram of the reactor instrumentation should be available for study by the operating staff.

(4) Safety-systems check lists should be obtained or developed including all checks of instruments.

(5) In addition to the checks of the individual instrument chassis, functional check lists should be made for all safety instruments.

(6) Procedures should be developed for normal start-ups, routine operations, shut-downs and for shut-down work.

(7) Check lists should be made for all routine maintenance required by equipment, such as lubrication, etc.

(8) Emergency procedures for coping with various situations including contamination or radiation incidents and fires should be written. These might include various topics depending upon the reactor:

(a) Loss of electric power;
(b) Rupture of cooling system;
(c) High radiation levels due to various conditions;
(d) Loss of ventilation;
(e) Malfunction of instrumentation;
(f) Flooding of various areas of the building;
(g) Jamming of one or more control rods;
(h) Fire; and
(j) Air contamination.

It is very good training for the supervisors of a new reactor to write the operating procedures, although, if the supervisors do not have enough experience, it may be necessary to obtain assistance.

17. RECORDS

Operating records are needed to ensure adequate surveillance of reactor operation, provide the supervisors with means of detecting malfunctions or abnormal operation, and provide a means of transmitting important operating information between operating personnel. They also give a statistical indication of future troubles and are often useful for reference purposes.

A standard log book should be used to record all activities at the reactor except those covered in detail in formal check lists. It is useful to note these under definite categories so that there is less likelihood of important activities being overlooked. Activities of such categories as operations, shut-downs, troubles, checks performed, maintenance, research activities, and samples irradiated should be reported each shift. Every shut-down of the reactor should be described in the log book along with complete reasons for the shut-down. It is sometimes impossible to specify the exact cause of a spurious shut-down; however, a considerable amount of information is often obtained from such an investigation.

Data from the log book and record sheets should be summarized in regular report form such as that shown in Appendix XVI. These reports should be summarized regularly, e.g. quarterly, to provide a permanent source of reference and to provide the reactor manager with information for a long-term evaluation of the operation.

17.1. Master copies

One master file should be kept of all procedures, drawings and records, such as the safety analysis report, change requests, etc., and this file should not normally be used in day-to-day operation. If kept separately, these documents are more likely to remain intact and complete than if they are continuously used. The master file copies should be used as a reference against which the operating copies should be checked from time to time for completeness. One person should be made solely responsible for maintaining the master file.

18. SERVICES

A number of special services are required to support work on the reactor and on the experiments in order that they can be operated. Standard services such as purchasing, accounting, and transportation are also needed.

Mechanical and electrical shops are required for repairing equipment and for fabricating experiment apparatus. Utilities required are mostly standard, but a few special ones, such as "clean" electric power and radioactive drains, are considered necessary. A list of shop equipment, radiochemical laboratory apparatus, and utilities is given below.

18.1. Radiochemical laboratory

A radiochemical laboratory is directly useful to the reactor in providing analyses of radioactivity in the reactor water and of radioactive contamination, in measuring nuclides in radioactive waste water before it is released into the public water system, in investigating problems involving corrosion, and in counting foils. A radiochemical laboratory provides the service necessary for successful utilization of the reactor in such important fields as activation analysis of samples, assay and separation of radioisotopes, and flux monitoring.

Equipment should include one or more ventilated hoods with absolute filters, sinks connected to the radioactive waste disposal system, and standard chemistry equipment including a laboratory bench with gas, water, vacuum, and compressed air. For counting samples a multichannel analyser is needed together with proper scintillation counters for counting gamma radiation and a detector for counting alpha particles, if any alpha work is contemplated. Some beta-counting equipment, such as a proportional gas flow counter is useful. A gross-gamma counter may also be worthwhile if there is a large number of samples to be counted for an experiment or process in which a total radiation measurement provides sufficient information.

18.2. Dosimetry

The determination of thermal neutron fluxes and neutron energy spectra are very important, since these provide the reactor manager and the experimenter with the necessary data to estimate burn-up of fuel and neutron dosage on experiments and to interpret fast-neutron irradiation effects and a number of other effects.

The dosimetry may be done by the radiochemical laboratory or by any other group. However, since the work is somewhat similar, it may be more economical to concentrate all such work in a single laboratory. The person in charge of dosimetry should receive special training so that he may apply any of the techniques required.

Thermal neutron fluxes should be determined from time to time in the reactor to establish the spatial distribution of neutron flux for calculating burn-up of fuel and for estimating fluxes in new experiments. Experimenters often irradiate foils or samples to provide a direct measure of the neutron flux in their experiment. There is no substitute for making the measurement at the same time and in the same position during which the experiment is performed. It cannot be assumed that the flux will remain constant and that, once it has been measured, further experiments can be performed without flux measurements. Thus there is a need for a central laboratory at each site which can provide uniform, precise measurements of flux. If each experimenter attempts to measure the flux himself, much time will be lost through duplication and a much less uniform set of results will be obtained.

18.3. Health-physics services

During the course of certain operations on a reactor and its experiments, there may be occasions when it is necessary to work in radiation fields. This can be done perfectly safely, if the exposure time is carefully calibrated and the total prior exposure of each individual is known. However, it is necessary to keep close control of the radiation exposure received by each individual by careful administrative procedures and prompt reporting of all exposures so that the cumulative exposure received by every individual is always available. The following services must, however, be available:

(1) Film badges must be developed and exposures estimated.

(2) Pocket electrometers must be read and recorded.

(3) Gamma, beta, and thermal and fast neutron measurements must be made and the working time must be determined when it is necessary to work in radiation fields.

(4) The contamination of gamma, beta, and alpha emitting nuclides must be measured regularly in areas likely to be contaminated.

(5) Body ingestion must be measured by various techniques such as urine analysis, whole-body counting, nasal smears, etc.

Since some of these services are quite complicated and expensive, whenever possible a central service should be supplied to a number of reactors. Such a service might apply to urine analysis, whole-body counting, etc.

18.4. Electrical and mechanical shops

A shop for mechanical work is required. Large reactors may require a more extensive shop and the types of experiments have a great deal to do with the size of shop needed. Loops and complicated experiments require much more shopwork than do simple experiments and a reactor which is just being put into operation might require a smaller shop than at a later date when many experiments are being built. Following are the most necessary tools for a small shop.

(1) One milling machine;
(2) One lathe, ten-inch (accurate to within 0.001 inch or better);
(3) One lathe, ten-inch (accurate to within 0.005 inch);
(4) One drill press;
(5) One band saw;
(6) Gas and electric welding equipment;
(7) Blacksmith equipment; and
(8) Hand tools.

An electrical shop for maintaining the reactor, a counting room and other instruments at the laboratory would include, as a minimum:

(1) Oscilloscope;
(2) Bridge;
(3) Oscillator;
(4) Pulse generator; and
(5) Miscellaneous electronic instruments and tools.

PART II. EXPERIMENTS

19. INITIAL PLANNING FOR EXPERIMENTS

The programme of starting a research reactor and for its subsequent routine operation should be aimed at the final goal of providing the maximum utilization for the various experiments. The programme will proceed much more smoothly and efficiently if it is determined what information will be needed and if the necessary tests are planned in considerable detail so that they may be performed in the early stages. As in the operation of a reactor, the design and operation of experiments require special skills and people must be trained in these. All these requirements depend on the probable utilization of the reactor. It is, of course, impossible to estimate correctly the utilization in all cases, but, by taking advantage of experience at other sites, it is certainly possible to make an estimate of the most likely utilization of the reactor. This will make it possible to prepare for the experiments much more intelligently. For example, if the reactor is expected to be used largely for radioisotope production and activation analysis, it should not be necessary to train people in the design of in-core or loop experiments. Instead it would be desirable to train radiochemists, obtain pure target materials, assay for any radioactive impurities, plan a limited programme of flux measurement in the core, and develop procedures for encapsulating and inserting and removing samples. Tests would be desirable on the reactivity effect of samples inserted or removed while the reactor was being operated as in a hydraulic or pneumatic tube.

If, on the other hand, the reactor is expected to have a number of in-core experiments, the probable and alternative arrangements of the core should be investigated with simulated experiments to obtain the effect on the flux pattern and the reactivity effects of experiments. Provisions should be made for attaching experiment safety devices to the reactor to give a shutdown whenever necessary; personnel should be trained in experiment design, safety evaluation, and operation and in fast and thermal neutron monitoring; and standards for experiment design should be established. While this is only a partial list, it serves to illustrate the requirements of different types of experiments.

A good set of design standards will eliminate a great deal of unnecessary design and prevent many mistakes.

(1) Whenever possible the experiment should be made inherently safe so that no hazard will ensue from any failure in the experiment or the reactor.

(2) When the experiment cannot be made inherently safe, it should be provided with safety devices to protect the reactor and personnel.

(3) Where protection for the reactor or personnel is necessary, high levels of reliability are required including provision for safe containment even if any component or credible combination of components should fail.

(4) When safety devices are used to protect only the experiment itself, they may have a much lower order of reliability. They should not normally shut down the reactor unless it is considered that the experiment is so valuable that this is justified.

(5) Special attention should be given to unusual situations or operations such as removal of samples from an experiment.

(6) All possible conditions of reactor operations should be considered for their effect on the experiment, such as start-up, normal operation, unscheduled shut-downs followed by an immediate start-up, maintenance, extended shut-down, fuel changes, core configuration changes, and rate of power changes.

(7) The experiment should be designed so that it will not cause the reactor to be shut-down unnecessarily. This includes provision for installing and removing the experiment in a reasonable time and for quickly putting the experiment in a safe condition should certain failures occur which require that the experiment be deactivated. While the latter flexibility cannot always be provided, it should be included when possible. For example, some means can often be found for withdrawing the sample quickly in event of trouble, so that the reactor can continue to operate or be started up quickly if it has shut down.

20. SAFETY EVALUATION OF EXPERIMENTS

All experiments must be reviewed for reasons of safety. While there are many variations of safety review, one will be described to illustrate the important features.

Experiments, in general, are likely to be less standard and to receive much less design attention and safety review than a reactor. This is to be expected, since only one or two persons may be involved in the design of an experiment, whereas a reactor usually has received a much larger design effort and has been reviewed more thoroughly. While most experiments in a low- or medium-power research reactor are likely to be quite innocuous if they do not contain fissionable material, many unforeseen hazards may develop and so all experiments must be carefully reviewed.

In one procedure an engineer from the operations group works with the experimenter during the design phase of the experiment and attempts to discover, as far as possible, any design features which should be changed. After carrying out whatever recommendations may be necessary for safety, this engineer recommends that the experiment be approved.

When the experiment design is complete (if the experiment is an extremely large one, a preliminary design review may be held), it is reviewed by the safety committee or a special experiment review committee consisting of senior staff members, most of whom have had experience with reactor experiments. The experiment is then approved as recommended, or rejected by the committee. In preparing the data for submission to the experiment review committee, a standard questionnaire (Appendix XXVIII) should be adopted so that all the necessary pertinent information is included. Such a questionnaire is also of considerable assistance in ensuring that all important points are considered by the designer.

The hazards of an experiment are related to the type of experiment as well as to the experiment sample itself. Neutron-beam experiments, for example, are usually not very hazardous and, except for shielding the direct beam and inserting or removing components in the beam hole, have few safety problems. At the other end of the scale, an experiment containing liquid or gas under high pressure and temperature or one containing nuclear fuel at a high temperature may have many problems. An arbitrary arrangement of common types of experiments in the order of increase of safety problems might be as follows:

(1) Neutron-beam experiments;
(2) Capsule experiments without electrical or coolant connections;
(3) Pneumatic and hydraulic tubes;
(4) Capsule experiments with connections;
(5) Loops with circulating liquid or gas under pressure; and
(6) Experiments containing nuclear fuel. (This could be again broken down into a subcategory as items (2) to (5) above.)

An extensive survey of the safety evaluation of each of these types has been done by CAGLE [5].

The most important determination in any safety evaluation is whether the experiment can fail, due to any credible circumstances, in such a manner as to endanger the reactor or personnel. In making this determination it is necessary to evaluate the consequences of each accident or failure which is considered credible. Among the most important factors are whether radioactive material will be released through the failure of some component, such as a pipe, vessel, instrument, valve, etc., and whether adequate provisions are made to prevent the radioactive material being spread to occupied areas. Also, of course, more common hazards such as fire, explosion, or poison must be evaluated, including the possibility that these may accompany or initiate the release of radioactive particles or gases. Every situation must be considered. For example, cases have occurred where capsules have floated to the surface of the water exposing highly radioactive sources of radiation.

The safety review should ensure that certain procedures which require close administrative control are written and will be followed step by step. If procedures are changed, they should be reviewed by competent staff members.

In evaluating the safety of experiments, it is usually assumed that only safety is of concern and that damage to the experiment which does not affect the reactor or personnel will not be considered.

20.1. Hazards due to failure of components

In studying the effect of failure of components, it is often assumed, in making the initial evaluation, that any single component may fail. In most cases, experiments should be designed so that no serious consequences will ensue from any single failure and if it is found that considerable hazards could so result, either the design must be changed or additional safeguards provided.

Not only the effects of the failure of any part of the experiment, but also the stoppage of any service such as electricity, water, and off-gas should be considered. Another important factor is the effect of any failure of the experiment sample on the subsequent removal operation. If a capsule should rupture, for example, the removal procedures may be rendered significantly more hazardous through release of radioactive gases or particles.

If it is determined that radioactive particles may be released through any malfunction of a component, some means must be provided to limit the spread of contamination. This may include a second line of containment around the experiment or components of the experiment which are considered likely to leak or rupture or it may involve performing certain operations, such as opening capsules, inside hot cells.

20. 2. Radiation and contamination hazards

In evaluating hazards from radiation and contamination, the maximum credible accident should be evaluated to determine if shielding is adequate and if dangerous amounts of radioactive materials may be released. The procedures and equipment for removing the failed experiment from the reactor should be evaluated as well as the normal operation. If radioactive gases or particles may be released, some means must be provided to safeguard the occupants of the reactor building as noted above. Cubicles surrounding the equipment in which the pressure is kept below atmospheric by means of off-gas or separate ventilation are often used. Provision for removing the radioactive iodine and particles from the gas stream should be provided, so that the contamination will not be discharged directly to the atmosphere. Filters and some sort of trap or scrubber to remove radioactive iodine are commonly used.

If the secondary containment system around hazardous experiments can be ruptured by any credible accident, a determination should be made as to whether hazardous amounts of exposure may be received by personnel. If this is considered to be credible, the experiment should be redesigned to provide greater safeguards or may not be done at all.

20. 3. Materials problems

Any new experiment should be evaluated to determine if problems are likely to result from the materials used in the construction. Special materials problems are discussed in section 24; however, other hazards may ensue from the use of certain materials, e.g. radioactive contamination may be considerably worse with some materials than with others. Corrosion must always be considered and the over-all effect of the materials on reactivity must be evaluated. The latter may be measured by inserting the entire experiment in the reactor using some safe procedure to measure the total reactivity effect.

20. 4. Safety devices

Many experiments where temperature or some other parameter may otherwise exceed safe limits are safeguarded by means of devices designed to control these parameters and to shut down the reactor or reduce the reactor power so that the parameter will not exceed safe limits. It must be determined in reviewing the experiment whether each parameter connected with safety is sufficiently monitored by reliable devices and whether there is a sufficient number of spare devices so that no single failure will jeopardize safety. Provision must be made for replacing or repairing a single safety device when it fails. The complete procedure for testing and putting such devices back into service should be specified.

The reliability of safety devices is extremely important. A certain amount of experience may be necessary to make an intelligent review of this and a programme should be planned at the very start of operations for developing criteria for the reliability of such devices. This will ensure that the experience obtained from previous failures is put to good use and the reliability criteria can, therefore, be expected to change as experience is gained. Certain devices may be inherently less reliable than others and, therefore, more spares or other provisions are necessary in case of failure. For example, thermocouples operating at high temperatures in reactors sometimes fail and spare thermocouples are usually provided and arranged in such a manner that one can be substituted quickly for one which has failed.

In the more complicated types of experiments, emergency power may be required, especially in such experiments as fuel samples cooled by loops where there is sufficient afterheat to require that the coolant be circulated for a certain time after the reactor is shut down. This type of experiment usually becomes very complicated and the design of the emergency power system must be reviewed very carefully to ensure that it is reliable.

Where some parameter of an experiment is controlled the devices used for this control are extremely important. For example, the temperature of a sample may be controlled by varying the temperature of a furnace inside the experiment. If the controller should fail, the temperature of the sample may increase to unsafe values and the safety devices must ensure that some safety action is taken, such as shutting off the furnace and/or shutting down the reactor. Safety devices should be completely separate from control devices. No condition which causes a control device to fail should affect the safety action of the safety device. Other devices and methods may also be used to reduce the consequences of the failure of control devices. For example, if a fuel sample in the reactor should melt, it might be arranged so that the melted fuel would fall into a temperature-resistant container rather than onto an aluminium surface which might, itself, be melted.

Where safety actions are required, such as shutting down the reactor or reducing its power to prevent some hazardous failure of an experiment, devices and circuits should be standard whenever possible rather than being designed entirely differently for each experiment. It is easier to evaluate the reliability of standard devices and circuits for which experience is available.

The instrumentation used to connect the safety devices to the reactor should provide for all the conditions likely to be required, such as disconnecting it from the reactor when it is in a safe condition, testing, etc. By providing for all these actions, temporary wiring is less likely to be installed in a reactor safety system where it might be forgotten and later itself create a new hazard.

Standards are also important in ensuring the reliability of welds in an experiment, since welds may be very prone to leak unless they are carefully made and tested. Inspection procedures should also be set up to ensure that the standard will be met. An out-of-pile testing programme is often necessary to demonstrate that the experiment will be safe under the conditions that are likely to be encountered.

20.5. Common hazards of experiments

Some of the problems frequently encountered in experiment design are given in this section.

In low-power reactors gamma heating may be no safety problem but where it is likely to be high it should be considered in the design. In experiments where there is a poor thermal connection with the wall of the container, the temperature may rise to unsafe values. The cooling of the outside surface of an experiment component in the core must also be evaluated and the effects of cooling stoppage must be known. Where high temperature may affect the safety of an experiment, especially in irradiating nuclear fuel or in certain cases of gamma heating, secondary containment, duplicate instrumentation, adequate numbers, types and locations of thermocouples, and other similar means are used to limit the hazards.

Experiments containing gas under pressure may be hazardous, especially if leaks are likely to release radioactive gas or particles. For example, if a pneumatic tube is operated under pressure, a leak in one of the pipes may release radioactive gas and particles or an experiment in the reactor containing pressurized gas may leak. Means must be provided to prevent hazardous leakage of contamination or the leakage may be contained in a second enclosure. Any malfunctions which would overpressurize an experiment must also be prevented, or means must be provided to reduce the consequences of such occurrences. For example, if an experiment is connected to a gas cylinder through a regulator, the possibility of the regulator failing should be considered and a relief valve or other device should be installed to limit the pressure to a safe value. Rupture of a pressurized experiment in the reactor which might release gas in the core must be considered since this might cause violent fluctuation of the power and, in a tank-type reactor, the tank might be overpressurized.

The reactivity worth of an experiment should be determined. If it cannot be estimated, it should be measured by inserting the experiment in the reactor using a critical measurement procedure. If there is any conceivable mechanism or failure which can cause the reactivity to change suddenly, such as the collapse of a void or movement of fuel, it must be controlled by limiting the total possible reactivity change which could occur (usually to less than 0.5% $\Delta k/k$ or whatever value can be handled safely). A few reactors permit larger amounts of reactivity to be controlled by single experiments, but this should be done only after the operating group has considerable experience.

20.6. Experiment safety during operation

The effects of reactor operation on the experiment and of the experiment on the operation of the reactor must also be considered, since, if there is any safety factor which limits the operation of the reactor, this must be specified and accepted. The normal operating condition of the reactor must be satisfactory to the experiment, including the maximum power which the reactor might achieve. If the power of the reactor should reach the level safety trip, the experiment might receive 30 to 50% more than normal flux. The rate of increase in power normally used in starting up the reactor must be safe for the experiment. If it is not, some other limit must be specified.

The change of flux and gamma heating during an operating cycle should be evaluated for its effect on an experiment.

20. 7. Interference with reactor

An experiment should be arranged so that it will provide as little interference with operation as possible. For example, it should normally be possible to install and remove it within a reasonable time and, in some cases where a failure of the experiment may require that it be removed or that the reactor be shut down, the design may provide for the sample to be withdrawn from the neutron flux in a very short time without disturbing the other components of the experiment. This is useful in putting the experiment in a safe condition if it should fail. It also permits the short-lived radioactivity to decay before the sample or the whole experiment must be removed from the reactor. In some cases, designs have provided for samples to be withdrawn from the neutron flux automatically if the flux or some other parameter should go too high. It is necessary, of course, to make sure that the reactivity effect of moving the experiments is not too great.

Shut-down operations involving removal and disposal of samples and/or in-core components should be planned in adequate detail to prevent the release of radioactive contamination or the exposure of personnel. Since it is often necessary to open equipment when removing samples and since the handling operations themselves may result in damage to radioactive samples, this is often the most hazardous part of the experiment and the review should be done with this fact in mind.

20. 8. Manning of experiments

The nature of an experiment may require that it be manned continuously for safety reasons, but in most cases this will not be necessary. However, the safety evaluation should determine those procedures and operations which require direct supervision. The safety review should ensure that procedures requiring close administrative control are written and will be followed step by step. If procedures are changed, they should be reviewed by competent staff members.

21. EXPERIMENT OPERATION

Several procedures for operating experiments are used at various reactors. In one procedure the experimenter is not allowed to design his experiment nor to operate it after it has been installed in the reactor. Instead, these functions are performed by the staff of the reactor operations group. In an organization where the detailed design, construction and operation of experiments is done by the operations group, this group may become very well trained in the work through long practice. However, this procedure may not allow the experimenter as much control over his experiment as he might desire and various compromises are possible to give the experimenter more responsibility. In one such compromise, the experimenter is encouraged to design and operate his experiment with some limitations for reasons of safety. While this method works with an experienced experimenter, it demands careful definition of the safety limitations and that an experienced person in the reactor operations group should work closely with the experimenter in the design and operation of the experiment.

21.1. Responsibility of operations group for utilization of the reactor

In nearly any new reactor, an active programme by the operations group is necessary to obtain full utilization of the experiment facilities. The reactor group must often find potential experimenters and assist them in planning experiments. Many scientists have little or no background in reactor experimentation and, unless some assistance is available, will require an extremely long time to prepare an experiment or perhaps will prefer to use other techniques with which they are more familiar.

A service in activation analysis and in radioisotope techniques is extremely helpful in making the reactor useful in industrial and scientific work. Unless such a service is available at the reactor, much of the potential benefits may never be realized.

In-pile experiments also usually require much assistance by the operating group in their design and safety review, since this group is usually more experienced than any other associated with the reactor.

21.2. Safety criteria

A set of criteria for the design of experiments should be collected to provide experimenters with a useful guide. A set of general criteria, which gives basic safety principles, is perhaps the best, since any specific situation may be compared against this to determine whether the criteria are satisfied [6].

21.3. Preferred components

As experience is gained, much detailed information as to specific instruments, components, and devices such as thermocouples will be accumulated. This information should be compiled in the form of a preferred component list to be used in future design. Such standardization will enable the experimenter to avoid repeating the mistakes of others and materially improve the reliability and safety of experiments.

21.4. Experiments with fissionable material

Experiments involving irradiation of fissionable material are naturally considered much more hazardous than other types. One risk which is often not taken into account is that uranium released into the reactor water may deposit on the various surfaces around the core and this results in a higher level of contamination in the reactor water than normal, since fission products are released whenever the reactor operates.

21.5. Double containment

Two containment barriers may be provided as additional safety for experiments which provide a potential hazard from possible releases of fission products or other undesirable material. In the case of a gas loop, for example, the main system of piping and equipment is considered one line of containment and the pipe or shield outside the first provides a second line of containment if it is leak-tight or properly off-gassed. The second line of containment surrounds equipment outside the reactor such as pumps, heat exchangers, etc., as well as the loop piping itself. In such an arrangement, it is usually considered necessary to monitor the region between the two containment barriers. If the first barrier should fail, it will, of course, be necessary to shut down the reactor and remove or repair the loop.

21. 6. Experiment information

For the use of the experimenter, the reactor manager should prepare a report on the experiment facilities of the reactor giving a description, dimensions, approximate fluxes, gamma heating, etc. Sketches of several typical experiments are helpful to give the experimenter an idea of how he may design his experiment for a particular facility. Examples of all types of experiments such as beam-hole, through-hole, re-entrant tube, capsule with leads, and uninstrumented capsule experiments may be illustrated if the reactor has provisions for all these. Also, pneumatic- and hydraulic-tube capsules should be described.

As noted previously, one of the most important and necessary services for the experimenter is the provision of data on neutron fluxes. In most new reactors it is necessary to train a person or group to make flux determinations, since the techniques are quite specialized. Data on fluxes and flux spectra should be collected as they become available. Often such data must be obtained from experiments from time to time and a policy should be made of recording them systematically. Thermal-flux data may be collected quite easily but, in a water-moderated reactor, this is likely to vary considerably from cycle to cycle depending upon the experiments, the arrangement of the fuel and other factors. Therefore, it is desirable to obtain flux data fairly frequently to ensure that it is representative of the condition at the time. In quoting flux data it should be realized that the figures often contain considerable errors, since it is difficult to be sure that the flux has not changed due to some change in the reactor or experiments. The only real answer to this problem would be to give information about doses measured rather than estimated fluxes.

21. 7. Experiment emergency procedures

If an experiment in the reactor requires attention during certain emergency conditions, instructions must be provided listing the possible hazards of the experiment; tie-ins, if any, to the reactor control system which may result in alarms, setbacks, or scrams; the action to be taken by the reactor operator if the person in charge of the experiment is not available; and the person to be called if trouble should develop with the experiment. Such information must be kept current and some sort of check list should be developed to be sure it is brought up to date after every shut-down when experiments may be changed. Appendices XXIX and XXX illustrate this.

22. REACTOR PHYSICS CONSIDERATIONS ENCOUNTERED WITH EXPERIMENTS

The reactor manager may be faced with the request to rearrange the fuel or reflector in order to provide better facilities for experiments. In some reactors it is the custom to keep the arrangement of the fuel intact while in others the fuel is moved as desired to furnish better neutron flux in some experiment facility or to provide room for an experiment. One of the early decisions that the reactor group must make should be the configuration of the operating core to be used and the policy of whether to keep a fixed fuel configuration or to move fuel for the benefit of experiments. Probably more experiments can be loaded with the latter policy, but it does raise many questions, among them the effects on other experiments. When the fuel arrangement is changed, either in element position or fuel weight, in order to produce a desired change in flux, gamma heating or other factors, some undesirable effect may well be produced in other experiments.

It is usually necessary to make flux measurements in a number of other core positions as well as the one in question in order to evaluate the effects of a change in the core. If tests are made to predict the effect of a new experiment, a mock-up of the experiment may be used in the core and the flux measurements made while the reactor is operated at low power.

Occasionally, in order to obtain an especially high fast-neutron flux in an experiment, it is desired to surround the experiment entirely with fuel. This usually makes the reactivity worth of the experiment very high. Different standards for maximum permissible reactivity worth of experiments have been used, and one common value is 0.5% Δk/k. Where the worth is more than 0.7% Δk/k, it is usually considered necessary to evaluate the hazards very carefully and to provide additional safety devices to prevent any sudden physical change which might cause the reactor to become prompt critical.

Experiments surrounded by fuel must be studied carefully for the effects of voids. Many experiments are in the form of hollow tubes containing a sample and, if the tube should suddenly fill with water or if the reverse process should take place (i.e. if a water-filled tube should suddenly be filled with gas), large changes in reactivity may occur. The reactor manager must be aware of the hazards and be satisfied that they are acceptable. In evaluating the effects, critical experiments may have to be performed by simulating different types of failures in an experiment mock-up.

In light-water-moderated reactors, most experiments are placed outside the fuel region either in the reflector or between the fuel and the reflector where they have lower reactivity worth than if they were surrounded by fuel. Such positions usually have a good thermal flux but a rather steep flux gradient, while the fast flux is less than that of the positions inside the core. In enriched, light-water-moderated type cores, it is unusual for an experiment in a reflector position (the size of a fuel element) to be worth more than 0.5% Δk/k.

Beam-hole experiments usually require some moderator between the end of the beam tube and the fuel. Beryllium, for example, may be used to reduce the number of fast neutrons in experiments both in beam holes and in core positions. Other experiments sometimes require that the fuel be changed in order to obtain a higher flux. Experiments requiring fast fluxes usually need to have fuel adjacent on one or more sides.

Experiment facilities sometimes have high flux gradients and for some experiments this is undesirable. Beam holes, for example, often have a high flux gradient as measured away from the core. Since the gradient may be even steeper in cores which are not well reflected or which have different arrangements, it is usually desirable for the experimenter to measure this gradient before he designs the experiment if a steep gradient may have undesirable effects.

Changes in experiments may affect other nearby experiments, and this is frequently a cause of concern between experimenters. An experiment may have a relatively stable flux, as long as no changes occur nearby, but this may be disrupted when an experiment is put into, or removed from, a nearby position.

Much time and money is sometimes spent in obtaining very precise measurements of neutron-flux distributions in a new reactor. For enriched cores, however, precise measurements are often not worthwhile because changes in experiments, fuel, burn-up, rod positions, core arrangements and other factors all cause the flux to vary from time to time. It has been found that with many reactors variations of as much as 30% may occur over a period of time due to the fuel cycle and changes in nearby experiments.

Reactivity effects of experiments are often required for safety analyses to determine what would happen if the experiment failed in various ways. The maximum effect is usually measured by installing the experiment or a mock-up of the experiment in the reactor and measuring the change in the critical position of the control rods. In a few laboratories where critical facilities are available, reactivity effects can be measured without disturbing the reactor operation; but in most cases it is necessary to make the measurements in the reactor itself. The effects of a series of typical experiments or experiment mock-ups may be measured during the time that initial low-power tests are being made with the reactor. In the case of a new reactor, these measurements will give the manager an appreciation of the worth of experiments in different positions in the lattice.

Gamma heating differs from one core design to another and, if not properly evaluated and provided for, may overheat portions of experiments. Measurements should be done in various positions of the reactor to obtain an approximate value for each position for the benefit of experiment designers.

A few fast-flux measurements may be made in order to provide some information for experiment design. Here again, experience has shown that very precise measurements are not necessary since the situation will be slightly different in every experiment, and new measurements will have to be taken at the time the experiment is being done if true values are desired.

23. EXPERIMENT FACILITIES

Each type of experiment facility has different uses and requires slightly different services, building arrangements, and reactor design. It is difficult to achieve a balance in the design so that each facility has the optimum space, services and access to the reactor, and it is often necessary to reach a compromise which best satisfies the different types of experiments planned at the particular reactor. Many research reactors lack many desirable features in their experiment facilities because they were built at a time when there was insufficient knowledge of the ways that the facilities would actually be used.

23. 1. Beam holes

Beam holes extending from the reactor core to the outside of the shield have been installed in almost all research reactors. They have been used for a great many types of experiments, but they are most useful for permitting neutron beams to come from the reactor core to experiments outside the shield. When they are used for loops or capsule irradiations in the typical water-moderated reactor, the high flux gradient may be found to be objectionable. It is also somewhat more difficult to install and remove certain experiments, such as loops, when beam holes are used rather than vertical core positions.

When the reactor is in operation, the beam hole must be shielded with plugs equivalent in quality to the reactor shield. These plugs and holes must have one or more steps in the diameter size to eliminate a straight path along the outside of the plugs and through which radiation can escape. In some designs, the beam holes are filled with water as a method of shielding during maintenance or when the beam is not being used.

Beam holes are generally provided with a metal liner which passes through the reactor shield and into the reactor tank,and in pool reactors this also passes through a section of the pool. In the latter case, the beam-hole liner may be welded to the liner of the pool (if it has a metal liner) or it may be sealed only at the outside of the shield so that the annular space between the liner and the concrete shield is filled with water. In this case, aluminium liners may be expected to corrode rapidly as the water becomes stagnant. The corrosion danger can, however, be lessened by pumping demineralized water from the pool clean-up system through this annulus so that there is no stagnation.

23. 2. Through-holes

A through-hole in the reactor may be a very convenient place to install a loop, provided that access is available to run the piping of the loop from one end of the through-hole to the other and that space is available for coolant circulating equipment, heat exchangers, instrumentation, etc. Through-holes may also be used as beam holes, provided that a scattering block is placed in the centre to scatter neutrons in both directions. If the gamma heating is very high, the scattering block may require cooling.

23. 3. Vertical experiments

Experiments in pool reactors are sometimes installed in vertical tubes which extend from the core to the water surface to allow connections to be made to control and measuring equipment outside the pool wall. Room is needed as close as possible to the top of the reactor or pool for the instrumentation and other equipment usually connected with such experiments. One arrangement is to provide a floor immediately below the top of the reactor pool so that the experiment equipment and instrumentation may be installed free of the interferences customarily encountered near the top of the reactor pool or tank.

23.4. Hydraulic- and pneumatic-capsule facilities

Hydraulic- and pneumatic-capsule tubes are very useful for irradiating samples for short periods of time from a few seconds to a few days or weeks. If the operating cycle of the reactor is one week, for example, it is inconvenient to shut the reactor down in the middle of a cycle just to insert or remove a specimen. This can be performed very easily with hydraulic or pneumatic tubes.

23.4.1. Pneumatic tubes

Pneumatic tubes are generally preferred to hydraulic tubes in reactors with fluxes less than 10^{13} n cm^{-2} s^{-1} because the capsules do not usually require cooling. Even at this flux, however, the temperature in the capsule may become quite high and it may be necessary to maintain air cooling if the sample is to be kept below 100°C. Pneumatically driven capsules have the advantage of being faster than those that are hydraulically driven and can generally be inserted and removed with a travel time of less than one second.

If air is used in a pneumatic system, it must be vented to an off-gas system provided with filters since it will become radioactive and, if uranium samples are being irradiated, it is advisable also that charcoal filters be provided either locally or in the off-gas system. Either pressure or vacuum may be used to remove the capsule. There is less danger from leakage when vacuum is used, but it is more difficult to get a high enough pressure difference to drive the capsule at high speeds.

The material of which pneumatic-capsule holders are made may be plastic, magnesium, or aluminium. Plastic is generally preferable, if the irradiation times are not too long, because very little induced radioactivity remains in plastic and, if the sample is not too radioactive, the capsule can be handled by hand. The life of plastic sample holders is not very long, however. Eventually they become brittle and may fall apart inside the pneumatic tube. The pieces from broken capsules are then likely to cause subsequent capsules to jam. It is necessary, therefore, to test the damage rate of the particular plastic used to determine how long it can be irradiated. After that time, the sample holders must be discarded. For longer irradiation times, it is preferable to use magnesium holders (usually an approximately 1% aluminium alloy is used), since magnesium becomes less radioactive than aluminium. Because of the possibility of capsules coming apart and leaving debris which might cause other capsules to jam, it is advisable to design the tubes themselves so that they can easily be removed and replaced. Plastics containing chlorine should be avoided since these may evolve radioactive chlorine during irradiation.

23.4.2. Hydraulic tubes

Many of the considerations for pneumatic tubes also apply to hydraulic tubes. Sample holders for hydraulic tubes must be made strictly watertight if the samples are to be kept dry. This requires particular care when welding and the welds must be leak-tested to ensure that they are watertight. The sample must also be heavy enough to sink in water and all samples should be tested for this.

In high-flux reactors the water pumped through hydraulic rabbit tubes must be delayed in a hold-up tank long enough to allow N^{16} to decay before it is released to the pool in which the tube loading station is located.

Since water cooling is available with hydraulic tubes, uranium samples of a size requiring cooling are sometimes irradiated. In such cases it is advisable to provide a safety device on the cooling-flow monitor for the tubes to shut down the reactor if the cooling flow should stop. It may also be advisable to divert the effluent water through a degasifier while the samples are being irradiated. This provides protection against a sample melting and releasing large quantities of gaseous fission products into the water.

23.4.3. Heat transfer

Heat-transfer problems in pneumatic and hydraulic tubes should be carefully studied to determine whether the samples inside the capsule can overheat through gamma or fission heating. If necessary, the sample may be packed inside the capsule in some material such as aluminium powder to conduct the heat to the walls of the capsule. All these precautions are especially important if fissionable material is irradiated, because of the possibility of fission-product release.

23.5. Critical facilities

Some large reactors have critical facilities associated with the reactor so that experiments on partially-burned fuel elements may be conducted without interfering with the operation of the reactor. In most reactors, of course, such experiments are performed in the reactor itself; however, this requires additional shut-down time. If a critical facility is planned, it is desirable to have a number of features:

(1) It should have easy access to the reactor so that partially-burned fuel or radioactive experiments may be moved to the critical facility without difficulty.

(2) The lattice in the critical facility should be as similar to that of the reactor as possible so that, if it is desired, experiments may be fitted into the critical facility and their reactivity effect measured before they are placed in the reactor.

(3) Since the critical facility with partially-burned fuel becomes almost as hazardous as the reactor itself, the safety precautions and procedures must be just as closely reviewed as those for the reactor.

23. 6. Pool irradiation facilities

With pool-type reactors or with tank-type reactors in pools, it is possible to irradiate experiments adjacent to the core without the necessity of putting the experiments through flanges in the tank. In general, this type of experiment is much simpler to build and to operate since no complicated path is required for the experiment piping nor is it subjected to the buffeting of high water flows. One very important advantage accrues to these experiments in that they may be retracted through the water when the neutron flux on the experiment must be reduced. This enables the experiment essentially to be removed from the reactor without the necessity of shutting down the reactor while the removal operation is being performed. Only if the experiment has a large reactivity effect may it be necessary to shut down the reactor before moving the experiment.

It is desirable, of course, to ensure that the pool-type experiments do not control large amounts of excess reactivity, but with light-water-moderated reactors the amounts of reactivity associated with pool experiments outside the fuel lattice is generally very small. The need for controlling the rate of reactivity change due to moving these experiments can, of course, be handled by some mechanical device which prevents the experiment from being moved rapidly.

Pool experiments can also be larger than those which have to be put in a lattice position and this is, naturally, another important advantage. The main disadvantage of pool experiments is that the flux gradient is usually high and the thermal flux may not be as great as that in experiment positions next to the fuel in the lattice.

23. 7. Thermal columns

Thermal columns containing graphite are often included as one of the experiment facilities in research reactors. In many cases, however, thermal columns have not been used to a very great extent because no programme required a very pure thermal flux. Operating problems with thermal columns have been encountered from graphite expansion and stored energy and from corrosion in locations where it was difficult to replace the material affected.

23. 8. Shielding facility

Pool-type research reactors are often used to study shielding by erecting the shields adjacent to the reactor core in such a manner that the radiation transmission through the shield may be measured. It is almost essential to have a bridge-mounted pool reactor for this sort of work so that the shield may be erected in a portion of the pool without the presence of radiation. The reactor may then be moved up to the shield after the pool is filled with water. Other arrangements for setting up shielding tests are, of course, possible by erecting the test outside a hole in the shield of a reactor [7]. Such facilities are more difficult to erect and install and, in fact, must usually be planned in the design of the reactor.

23.9. Mock-up

A mock-up of the reactor core is very useful for fitting experiments which are planned to be put in the lattice next to, or even inside, the fuel. It is also, of course, useful for testing new fuel elements, for investigating trouble with control rods and many other problems. For this purpose the mock-up should be made dimensionally identical to the reactor core so that an experiment which fits one will fit the other. However, ideally a core mock-up should not be enclosed in a tank since it must be completely accessible for maximum visual observation.

23.10. Building arrangement and equipment required

If possible, the reactor building should provide separation of each type of experiment from other types. Although this is not absolutely necessary, it would greatly promote the use of the different facilities and reduce the interference of one type of experiment with others. The equipment needed for each type of facility is slightly different in each case and experience indicates that a number of special features could be included at little or no extra cost. Generally, however, most facilities require only some variation of the equipment typical for beam hole and vertical experiments.

23.10.1. Beam-hole requirements

23.10.1.1. Shields for removing experiments from beam holes. The size and type of shield necessary for handling the experiments depends to some degree on whether the reactor can be moved away from the beam holes, as in some pool reactors, or whether the fuel can be unloaded easily, as in some tank reactors. If the difficulty of moving the fuel is too great, it may be necessary to insert or remove equipment or experiments into, or out of, the beam hole while the fuel is in the reactor. This requires that the shielded carrier and the beam hole have special features. For example, if an experiment or collimator has been pulled into the shielded carrier and the carrier is to be moved to another location, the open beam hole must be shielded with five inches or more of lead. This is most easily done if a beam-hole shield door has been provided within the reactor shield. If this has not been provided, the carrier may be backed away from the reactor far enough for a shield plug equipped with extension handles to be set into the hole by men standing on either side of the beam hole.

Since particles of dust or other material may be withdrawn from a beam hole when an experiment is removed, it is desirable that an air sweep be provided at the mouth of the beam hole to keep the particles from being released. This problem is dealt with more extensively in section 14.7.3.

The shield itself should be easy to move so that an experiment removed from a beam hole may be transported to storage, to a hot cell or other destination; it may be moved on wheels or the shield proper may be removed from a wheeled cradle and transported by truck or special device. If the experiment contains radioactive fission products, it may be desirable to attach an off-gas suction to the shield for some period of time to detect whether there is any leakage of gaseous fission products and to prevent these from escaping directly to the atmosphere.

The shield should have a shielded door at the end in which the radioactive experiment is located. The opposite end may or may not require a shielded door, but this can usually be attached manually if necessary. The material of the shield may vary from unclad lead to solid steel or lead-filled stainless steel. If lead is used, it may be difficult to handle the shield proper without its steel cradle. Also unclad lead and carbon steel often corrode badly. In the long run, if the shield is used a great deal, it is generally more economical to use stainless steel with lead filling. Acceptable, limited-usage shields for beam-hole experiments have, however, been built out of lead bricks tack-welded together on a steel cradle or platform.

If the shield is used for a number of other purposes, such as while handling vertical experiments and moving samples to and from hot cells, it may be worth considering special features such as dividing the shield into segments fastened together with flanges so that the length may be varied according to need. Other special features include plugs through the walls of the shield onto which rollers can be fastened. These rollers are of considerable assistance if very heavy plugs must be pulled from a beam hole or pushed from the shield into a beam hole.

23.10.1.2. Alignment of beam-hole shields. There may be some difficulty in aligning the shield with the beam hole, especially since radiation from the open beam hole may be so intense as to preclude any visual adjustment. For this reason, it is often helpful to have special means of placing the shield in proper alignment. Steel plates may be laid in the floor on which tracks can be positioned or the tracks may be left permanently in the floor. Bench marks may be placed in the floor so that the beam-hole shield can be aligned with the hole and marks may be placed on the vertical face of the reactor shield to be matched with similar marks on the shield by adjusting the vertical and horizontal position of the shield. Since beam holes may be at slightly different heights above the floor, it is an advantage to be able to adjust the height of the shield with a hydraulic jack or other device.

23.10.1.3. Clearance of beam-hole components. The shielding plugs, experiments, collimators, or other apparatus placed in beam holes are sometimes made with a very small clearance between their diameter and the inside diameter of the hole. In practice, this is very likely to result in galling, especially where one or both materials are aluminium. If a clearance of one-fourth inch is provided, the probability of a plug being jammed can be reduced considerably.

23.10.1.4. Storage. Storage of beam-hole plugs, collimators, and radioactive experiments removed from any facility presents a problem, since objects removed from the reactor are radioactive and must be shielded when removed from the portable shield. While temporary shields of concrete blocks or other material may be built for this purpose, it is more convenient to mount a number of steel pipes of approximately the same diameter as that of the outer portion of the beam holes and the same distance above the floor. These can be cast in the wall of the reactor building, if anticipated at the time the reactor is built; or the pipes can be shielded with concrete or earth. They should be placed in a location accessible to the shield used for the beam holes and other facilities. It is a good idea to provide off-gas at the inner end to dispose of any radioactive gas which may be given off by an experiment placed in the hole. Such a need might never occur, of course, unless the storage holes are used for a special class of experiments.

23.10.1.5. Services. The services for beam holes and other facilities generally include compressed air; piping in which gases or liquids could be supplied to an experiment located behind whatever shielding or shutters are placed in front of the hole; water; low-level (and sometimes high-level) radioactive waste drains; off-gas; and perhaps others. The piping may be arranged so that any service may be connected to an experimental apparatus by use of a rather complicated system of valving. It is recommended, however, that the different services be connected by using some simple device, such as a spool piece, so that there will be less likelihood of a wrong service being connected by mistake.

23.10.2. Building arrangements and facilities required for vertical experiments and loops

Vertical experiments and any experiment installed with connections through the top or bottom of a pool or tank-type reactor require slightly different facilities than do beam-hole experiments.

Space near the top or bottom of the reactor is needed for the experiment instrumentation and other equipment attached to the experiment. For loops, equipment cells and control instruments are needed as close to the reactor as possible. Space in parts of the building some distance from the reactor can be used for this equipment, of course, but the cost is greater due to longer piping, cables, etc.

23.10.2.1. Leads from experiments. If the reactor is a tank type, experiment piping or electrical leads can only be installed in the tank through flanges in the top or sides of the tank. Some desirable criteria have been developed from experience.

(1) It should not be necessary to disturb the experiment piping each time the reactor is refuelled.
(2) The experiment piping outside the reactor tank should be shielded or arranged so that it can be shielded when necessary.
(3) It should be possible to remove the experiment, including all its associated piping, from the reactor tank without difficulty.
(4) During removal, if the experiment is very radioactive, it should be possible to put it into a shield or remove it under water so that personnel are not exposed to high radiation levels.

23.10.2.2. Shields for vertical experiments. Shields for vertical experiments may be the same ones used for beam-hole experiments, if proper handling attachments and a door closure system are provided so that experiments may be drawn in from the bottom while the shield is suspended above the tank or pool. It is also possible to use a shield without a bottom door by lowering it into the pool and raising the experiment high enough to be placed in it. It is often more difficult to discharge the experiment from such a shield, however, into a hot cell or other facility.

24. PRECAUTIONS IN THE USE OF MATERIALS

24. 1. Compatibility of material

The first design for an experiment, particularly by inexperienced designers, often includes material of a type or amount which should not be put into the reactor for one reason or another or which should be used with certain precautions. A partial list of such material is given below.

24. 1. 1. Fissionable material

If fissionable materials are available to experimenters, a special control has been found necessary on the amount which may be irradiated in a reactor depending upon the neutron flux, gamma heating, and heat-loss rate. For example, if too large a piece of U^{235} is placed in a pneumatic tube which has little or no cooling, it will melt almost immediately when exposed to the core neutron flux.

24. 1. 2. Wood

It is sometimes convenient to use wood for a neutron shield since it is cheap and easy to fabricate. Unfortunately, however, it sometimes swells under radiation and eventually decomposes so that the part nearest the reactor becomes brittle and resembles charcoal. In one experiment, for example, some wooden plugs were used in the innermost section of a beam hole to shield against neutrons. After a short time, the plugs swelled and became stuck so that it was necessary to cut them out with long-handled tools.

24. 1. 3. Graphite

Graphite has, in the past, not been considered suitable for use in water-aluminium systems, since, on several occasions, it has appeared to cause rapid corrosion of the aluminium. There is, however, some evidence that graphite may be compatible with aluminium, provided that there is good water circulation between the two materials and there is no chance for water to become stagnant. A can of aluminium containing graphite corroded so badly that the can swelled, but this might not have happened if there had been enough openings in the aluminium can for the water to have circulated around the graphite. In any case, frequent measurements should be made of any graphite in the reactor in order to detect any corrosion or swelling in the early stages. However, unless there is a compelling reason, its use should be avoided in this kind of application. Other cases have been observed where graphite samples have swelled apparently due to fast neutron irradiation effects.

24.1.4. Copper and copper alloys

Copper and copper alloys are generally excluded from water systems because of experimental evidence that they increase the corrosion rate of aluminium. Experience, however, seems to indicate that if only moderate amounts of copper or brass are present, but not in direct contact with aluminium in the system, the corrosion rate may not be serious, provided the resistivity of the water is kept high.

24.1.5. Iron and steel

Corrosion rates on cast iron and carbon steel have been acceptably low with demineralized water systems and steel samples placed in the water have shown corrosion rates of approximately four mils per year [8]. Of course, iron and steel would not ordinarily be selected for use as reactor material because of the heavy rust deposits which form on the surface and absorb radioactivity from the water. This rust is liable to become very radioactive following a release of radioactivity in the core. However, experience has demonstrated that it is possible to use non-standard materials such as these; for example, a cast-iron pump could be used in an otherwise aluminium-stainless steel system.

24.1.6. Plastics and other organic materials

Great care should be used in approving plastics and other organic materials for insertion into a high radiation field, especially around the reactor core. This is because practically all plastics are affected by radioactivity, some to a much larger degree than others. If plastic is suggested, it is necessary to know what radiation it will be subjected to, what radiation dose it can withstand and whether it will deteriorate enough to make the application unfeasible. There are several special applications for plastic, however, for which it is hard to find a substitute. One example is sample capsules used in pneumatic tubes - sometimes called "rabbits". When a sample must be brought out of the reactor quickly enough to handle the material immediately, it is often inconvenient to use metal capsules. Aluminium capsules, for example, may have too high an activity in the period immediately after being removed from the reactor, due to Al^{28}. Plastic, on the other hand, generally comes out of the reactor with insignificant amounts of induced activity and, thus, the radioactivity which the experimenter must handle is only that of the materials inside the capsule. By careful planning this can be kept to a very small value and the experimenter may be able to begin his work on the sample within a few seconds after it has been brought out of the reactor.

Neoprene gaskets, for example, should not be used in regions having more radiation dose than neoprene can readily withstand without damage. If used in regions where the gaskets cannot be changed, radiation may eventually cause the gasket to disintegrate and result in the entire experiment being lost. Plastics containing chloride, such as vinyl chloride, have been observed to give off large amounts of radioactive chlorine gas.

24.1.7. Liquids

Most liquids such as water, oil, etc., evolve gases when irradiated in a reactor. Consideration must be given to safe disposal of the gases, otherwise pressures may rise to unsafe values. For example, oil samples sealed in quartz ampules have developed so much gas pressure that the ampules have exploded.

24.1.8. Chemical compounds

The stability of chemical compounds should always be evaluated carefully before irradiation. Some compounds are quite unstable and may decompose in such a manner as to cause a hazard. An iodine compound, for example, decomposed so that elemental iodine was given off and this had sufficient vapour pressure to escape as a gas, contaminating equipment and some personnel during removal from the reactor.

24.1.9. Mercury

Mercury is generally excluded from aluminium-water systems because of the possibility of aluminium corrosion being induced by the mercury. All instruments containing mercury are kept away from the immediate area of the reactor pool; and mercury-containing instruments must be approved as leak-proof before being brought into the building.

24.2. Corrosion of aluminium

Aluminium corrosion in water generally is not a problem as long as the specific resistance of the water is kept above 300 000 Ω cm; This is normally maintained by the use of an appropriate demineralizer (see section 13.2.3). Aluminium is also considered to corrode more swiftly in the presence of copper ions in the water, but experience has shown that this may not be the case where the water resistance is kept very high. However, cases have occurred where aluminium has corroded under other conditions. For example, in one case where the space between the aluminium liner of a pool and the concrete remained wet, severe pitting of the aluminium occurred [9]. In order to ensure that the water quality remains high in all parts of the pool, efforts should be made to avoid stagnant zones. As an example, a rack for storing fuel elements in the pool should have a screen in the bottom instead of a plate. This permits water to circulate through the rack and prevents a local region of low-quality water from being formed.

The heat exchangers in research reactors are usually fabricated of either aluminium or stainless steel in preference to copper or brass. This prevents water containing ions of the latter materials from coming into contact with the fuel elements, which are generally aluminium clad. When aluminium heat exchangers are used, it is necessary to keep the pH of the secondary reactor water carefully adjusted to avoid excessive corrosion. The use of a demineralizer should prevent corrosion by the primary water and trouble is more likely to occur on the secondary side of the heat exchanger, especially if the system is shut down and stagnant for some time, A successful water-treatment plan for aluminium systems has been designed on the basis of careful pH control and the addition of chromate [10]. An aluminium heat-exchanger in the ORR, for example, has been operated for five years with no appreciable corrosion in water treated by this method.

24.3. Corrosion of constructional materials

It is good practice to place small coupons of aluminium or other constructional materials used in the reactor system in the pool or reactor water and to observe these from time to time to determine whether any corrosion is taking place. At regular intervals coupons are removed, defilmed and weighed to determine the average depth of corrosion. Pitting-type corrosion is usually more serious in aluminium and evidence of this merits a careful investigation. As stated previously, however, no corrosion problems have been encountered with good demineralized water. All the aluminium-corrosion problems have been due to water of low quality.

24.3.1. Magnesium

Magnesium corrodes rather rapidly in an aluminium-water system even though the water quality is high. For this reason any magnesium alloys should be checked frequently and, unless they are to be used for only short periods of time, their use should be discouraged.

24.3.2. Rhenium

Rhenium corrodes only slightly in water, but this rate is sufficient to release considerable quantities of radioactivity. The oxide is particularly dangerous, as it is very soluble in water and has an unusually low sublimation temperature. An example from actual experience with this material can demonstrate its dangers. In this case unclad rhenium was irradiated in contact with water and so much radioactive rhenium was released that the sample had to be removed and placed in a hot cell where its vapour pressure was sufficient to release considerable amounts of radioactive vapour in the cell. Before irradiation, corrosion tests had been made in boiling water and no corrosion was detected. In the reactor, however, some surface oxidation of the rhenium occurred, probably due to hydrogen peroxide or oxygen in the reactor water. When the unclad rhenium was put into a hot cell, its temperature increased, due to its radioactivity, and caused the oxide to sublime. This incident also illustrates the need of knowing as much as possible about the properties of a material before it is introduced into a reactor.

24.3.3. Uranium carbide

Because uranium carbide becomes distributed widely if exposed to water, it must be carefully canned. A capsule of uranium carbide which ruptured in a reactor released many more fission products in the water than in comparable cases where uranium-aluminium alloy fuel has melted.

24.3.4. Tantalum

Tantalum must be handled carefully because of the large amounts of radioactivity that can be released from the surface after irradiation. In a case where tantalum was used in an experiment, the hot cell in which the experiment was cut apart became badly contaminated from radioactive tantalum.

24.3.5. Beryllium

Beryllium has been shown to grow, apparently due to the formation of gas from fast-neutron irradiation. At approximately 10^{22} n/cm^2 (> 1 MeV) the beryllium exhibits appreciable growth. Reflector pieces at the ORR (3 in × 3 in × 30 in) have bowed as much as 0.050 in along their length. The side next to the fuel was concave, indicating that this expanded more than the other. This does not make beryllium undesirable as a reflector material, but, in reactors of > 10^{14} n cm^{-2} s^{-1} flux, the beryllium must be designed so that it may be replaced easily and a programme and devices must be prepared for making regular measurements. If allowed to stay in the reactor too long, the beryllium may break and, of course, dimensional tolerances might be exceeded, causing jamming.

Approximately four years irradiation were required to cause beryllium-reflector pieces to bow 0.050 in in the ORR.

PART III.

FUNCTIONAL REQUIREMENTS OF REACTOR SYSTEMS

In the following part the functional requirements of the reactor, its various auxiliary systems and important components are discussed from the point of view of operation and various design features, both important and undesirable, are pointed out. While reactor designs may differ considerably, systems can be compared on the basis of the functions they perform and of their important features, such as ease of operation, reliability, safety, effect of abnormal conditions and other factors.

If it is found that the features of the reactor being compared are superior to those listed, the reactor staff will be reassured of the safe and efficient operability of the reactor. If it is found that certain desirable features or capacities of the system are lacking, the operating staff should decide whether additional administrative controls or safetv devices are necessary.

25. CORE DESIGN CONSIDERATIONS

No attempt will be made here to specify the reactor-physics and heat-transfer criteria desirable from the operational standpoint, although it is obvious that the operating staff would prefer the reactor to be safe under any condition. This is not always possible, however, or at least certain controls are often required to make it so and the design should set forth all conditions requiring safety precautions in such terms that the operating staff will be able to evaluate the safety implication of new and unforeseen conditions.

As far as possible, it is desirable to have the reactor so inherently safe that no hazards will ensue if equipment malfunctions occur or any error is made by the operator. Experience indicates, however, that it is possible to have a number of failures which cause release of fission products, release of large amounts of radioactivity or high radiation levels. Furthermore, the operating staff sometimes fail to foresee possible malfunctions arising from non-routine conditions, especially during a shut-down or a start-up just after a short shut-down. Except for experiments, the most likely causes of serious trouble are fuel-element failures caused either by blockage of cooling flow or damage from hydraulic forces. Reactivity accidents, while less likely to occur, may be extremely hazardous.

When the reactor is not inherently safe, it is the responsibility of the reactor manager to provide safety under all conditions by administrative control or any necessary device or procedure.

The reactor manager and supervisor must be familiar with all conditions where the reactor is not inherently safe and must evaluate, under each new situation, the reliability of the designed or engineered safety provided by the designer. This is especially important for conditions which were not foreseen in the design, and the reactor operating staff must evaluate each new situation in terms of the hazards and whether supplementary procedures or safety devices are required.

The reactor manager should never take it for granted that the reactor is inherently safe or that the designed safety is sufficient for a new situation.

Those features of the design which give the core some degree of inherent safety should be clearly identified to aid the operating staff in evaluating operations, experiments, or changes. Their function and limitations in bringing the reactor to a safe condition should be described so that the operating staff will apply the proper control and not ascribe greater inherent safety to the system than it actually possesses nor inhibit the action of the system by any change.

26. FUEL

The fuel elements for a reactor should have such a uranium loading ("weight") that the desired combination of burn-up, flux patterns, and other factors are obtained. Provision must be made for storing the fuel safely both before and after it is used. Furthermore, problems may occur in the procurement of new fuel elements, especially before procurement is established as a routine.

The integrity of the fuel is obviously very important since, if elements should fail structurally, plates might collapse so that certain areas would not receive proper cooling. If the cladding is not properly bonded to the fuel-bearing core, poor heat transfer may cause the core to melt the cladding. Also, if the fuel is not kept clean during manufacture, so much uranium may be left on the surface as to cause a high concentration of fission products in the coolant.

The fuel must be of such a design that it is not likely to be incorrectly loaded or that later, when the reactor is critical, it could not conceivably fall further into the core in such a manner as to increase the reactivity.

26.1. Choice of element weight for new reactor

In determining the fuel loading for a new reactor, the element weight to be used must be considered from an operational aspect, especially for reactors in which xenon poisoning and burn-up reactivity values are not negligible. Elements of several different weights can be used initially in such reactors to get the same reactivity balance, core size and approximately the same fluxes in a cold core as with the equilibrium-fuel condition of a partially burned core. The advantage of a multiweight core is that it gives more flexibility in loading the size of core expected after equilibrium conditions have been reached, and the flux pattern of such a core can be made closer to that eventually achieved with an operating core. If single-weight elements having a fairly heavy weight (such as 200 g for an MTR-ORR-type element) are used, the new core could not be loaded to its equilibrium size because the excess reactivity would be too great. The fluxes in experiment facilities in the smaller core would be very unlike those eventually achieved with an operating core, and the reactor would also have to be operated at reduced power until sufficient burn-up was obtained to permit a larger core to be loaded.

If light-weight elements were used, it might be possible to load the size of core desired, but the flux pattern would differ somewhat from that eventually achieved in the operating core. The elements would not have varying degrees of burn-up as in an operating core where some elements are new and others are almost ready to be removed. The reactivity of such a core would also be different from that of the operating core. Finally, the burn-up which can be achieved with light elements is much less than that with heavy elements. In an ORR-MTR type reactor a 200-g element, for example, may be normally burned until only about 130 grams of U^{235} remain. If 140-g elements were used, however, only 5-10 g of burn-up could be obtained for reactivity reasons; and each element would last only about one seventh as long as the heavier element. Thus light elements result in higher fuel costs from fuel fabrication, reprocessing, shipment and lease charges. Taking all these factors into account it is worth considering the element weights that are to be used, not only initially but also later when the core may be loaded with experiments or the reactor power may have been increased, etc.

26.2. Comments on fuel element procurement and specifications

It is worth spending considerable effort on the development of specifications for the procurement of fuel elements. Because of the general use of plate-type fuel elements, some of the important problems encountered in developing specifications for their procurement are listed below.

Standards for fuel-element specifications are being formulated by professional groups but, until they have been developed and demonstrated as adequate, it is recommended that copies of specifications successfully used at other reactors be obtained, together with comments relative to any shortcomings which have been found. With such specifications and a history of the success experienced in their use, many pitfalls can be avoided.

One of the most important features in the specification should be a clear definition of who is responsible in the event of faulty elements being produced. Full responsibility is usually placed upon the fabricator to supply sound elements and to replace any faulty ones.

26.2.1. Dimensional specifications

The most important dimensional specification is that of plate spacing, since this determines the coolant flow between plates. Other specifications for alignment, straightness, twist and functional fit must also be included. This sort of specification can often be best checked by fabricating a jig which duplicates the lattice space into which the element must fit. If a mock-up of the core is available, this may also be useful for checking new elements.

26.2.2. Welds

Welds are an important factor in fabrication, since the failure of even one may result in the element coming apart; a weld specification should therefore be included.

26.2.3. Weight of fuel

It is also very important to specify the weight of uranium in each fuel plate and it is probably best to put the full responsibility for this onto the fabricator by having him certify that the weight of uranium in each plate is within acceptable limits.

Until recently, the weight of fuel per plate was verified by destructive-test methods performed on a small percentage of the plates in a batch. However, several methods of non-destructive analysis are now in use for verifying the fuel concentration, e.g. gamma-scanning techniques or criticality measurements. This can be best used for individual plates, although the test must be performed before the plates are assembled into the completed elements. A fourth technique has been developed for measuring assembled elements [11]. Plates containing more than the desired amount of uranium might, of course, cause serious problems of heat transfer but experience to date has not shown that such an error in manufacture is very likely. Overheating in fuel elements caused by local flow blockage must be constantly guarded against and instruments are being developed to detect boiling in non-boiling reactors [12]. When these are developed, they will also provide additional means of detecting a fuel plate or element containing so much uranium as to cause boiling.

26.2.4. Inspection

In performing inspections and tests it is recommended that standard methods be adopted whenever possible, since more information can usually be obtained about their accuracy and reliability.

An inspector representing the purchaser should be free to visit the fabricator's plant as desired to observe and obtain samples. All elements should be inspected by the purchaser's inspector before they are accepted.

The maximum depth of dents and scratches should be specified, with the purchaser's inspector having the option of granting a waiver in borderline cases.

26.2.5. Contamination

Contamination of fuel plate surfaces with uranium has been a serious problem, but it has become much less so as better methods of cleaning plates during manufacture have been developed. It may be desirable to specify the method of cleaning and also the cleanliness of the rolls used to fabricate the plates. Several methods of analysis are also available for detecting contamination. Among these are alpha counting and a technique whereby a thin layer of the surface is scraped off and then analysed.

It is obvious that elements should be clean and free of dirt, metal chips and other foreign material.

26.2.6. Tests

The purity of structural materials should be specified and certified and a certain number of samples may be submitted for analysis. Similarly, a small number of elements may be fabricated and submitted for extensive testing before the major portion of the elements are fabricated. This enables the purchaser to make flow tests and reactivity measurements and to operate the elements in the reactor to uncover any weaknesses before a large number are produced.

The location of the uranium-alloy section of the plate must be determined to be within the prescribed area, to ensure that fuel-bearing surfaces are cooled. This may be done by radiography or fluoroscopy but, since the cost of radiographing all plates may be too great, it may be preferable to radiograph only a small number of the plates and depend on fluoroscopy when checking the remainder. Radiography is also useful for detecting any inhomogeneity in the alloy. If an undetected high concentration of uranium should occur at one point, this might result in burn-out when the plate is in operation. Again, however, under the present manufacturing and inspection methods this does not appear to be very probable.

A blister test is often used to detect lack of bonding of cladding to the fuel alloy. This is done by heating the plate in a furnace and visually examining the plate for small bumps or blisters. Recently, ultrasonic examination has begun to be used for this test and should be considered, as perhaps more sensitive and easier to perform.

It is customary for a certain number of plates to be cut apart and the cross-sections examined to determine whether the thickness of cladding and alloy meet specifications. Samples may also be analysed for fuel content. The number of samples to be tested for each particular test must be chosen with due regard to the confidence level required and the chances of fabrication errors. Also the number of plates to be destroyed in testing must, of course, be decided upon with due consideration to the cost involved.

If a plate is brazed, there is a chance of flux being left on the surface or occluded in the braze. This is likely to cause corrosion when the element is put into water. Mechanical fabrication techniques avoid this difficulty; however, tests are required to ensure adequate strength of the joint between the fuel plate and side plate.

The strength of a fuel plate which is assembled into a side plate may be tested by pulling the plate or a section of the plate out of the side plate with a tensile machine. The importance of this test is demonstrated by the fact that elements have occasionally failed in hydraulic tests or in reactors having high coolant velocities because of the difference in pressure between the inside and the outside of the element or the difference in pressure between flow passages. For this reason, it may be desirable to make flow tests on a few representative elements if the flow rate in service is so high that a large pressure drop is expected. Under high flow conditions the pressure at the bottom of an element may be considerably different on the inside than it is on the outside. This depends, of course, upon whether the flow passages between adjacent elements duplicate those inside the element including entrance and exit pressure losses.

Occasionally, efforts have been made to include the reactivity effect of new elements in the specifications. In most cases where this has been attempted, however, it has been difficult to write the specifications in a form which did not greatly increase the cost of the elements and experience has not shown such a specification to be necessary. The purchaser can, of course, make reactivity measurements in his own reactor and if the reactivity is greatly different from that expected, the element may be cut apart to demonstrate that the uranium was improperly loaded or that poisons had been incorporated in some of the structural material. The specification or purchase order should make it the responsibility of the fabricator to recompense the puchaser for such errors as improper uranium content or presence of neutron poisons.

26.2.7. Packaging and numbering

Elements should be individually packaged so that they will remain clean during shipment and storage. Transparent plastic, which itself has no corrosive effects on the elements, is a desirable packaging material.

Each element should be numbered in numbers two to three inches high inscribed on a non-fuel bearing portion of the element. This is necessary for identifying the elements under water. The numbering system should identify the manufacturer as well as the element.

27. CONTROL RODS

Since the control rods are the most important safety components in the reactor safety system, they deserve very careful attention during design and operation. While this has long been recognized, it is worthwhile examining some of the criteria which have been proposed for their design. BATES [13] proposed criteria for power reactor control rods which appear to hold equally well for research reactors.

The minimum acceptable total worth of the rods varies considerably at different reactor installations. At some locations a two-to-one ratio of the total rod worth to excess reactor loading, based on a cold-clean core, is observed. Different criteria are used elsewhere (see section 5.9). The total number of rods must, however, be such that malfunction of a significant number of the most valuable rods will not prevent a scram and so cause a subsequent melt-down of the reactor.

The control rods must never be subjected to an unbalanced force resulting from equipment failure, misoperation, or any other credible accident that would result in their being inadvertently withdrawn or ejected from the core.

No ultimate safety action designed to protect a reactor should ever be prevented by any failure or credible combination of failures or misoperation of rod-drive mechanisms or their auxiliaries.

In stationary reactors, control rods should not scram against gravity nor should any mechanical device used to accelerate the rod initially interfere with the normal acceleration from gravity.

There must be a definite seating position for the control rod in the core. No failure of the rods or rod-drive mechanism should ever permit any rod or rods to fall through, or out of, the core.

The positions of all rods must be known or be quickly ascertainable at all times. Of particular importance is the knowledge that any rod is attached to the drive mechanism and/or is seated in scram position.

Under no circumstances should the rod drives be capable of withdrawing the control rods at rates in excess of those established in the reactor design as being safe.

The control rods must never be able, in their movement, to accidentally displace in any direction any fuel considered to be part of the reactor core or blanket. This, of course, does not apply to any fuel which may be part of the control-rod assembly.

27.1. Reliability

The multiplicity of control rods is one of the chief safety features in that if the rods can be kept completely independent there would be little chance of more than one rod failing to operate at a time. However, the rods are necessarily of similar design so that a fault in one is likely to exist in others; and they may be mechanically connected by grids or other devices which may, if misaligned, cause all rods to fail. Other similarities, such as the maintenance given the rods, may exist which render them less independent than intended in the design. Consequently the reactor staff must pay particular attention to any failure or malfunction which may, if aggravated or under other conditions, cause more than one rod or even all rods to fail to operate at the same time. Mechanical faults such as jamming or misalignment may affect all rods, and, if such troubles should be indicated, the reactor manager should make certain that repairs are made so that there is no chance of more than one rod being affected.

27.2. Testing

Control rods should be tested regularly to ensure that they are working properly, especially whenever maintenance or any other operation has been done on them or in the region surrounding the rods.

Release time, the time required for the rod to be released from the driving mechanism and begin to move after the signal to release is initiated, should be measured regularly. This test is designed to reveal any faults in the release circuitry or in the latch mechanism.

Insertion time, the time for the rod to move from its withdrawn position to the fully inserted position, should also be measured regularly. It provides a very good test for any binding, jamming, warping, or bending of the rod or malfunction of bearings which may prevent its free insertion. Limits should be specified for these tests which the control rods must meet. If any of the limits are exceeded, the rods should be repaired so that the limits are met in the tests.

27.3. Control-rod worth

The worth of the control rods should be determined originally, both individually and in bank, over the distance of travel in normal operation; the total worth of each rod in the bank should also be determined. In a light-water reactor of the pool type or similar types, it is difficult to obtain the correct differential worth of the rods in any position except near their normal operating position, due to shadowing effects which occur when one rod is inserted or withdrawn more than the other rods (which also must be moved in the opposite direction to compensate). A method is needed which does not require that each point on a rod be measured. Such a test, which is especially easy to perform, is the rod-drop test [14]. This, however, gives results which are only relative and must be used with caution in assigning absolute rod worths. It appears to be valuable, however, when making regular checks to determine that the worth of a rod has not changed greatly from some previous value.

Rod worths may be determined by poisoning the core or by measuring periods. While the poisoning method may be used easily with a new reactor, it becomes a considerable problem if experiments are in the core. The material used for poison – usually plastic impregnated with boron – may be damaged by radiation if used with partially burned fuel. These and other factors make the poison method difficult to use after operation has begun. The period method is satisfactory only for that portion of the rod which is near the critical position.

27.4. Value of individual rods

No single rod should be worth so much that the reactor could be made critical if it is fully withdrawn while the other rods are inserted. This is an important safety factor since the reactor would be considerably more hazardous if it could go critical on a single rod (see section 5.9).

27.5. Rate of rod withdrawal

The rate of rod withdrawal differs considerably for different reactors. In some it is set to add as much as 0.1% $\Delta k/k$ per second, while in others the value is as low as 0.02% $\Delta k/k$ per second. One reason for a high withdrawal rate is to override xenon in high-flux reactors where the xenon poisoning grows rapidly after shut-down. In reactors with less xenon poisoning, the need of high withdrawal rates may not be so great. Whatever rate of reactivity addition is chosen, the safety system, even under the worst conditions of malfunctioning of the control system, should be able to reduce the power before damage occurs to the reactor.

27.6. Material problems

Some control rods have a beryllium section and a cadmium section so that they may be operated as part of a beryllium reflector surrounding the core. Several instances of beryllium swelling have occurred which have caused the rods to be bent (see section 24.3.5). In order that beryllium rods may be removed before they begin to jam, some means should be provided for gauging them periodically for straightness.

In control rods which have cadmium-poison sections canned in aluminium, swelling of the aluminium can has been observed in several cases. This happens when the water velocity through the cadmium section is very high, causing a considerable pressure drop along the length of the section, and is due to a leak in the upper end of the aluminium sheathing. This admits water at a point of high pressure and the pressure is then is transmitted between the cadmium and aluminium to the bottom end of the section. The pressure on the inside of the sheath at the bottom is higher than that on the outside and may cause the thin aluminium sheathing walls to bulge. In some cases a normally 2.5-in square opening has become restricted to less than 1.5-in square. This has been prevented by purposely leaving openings in the lower end of the section. This has the disadvantage, however, that some cadmium will be found in the primary water.

Swelling of control rods containing boron carbide has been observed – apparently due to gas evolved from the neutron reactions. As with the beryllium rods, boron-carbide rods should be gauged regularly so that swelling may be detected before the rods jam in the core.

27.7. Release mechanism

Any of several types of release mechanisms, including magnets or latches, may be used. The main disadvantage of magnets is that in most designs they must be operated above the rods and this requires that all the control drives must be at the top of the reactor. For some types of research reactors this has the disadvantage that it leaves less room for experiments to be inserted into the reactor core from above. Latches are generally used for rods driven from below and these offer many more mechanical problems than do magnets.

27.8. Control-rod drives

Drives should be provided with some means of indicating their position to the operator in the control room. Also the drives should be provided with upper-limit and lower-limit switches so that there is less chance of their being withdrawn to the point where the motor stalls or some failure occurs. Similarly, the lower-limit switch should prevent the drive from exerting force against the control rod or parts of the reactor in such a manner as to cause damage. Unless these limit switches are carefully maintained, they can easily fail to prevent such trouble.

27.9. Seat switch

A switch should be provided on the control rod to indicate to the operator if the rod is seated in scram position or not. This is most important information since it tells the operator whether the rod has inserted properly during a scram. Without this information, it may be difficult to determine whether the reactor is shut down by a sufficient margin, e.g. the control rods might be jammed in a partially withdrawn position.

28. INSTRUMENTATION

The importance of reactor instrumentation in safe operation and control is obvious. The reactor staff must be carefully trained in the proper use and maintenance of instrumentation and in the appreciation of problems associated with the instrumentation.

No attempt is made here to treat detailed instrument design but instead to list from an operational aspect some general criteria, to cite some problems which have been encountered which could not always be foreseen during design, and to give some indication of the vigilance required of the reactor staff. For further guidance a list of the suggested minimum safety and control instrument channels for water-cooled forced-circulation reactors is given in Table III.

TABLE III

SUGGESTED MINIMUM SAFETY AND CONTROL INSTRUMENT CHANNELS FOR WATER-COOLED FORCED-CIRCULATION REACTORS

Channel	Number of channels	Start-up (Full-power mode)	Start-up (Low-power mode)	Power operation (Full-power mode)
Power level	2	x	x	x
Period	1	x	x	
Counting channel	1	x	x	
Coolant flow	2	x		x
Temperature difference	1	x		x
Fission-product monitor	2	x		x

28.1. General criteria applicable to reactor instrumentation

The control and safety instruments must monitor the neutron flux in the core over the whole range from start-up to full power.

Withdrawal of control rods should be prevented if a minimum counting rate is not present in the start-up channels. This is necessary to prevent a start-up accident due to lack of a neutron source.

When required, instruments must be compensated for gamma radiation, i.e. the gamma radiation must not cause such a high background in the neutron channels designed for low-power indication that there is a possibility of the reactor being started up and going supercritical on a dangerously fast period by the time the safety channels begin to function.

The reactor safety instrumentation should shut down the reactor by activating the safety system before a dangerously high power is reached.

Well-tested components with which the maintenance staff is familiar and for which spare parts are readily available should always be used wherever possible. Substitute instruments are often less reliable and rarely simple to replace when they fail.

28.2. Safety instrumentation

The safety instrumentation should be separate from the control and monitoring instrumentation and should have standards of reliability which are commensurate with safety requirements and higher than those expected for the latter instrumentation. Independent, redundant safety channels may be used when extra reliability is required (see 28.3).

The time required for the safety instrumentation to initiate safety action, usually the release of the control rods, must be short enough so that the largest credible insertion of reactivity will not cause damage to the reactor.

Channels which monitor parameters necessary for safety, such as coolant flow, should have the same degree of reliability as neutron safety channels. This instrumentation should safeguard against the overheating of the fuel, excess pressure and every other factor detrimental to safety.

The safety channels should function independently of action by the operator, i.e. he should not have to perform any operation to initiate the proper action of the safety channels. Similarly, he should not be able to prevent the action of the safety channels by any simple error.

The reactor staff should be aware of the fact that the original design may not always provide adequate protection against unforeseen effects from changes in temperature, flux, gamma background, operation of facilities, or other causes. These may cause two or more safety channels to fail or increase the probability of their failing at the same time. Such a situation reduces the reliability of supposedly independent channels and greatly increases the probability of safety-channel failure.

When possible, safety systems should be constantly checked for accurate operation. It is preferable, of course, for the complete channel to be so monitored; but, if this cannot be done, as much of the channel as possible should be monitored constantly and some means developed for testing the whole channel at regular intervals. Safety channels may never have an opportunity to shut down the reactor during normal operation and so occasional tests should be made, e.g. in such a way that when the reactor is started up after a shut-down the scram trip will operate at or below the normal power level.

Provisions for blocking out safety channels should be avoided, except in cases where spare channels have been provided so that maintenance may be done during operation. If block-outs are provided, they should be equipped with warning signals, locked switches, interlocks and be governed by administrative controls both to prevent their being activated inadvertently and to ensure that the operator is aware of those which are activated.

The neutron-sensitive instrumentation must predominantly "see" neutrons from the core rather than photoneutrons from the reflector or other sources.

The adjustment of safety channels, for whatever purpose, should be carefully controlled. Adjustments may be made under certain conditions;

for example, neutron safety chambers may have to be moved to compensate for movement of the control rods which changes the neutron flux in the vicinity of the chambers. In such conditions, the supervisor must exercise additional administrative control to compensate for the fact that the channel being adjusted may not be reliable until after the operation of moving the chamber has been completed and some check has been made to ensure that the channel is again operating properly.

28.3. Sensitivity to fuel movement

If the core design permits, some of the instrumentation should be sensitive to fuel movements during shut-downs. The movement of the minimum amount of fuel which can be observed on the nuclear instruments under different conditions of core geometry, gamma background, etc., should be established and the operators should be instructed to observe these instruments when loading fuel. This procedure gives a great deal of extra protection against fuel-loading mistakes which might make a shut-down reactor supercritical.

28.4. Redundancy

Independent, redundant systems are often regarded as the best means of providing high reliability. An independent, redundant system is defined as one in which two or more channels monitor the same parameter, and each provides independent safety action if the safe limit is exceeded. Much effort is required to keep the channels completely independent, not only by avoiding common connections but also protecting them from the action of some outside factor which may adversely affect both channels. However, EPLER [15] points out that redundancy may be overrated as a means of achieving reliability of safety systems if all factors are not carefully considered.

Much stress has been placed upon the importance of redundancy as a factor in reactor safety instrumentation and it is worth citing a number of examples where the independence of safety or control channels was found to be prejudiced by some fault or condition which greatly increased the probability of simultaneous failure; although the channels were designed with every intention of keeping them independent. Location alone has been the cause of a number of troubles on this score.

(1) The flooding of a beam hole in the ORR was found to affect some of the safety channels by a factor of five [16].

(2) A massive reflector of beryllium around the core of a reactor had an appreciable effect in masking the multiplication of the core during start-up, due to the photoneutrons from the beryllium; this made the neutron safety channels less sensitive than expected. This effect, of course, increased as the fission product activity increased in the core.

(3) In another case, a neutron source behind the neutron-sensitive safety chambers caused an increase in their signal when the chambers were moved away from the reactor core.

(4) High temperatures in chambers resulted in damage to chamber components which might have caused simultaneous failures if the damage had not been discovered.

(5) Gamma "pile-up" caused unexpectedly high output from fission chambers.

(6) Neutron chambers, initially located below a reactor core, had to be moved to locations on the sides to escape the effects of gamma radiation from the fuel section of the control rods.

(7) In a similar case a fission chamber beneath the core gave anomalous response due to the movement of the fuel section of the control rods [17].

(8) In another reactor the cables of fission chambers located near the bottom of the core were damaged by radiation. The chambers were not provided with means for being moved away from the core, and this made the cables fail rapidly. Consequently, it was necessary to provide mechanisms for withdrawing the chambers after start-up.

(9) Gas-flow neutron chambers have sometimes been connected to a single gas supply and when wet gas was used inadvertently, all channels were affected. The obvious remedy was to provide a separate gas cylinder for each channel.

In keeping channels as independent as possible, the location of the sensing elements is sometimes an important factor. In one example, cited above, flooding of a beam hole affected one channel by a factor of five but other channels with chambers in other locations were not affected so greatly. In another case water flooded the normally dry region around a neutron chamber reducing its response; other chambers were not affected.

Many of these examples show that the unanticipated coupling of instrument channels is due to changes which occur because of temperature, changes in energy and spatial distributions of neutron flux, changes in the radiation background level at the chamber location, effects of movement of control rods and of other facilities on the chambers. The conclusion which can be drawn from this is that the safety channels are sometimes not as independent as anticipated in the design. Safety analyses which are based on complete channel independence and assume that only random failures will occur, are often not valid.

28.5. Coincidence versus redundant channels

Reactor safety systems are usually based upon redundant (one out of two or more channels) or a coincidence (two out of three or more) system. The first is simpler, cheaper and presumably more likely to result in safety action since any one channel can initiate the action. However, it is also more likely to result in spurious shut-downs since any channel may shut down the reactor if it fails. Proponents of the second system claim that the loss of safety in requiring that at least two channels agree before a shut-down occurs is so slight as to be negligible since there is no limit on the number of channels. For example, a two-out-of-eight-channel system might be used if desired.

Another advantage of the coincidence system lies in the ability to test one channel at a time without interfering with the ability of the other channels to provide safety action. Some systems have even been designed to test each channel in a coincidence system either fully automatically or at the request of the operator. The coincidence system reduces the chance of spurious shut-downs due to failure of one channel, but it is more complex and requires careful design.

A typical research reactor does not necessarily require this degree of freedom from spurious shut-downs. Furthermore, experience indicates that, with a well-planned and well-executed maintenance programme, a system of redundant independent channels (where any single safety channel can shut the reactor down) can be made very nearly as free of spurious safety action as the coincidence system.

For example, two channels of power level are usually included in research reactor instrumentation and, if it is considered necessary to avoid spurious shut-downs, a third channel is provided so that if one becomes unreliable it may be blocked out without shutting down the reactor. If, for example, xenon poisoning is considerable and there is a slight delay while a safety channel is being repaired and if it cannot be blocked out, the reactor might be poisoned so that either the fuel would have to be changed or the xenon allowed to decay before the reactor can be restarted. Many reactors are, however, successfully operated with only two such channels; the third gives extra reliability for reactors where reliability of operation is especially important. Similar considerations apply to start-up channels, of which two are usually required, and to other safety instruments.

28.6. Block-Outs

The use of block-outs must be treated with extreme caution because of the ease with which they may be misused. With some block-out designs, it is possible, through operator error or forgetfulness, for the block-out to be left in such a condition that further operation would be hazardous. When possible, block-outs should be arranged so that only a permissible number of each type of safety system can be blocked out.

A direct block-out of a safety channel should be permitted only if an extra channel has been provided so that maintenance work may be performed on one channel at a time during operation. (It should not, of course, be possible to block both at the same time.)

28.7. Gamma chambers

Gamma chambers have been incorporated in the safety system of some reactors to provide protection under conditions where the neutron-sensitive ion chamber or fission-chamber channels are not reliable. Neutron-sensitive chambers are susceptible to intolerable losses of sensitivity if the area surrounding the chamber or a beam hole near the chamber becomes flooded with water. A chamber located near an empty beam hole may see a reduction in flux by as much as a factor of five if an adjacent beam hole is flooded with water. Because gamma rays are not attenuated by water as much as neutrons, gamma chambers are ideal safeguards against such incidents. They are, however, reasonably reliable only over the range of full-power operation. If they are used, the designer should endeavour to make them as reliable as the normal neutron-sensitive instruments.

28.8. *Fission-product monitor*

In reactors where there is a possibility of the fuel overheating as the result of a coolant blockage, etc., some sort of fission-product monitor may be necessary. In practice the simpler instruments have been adequate to detect large releases of fission products, but more sophisticated ones are needed for smaller amounts. Various types of monitors are discussed in section 31.5.1 below.

28.9. *Locking of control rods*

A switch or other device should be provided which will allow the operator to deactivate the control-rod drives when the reactor is shut down, so that there is no possibility of inadvertent movement. This is an important feature since there is a possibility that the rods may be caused to move during maintenance operations. It follows, of course, that when the lock switch is unlocked the operator must be in attendance and ready to take appropriate action if the control rods should begin to move.

28.10. *Excess reactivity controlled by automatic system*

When an automatic control system is used, it may operate a low-worth control rod or it may control a portion of one of the main control rods. In either case, the reactivity controlled by the automatic system should be substantially less than that which could make the reactor prompt critical.

28.11. *Relationship of the reactor operators to the instrumentation*

The operator should not "be a part" of a safety channel, i.e. proper operation of the safety channels should never be dependent on an operator since he is much less able to perform a given operation consistently and reliably than an instrument. Instead, the safety system should be designed to safeguard the reactor in spite of any simple error the operator might make.

The designer is often faced with the choice of designing the control system so that either the operator performs a great number of functions or it is as automatic as possible and the operator is free to observe the instrumentation and to watch for any sign of malfunction. If the operator is given too many functions to perform, all his time may be occupied with repetitive actions involved in controlling the reactor or some equipment associated with the reactor. An instrument can generally do this better and more reliably than can a human operator. The operator does, however, have a very important function, doing the things which instruments cannot do, i.e. checking instruments, either singly or against each other, and interpreting any abnormal behaviour. Even here, of course, there are certain occasions where instruments can be arranged to check on other instruments and such automatic checks are very desirable. However, there are many situations where an operator is the only means available for checking inanimate instrumentation.

28.12. Testing

All safety instrumentation must be capable of being tested without excessive difficulty. Full reliability cannot be ascribed to safety devices which cannot be tested regularly. For example, a device such as a "shot tube" containing boron-steel shot is sometimes arranged so that when tripped the shot can be dropped into a vertical hole in the reactor. Because it is very difficult to remove the shot once it is dumped, such devices are so difficult to test that they are not tested often enough to guarantee their reliability. (Similarly "reactor fuses", as developed so far, are untestable.) In designing safety devices for reactors, therefore, considerable thought should be given to methods for testing. Whenever possible, testing devices should be incorporated as part of the reactor console so that tests may be conducted readily. Where sufficient instruments have been installed, permanently mounted test equipment will permit the operator to make frequent tests by removing each channel, in turn, from the safety system and testing it.

Whenever possible, tests on reactor safety channels should be made on the complete channel rather than on a portion of it. In cases where only a portion of a channel can be tested frequently, the operator should understand clearly the limitation of the test and, at less-frequent intervals, test the other portions. Regular functional tests should be carried out on every safety instrument using formal check lists to ensure that nothing is overlooked.

28.13. Experiment instrumentation

Experiment instrumentation and that used for special experiments on the reactor itself should be designed and tested, insofar as possible, according to the same safety standards as used for the basic reactor safety system. A consistent set of criteria for experiment safety instrumentation should be developed and followed.

Safety instrumentation for experiments must be carefully connected to the reactor through a standardized and well-designed switching circuit [18]. Unless this is done, experiment instrumentation may be connected to the reactor in a variety of makeshift ways which do not provide for all the operations likely to be encountered, such as testing and detaching from the reactor when the experiment is terminated. There is a likelihood of temporary wiring used for special tests being inadvertently left in place. This can be avoided with well-marked selector switches for each experiment to allow both a testing and operating mode.

28.14. Modifications to instrumentation

The operating staff should be given as much information as possible about the basis for the design of the instrumentation, so that they can evaluate any change which appears necessary. There is always the danger of a change being made which decreases the efficiency of the instruments simply because the design was not fully understood.

This is particularly so for all modifications to safety instrumentation which should be reviewed and formally approved by staff personnel who are familiar with the design. Permanent records should be kept of all changes and care must be taken to ensure that all personnel know of the change and the reasons for it. Special care must be taken in those cases where temporary changes are made and where it is decided not to issue a formal change notice.

28.15. Minimum safety control instrument channels

The reactor manager should recognize and make plans for the number of instrument channels required to be in operation for the different modes in which the reactor is likely to be operated. For example, it may be necessary to make a number of low-power start-ups for checking criticality, for making flux determinations, and for other purposes where the power does not exceed 0.1% of full power. Under these conditions it may be perfectly reasonable to omit certain safety channels. Likewise, after the reactor has started up and is operating at full power, the start-up channels are no longer especially important and as long as the reactor continues to operate at full power it might be reasonable to permit the start-up channels to be out of service. The most important thing, however, is that the decision in this whole matter be made on a logical basis rather than on the spur of the moment. Table III lists the suggested minimum number of channels for water-cooled forced-circulation reactors.

29. REACTOR VESSEL

Where a reactor is enclosed in a tank or pressure vessel, provision will have to be made for the convenient insertion of experiments and for handling them after irradiation. It is desirable to carry out refuelling whilst experiments are in place and without disturbing them. This also implies that refuelling should be so planned that it can be carried out in a reasonable period of time.

It may also be necessary to install experiments inside tubes extending from the top of the vessel down to the core. If the water flow rate is high, the water may impinge against the tubes and cause serious stresses and vibrations. Brackets should be provided on the tank walls at suitable elevations to support the tubes. Flanges should also be provided for the tubes in the top of the vessel, and at the sides of the vessel for experiments having flexible connections.

The effect of all conceivable operating conditions should be studied to determine if the vessel might limit the future operation of the reactor. Effects of temperature changes, maximum pressures, unbalanced pressures caused by misoperation of an experiment, and any other condition which might affect the vessel, should be examined.

29.1. Lattice

All parts of the reactor lattice should be designed for easy removal and replacement should they become damaged. Since the structural material of the lattice will become quite radioactive, it should be possible to remove all components remotely. The operating staff should practise removing these components during the period before a new reactor begins operation.

29.2. *Gas release from experiments*

Some experiments may contain gas under pressure. If this pressure is higher than the test pressure of the reactor vessel, there is the possibility that the vessel will be overstressed if the experiment should rupture. The reactor designer can avoid this situation by providing additional space for the experiment to be doubly jacketed. If the primary experiment tube should rupture, the second jacket would then prevent the high-pressure gas from being released inside the tank.

29.3. *Venting*

It is advisable to arrange a means of venting gas which may collect at the top of the reactor vessel. In systems having a degasifier there is little likelihood of such gas collecting (see section 31.3). However, several arrangements have been used where venting was required:

(1) A manually operated venting valve may be installed in the top of the tank with some means of determining whether gas or air flows through the line.

(2) A small vent line may be installed from the top of the tank to a point of low pressure in the system. (This allows a small stream of water to bypass the core and sweep any gas into the main water line where provision may be made for its removal.)

(3) A device such as a ball-float valve may be used which will permit the gas to escape while preventing the flow of water.

29.4. *Window*

Another valuable design feature is a window in the top of the tank to enable the operator to observe the fuel during operation. This permits the early detection of many possible adverse conditions before any serious consequences result. For example, a fuel melt-down, due to one or more elements becoming so badly plugged with debris that they do not receive sufficient cooling, may be prevented by the visual examination of fuel for such debris during start-up. Similarly, such malfunctions as a broken experiment tube may be readily detected.

29.5. *Trash collection*

Among the problems encountered with reactor vessels is that of trash or debris collecting in the bottom. If the reactor has bottom-drive control rods, trash is troublesome since it may jam the drive tubes or cause severe galling. The designer should provide some means of preventing trash collection, such as by directing the waterflow path across the bottom of the vessel so that any debris is swept out into the water stream where eventually it can be removed by filters or strainers. Raised ledges around the holes through which the drive tubes and other tubes penetrate the bottom of the tank may also help prevent the entry of foreign materials.

30. REACTOR POOLS

Besides reactor pools proper, many reactors have a pool of some sort for storing spent fuel elements or other radioactive material. Apart from such specific storage space, space should also be found for radioactive components used in performing experiments in the reactor and for placing carriers or shields on the floor while they are being loaded.

The depth of the water must be sufficient to give the necessary shielding for the material to be stored. If the pool is used only for storing fuel elements, a depth of 10 to 12 feet is generally sufficient. If a reactor is operated in the pool, the depth must be considerably greater — of the order of 20 or more feet above the reactor core, depending upon the power level. Consideration should be given as to whether some parts of it might be shallower — a shallower pool offers much less difficulty in performing underwater operations than one of 20 to 25 feet depth.

30.1. Lighting

Some pools are illuminated by lights installed in the walls, but these require special designing so that the lights can be changed, and consequently portable lights suspended in the water are often used instead. Portable lights are necessary to provide local illumination for work in the pool, and are, of course, easier to maintain and repair.

30.2. Cleaning

The pool should be designed so that sections may be drained and cleaned occasionally. This may not be possible if the reactor is in one portion of the pool. Even here, however, it is desirable to be able to empty other portions of the pool reasonably easily.

An overflow drain around the pool, or at least a small portion of it, at the water level is most useful for skimming any dust or trash off the surface. The drain from this overflow should return to the recirculating cooling and cleaning system. If there is considerable recirculation, only a small fraction need overflow in order to keep the surface clean.

In pool-type reactors, the floor of the pool is likely to become covered with dirt and trash which is difficult to remove. By providing a simple connection to the main circulating system it is often possible to suck this material off the pool bottom through a vacuum-cleaner-type nozzle connected to a filter.

Some means must be provided to keep the water clean for good visibility, control of radioactive contamination in the water and to reduce corrosion of material stored in the pool. If, for example, aluminium fuel elements are stored, the specific resistance should be greater than 250 000 Ωcm and the pH should be controlled between 5.5 and 6.5. If any of the fuel elements release radioactive nuclides into the water through corrosion, the radioactive contamination will gradually increase and the water will become a source of such contamination whenever tools are removed. For this reason, it is advisable to circulate water through a cleaning system (see section 31). Other problems connected with the prevention of corrosion have been dealt with in section 24 above.

30.3. Liners

Water leakage must be low, especially if the canal or pool walls are part of the reactor building since the water may carry radioactive contamination into areas where experiments are being done. This is undesirable and the leakage should either be controlled or prevented entirely by having some sort of metal liner in the pool.

Pools have been built both with and without metal liners. Many of those without liners, however, exhibit some leakage through the concrete and, if real leak-tightness is desired, it is necessary to install a metal liner. Either stainless steel or aluminium may be used. Stainless steel is much superior from the standpoint of corrosion resistance, especially on the interface with the concrete structure, and of ease of decontamination, but it is more expensive. Aluminium has been used successfully at a number of facilities but, if it is used, it is advisable to take several precautions:

(1) If water leaks into the region between the aluminium and the concrete, pitting-type corrosion will result under certain conditions [16]. Because of this corrosion hazard, it is desirable to have some way of monitoring the region between the concrete and the aluminium liner for water. This may be done either by having a drain from the region between the liner and the concrete or by connecting a vacuum system with cold traps to this region. By measuring the amount of moisture collected in the cold traps, it is usually possible to detect any appreciable leak.

Bitumastic or plastic coatings on the concrete side of the aluminium appear to very helpful in preventing corrosion; however, these coatings are of questionable utility in regions of high radiation because of the possibility of decomposition and release of quantities of gas. The decomposition of such a coating will decrease the heat transfer from the concrete to the pool and radiation heating may thus become a major problem in the concrete.

30.4. Unlined pools

In pools which are unlined, water sometimes seeps through the walls causing unsightly stains on the walls and wetting equipment. With this type of pool, troughs may be provided around the outside of the pool where any leakage could be collected and discharged to a drain. If the pool is partly below ground, a small amount of leakage into the soil may not be so important, provided the water which leaks cannot contain enough contamination to cause a hazard. Pools with concrete exposed to the water have the disadvantage that the concrete absorbs radioactive nuclides from the water and, if the water contains many long-lived radionuclides, the walls may become quite radioactive. The radionuclide content in the water can be kept at a very low level by a recirculating demineralizer system. Experience indicates that normally the concrete does not leach badly enough to cause the demineralizer beds to become depleted rapidly.

30.5. Access through walls

If the wall of the reactor pool is above floor level, there is often need for experiment piping or wiring to be brought through the wall of the pool and special pipes and lead-throughs should be incorporated for this purpose. This is especially convenient if it is possible to locate experiment equipment next to the pool wall.

30.6. Draining of pool

In pools having bridge-mounted reactors, it is often desirable to move the reactor and all other materials out of the way so that one section of the pool may be drained for maintenance or installation of equipment. In such cases the reactor, radioactive fuel, and other material must be moved to one section of the pool while the other section is isolated by means of a gate (see 30.8). This section should be large enough to move all radioactive material 10 feet or more beyond the gate; otherwise, radiation may be too high in the section which is drained. Several other arrangements may be used to provide the necessary shielding. One is to have a deep pit in which fuel elements and other radioactive material may be stored. This may reduce the size of the pool required at the expense of making one portion somewhat deeper.

30.7. Storage racks

All storage racks holding fuel elements or other objects in the pools should have ample space for the water to circulate freely around and through the elements. If the water becomes stagnant inside the rack, a marked increase in corrosion is likely to occur, especially with aluminium fuel elements. The rack design must, of course, also be such as to preclude accidental criticality through adequate spacings between elements and racks even if all elements were of the maximum loading used.

30.8. Gates and platforms

Gates are often used in reactor pools to separate one section of the pool from another, thus enabling one section to be drained as necessary. The gates may have vertical sides or be trapezoidal in shape. The latter has an advantage in that the gate does not have to be lifted as high to clear the gate walls.

The gate may be placed between opposite walls or, more often, abutments may be built out from each wall. Since experiments of one type or another may make it desirable to run piping underwater the full length of the pool, a number of flanged ports through the abutment should be provided so that piping may be installed later without interfering with the action of the gate.

A working platform is necessary, so that various underwater operations may be performed. This platform should be arranged to roll back and forth over the pool.

30.9. *Effect on building ventilation*

If the pool is operated at too high a temperature, the water vapour released in the building will cause condensation on the cold surfaces. However, if the temperature is kept below 100°F, this seems to cause no problem.

31. WATER SYSTEM

The water in most water-cooled reactors serves several purposes: as a radiation shield, as a moderator, as a coolant, etc. However, the water quality must be properly maintained so that the constructional materials will not corrode excessively; so that impurities, which might become radioactive in passing through the core, are kept at an acceptably low concentration; and so that radioactive nuclides released into the water from the fuel are continuously removed. Continuous removal of these nuclides is necessary to prevent the accumulation of long-lived radionuclides which increase contamination problems. Good water clarity must be maintained to permit visual observation. Finally, it should be possible to monitor the resistance, radioactivity, pH, temperature and any other parameter of the water system necessary to alert the operator to any abnormal condition.

31.1. *Water purity*

One of the most important indications of the quality of the water in a reactor is its specific resistance. This can be monitored readily with an appropriate conductivity cell which may also be used to automatically signal either a failure of the demineralizers or a release of impure water into the system. The corrosion rate of the components of water systems and the control of the radioactivity in the water are both dependent on the proper functioning of the demineralizers and, therefore, a good monitoring programme is essential. Since the specific resistance of a water system does not usually drop very rapidly, a sampling-and-analysis procedure can be used successfully, if a continuous monitor is not available. However, the latter is most convenient and may be justified on most reactors.

31.2. *Maintaining water purity*

Water will not remain clean in reactor systems for the following reasons: it dissolves a number of materials from the system structure; radioisotopes are formed from the material in the water as it passes through the reactor or by recoil from the fuel; radioactive gases may be dissolved in the water and diffuse from it into the reactor building; algae may grow in the system until the water becomes turbid; and trash and foreign material may be dropped into the water. It is thus necessary to clean the water continuously and a variety of devices are used for this.

31.2.1. Strainers

The strainer is one of the simplest yet most necessary of the cleaning devices. It is absolutely essential in systems where water is circulated through the reactor. Several reactors have been operated without strainers and, in nearly every case, the reactor lattice becomes the best strainer in the system and collects trash which has inadvertently entered the system during maintenance, fuel changes, or other operations. In a few cases, the debris collected in the fuel has stopped the flow through one or more elements to such an extent that fuel has melted.

The strainer should have apertures smaller than the cooling channels in the fuel so that whatever passes through the strainer will also pass through the fuel. There is some danger that the strainer basket itself may fail, releasing pieces of a size that might block a fuel element and it is therefore most necessary to schedule regular inspections of the strainer to remove any trash and to determine the condition of the strainer basket.

Strainers should be located in the water lines as close to the inlet of the reactor as practical so that there is little likelihood of maintenance operations injecting trash between the strainer and the reactor.

31.2.2. Filters

While the entire flow can be passed through a strainer, its apertures are usually too large to remove fine particles from the water and further filtration is necessary, particularly to remove any turbidity which may prevent visual operations in the reactor or in a pool. A good filter in a by-pass stream, representing a fraction of the main flow, is usually sufficient to maintain good clarity. While a demineralizer bed makes a good filter, the demineralizer flow may not be great enough to clarify the water sufficiently and it is less expensive to install a filter than a larger demineralizer.

The flow capacity required through a filter depends upon the volume of the system, whether open so that atmospheric dust and algae may accumulate or closed so that most extraneous material is kept out, whether composed of corrosion-resistant materials or of materials such as carbon steel or cast iron which release flocculent material into the water.

Several types of filters have been used successfully. The cloth-wound-cartridge type is quite satisfactory but must be changed every few months. A sintered stainless-steel cartridge is more expensive but quite efficient and it has the advantage that it can be cleaned by backwashing it with acid, caustic, or other agents. For filters likely to become highly radioactive, the stainless-steel cartridge has an additional advantage in that cleaning can be effected without exposing personnel to radiation. If the filters are to be cleaned in place by acid or other agents, it is, of course, necessary to provide suitable drains for the radioactive waste.

If the reactor system is composed of aluminium, stainless steel, or other relatively non-corrosive material, the filters do not normally become very contaminated and a cloth-type cartridge is quite satisfactory. However, cloth filters have to be changed regularly otherwise they will disintegrate.

Filter rates of 30-100 gallons per minute have been very successful in clarifying water in a reactor system with a volume of 100 000 gallons. Systems containing carbon steel or cast iron require higher filtration rates.

3.1.2.3. Demineralizers

Demineralizers, using columns of ion-exchange resins, have been used so successfully in removing both radioactive and non-radioactive ions from the water and in maintaining high water quality that they have become almost standard equipment. They are especially important for removing long-lived radionuclides from reactor water since these would build up, if not removed, to a level such that the contamination problem from the water would be very serious. If the inventory of long-lived radionuclides in the water is kept low, tools and other objects removed from the water cause much less trouble from the standpoint of contamination.

The size of the demineralizer required depends upon the volume of the system, the materials exposed to the water, the power of the reactor, the surface of water exposed to the atmosphere, and other factors. For most pool reactors having corrosion-resistant materials exposed to the water, a demineralizer capacity in the range of 25 to 70 gallons per minute would be sufficient to maintain a specific resistance of above 300 000 Ωcm.

The demineralizer may be built in any of several forms of which the simplest is one having separate cation and anion columns. Other arrangements consist of a single mixed-bed column or a large mixed-bed column preceded by small cation and anion columns. The last arrangement may cost somewhat less than the first, especially since the mixed-bed column does not become very radioactive and thus requires little or no shielding. Experience has shown that most of the radioactivity in the water is removed in the small columns even though the throughput of water may be as much as five times the amount normally recommended for the size of resin bed. The mixed-bed column (or large cation and anion columns) is, however, necessary to maintain the water quality if small cation and anion columns are used. Typical performance of such an arrangement is given in Table IV.

In practice, the cation column in the reactor primary system accumulates most of the radioactivity and must often be shielded from direct access; the anion column normally accumulates less radioactivity – though it does accumulate most of the radioiodine. Regeneration usually reduces the radiation from the columns to approximately one-tenth the previous value.

The demineralizer resin may be either regenerated or discarded when it is depleted and, even if it is regenerated, it may require replacement after a few years due to normal degradation of the resin. When changing resins, if the depleted resin can be regenerated before being discarded, most of the radionuclides can be removed so that the resin can be handled with less precaution against radiation. It may even be placed in a simple container such as a steel drum. Naturally, if it must be discarded while still radioactive, greater precautions are necessary. For example, it may be necessary to flush the resin from the column, through a line provided at the bottom of the resin bed, into a shielded container. The water can be drained through a screen which retains the resin. The resin may be stored for a number of months until most of the radioactivity has decayed, or it may have to be moved in a shielded container to a place of disposal. In normal operation, most of the radionuclides in a resin have fairly short half-lives, such as sodium-24 and iodine-131.

TABLE IV

PERFORMANCE OF SMALL CATION AND ANION COLUMNS FOLLOWED BY A LARGE MIXED-BED ION-EXCHANGE COLUMN IN THE LITR

(Flow rate -40 gall/min)

Column	Resin (ft^3)	Gross gamma (cpm/ml)		pH		Specific resistance ($\Omega cm \times 10^{-6}$)	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Cation	4	17000	4000	5.8	5.0	1.3	0.8
Anion	4	4000	1150	5.0	6.2	0.8	1.0
Mixed bed	30	1150	875*	6.2	5.9	1.0	1.5

* This is largely due to dissolved radioactive gases which could be removed with a degasifier but which are not removed by an ion-exchange column.

If the columns are to be regenerated, provision must be made for supplying the columns with acid and caustic and for connections to the waste system. In cases where it is necessary to limit the volume of hot waste, it is customary to send the first part of the regenerating solution to the hot-waste system, since this contains the major part of the radioactivities, and to send the remainder of the regenerant and wash water to a low-level waste system. Provision must be made, of course, in the piping for the rather high flows required for backwashing following regeneration.

Because of the consequences of acid or caustic being discharged into the reactor primary system by an error in valving, it is important to provide very positive separation of the column during the regeneration procedure. This may be done by special locked valves or by removing flanged portions of the pipe lines so that the resin columns are completely isolated from the rest of the system.

The pH of the water system can be controlled to some extent either by varying the ratio of anion to cation resin or by providing piping so that the anion column may be partially or completely by-passed to give a lower pH. It is generally not necessary for this to be done in ordinary aluminium-fuel reactors in which the water should be kept at a pH of between 5.5 and 6.5.

It may be desirable to place the ion columns in concrete cells with additional lead shielding for the cation columns if access to the cell is desired. Having the ion columns in cells gives an extra measure of safety in the event of a massive release of radioactivity, as from a fuel-melting incident. In such an event, the ion-exchange columns would be the main device for removing radioactive fission products from the water and would become very radioactive. It should be possible to perform all the operations involved in regenerating or removing the resin without entering the cell.

It is convenient, although not necessary, to have an integrating flow meter on the demineralizer so that the operator can determine, after some experience, approximately when the demineralizer will have to be regenerated or the resin replaced.

The resins used in reactor-water systems sometimes become breeding grounds for bacteria and dead bacteria often collect in points of low velocity in the system. For this reason, special bacterial treatment of the resin columns may be necessary.

31.3. Degasifier

For high-power, water-cooled research reactors it may be worth installing a degasifier to remove radioactive gases from the water. Reactor water is, normally, fairly well saturated with dissolved gases which may become radioactive in passing through the core, e.g. argon. Also, if fission products are released into the water, fission-product gases will be present and may diffuse either from the reactor tank, if it is open, or from the reactor pool. This problem is usually not serious in the lower power ranges; but at high power and flux a slight uranium contamination of the surface of the fuel or an experiment becomes noticeable, and fuel elements removed from the reactor may release gases which may diffuse from the pool into the building.

A degasifier will remove a large fraction of the gases in the system so that less will diffuse into the reactor building. Obviously, in the case of an accident where large amounts of fission-product gases are released into the water, a degasifier is a very important safety feature.

31.4. Provision for sampling and analysing reactor water

In order that various types of monitors may be installed, it is desirable to leave taps in the water system so that side streams may be removed either for continuous monitoring devices or for taking samples to be analysed in the laboratory. One such tap should be as close to the reactor as possible and others should be located before and after the demineralizers so that a measure of their efficiency may be obtained.

Alpha and soft beta emitters cannot be detected by the common gamma monitoring systems and, where there is a possibility of these being released into the water from an experiment, it is usually necessary to sample the water regularly and make laboratory analyses.

Laboratory analyses are advisable for all water-system-purity control checks including pH, specific resistance, and gross radioactivity, even if some continuous monitors are provided. Accordingly, a certain amount of laboratory test apparatus is necessary at the reactor including a pH meter, conductivity meter, and a sensitive gamma counter. Less frequent analyses, such as alpha and beta analyses and radioisotope identification and measurement, may be done in a central laboratory.

31.5. Monitoring

Although the degree of monitoring required varies from a great many continuous devices to a few simple tests performed in a laboratory, a certain minimum amount of monitoring is required either to avert many of the common problems or to detect them in time to take proper control measures. By keeping a careful watch on the radioisotopes present in the water, their proportion and amounts, it is often possible to detect failures in fuel, experiments and reactor components.

The easiest monitor to install and operate is an ion chamber measuring the total beta-gamma radioactivity in the water. This must, generally, be measured through a pipe wall; and, therefore, certain radionuclides, such as soft beta emitters or pure alpha emitters, may not be detected. However, special techniques may be used to detect these also. Since soft beta emitters or pure alpha emitters can usually be released only from experiments or sample irradiations, it is usually acceptable to rely on laboratory analyses of water samples for detection. Any appreciable failure involving fuel will release enough hard beta and gamma emitters to be detected easily by a simple ion-chamber channel. In a reactor with a circulating water system, the water will contain enough N^{16} immediately after leaving the core to mask the normal level of other radioactivities. In addition, there will be other short-lived gamma emitters with similar characteristics. Therefore, it is customary to locate the detector at a place where the 7-s N^{16} has decayed away. This arrangement, of course, has some disadvantage in that the monitor will not see the water for a minute or longer after it leaves the core and any massive failure of fuel would be undetected during this time. However, the monitor in a location where little N^{16} is present is much more sensitive to the slowly increasing, or small, releases of radioactivity which are more apt to be encountered than a massive fuel-element failure. If an N^{16} monitor is installed it should, of course, detect a massive failure of fuel almost immediately.

Installed resistance cells are useful for checking the performance of the demineralizers. Continuous measurement of pH in the reactor water is not necessary as long as the specific resistance is high, and it is perfectly adequate to make laboratory determinations of pH.

Laboratory measurement of the specific resistance of the water is important to detect any local region in the pool where the water quality may be low due to poor circulation. Laboratory measurements are superior for this purpose because the samples can be taken at a number of places, whereas the installed instrument gives a measurement at one location only.

31.5.1. Fuel-element failure monitors

Many types of devices for detecting the sudden release of fission products have been proposed [19-22]. Most of these depend upon sensing fission-product radiation as close to the reactor as possible so that the operator will be warned and can shut down the reactor quickly or the monitor may cause an automatic shut-down.

In cases where fuel has actually melted, no great sensitivity has been necessary and instruments such as N^{16} monitors or a radiation monitor on the exhaust of a degasifier have given ample indication. However, when only a small amount of fissionable material is exposed, the amounts of fission products given off are much smaller and more sensitive instruments are required if it is desired to detect the release immediately. Most reactors do not have such instruments and, in practice, they have seldom been needed to detect a serious melting, since this is generally satisfactorily detected by the less sensitive monitors. Sensitive instruments are sometimes very useful for detecting a defective element, however, in cases where one element releases enough fission products to cause a problem. Minor releases may be caused by small amounts of uranium contamination on the surface of the element, by a hole in the cladding or by any defect which exposes uranium to the coolant. In such cases, samples may be drawn from each element immediately after the reactor is shut down and tested with a sensitive detector and, where the design of the reactor permits, the samples may be taken while the reactor is operating.

31.5.1.1. Fission-iodine detector. This consists of ion-exchange columns to remove radioactive cations from a small side stream of water which has been out of the reactor long enough for the 7-s N^{16} and other short-lived activities to decay. The anionic radionuclides are then accumulated in an ion-exchange column and one of the gamma energies emitted by fission iodine may be measured with an appropriate detector. This device has the advantage of being quite specific, but it has the disadvantage of not detecting the event at the instant it occurs. It offers the possibility of comparing the ratios of iodine isotopes having different half-lives from which it is sometimes possible to determine whether the failure occurred in new fuel or in fuel which had been previously irradiated. This information may help to identify the fuel element or experiment involved.

31.5.1.2. Fission-gas detector. Fission gases can be utilized to signal the release of fission products in a manner somewhat similar to that of the fission-iodine detector. A side stream of water is passed through a vacuum degasifier, and the gases which have been removed may be monitored directly or, if it is desired to increase the sensitivity, passed through a charcoal-filter trap. Some of the daughters of the fission-gas chains are solids and these, together with some of the gases, accumulate in the trap and may be detected at lower concentrations than if the gas were monitored directly. This system is very sensitive to a large release of fission products even without the trap.

31.5.1.3. N^{16} monitor. Many reactors have monitors to measure N^{16} in the water after it has passed through the core and, in practice, these serve as excellent detectors for fission-product release from the fuel. The N^{16} monitor often gives good agreement with the reactor power, provided the flow rate is constant. If, however, the primary water system flow is not constant, as in the case where a modulating by-pass valve is installed around the heat exchangers, it is more difficult to relate N^{16} to power if the detector has not been located where it is as little dependent on flow as possible.

31.6. Corrosion

Because corrosion control is such an important factor, it is advisable to provide places in the water system where corrosion samples may be left for months or even years and removed for inspection from time to time.

All of the materials used in the water system as well as couples of the various materials should be tested.

The more common corrosion problems are dealt with in section 24 under the various metals concerned.

31.7. *Radioisotopes commonly found in research-reactor water systems*

The predominant medium-long-lived radioisotope ordinarily found in the water systems of reactors with aluminium-clad fuel is Na^{24}. This is usually accompanied by small amounts of the fission-product iodine isotopes, although the latter vary widely depending upon such factors as the amount of uranium contamination on the surface of the fuel, exposed uranium from experiments, and uranium which might have become deposited on the surface of the reflector and surrounding reactor structure. This last source of fission products may not be encountered often, but it usually accompanies any release of uranium into the water system, as from a fuel or experiment failure. The presence of U^{238} is signalled by Np^{239} and enriched U^{235} contains enough U^{238} to give a considerable amount of Np^{239}. Other isotopes may give information about conditions in the reactor. For example, Cd^{113} is found if the cadmium in the control rods is exposed to the water. An experiment may release radioisotopes not found in other experiments or in the reactor itself and, in order to detect these and isolate their source, it is desirable to analyse the reactor water regularly for the radioactivities present as well as whenever an unexplained increase in the total radioactivity occurs.

31.8. *Algae*

Algae are a problem in some pool-type reactors where the organisms grow in the water even though it is demineralized. While it would be possible to poison the algae by adding suitable chemicals to the water, this is not usually desirable because the material might become radioactive and cause a contamination problem. Conditions fostering the growth of the algae appear to be sunlight and stagnant water. Circulation of water through a moderately fine filter is a simple and efficient means of removing algae to a degree that they cause no turbidity or other interference with operation. The amount of filtration required depends upon the quantity of algae present. If the algae are allowed to increase, they may collect upon the surfaces and the accessible ones, such as the pool walls, may have to be cleaned.

31.9. *Radiolytic gas*

Decomposition of the water into hydrogen and oxygen must be of concern to the reactor manager. In most low-power research reactors it is no problem except that these gases may accumulate at certain points in the systems, such as in a vapour space in a surge tank. Some systems have sampling lines or special valves at the high points in the systems which allow bleed-off of gas but which stop water. In any case it is recommended that any vapour space be checked occasionally for the concentration of hydrogen. If it is above the explosive limit, consideration might be given to providing a small air sweep through the vapour space to reduce the concentration.

32. EMERGENCY COOLING

For reactors of medium and high power, the afterheat, or heat produced in the fuel by the decay of fission products after shut-down, represents a serious design and operational problem for the case where the coolant flow suddenly stops or if the coolant should be lost suddenly.

32.1. Need for emergency cooling

The need for emergency cooling depends largely upon the specific power of the reactor fuel. For ORR-type cores with power levels up to 20 MW, tests have indicated that thermal convection provides enough cooling for afterheat following shut-down [16]. This refers to ORR-type fuel elements open at the top and bottom. In reactors having more complicated fuel cooling passages, thermal convection may not be so effective. Also, such cooling systems assume that the water remains in the reactor.

If the water is lost from the reactor core, afterheat becomes serious at an original steady-state power level of about 2 MW, according to tests done at the LITR [23]. Protection against sudden loss of water requires that some auxiliary water source be provided. For the 3-MW LITR, this has been done in the following way. A tank of approximately 500-gallon capacity is kept filled by the recirculating water, and this is connected to sprays located above the core. In case of loss of water, the tank feeds these sprays by gravity at approximately 3 gal/min. Tests at the LITR indicate that this amount of water sprayed over the fuel is sufficient cooling to keep temperatures in the fuel at approximately 100°C. Additional cooling may also be provided, such as independent systems for spraying water over the core. For example, an independent spray system operated by a manual valve might be provided.

32.2. Auxiliary cooling devices

If it is necessary to provide auxiliary devices to guarantee circulation following loss of the main pumps, various emergency power sources may be used to continue some circulation for several hours following a power failure [24]. The first essential action following loss of flow is, of course, that the reactor be shut down. This would normally be done by a flow safety device, ΔP across the core, or some other safety device usually with independent, redundant channels if the hazard is considered very great. Several seconds or tens of seconds are generally required for the main pumps to slow down and stop and during this time some emergency power source must begin circulating water through the core. Some of the various devices which have been used are as follows.

(1) Gasoline-driven pump. This is not regarded as having very high reliability and, if used, more than one would be required to give good reliability in case of an accident.

(2) Electrically driven pump powered by either an emergency power source or batteries. Here again, one unit would not generally be considered to give adequate reliability.

(3) DC electric motors. These are connected to the main pump shafts and driven by batteries which operate the pump at low speed if the main motors stop. Redundant, independent units are also required to give a high degree of reliability.

(4) Thermal convection loop. This may be arranged so that one or more valves open if the main pumps stop, providing a path for water to circulate through the core and back into the pool. This can most conveniently be used if the vessel is surrounded by a pool to furnish the coolant. The reliability of the device used for opening the loop must, of course, be examined very carefully.

(5) Head tank. A head tank to furnish flow through the core for several hours after shut-down is one of the most reliable devices. However, in the event of a fuel melting incident, very radioactive water could enter such a tank and there would be considerable radiation from it unless it were shielded. Shielding might be feasible, of course, if the tank were located on a hill near the reactor.

33. REACTOR BUILDING

The operation of the reactor and construction and installation of experiments can be made much easier and safer through the appropriate arrangement of the reactor building and auxiliary systems. While it is obviously impossible to foresee every requirement in advance, sufficient experience has been accumulated to suggest a number of features which will materially increase the effectiveness of the reactor.

33.1. Arrangement of reactor building

The architectural design of the building should take into account the need for separation of the various areas where contamination might be released. As noted in the section on ventilation (section 34), the air flow should be from the clean areas into the areas more likely to become contaminated. Likewise, the traffic of personnel in the building should be arranged so that it by-passes the areas likely to be contaminated, whenever this is possible. To this end, the offices, shops, control room and other areas which will be less likely to become contaminated should be in a separate wing or even in a separate building from the reactor. If they are in the same building, however, they should be distinctly cut off from the reactor area and their main access should be arranged so that it is not necessary to pass through the reactor areas to get to the clean areas. It may be decided not to adopt this principle of separation of the clean areas if no hazardous experiments are to be conducted; however, for the more hazardous types of experiments, it is advisable to provide a separate part of the building where ventilated and shielded equipment cells may be built for each experiment when necessary. Each experiment may then be provided with its own ventilation so that contamination from one experiment would be less likely to spread to other experiment locations or to the whole building.

Neutron-beam experiments are less likely to be sources of contamination than are fuel loops, capsule irradiations or material irradiations. If only neutron-beam experiments are performed in the beam holes, this region might be separated from the section containing the cubicles and loop equipment cells of other experiments.

The safety of the reactor building and adjacent facilities can be improved by grouping areas of possible contamination as close together as possible. For example, the gaseous and liquid waste disposal facilities could best be grouped on one side of the building and the water treatment facilities might occupy an adjacent side of the building or a separate building near that side of the reactor building. By this sort of arrangement areas most likely to become contaminated are somewhat removed from the general traffic so that there is less chance of contamination being spread through clean areas.

Lightning protection should be provided for the important equipment, especially for any emergency equipment.

33.2. Decontamination facility

An area should be available for decontaminating material which has become contaminated during normal operation or in an emergency. This should be part of the general "contamination" area noted above.

33.3. Space

The space necessary for operation should be carefully considered throughout the reactor building, especially the space needed for experiments. Beam-hole experiments tend to become very crowded if holes are closer together than about 10 feet at the point where they leave the reactor shield and if the width of the area behind each beam hole is less than 30 feet. The space behind the beam holes should be large enough to provide room for the experiment control panels, equipment, etc. Traffic should be routed around these areas so as not to interfere with the beam-hole experiments.

Space is especially needed near the reactor for loop or capsule experiments which require both external and in-reactor equipment. Such space has not always been provided and many experimenters have, consequently, had to locate the external equipment in remote areas of the building. This has necessitated long and expensive lines being run from the reactor to the equipment and these lines, if they carry radioactive material, must be shielded and surrounded by secondary containment. In addition to being as close to the reactor as possible, this space should have a floor loading capacity sufficiently high for shields to be built around the equipment where necessary.

33.4. Floor loading capacity

Care should be taken to see that the floor loading capacity in the various areas of the building is sufficient for the equipment likely to be used. The areas where heavy floor loadings are likely to occur are:

(1) The main entrance where carriers and large shields must be brought in by trucks or stored;

(2) Some or all of the pool floor which must be sufficiently strong to hold any of the large shields likely to be used there;

(3) The area around the beam holes which must often support heavy shields for experiments in the beam holes;

(4) Areas where loops or similar experiments will be conducted and which will need shields or special cells; and

(5) Certain areas around a hot cell, if this is planned, which must support shields for insertion and removal of experiments.

33.5. Clothes-changing facilities

Changing rooms for personnel should be located in or near the reactor building, preferably near the main entrance, so that, in the case of a contamination incident, they are conveniently located for the workers as they enter the building for the clean-up operation. They should be separately ventilated so that they are less likely to become contaminated. Their arrangement should permit contaminated clothing to be removed in one section, after which the worker could wash before passing to the clean section.

33.6. Provisions for emergencies

In addition to the normal safety facilities, the building should be arranged to provide for emergencies in which the building, or portions thereof, may become contaminated. A monitoring station for checking contamination and counting smear samples is necessary and it should be borne in mind that, if it is not outside the contamination area, it may become inaccessible through contamination. This station should also be ventilated in such a manner that it is not likely to become contaminated.

33.7. Visitors

Space should be provided for visitors so that they can enter the reactor building during reactor operation without interfering with operations, particularly in the control room. For example, it is very convenient to have a glassed-in gallery adjacent to the control room to provide visitors, and operating staff, with a good vantage point to observe the instrumentation without actually entering the control room. This gallery should be large enough for the operating crew to hold discussions where the reactor instrumentation can be observed without interfering with the operator at the control desk.

33.8. Air conditioning

The need for air conditioning in the reactor building should be determined, based upon local conditions of temperature and humidity. It is apt to be needed in the control room and, perhaps, in the whole building, if instrumentation for experiments is located in various sections. If the instrumentation requires cooling, it may be desirable to supply cool air in special ducts for the purpose. Separate temperature controls, if available, may make it easier to cool the instruments.

33.9. Hoist

A hoist is an important auxiliary to the reactor building. This must be used in moving equipment, shields, reactor components and other heavy objects. Consideration should be given to the speed or speeds the hoist should have, whether to have pendant- or cab-operated controls, the noise problem from the hoist, its capacity and any safety precautions necessary. To anticipate the case of a control relay jamming and thereby preventing the operator from stopping the hoist, a disconnect switch should be provided which can be thrown to cut off the power. This should be capable of being locked out and should be conveniently located. Because of the importance of the hoist, special attention should be given to ease of inspection of the cable and hook and to the constant observation of the state of the cable on the drum during operation.

33.10. Exposed surfaces

Insofar as possible, the reactor building should be designed with a minimum of exposed surfaces such as piping, ducts, etc., which may become contaminated in the event of an accident and which would be difficult to clean. The ideal arrangement would be to have the interior surfaces of the building smooth and flat so that, if decontamination were ever required, the surface to be cleaned would be the minimum and would be easily accessible. With this in mind, the designer could incorporate features such as piping galleries, ducts, etc., into the structure, so that most of those surfaces which are difficult to clean would be put into galleries which would not become contaminated. Of course, this might increase the costs somewhat and the probability of serious contamination may not be considered great enough to justify the added expense.

33.11. Drains

The designer should decide whether all floor drains in the reactor building should go to the low-level radioactive waste system. This is customary in many reactors since it is assumed that there is always the possibility of radioactive waste being released in the building. If, however, the quantity of low-level waste must be reduced, two sets of floor drains — one for non-radioactive waste — would be worthwhile, so that cooling water from such equipment as is unlikely to release radioactivity (for example, an air conditioner) can be piped to the non-radioactive drain. In many places such inactive drains are made available to experimenters in such a way as to exclude the possibility of spills on the floor reaching them.

33.12. Wiring from experiments to the control room

Open wireways, in which wires may be changed readily, are especially convenient for routing wiring from experiment components at the reactor to both the reactor control room and to the experiment control panels.

34. VENTILATION AND CONTAINMENT

Ventilation and containment are very closely related since ventilating air leaving the reactor building might possibly be contaminated. By properly routing the flow of the ventilating air, those sections of the reactor building where releases of contamination are most likely to occur may be kept at a lower pressure so that leakage of radioactivity into the more occupied areas of the building may be prevented. Some reactors use the closed type of containment in which all ventilation is stopped, if radioactivity is released inside the building, and the building is kept sealed so that little or no radioactive material may escape. A second type of containment, particularly applicable to research reactors, consists of a dynamic system whereby air continuously leaks into the building which is kept at a slightly negative pressure. The exhaust air is passed through a cleaning system which removes practically all of the dangerous radionuclides before the air is released.

34.1. Ventilation

A number of ventilation criteria have been developed which are especially applicable to the dynamic-containment type of design.

(1) The ventilation system should release no dangerous quantity of radionuclides to the environment.

(2) Ventilation should be adequate to provide desirable air movement, temperature, and freshness.

(3) One or more separate ventilation systems, having superior provisions for cleaning, may be provided to remove radioactive iodine and particles from contaminated air from hot cells, equipment cells or other local areas likely to release radioactive nuclides in high concentration. Systems with such capabilities are commonly entitled "cell ventilation". A cell-ventilation system may be used to maintain a whole building under a negative pressure and, when used in this manner, might be termed "containment ventilation". Ducts from cell-ventilation systems may be connected to experiment cubicles, hot cells etc. so that these areas are kept at a lower pressure than the surrounding building. Such usage requires careful dampering of the various intakes to ensure desirable pressure and flow distributions.

A second ventilation system, called "off-gas", is sometimes provided for highly concentrated radioactive gases or particles released from experiments, such as fuel loops and highly radioactive experiments inside hot cells. This usually has a much smaller capacity than cell ventilation, operates at a higher negative pressure and has a more elaborate cleaning system. In a typical installation, off-gas may be attached directly to a loop so that any release of gas would normally go into the off-gas. The cell ventilation would be used to ventilate the cubicle surrounding the loop equipment so that, if a leak occurred, this would be drawn off safely. In other words, the cell ventilation would act as a second line of containment.

(4) The ventilation system should be sufficiently reliable to prevent the release of radioactive material and it should be designed so that it can be tested regularly.

(5) It is preferable to keep safety equipment, such as cell ventilation and off-gas, operating continuously rather than have it start on demand.

For example, in a dynamic containment system, the cell or containment ventilation system, which supplies the suction to maintain negative pressure in the building, might be designed to start only after a release of radioactive gas occurred, or it could be operated continuously. From the standpoint of reliability, the latter is preferable.

(6) If the normal building-ventilation system must close automatically so that exhaust air passes only through the containment-ventilation system, the equipment must either be very reliable or the openings sized so that a failure of a louvre or other single component does not create a hazardous leak from the building.

(7) The system, or systems, should be arranged so that experiments requiring special ventilation may readily be connected in such a manner that the experiment, hot cell, or cubicle may be maintained at negative pressure with respect to the surrounding building areas.

34.2. Dynamic containment

In the dynamic containment system mentioned above, ventilation is an integral part of the containment. Some useful criteria are given below.

(1) The containment system should prevent releases of hazardous quantities of radioactive materials outside the building and should help restrict them from spreading to occupied areas inside the building. If a release of radioactive material does occur, it should be contained within the smallest area possible.

(2) Containment systems should be used whenever necessary to provide a second or third line of defence against release of radioactive material from experiments or areas inside the building. For example, containment ventilation might be used to keep the interior of an equipment cell at a lower pressure than that of the surrounding building by connecting a branch of the main ventilation duct to the cell. The interior of the duct could be kept at rather low pressure and, since there should be only a small leakage from the building into the cell, the pressure of the cell could be adjusted by dampers to be below that of the building.

(3) Reliability of systems should be commensurate with the hazards involved. Following are some typical criteria adopted for systems in which a high degree of reliability is required.

(a) No single failure should prevent the operation of the system.

(b) Containment should not be jeopardized if all personnel have to be evacuated from the building. Any necessary controls must be available at some remote location.

(c) The system must be designed so that it may be tested regularly.

(4) Areas where the probability of a release of radioactive material is high, such as hot cells and experiment equipment cubicles, should be maintained at a negative pressure with respect to areas outside the cell or cubicle.

(5) When possible, the building should be divided into separate compartments, separately ventilated, so that a release in one area will not spread throughout the building.

(6) Areas where there is equipment of special hazard, such as loop pumps and heat exchangers, should be monitored so that a warning may be

given and the experiment or reactor shut down and any other necessary action taken as soon as a failure occurs. This is especially applicable in such cases as a loop equipment cubicle where the piping and associated equipment is the primary containment. If a leak develops in this piping or equipment and is detected by a monitor inside the cubicle, it might be desirable to shut down the reactor and place the building in the containment mode if it is not normally operated in this mode.

(7) Adequate instrumentation should be installed and a course of action should be developed which would enable the operator to cope with any release likely to occur. Some of the preparations would include:

(a) Radiation and air-contamination monitors should be provided in suitable areas of the building so that the operator at the control desk will receive warning of a release within a reasonable time. Since the first indication of a release of radioactivity into the water system would usually be high radiation from the outlet water lines, instrumentation should be arranged with this in mind. Routine checks should be made with a radiation source to ensure that the monitors are operable.

(b) The radiation or airborne radioactivity levels at which the building should be evacuated should be clearly defined and provisions made to signal this to the operator so that he may take the necessary action, such as ordering a partial or complete evacuation of the building, without delay.

(c) Since evacuation levels for airborne radioactivity are generally set for the most hazardous radionuclides and since the nuclides generally released from experiments in any large quantity are much less hazardous, provision should be made for samples to be analysed quickly. It is often important to measure several different nuclides to determine whether the material came from an experiment or from a new or old fuel element.

35. UTILITIES

While it is often assumed that utilities, such as steam, electrical power, compressed air, etc., are so standard as to require no special consideration, the efficiency, safety and convenience of a reactor may be considerably influenced by the way in which these and other utilities are designed and supplied.

35.1. Electrical power

Electrical power usually causes by far the greatest problem of all utilities. If it is not dependable or has variable frequency or voltage, it may be difficult to operate reactor instrumentation which has been designed on the assumption that the power will be consistent and reliable. In such cases the designer should give careful consideration to the use of batteries as the source of power for instrumentation in both the reactor and experiments. Batteries could, of course, be supplied by the normal power through chargers.

Where reliability is important, as in reactors having high-power fuel test loops, two separate feeders from separate transformers should be considered so that if one feeder fails, the second may continue to supply the necessary power.

Ground connections sometimes cause trouble when several experiments are connected to a common ground. Where this is important, separate grounds should be supplied for each experiment which might be affected by this condition.

35.1.1. Normal power and instrument power

Normal power circuits should be supplied to those portions of the reactor where industrial equipment, electric tools and similar equipment may be used. Care must be exercised to make sure that none of this type of equipment is connected to "instrument-power" circuits. These are special electrical circuits supplied from separate transformers and are used to provide power suitable for instruments. Only small resistive loads are permitted to be connected and, while these circuits must be kept separate from normal power, both must be reasonably easily available in each area, otherwise it may be difficult to prevent small electric tools from being attached to the "instrument" circuits.

35.1.2. Voltage

If fairly large industrial equipment, such as pumps and motors, is likely to be required for experiments, it is desirable to have high-voltage (such as 440 V) power available in the general area where the equipment may be installed. Lower voltages are usually supplied to all areas where experiments or reactor equipment or instrumentation is installed.

35.2. Emergency power

If the failure of the normal electric power at the reactor or experiments may cause a health hazard to personnel or damage to the equipment, some form of emergency power should be readily available to anticipate and prevent such a danger. Some form of emergency lighting will probably be required and, in some reactors, certain instrumentation, e.g. radiation safety instruments and control-rod seat switches to indicate the position of the control rods, will also need emergency power. In addition, some experiments may be involved, especially if cooling is required following shut-down. A gas loop, for example, in which a fuel element is being tested may require emergency power for afterheat protection even more than the reactor itself. However, if the problem is only the preservation of experiment data and loss of power will result only in the local failure of an experiment without prejudice to the safety of the reactor or occupants of the building, emergency power is obviously less important.

35.2.1. Central versus local emergency systems

Among the questions which the designer must resolve is whether to furnish emergency power from a large central system or from smaller individual systems for each experiment, pump, etc. While the larger central system may appear to be best, the designer must be certain that it has the degree of reliability required. For a reactor in which afterheat protection is absolutely required, it is questionable whether a single device of any sort would be considered adequate.

35.2.2. Types of emergency power

Several types of emergency systems may be used. Among these are a diesel generator, a battery system, a gasoline engine, a fly wheel generator or some other device which will furnish power for a short time. In general, the choice of equipment depends upon the degree of reliability desired and on whether the power must be free of interruption. The design which has demonstrated the greatest reliability is one with a number of separate battery units, each operating continuously. Lesser degrees of reliability are achieved by a continuously operating diesel generator or with a diesel arranged to start on demand. Where it has been found possible to use them, fly wheel generators have demonstrated excellent reliability.

35.2.3. Interruption-free power

It should be decided whether it is necessary to have power on the reactor instrumentation at all times to preserve records from recorders and provide the operator with information during reactor shut-downs caused by failure of the main electric power; not all reactor systems have this feature. In those designs where the instrumentation is supplied from the normal power system, it is maintained that the instrumentation can only provide information and cannot usually function to provide safety action after the main electric power supply has failed. On this basis it is not as vital a safety matter to keep the instrumentation operating as it may be to provide emergency cooling or some other safety action.

35.3. Potable, process and demineralized water

It is usually desirable to have potable water, process water, and demineralized water systems available at a research reactor. Potable water is connected to drinking fountains and sinks. Process water is supplied from the potable water system either through an air break or through an isolating valve such as a back-flow preventer, which will guarantee separation, and is used for supplying cooling to experiments or devices where there is a possibility of radioactive material entering the water system during a period when the water pressure is low.

Demineralized water is used for make-up in the reactor system and for any experiments in which water passes through the reactor.

35.3.1. Recirculating cooling water

Since process water is used largely for cooling experiments and, when discharged, must usually be treated as low-level radioactive waste, it is desirable to reduce the volume to a minimum in order to reduce the cost of waste treatment. A recirculating cooling system will accomplish this since none of this water need be put into the low-level waste.

35.4. Air

A separate air system for instrumentation (if pneumatic instruments are used) should be provided with the proper devices to clean and dry the air. Such a system should not be used for industrial equipment, such as air hammers and air drills, which should be supplied from a separate system.

35.5. Communications

One important utility is a public-address system to enable the operator to inform the occupants of the building about an emergency and give necessary directions. The location of the speakers should be such that announcements can be heard in all locations. It is also advisable to provide a microphone outside the building, so that, in event of an evacuation, announcements may be continued from the outside.

35.5.1. Evacuation alarm

An alarm (often known as the "evacuation horn") is frequently included so that in an emergency the occupants may be warned quickly to leave the building. The public-address system should automatically override or stop the evacuation horn while announcements are made. The alarm should also have switches outside the building as well as inside, so that the signal could be either initiated or turned off from the outside.

35.5.2. Start-up horn

In addition, it may be considered worthwhile to have a reactor start-up horn which is actuated by the starting circuitry and which sounds before the rods are withdrawn. This has the disadvantage that during control-rod checks the horn sounds and the occupants must be informed that the reactor is not starting up. However, it is a desirable safety precaution in reactors where there is a possibility that experimenters may open a beam hole or other facility, thereby producing dangerous radiation levels if the reactor should start up. Other communications are useful for normal operation and during checking of experiments and reactor components such as control rods. Some of the other devices which have proved useful are sound-powered telephones, speaker-microphone combinations at various locations and, of course, telephones at or near all experiment instrument panels and in the control room.

36. TOOLS

A large number of tools for remote operations may be required for use in research and test reactors and as many as several hundred may be accumulated over a period of several years. They often have handles from 18 to 25 feet long and storage often becomes a problem.

36.1. Storage

A sunken pit, if it can be provided in the reactor building, is a convenient means of storage. If suitable wall space is available, the tools can be stored in a rack attached to the wall. However, when releasing the tools from the building hoist, an operator must climb to the station at the top of the rack to release the tool. (It is generally advisable to store the tools suspended vertically to prevent their becoming bent.) In a small pool reactor the tools may be very few in number and they might even be stored on the walls of the pool.

36.2. Weight of tools

Care should be taken to avoid designing tools that are heavier than necessary, since heavy tools are so difficult to use that operators often prefer to build a new, lighter tool. In cases where the tool must be heavy because of strength or other requirements, consideration may be given to attaching floats to compensate for the weight when the tool is immersed in water. This enables the operator to handle the tool during the underwater manipulations without assistance from a hoist. Such floats should obstruct the operator's view of the work being done with the tool as little as possible. Experience has shown that there is less chance of damage if the operator can "feel" the load on the tool.

36.3. Use of tools with hoist

When the building hoist or crane must be attached to a tool in order to lift some object from the reactor lattice, great care should be taken to avoid exerting more force on the lattice than is safe. Various devices have been designed to avoid overstressing the lattice components. One, for example, consists of a spring with an indicator so that the operator can observe when he has lifted the weight limit. If the object should stick or jam in the core and more force should be exerted by the hoist, inadvertently or otherwise, the indicator can be observed by the operator and the force decreased before damage is done. A small hand-operated hoist attached to the building hoist is sometimes used and all movement of the object is done by the operator using the hand hoist until clear of obstruction in the lattice.

Consideration should also be given to the safeguards necessary in handling highly radioactive objects such as fuel elements. When these are attached to the building hoist, it is possible, through some malfunction or error, to raise them out of the water and create dangerous radiation fields. Some of the possible precautions have been touched on in section 11.5.

37. SHIELDED CARRIERS

Shielded carriers for shipping fuel or for removing experiments from the reactor and transporting them to hot cells or other locations require special consideration. Since carriers are expensive, they should be made as adaptable as possible. The design of carriers built for shipment outside the reactor area by commercial vehicles is often bound by stringent regulations, but these need not be followed for purely local carriers and, while there is a limit to how versatile carriers may be made, some of the criteria to be considered in their design are given below.

If a carrier is to be used for shipping fuel, the heat production of the spent fuel should be determined and a decision should be made as to whether the carrier requires cooling. If supplementary cooling is necessary, criteria for reliability of the system must be carefully prepared. Whenever possible, it is much simpler to allow fuel elements to cool in a storage pool long enough for supplementary cooling to be unnecessary.

Criteria on structural strength, drop-test endurance, and the fireproofness of the carrier must be determined, if not specified by shipping regulations.

If a cladding is used over lead or other shielding material, some consideration should be given to means of testing the sheath for tightness so that, if the carrier is immersed in pools or canals where the water is contaminated, the space between the lead and the sheathing will not become contaminated. This can be done by pressurizing this space regularly and testing for leaks. Such tests are usually done frequently in order to detect a leak soon after it develops.

The material of construction is an important factor in carrier usage. Carbon steel is sometimes used for the sheath because it is cheap and easy to fabricate. Experience shows, however, that rusting cannot be prevented and that carbon steel is difficult to decontaminate because of the absorption of contamination in the rust. Stainless steel is the best sheathing for any container which is to be used repeatedly.

Lead is the most common filling for carriers; but the design must take into account the requirements for drop testing, fire resistance, and the tendency of the lead to shift slightly during service. Depleted uranium and other dense materials may be used instead of lead and, because of a high density, would permit the carrier to be smaller and lighter. These advantages must be weighed against the increased cost of fabrication.

If the carrier is shipped dry, means must be provided for draining the carriers which are loaded under water. Care must be exercised in locating drain pipes which are welded to both the inner-cavity liner and the outer shell. If the carrier is lead filled, experience has shown that the lead may shift slightly and crack the welds of the drain-tubes.

Special-purpose carriers which may be required for use within the laboratory or reactor building may have special features to permit a variety of uses. Flanges may be provided on the ends of a carrier so that different devices may be attached, such as sliding doors, additional sections, etc. Provisions may be made for handling the carrier in either the horizontal or vertical position. This generally requires that special lifting lugs be provided and that doors at the ends be made so that they can be operated in either position. Special cradles for holding and positioning carriers may be useful when the carriers are used in the horizontal position.

Off-gas connections are also advisable when samples which may leak radioactive gases are likely to be handled. It is common practice to keep the off-gas system connected to the carrier and in operation after a sample has been introduced until tests show that the sample is not leaking radioactive gas.

If carriers are to be aligned with a matching hole, such as a beam hole or a hot-cell port, positioning marks or devices can be helpful. When used at a beam hole or hot-cell port where radioactive dust may be drawn out into the carrier, an air sweep should be provided at the mouth of the carrier. This can be done by providing a pipe connection in the carrier itself or in a collar attached to its mouth. The air should, of course, be filtered.

38. HOT CELLS

Large experiment assemblies are often cut apart to obtain the samples being tested close to the reactor in order to reduce the problem of transporting them from the reactor building to special hot cells where metallurgical, chemical and other tests may be conducted. Furthermore, inspection facilities are often needed for investigations on equipment failures in experiments or in the reactor itself. Experience has shown that it is convenient to have a hot cell equipped for performing disassembly work in the reactor building, or immediately adjacent to it, so that samples, fuel elements and various research and reactor equipment may be inspected or disassembled without difficult problems of transportation.

Only the features of the hot cell which pertain to its use in the reactor building will be described. Other features common to all hot cells such as shielding, windows, types and numbers of plugs in the walls, utilities and radioactive waste provisions are not covered.

38.1. Accessibility

Two of the problems of operating hot cells in a reactor building are transporting items from the reactor to the cells and shipping samples and scrap from the hot cells to other areas. In the arrangement where the hot cell is built adjacent to the reactor pool, it is possible to pull experiment or loop components from the pool up through the floor of the hot cell where equipment is provided for cutting the tubes apart to obtain the samples. Provision should be made for shipping the resultant scrap material to a burial ground or other disposal facility. The amount of this scrap is often large and, therefore, the cell openings and other provisions for handling scrap should be of generous dimensions. A scrap container can be removed from the top, or side, of the hot cell by placing a carrier over, or in front of, a hole and pulling the container into the carrier. This requires a suitable working area and access by a hoist of, generally, at least 10-ton capacity. It would also be possible to remove the scrap through the bottom if the cell were so designed.

38.2. Separation

The hot cell is a potential source of radioactive contamination and, because of this, it is desirable to have it in a separate compartment from other areas of the reactor building. A convenient arrangement is to have the hot cell in one end of the reactor pool with access from the pool to the bottom of the hot cell. A wall should separate the hot cell from the rest of the reactor building, and a floor should be built at the top of the hot cell as well as at the normal working elevation. This upper area should be provided with a bridge or monorail hoist so that carriers could be moved to and from trucks either inside or outside the building. The top of the cell should be provided with plugs for installing or removing large equipment and with smaller plugs, approximately one foot in diameter, for inserting and removing smaller equipment and scrap containers.

A side door into the cell is desirable for personnel entry, and a decontamination room of approximately the same size as the cell should be provided outside this door.

The floor around the hot cell should include free space approximately 20 feet wide and approximately 500 square feet of extra space for maintenance and storage of equipment.

38.3. Ventilation

Ventilation of the hot cell should provide a negative pressure of approximately one inch of H_2O inside the cell. Instruments should be provided to alarm if the pressure difference to the atmosphere is less than this value. A ventilation feature to provide extra cooling might be necessary if the cell in-leakage is not great enough to cool the cell. One such system provides for a high air flow to be recirculated through filters and a cooler while only a small flow, enough to maintain a negative pressure in the cell, is withdrawn and sent to an off-gas system.

Roughing filters (i.e. filters of, for instance, glass wool which will remove larger particles) should be provided inside the cells, and the ducts from the cell to the gas disposal system should either be underground, shielded, or an additional absolute filter should be arranged just outside the cell in an area where the filter could be shielded if necessary. It is assumed, of course, that the air would pass through a second set of filters before being discharged to the atmosphere. All filters should be arranged so that they can be changed without danger of spreading contamination or of personnel exposure.

38.4. Cell interior

Stainless steel linings offer many advantages, especially in ease of decontamination. If the cell is not used for cutting fuel, this may not be a major problem. However, unexpected contamination sometimes occurs. For example, tantalum used in an experiment for thermal radiation shields released considerable quantities of contamination inside a cell. The radioactive tantalum deposited on surfaces inside the cell and on the filters. It was possible to change the filters remotely, but the interior of the cell had to be washed repeatedly using remote tools and decontaminating solutions. If trap doors are provided for bottom loading, it must be possible to seal these so that the floor does not leak when the cell is washed.

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APPENDICES

APPENDIX I

OUTLINE OF A TRAINING COURSE IN REACTOR OPERATIONS

The following is an outline of the major topics which should be treated in training the operating staff of a research reactor. The depth of treatment should vary with the responsibilities of the different groups involved; e. g. technical specialists, senior supervisors, junior supervisors and operators. Whenever possible, the material should be presented so that it is applied to the reactor for which the training is being conducted, especially for the junior supervisors and operators. Most of the material can be taught from standard texts except for that given the operators, who generally have secondary school educations, where it is necessary to present the material in a non-technical fashion emphasizing in a qualitative way the practical, operational aspects.

Radiation safety

(1) Matter and radioactivity
(2) The effect of radiation on matter, the penetrating properties of radiation
(3) Radiation measurement
(4) Permissible and normal doses, effects of large doses
(5) Protection against radiation
(6) Transferable radioactive contamination
(7) Special features of radiation and radioactive contamination
(8) Operating limits

Reactor physics

(1) Chain reactions and the fission process
(2) Criticality; delayed neutrons
(3) Subcritical multiplication
(4) Kinetics of supercritical reactors
(5) Flux, neutron density and energy, cross-sections; flux and power distributions
(6) Xenon and samarium poisoning
(7) Temperature-power effects
(8) Effects of control rods, fuel burn-up
(9) Accidents and hazards

Heat transfer and fluid flow

Heat Transfer

(1) Importance of heat transfer in a nuclear reactor
(2) Source of heat in a nuclear reactor
(3) Terms used in describing heat
(4) Problems illustrating the usage of heat terms
(5) Terms used in describing heat transfer
(6) Applications of heat-transfer terms
(7) Special heat-transfer problems in a nuclear reactor

Fluid flow

(1) Terms used in describing fluid flow
(2) Equations used in fluid flow
(3) Problems illustrating the usage of fluid flow terms
(4) Special problems in fluid flow

Instrument and controls

(1) Definition of terms
(2) Principles of instrumentation and controls system analysis
(3) Principles of nuclear radiation detectors
(4) Nuclear instrument channels
    (a) General
    (b) Start-up
    (c) Intermediate
    (d) Power
    (e) Servo
    (f) Interrelationship between channels
(5) Principles of process instrument detectors
(6) Experiment controls
(7) Logic and elementary diagrams

APPENDIX II

ORR START-UP CHECK LIST

NOTE: The person making start-up checks should initial each check after completion and must follow the start-up until N_L is reached.

Date ______________________

Shift ______________________

*Type of run ______________________

A. TANK AREA

1. All core pieces in place and properly seated. ______________________
2. Experiments properly arranged in reactor tank. ______________________
3. Hold-down arms properly seated and locked. ______________________
4. All work in core completed and final inspection check sheet made out. ______________________
5. Access cover replaced and bolted down. ______________________

B. EXPERIMENTAL FACILITIES

1. All experimental changes completed. ______________________
2. Experimental information sheets completed. ______________________
3. Individual experiment safety check sheets completed by instrument engineers. ______________________
4. All experiments ready for power operation and experimenters notified of start-up. ______________________
5. Special start-up requests noted. ______________________

C. WATER SYSTEMS

1. Reactor pool filled to proper level. ______________________
2. All pool alarms cleared. ______________________
3. Pool circulating system ready for service and vented. ______________________

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* Critical – C, Power – P, and Training – T.

4. Pool demineralizer in service. ____________________

5. Reactor system filled and vented. ____________________

6. Reactor water flow established. ____________________

7. All disconnects on DC units 1, 2, and 3 closed and minimum requirements of this system have been met for power operation. ____________________

8. Degasifier in service. ____________________

9. Reactor demineralizer(s) in service. ____________________

10. Both secondary coolant loops filled, treated, and ready for service. ____________________

11. Flow through bypass filters. ____________________

12. Reactor primary bypass valve system in automatic and temperature setpoint established. ____________________

13. Reactor secondary system in automatic and temperature setpoint established. ____________________

14. Cooling water to horizontal beam holes, HN-1, and HN-4 (refer to status sheet). ____________________

15. Cooling water to north facility. ____________________

16. Cooling water to south facility. ____________________

17. Subpile room:
    -- Demineralized water supply to drive seals. ____________________
    -- Demineralized water supply to annulus of bottom plug. ____________________
    -- Servo tachometer plug connected to servo rod-drive motor. ____________________

D. INSTRUMENTATION CHECKS

1. All utility services in order:
    -- Power circuits L-31 through L-42 plus L-46 located in front power cabinet. ____________________
    -- LX-1 through LX-4 plus LX-6 and 8 located in front power cabinet. ____________________
    -- L-1 through L-16 located in rear power cabinet. ____________________
    -- Air supply. ____________________

2. All nuclear instruments turned on at least ½ hour prior to operation of reactor. ____________________

3. Ionization-chamber positions. Check log book for any movement during shutdown. ____________________

*4. Both log-N amplifiers calibrated with recorder and set on "Operate." ____________________

*5. Safety channels No. 1, 2, and 3 calibrated. ____________________

*6. Both CRMs calibrated with recorder and set on "Use." ____________________

*7. Shim-rod-drive safety switch and performance checkout test performed following any work on the drive units. ____________________

*8. Magnet current checked and adjusted properly. ____________________

9. Rods raised off seat positions and scrammed with the Jordan button on each of the three sigma amplifiers in turn. ____________________

10. Step 9 repeated but rods scrammed with each log-N amplifier by turning switch from "Operate" to "HI Calibrate." (Reset to "Operate" position.) ____________________

*11. Check any one experiment scram to ensure that rods drop. ____________________

12. Air monitors "Normal." ____________________

13. Monitrons "Normal." ____________________

14. Microammeter range switch set properly. ____________________

15. Microammeter set on "Recorder." ____________________

16. Public-address system operating properly. ____________________

17. All instrument channels working properly and corresponding recorders tracking. ____________________

E. SHIELDING CHECKS

**1. HB-1 through HB-5 shield blocks in place. ____________________

**2. HB-6 shield closed and key in possession of Operations. ____________________

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* Before start of cycle.

** Or collimator flooded with water valves locked open.

**3. HN-1 through HN-4 shielding in place. ______

4. HS facility--Containment cell inspected, valves checked for proper orientation, and cell closed if an experiment is installed. Information recorded in log book. ______

5. Pipe chase closed. ______

F. CHECKS ON COUNT-RATE CHANNELS

1. No. 1 and 2 fission chambers inserted. ______

2. Poolside count-rate speaker deactivated. ______

3. No. 1 and 2 gamma-chamber recorders on "HI" sensitivity. ______

G. OTHER CHECKS

1. Next cycle power schedule reviewed and understood. ______

2. Both water activity electrometers operating (also common power supply). ______

3. Scrubber checked and operative--building containment check acceptable. ______

4. Establish flow in the hydraulic tubes. ______

5. Ten minute prestart-up warning issued over public-address system. ______

6. At 5 MW inspect the core through the porthole for obstructions and complete the core inspection check sheet. ______

7. Magnet currents read and posted one hour after 30-MW operation with all safety recorders reading 100. ______

** Or collimator flooded with water valves locked open.

APPENDIX III

PRE-STARTUP OR INSTRUMENT CHECKS

Date ______________________ Instrument Foreman ______________________

Operations Supervisor ______________________ Instrument Technician ______________________

I. CHECKS WITH SIMULATED FLOW

Remarks

A. Conditions: Mode switches in OFF, operator start, power buses (switches) on, clutches made up, breaker L-10 in control room in OFF, and raise-test switch in NORMAL. ______________

Simulated Restored

1. To simulate pool cooling flow in RUN circuit:
   Jumper 125 to 125A in JB-PX No.1 ______ ______

2. To simulate reactor ΔP (>15.3 psig) in scram circuits:
   Jumper 339A to 340 in JB-PX No.1 ______ ______
   Remove wire 358 in JB-PX No.1 ______ ______

3. To simulate reactor cooling flow (>14 000 gpm) in scram circuits:
   Jumper 339 to 339A (on CP-18) in TB-A ______ ______
   Remove wire 359 (on CP-18) in TB-A ______ ______

4. To simulate reactor cooling flow (>17 000 gpm) and ΔP (> 21.4 psig) in setback circuit:
   Jumper 422 to L1 at R79 in Relay Cab. "X" ______ ______
   Jumper 421 to L1 at R78 in Relay Cab. "X" ______ ______

5. To simulate north and south facility flow in setback and auxiliary reverse circuits:
   Remove wire 407 (onFF-1) in TB-A ______ ______
   Jumper 420 to 420K (on FF-1) in TB-A ______ ______

6. Clear all scrams and reset all cleared annunciators:

B. LOG N RECORDERS

Log N #1 (Log N # 2)

1. Switch channel selector switch to channel being checked. Turn log N amplifier switch to OPERATE. Turn recorder off and crank recorder indicator left. ______ ______

2. RS4 (RS57) Crank recorder right . R65 energizes as recorder is cranked to right through 0.001. Leave energized. ______ ______

3. RS34. Turn log N amplifier switch off of OPERATE. R65[1] should be de-energized. Return switch to OPERATE. R65 should be re-energized. Turn channel selector switch to other channel. R65 should be de-energized. Return switch to channel being checked and R65 should be re-energized. ______ ______

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[1] R65 is located in cabinet "A" - rear: column 2, row 3.

4. RS6 (RS59). Pull breaker on "pool cooling pump" in basement. Hold RUN button. RUN should be obtained as recorder is cranked right through 0.6 N_L. ________ ________

5. RS5 (RS58). Reactor should drop out of RUN as recorder is cranked left through 0.33 N_L. Leave out of RUN. ________ ________

6. RS7 (RS60). As recorder is cranked right through 1.8 N_L a REVERSE[2] should occur. Return log N to ground set. Turn on recorder (leave last recorder tested OFF throughout the test). ________ ________

C. DELTA T

ΔT # 1 (ΔT # 2)

Conditions: Obtain RUN. Obtain SERVO using console button. Set log N period recorder on infinity and set log N recorder >1.8 N_L. ________ ________

1. RS18 (RS47). Crank recorder to the right. An alarm should occur at 13°F. ________ ________

2. RS19 (RS48): Setback
   RS28 (RS51): Auxiliary Reverse
   Raise servo demand. As recorder is cranked right through 13.5°F the servo demand should start down. After ~5 sec a REVERSE should occur and reactor should go into MANUAL. ________ ________

3. RS20 (RS49): Drop-Out Scram R28
   RS20X (RS50): Make-Up Scram R28X
   Ensure that all slow scrams are cleared. As recorder is cranked right through 15.5°F both SLOW SCRAM lights on console should turn on. (Observe when testing ΔT # 1 that magnet amplifier current has been reduced to zero m.amps.) ________ ________

D. OUTLET TEMPERATURE

1. RS21 (RS52). Same test as C.1 except that setpoint is 134°F. ________ ________

2. RS22 (RS53): Setback
   RS29 (RS56): Auxiliary Reverse
   Same test as C.2 except that setpoint is 135°F. ________ ________

3. RS23 (RS54): Drop-Out Scram R28
   RS23X (RS55): Make-Up Scram R28X
   Same test as C.3 except that setpoint is 140°F. ________ ________

E. COUNT RATE RECORDER

Conditions: Have log CRM in USE; count rate period recorder OFF and indicating an infinite period; count rate recorder OFF; log N recorder OFF and cranked left of 0.001 N_L; fission chamber in AUTOMATIC ____________________

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[2] REVERSE should be indicated by an indicator light above the REVERSE-BYPASS switch.

1. RS8, 9. Monitor the voltage on wire 146 at R65-3 with the count rate recorder cranked from left to right[3]. The following should be observed: below 1.5 cps, no voltage; above 1.5 cps and below 8000 cps, 115 VAC; above 8000 cps, no voltage and fission chamber should begin to withdraw. ________

2. RS40. Crank recorder to left, above 100 cps fission chamber should continue to withdraw. As recorder is cranked through 100 cps fission chamber should stop withdrawing. ________

3. RS41. Crank recorder left of 20 cps. Press instrument start request button. Fission chamber should start inserting. As recorder is cranked right through 20 cps, R67[4] should pick up and fission chamber should stop inserting. After instrument start is obtained crank recorder left through 20 cps and "instrument start trip out" annunciator will sound. Clear this annunciator by cranking log N recorder to right through 0.6 N_L. Turn C.R. recorder on and establish C.R. at >1.5 cps and <8000 cps. ________

4. RS39. Monitor the voltage on wire 146 at R65-3 and observe the following: calibrate switch in USE - wire has 115 VAC; calibrate switch in CALIBRATE - wire has no voltage. Return calibrate switch to USE. ________

F. GAMMA CHAMBER RECORDERS — #1 #2

Ensure all scrams are cleared and that all clutches are made up or simulated. When recorder is cranked right through 147, magnet power will be cut off. (This is observed at magnet amplifiers since scram relays are not effected.) ____ ____

G. SAFETY LEVEL RECORDERS — #1 (#2) <#3>

Conditions: Obtain RUN and then SERVO for all tests. Turn all safety level recorders OFF.

1. RS30 (RS31) <RS32>: Setback
   RS12 (RS13) <RS14>: Alarm
   Raise SERVO SETPOINT (demand) to ~3 MW. As recorder is cranked to the right through 1.1 N_F (110) the servo demand should start decreasing and SAFETY LEVEL annunciator should sound. Crank recorder left to clear annunciator and stop setback. (Check all three channels before proceeding to G.2.) ____ ____ ____

2. RS67 (RS68) <RS69>. Raise servo setpoint (demand) to ~3 MW. Crank all recorders left of 0.6 N_F (60). Remove jumper on R79 so that reactor cooling flow is simulated as <17 000 gpm but > 14 000 gpm. As recorder is cranked right through 0.6 N_F (60) servo demand should start decreasing. Setback should stop as recorder is cranked left of 0.6 N_F (60). (Check all three channels and restore jumper on R79 before proceeding to G.3.) ____ ____ ____

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[3] R65 is located in cabinet "A" - rear: column 2, row 3.
[4] R67 is located in cabinet "A" - rear: column 5, row 5.

3. Same test as G.2. Except remove jumper on R-78 so that reactor ΔP is simulated as < 21.4 psi but > 15.3 psi. (Check all three channels and restore jumper on R-78 before proceeding to G.4.) ____ ____ ____

4. RS44 (RS45) <RS46 >. As recorder is cranked to right through $1.2\ N_F$ (120) a REVERSE should occur. Turn on recorder. ____ ____ ____

H. LOG N PERIOD RECORDERS # 1 (# 2)

1. RS33 (RS65). Obtain RUN. Obtain SERVO. Crank log N recorder to right of $1.8\ N_L$. Raise servo setpoint (demand) to ~3 MW. As log N period recorder is cranked left through -100 sec R82[5] should pick up. By cranking ΔT recorder right through 135°F a SETBACK should be initiated. After the setback continues for ~10 sec crank period recorder to right through -100 sec. R82 should drop out and ~5 sec later a REVERSE should occur. (Check channel # 2 by cranking outlet temperature recorder right through 135°F.) ____ ____

2. RS1 (RS61). Crank the log N recorder between $0.33\ N_L$ and $0.001\ N_L$. As period recorder is cranked right through 30 sec R4[6] should drop out. Push a shim rod WITHDRAW button and R6[7] should not pick up. With reverse-bypass switch in BYPASS R4 should pick up and pushing a shim rod WITHDRAW button should pick up R6. ____ ____

3. RS2 (RS62). Monitor the voltage on wire 146 at R65-3 as the period recorder is cranked from left to right. The following should be observed: to the left of 20 sec - 115 VAC; as recorder is cranked right through 20 sec - no voltage; push FAST PERIOD PERMIT button and hold reverse-bypass switch in BYPASS - 115 VAC. (Maintain this condition for test H.4.) ____ ____

4. RS42 (R64). As period recorder is cranked to right through 10 sec voltage of wire 146 at R65-3 should drop from 115 VAC to zero[8]. ____ ____

5. RS3 (RS63). As period recorder is cranked right through 5 sec a REVERSE should occur and the 5 SECOND PERIOD annunciator should sound. ____ ____

I. COUNT RATE PERIOD

1. RS37. Set the selected log N period recorder on infinity and the log N recorder between $0.33\ N_L$ and $0.001\ N_L$. As count rate period recorder is cranked right through 30 sec R4 should drop out. Push a shim rod WITHDRAW button and R6 should not pick up. With reverse bypass switch in BYPASS R4 should pick up and pushing a shim rod WITHDRAW button should pick up R6. ____

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[5] R82 is located in cabinet "A" - front: column 7, row 3.

[6] R4 is located in cabinet "A" - rear: column 1, row 3.

[7] R6 is located in cabinet "A" - rear: column 2, row 2.

[8] To take the reactor out of FAST PERIOD PERMIT mode temporarily jumper wire 321 to L-1 on R10. R10 is located in cabinet "A" - front: column 2, row 6.

2. RS36. Monitor the voltage on wire 146 at R65-3 as the period recorder is cranked from left to right. The following should be observed: to the left of 20 sec - 115 VAC; as recorder is cranked right through 20 sec - no voltage; with FAST PERIOD PERMIT and with reverse-bypass switch in BYPASS - 115 VAC. (Maintain this condition for test I.3.)

3. RS43. As period recorder is cranked to right through 10 sec voltage of wire 146 at R56-3 should drop from 115 VAC to zero.

4. RS38. As period recorder is cranked to right through 5 sec a REVERSE should occur and the 5 SECOND PERIOD annunciator should sound. (See footnote 8 on previous page.)

J. SAFETY MONITORS

#1 #2 #3

1. Switch the selected log N channel to GROUND and observe that the SAFETY TROUBLE alarm is actuated.

2. Disconnect the safety level channel at the preamplifier and observe that the SAFETY TROUBLE alarm is actuated. (Following the test each channel except the last tested should be reconnected.)

3. With one safety level remaining disconnected from test J.2, disconnect one of the remaining safety level channels at the preamplifier. The TWO SAFETY TROUBLE annunciator should alarm and a reverse should be observed. (Indicate channels disconnected during this test.)

K. PRIMARY COOLING WATER ACTIVITY MONITORS

1. Reactor. Cut recorder off. As recorder is cranked right through 200 mr/h an alarm should occur.

2. Pool. Same test as K.1, except that setpoint is 30 mr/h.

L. SECONDARY COOLING WATER pH MONITORS

Reactor Pool

1. Recorder High Alarm Point. This test must be made with the recorder operating and, thus, the balancing motor must be opposed manually. As recorder is cranked to right through 7.75, an alarm should occur.

2. Recorder Low Alarm Point. Same test as L.1 except alarm occurs as recorder is cranked left through 6.75.

3. Recorder Power Failure. Ensure that no alarm exists on the channel. An alarm should occur as recorder amplifier is turned off.

4. Local Indicator Power Failure. Ensure that no alarm exists on the channel. An alarm should occur as power is cut off of local pH indicator. At the same time, the control room recorder should drive to the left and remain there until power is restored.

M. PUMP BEARING TEMPERATURE ALARM

1. Turn recorder (at main pump house annex) OFF. An alarm should occur.

2. Crank the recorder to the extreme right. While observing the recorder indication, turn on the recorder. As recorder drives to left, record the indication when the alarm clears (~94 °C).

N. BUILDING VENTILATION

Conditions: Obtain RUN. Set log N period recorder on infinity and set log N recorder $> 1.8\ N_L$. (These conditions will remain in effect for test O.)

1. Jumper 424 to L1 (in FF-1) in TB-A

2. RS.82 (FS-59A). Obtain SERVO. Raise servo demand. Close damper in ORR basement to the half closed position. (This stops air flow in the duct in which the sail switchers are located.) Observe that an ALARM and SETBACK occur. After ~5 sec a REVERSE should occur. The anemometer should read ~2500 cfm.

3. Open damper.

4. Remove the jumper (424 to L1) on FF-1 in TB-A.

5. Jumper 423 to L1 (on FF-1) in TB-A.

6. RS-83 (FS59B). Same test as N.2.

7. Remove the jumper (423 to L1) on FF-1 in TB-A.

O. NORMAL OFF-GAS

Conditions: Obtained in Step N. (These conditions will remain in effect for test P.)

1. PS63A. Obtain SERVO. Raise servo demand. Slowly equalize the dp cell, PT-63, on the second level, north balcony. Observe the RED pen on the normal off-gas recorder. When the indicated vacuum is decreased to </-25/ in wg an ALARM should occur.

2. RS88 (PS63B): Setback.
RS89 (PS63C): Reverse. Continue equalizing the dp cell, PT-63. When the indicated vacuum is decreased to </-20/ in wg a SETBACK should be initiated. When the indicated vacuum is decreased to </-19/ in wg the voltage on wire 420Q in JB-PX No. 2 should be decreased to zero volts (indicating that an experiment reverse has been initiated).

3. Reactivate the dp cell, PT-63.

4. PS64A. Obtain SERVO. Raise servo demand. Slowly equalize the dp cell, PT-64, in the process instrumentation panel (east of the pipe chase entrance in the ORR basement). Observe the GREEN pen on the normal off-gas recorder. When the indicated vacuum is decreased to </-25/ in wg an ALARM should occur.

5. RS90 (PS64B): Setback.
   RS91 (PS64C): Reverse. Continue equalizing the dp cell, PT-64. When the indicated vacuum is decreased to </-20/ in wg a SETBACK should be initiated. When the indicated vacuum is decreased to </-19/ in wg the voltage on wire 420R in JB-PX No. 2 should be decreased to zero volts.

6. Reactivate the dp cell, PT-64.

P. PRESSURIZABLE OFF-GAS

Conditions: Obtained in Step N.

1. PS61A. Obtain SERVO. Raise servo demand. Slowly equalize the dp cell, PT-61, on the second level, north balcony. Observe the GREEN pen on the pressurizable off-gas recorder. When the indicated vacuum is decreased to </-25/ in wg an ALARM should occur.

2. RS86 (PS61B): Setback.
   RS87 (PS61C): Reverse. Continue equalizing the dp cell, PT-61. When the indicated vacuum is decreased to </-20/ in wg a SETBACK should be initiated. When the indicated vacuum is decreased to </-19/ in wg the voltage on wire 420 in JB-PX No. 2 should be decreased to zero volts.

3. Reactivate the dp cell, PT-61.

4. PS60A. Obtain SERVO. Raise servo demand. Slowly equalize the dp cell, PT-60, on the east side of the pressurizable off-gas filter pit. Observe the off-gas recorder. When the indicated vacuum is decreased to </-25/ in wg an ALARM should occur.

5. RS84 (PS60B): Setback.
   RS85 (PS60C): Reverse. Continue equalizing the dp cell, PT-60. When the indicated vacuum is decreased to </-20/ in wg a SETBACK should be initiated. When the indicated vacuum is decreased to </-19/ in wg the voltage on wire 420N in JB-PX No. 2 should be decreased to zero volts.

6. Reactivate the dp cell, PT-60.

Q. Restore control system to normal as indicated in Section I.A.

II. CHECKS WITH ACTUAL FLOW
(With raise-test switch in NORMAL)

A. REACTOR PRIMARY COOLING SYSTEM

1. Setback (See test G.2)

   With the primary bypass valve in manual control and set at $\sim$40% open, start the primary pumps and fully open the pump discharge valves. Slowly close one pump discharge valve while observing relays R78 and R79.

   a. RS66 (PdX 55A), R78. R78 should drop out when reactor $\Delta P < 21.4$ psi.

   b. RS16 (FX1A1), R79. R79 should drop out when reactor cooling flow $< 17\,000$ gpm

   c. Reduce flow to $< 17\,000$ gpm (i.e., full flow from two pumps for next test).

2. Scrams (due to low flow)

   a. Conditions:

      To simulate reactor ΔP (> 15.3 psig) in scram circuits:
      Jumper 339A to 340 in JB-PX No. 1
      Remove wire 358 in JB-PX No. 1

   b. RS17 (FX1A3), R28
      RS17X (FX1A4), R28X
      Reduce cooling flow slowly. As flow decreases to $< 14\,000$ gpm, a SCRAM condition should be observed on both channels.

   c. Increase cooling flow (i.e. full flow from two pumps) and clear all scrams.

   d. To restore normal conditions:
      Remove jumper (339A to 340) in JB-PX No. 1
      Replace wire 358 in JB-PX No.

3. Scrams (due to low ΔP)

   a. Conditions:

      To simulate reactor cooling flow ($> 14\,000$ gpm) in scram circuits:
      Jumper 339 to 339A (on CP-18) in TB-A
      Remove wire 359 (on CP-18) in TB-A.

   b. RS24 (PdX 55C), R28
      RS24X (PdX 55B), R28X
      Reduce cooling flow slowly while observing reactor ΔP. As ΔP decreases to < 15.3, a SCRAM condition should be observed on both channels.

   c. Increase cooling flow (i.e. full flow from two pumps) and clear all SCRAMS.

   d. To restore normal conditions:
      Remove jumper (339 to 339A) on CP-18 in TB-A
      Replace wire 359 (on CP-18) in TB-A.

4. Activation of Low-Level Scram Circuits
   a. The Console (left panel) Meter monitoring the low level scram circuit for No. 1 safety channel should increase (from the previous zero reading) to >10 when cooling flow is decreased to $<12\,000$ gpm.

   b. Same as previous test except that the monitoring meter for No. 2 safety channel should be activated when ΔP is decreased to <11 psi.

   c. Same as previous test except that the monitoring meter for No. 3 safety channel should be activated when Raise-Test switch is in TEST position.

B. POOL PRIMARY COOLING FLOW

1. Conditions:

   Establish full pool cooling flow (~700 gpm)
   Jumper L. 1 to 125A (on RF 3B) in JB-PX (run mode will be obtained).
   (The selected log N recorder should be $<0.33\ N_L$.)

2. RF 3B-1. Slowly decrease pool cooling flow. As flow decreases to <550 gpm, the reactor should drop out of RUN mode.

3. Remove the jumper (L. 1 to 125A) in JB-PX.

4. Increase pool cooling flow to ~700 gpm.

C. NORTH AND SOUTH FACILITY COOLING FLOW

Conditions: Establish reactor cooling flow $>17\,000$ gpm. Establish facility cooling flow using a facility cooling pump. Obtain RUN. Set log N recorder $>1.8\ N_L$. *(In each test the first recorder switch listed is* in the setback circuit, the second in the auxiliary reverse circuit, and the flow switch in the alarm circuit.)

1. RS78, RS79, FS302A1. Obtain SERVO. Raise servo demand. Open the equalizing valve on FT 302A[9]. Observe that an ALARM and SETBACK occur. After ~5 sec a REVERSE should occur. Close the equalizing valve.

2. RS80, RS81, FS302B1. Same test as II. C. 1 except that FT302B[9] is equalized.

3. RS70, RS71, FS731A1. Same test as II. C. 1 except that FT731A[10] is equalized.

4. RS72, RS73, FS731B1. Same test as II. C. 1 except that FT731B[10] is equalized.

5. RS74, RS75, FS751A1. Same test as II. C. 1 except that FT751A[10] is equalized.

6. RS76, RS77, FS751B1. Same test as II. C. 1 except that FT751B[10] is equalized.

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[9] Located in north-south facility switch panel (north of subpile room).

[10] *Located in process instrumentation panel (east of pipe chase entrance).*

III. ANNUNCIATOR CHECK LIST

A. PROCESS ANNUNCIATORS

		As Found Condition		
		Alarm	Lights	Remarks
AP 1.	Test Blocks			
AP 2.	Test Blocks			
AP 3.				
AP 4.				
AP 5.	Pool Demin. Resistivity			
AP 6.	Storage Tank Level			
AP 7.	Pool Water Activity			
AP 8.	Pool Water Low Resistivity			
AP 9.	Pool Cooling Temp. >95°F			
AP10.	Pool Level			
AP11.	Reactor Pressure			
AP12.	Facility Cooling			
AP13.	ΔT			
AP14.	R Demin. Exit Resistivity			
AP15.	R Outlet Temperature			
AP16.	R Inlet Temperature			
AP17.	R Water Activity			
AP18.	R Water Low Resistivity			
AP19.	Main Flow			
AP20.	Low Shutdown Coolant			
AP21.	Freezing			
AP22.	Water Test			
AP23.	No Pool Cooling Pump			
AP24.	Emergency Pump Blocked			
AP25.	Reactor Δ Pressure			
AP26.	Reactor Tower Fans			
AP27.	Degasifier			
AP28.	Main Pump Bearing Temp.			
AP29.	Catch Tank			
AP30.				
AP31.	Pool Tower pH			
AP32.				
AP33.	R Exch. Sec. Pump Press. Lo			
AP34.	R Tower Basin Water (Level)			

	As Found Condition		
	Alarm	Lights	Remarks
AP35. R Exchanger Sec. Temperature			
AP36. DC 3			
AP37. R Tower Basin			
AP38. DC 2			
AP39. R Tower pH			
AP40. DC 1			
AP41.			
AP42. R Sec. Radiation High			
AP43.			
AP44. P.O.G. Press. Hi			
AP45. N.O.G. Press. Hi			
AP46. Degas. Activity Hi			
AP47.			
AP48.			
AP49.			
AP50.			
AP51.			
AP52.			
AP53.			
AP54.			
AP55.			
AP56.			
AP57. Build. Vent. Lo			
AP58. Scrubber Elect.			
AP59. Caustic Level Lo			
AP60. Emerg. Pump Start			
AP61. Sump Level High			
AP62. Pump No. 1 Failure			
AP63. Sump Level Low			
AP64. Pump No. 2 Failure			
B. NUCLEAR ANNUNCIATORS			
AN 1.			
AN 2. Experiment Reverse			

	As Found Condition		
	Alarm	Lights	Remarks
AN 3. Experiment Setback			
AN 4.			
AN 5. Instrument Start Tripout			
AN 6.			
AN 7. Monitrons			
AN 8. Air Monitors			
AN 9. Fast Scram			
AN10. 5 sec. Period			
AN11. Insert 5 Rods			
AN12. 1.8 N_L in Start			
AN13. Safety Level			
AN14. Safety Trouble			
AN15. Servo wdr Limit			
AN16. Two Safety Troubles			

C. EXPERIMENT ANNUNCIATORS

	Alarm	Lights	Remarks
AE 1. GCPR Common			
AE 2. GCPR Exp. 1			
AE 3. GCPR Exp. 2			
AE 4. GCPR Exp. 3			
AE 5. GCPR Exp. 4			
AE 6. GCPR Exp. 5			
AE 7. GCPR Exp. 6			
AE 8. GCPR Exp. 7			
AE 9. F-9 Shields			
AE10. B-9 Reagan			
AE11. C-1 Carroll			
AE12. GCPR Exp. 8			
AE13. F-2 GE			
AE14. F-1 Waugh			
AE15. HN-1 REED			
AE16. B-1 GE			
AE17. Solid State			
AE18. MSR			
AE19. GCR Loop 1			

	As Found Condition		
	Alarm	Lights	Remarks
AE20. South Facility (18 in plug)			
AE21. GCR Loop 2			
AE22. Hydraulic Tube			
AE23.			
AE24.			

APPENDIX IV

ORR HOURLY READINGS

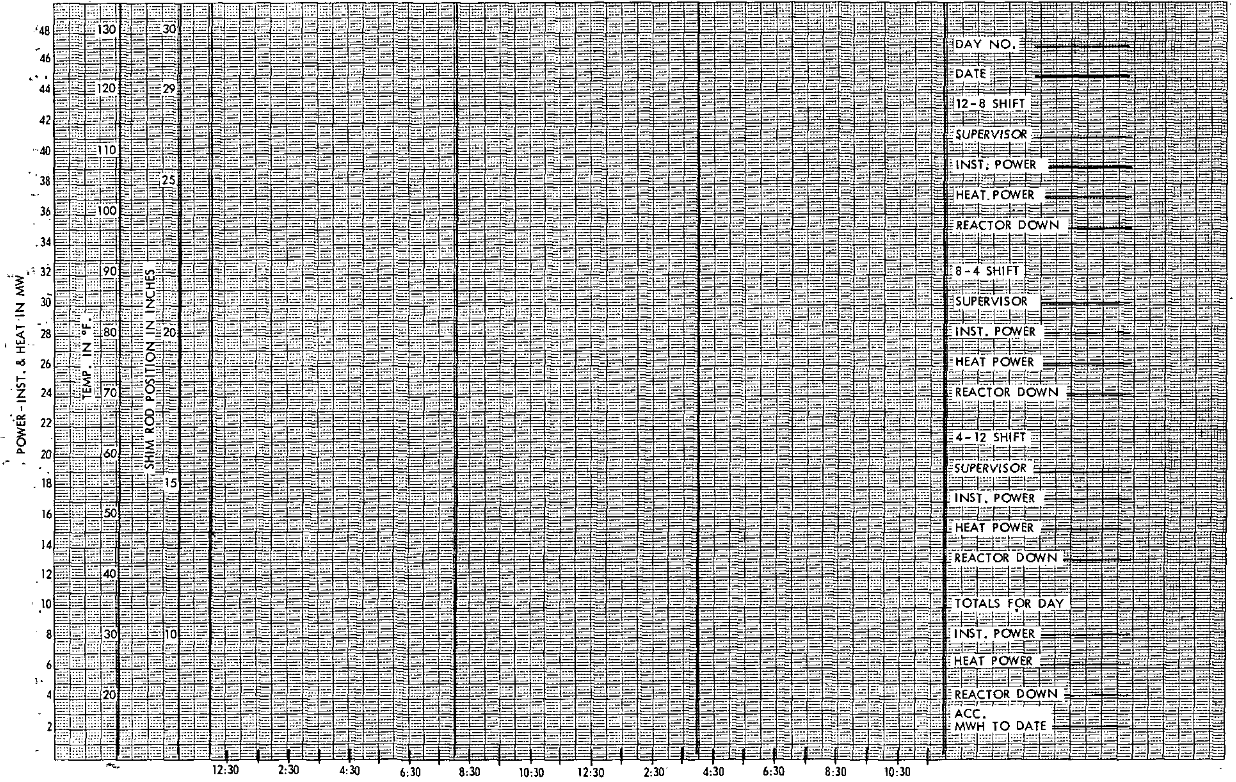
Date	Day Number
Shift	Supervisor

Time								
Storage tanks - % full								
Temperature reactor water in (T_1) °F								
Temperature reactor water out (T_2) °F								
Reactor water flow - gal/min								
ΔT								
Thermal power (reactor primary) $\Delta T \times$ gal/min $\times 1.465 \times 10^{-4} = MW_1$								
Temperature reactor pool water in (T_3) °F								
Temperature reactor pool water out (T_4) °F								
Pool water flow - gal/min								
$T_4 - T_3 = \Delta T'$								

Time								
Thermal power (reactor pool) $\Delta T' \times$ gal/min $\times 1.465 \times 10^{-4} = MW_2$								
$MW_1 + MW_2$ = Total heat power - MW								
# 1 Safety channel								
# 2Safety channel								
# 3 Safety channel								
μμ Ammeter								
Log N								
Outside temperature °F								
Radioactivity reactor water								
Radioactivity pool water								
# 1 Shim rod- inches out								
# 2 Shim rod- inches out								
# 3 Shim rod- inches out								
# 4 Shim rod- inches out								
# 5 Shim rod- inches out								
# 6 Shim rod- inches out								

APPENDIX V

DAILY OPERATING CONDITIONS
(Power diagram)



APPENDIX VI

ORR ACCUMULATED INSTRUMENT POWER

							Date	Day number
12-8 Shift			8-4 Shift			4-12 Shift		
Supervisor			Supervisor			Supervisor		
Time	Instrument power	MWh	Time	Instrument power	MWh	Time	Instrument Power	MWh
	Total			Total			Total	

Power level changes. Time and changes are to be recorded

APPENDIX VII

POWER CHANGES AND ACCUMULATED ENERGY

Date	Supervisors	12-8
		8-4
		4-12

12-8 Shift			8-4 Shift			4-12 Shift		
Time	Power	kWh	Time	Power	kWh	Time	Power	kWh
	Total kWh			Total kWh			Total kWh	

APPENDIX VIII

ORR DAILY SUMMARY

Day No.	Date	Engineer

I POWER

Shift	Hrs. Op.	Hrs. Dn.	MWh		Accum. (inst.) power MWh
			Inst.	Heat	
12-8					Previous total
8-4					Day's total
4-12					Current total
Total					

II DEMINERALIZERS

	N. reactor dem.			S. reactor dem.				Pool-demineralizer		
	pH	Res.	c/m/ml	pH	Res.	c/m/ml		pH	Res.	c/m/ml
Inlet							Inlet			
Exit							Cation			
Anion							Exit			
Cation										

Day's throughput ______ gal. Day's throughput ______ gal. Day's throughput ____ gal.

III COOLANT

	Reactor	Pool		Secondary	
				Reactor	Pool
Inlet T	°F	°F	Time		
Exit T	°F	°F	pH		
Δt	°F	°F	CrO_4		
Max. pH/Res.			T.S.		
Min. pH/Res.			c/m/ml		

NOTE: Use averages for the three shifts wherever possible.

IV COMMENTS

APPENDIX IX

8-4 SHIFT ORR DAILY CHECK SHEET

Date			Filled out by			
	Friday	Saturday	Sunday	Monday	Tuesday	etc.
REACTOR PRIMARY						
Expansion joints						
Decay tank (top flange)						
Shutdown pump seals						
Bypass filters						
24-in strainer						
Shell and tube heat exchangers						
Hand and check valves						
Bypass valve						
Pump seals						
Motor bearing temperature						
Housing vibration						
REACTOR SECONDARY COOLING TOWER						
Pump packing (should have slow leakage)						
Oil level bearing reservoir						
Motor and pump bearing temperature						
Housing vibration						
Basin level						
Water distribution (top of tower)						
Water condition (debris, slime, and algae)						
Basin screens						
Bypass valve						
Fan motor bearing temperature						
Fan motor housing vibration						
Geareducer oil level						
POOL SECONDARY COOLING TOWER						
Pump seals (should have slow leakage)						
Motor bearing temperature						
Housing vibration						
Basin level						
Water condition (debris, slime, and algae)						
Basin screen						
Ball float valve						
Fan motor vibration						
Fan motor bearing temperature						
ALL SUMP PUMPS						
Pumps operating properly						

APPENDIX X

4-12 SHIFT ORR-DAILY CHECK SHEET

Date	Filled out by				
	Wednesday	Thursday	Friday	Saturday	etc.
* Area checked for malfunctions					
* EMERGENCY POWER SYSTEM:					
a. Transfer mode switch in "normal"					
b. Diesel mode switch in "auto"					
c. Fuel Valve of diesel pointed West					
* Log and clipboards checked for spec. assignments					
* Batteries on DC # 1 and DC # 2 Motors					
* Checks sumps					
* Experiment checks where necessary					
* Demineralizer's pH and resistivities logged					
* Third floor level straightened up					
* Weekly checks					
* Storage tank level					
* Equipment placed in cabinets where possible					
GASOLINE-DRIVEN EMERGENCY PUMP:					
a. Motor run for 5 minutes					
b. Check level in gas tank					
c. Check radiator water level					
d. Check oil level					
e. Check water level in batteries					
f. Valve on pump opened to bleed off air					
Pool and reactor sec. system readings logged					
All flashlights in control room and operating					
Corrosion experiment					
Degasifier in proper operation					
Check cold trap readings and service					
Hyd tube samples "in" and "out"					

* To be performed during shutdowns

APPENDIX XI

12-8 SHIFT ORR DAILY CHECK SHEET

Date	Filled out by				
	Saturday	Sunday	Monday	Tuesday	etc.
* Area checked for malfunctions					
* EMERGENCY POWER SYSTEM:					
a. Transfer mode switch in "normal"					
b. Diesel mode switch in "auto"					
c. Fuel valve of diesel pointed West					
* Log and clipboards checked for spec. assignments					
* Batteries on DC 1 and DC 2					
* Check sumps					
* Experiment checks where necessary					
* Demineralizer's pH and resistivities logged					
* Yellow hot cans emptied					
* Daily report for previous day complete					
* Building CAMs and monitors operating					
* All supplies checked					
* Cutie-pies and survey meters					
* Off gas water traps					
a. Blow down catch tank					
b. Fill seal tank					
* Storage tank level					
Reactor and pool secondary system readings logged					
Corrosion test experiment					
Degasifier in proper operation					
Cold traps, read and serviced					
Hyd. tube sample "in" and "out"					
Purge specified beam holes					

* To be performed during shutdowns

APPENDIX XII

ORR DAILY WATER SYSTEM CHECKS

Day

Operator

REACTOR SYSTEM

		Control room	Pump house
Tank ΔP lb/in^2	Bypass filter flow (gal/min)		
Tank top pressure lb/in^2	Primary flow (gal/min)		
Facility cooling flow gal/min	Reactor exit temp. °F		

North demineralizer flow gal/min, Integrator ( ) × (1.5) = gallons

South demineralizer flow gal/min, Integrator ( ) × (1.5) = gallons

Strainer ΔP (inlet) - (exit) = lb/in^2

Primary pumps		# 1	# 2	# 3	Shutdown	Emergency
Exit lb/in^2						
Inlet lb/in^2						
Motor amps						
Bearing temp.	North					
	South					

Secondary mean temperature °F	Pump exit (PI 56) lb/in^2	Return line (PI) lb/in^2

POOL SYSTEM

Primary flow gal/min		Secondary flow gal/min
Demineralizer	Flow gal/min	Integrator ( ) × (1.8) = gallons

RECORDED IN LOG BOOK

Sump counts, demineralizer data

All main pump DC battery cells Sp G read, lowest logged

DAILY SCRUBBER CHECKS

Sump level	Caustic tank level
pH	Specific gravity

Total solids

Turn # 1 electric pump off. The air-driven pump should come on. ______________

Check with the control room. The following annunciators should be in alarm condition:

Pump # 1 failure	Emergency pump start

Turn # 1 electric pump back on to clear the alarm conditions. ______________

Turn # 2 electric pump off. The air-driven pump should come on. ______________

Check with the control room. The following annunciators should be in alarm condition:

Pump # 2 failure	Emergency pump start

Turn # 2 electric pump back on to clear the alarm condition. ______________

If the total solids analysis is greater than 1000 ppm, purge the system until the solids drop below 1000 ppm. Air pump oil supply. ______________

Air pump oiler checked and oil added if necessary. ______________

OTHER CHECKS

Beam hole liner air purge	Large facility lead detectors	Pog blower

APPENDIX XIII

DAILY ROUTINE INSTRUMENT CHECK LIST FOR ______________

Date	Time ☐ a.m. ☐ p.m.	Inst. tech.	Shift engineer
Heat power level ☐ kW ☐ MW	Charts on all recorders	Check std. motors Model H	Ink on all recorders
Check batteries	PA system check	Sound powered phones	

Gamma chambers (% power)		Log N channels (% power)		Safety channel recorders (% power)		
# 1	# 2	# 1	# 2	# 1	# 2	# 3

Magnet amplifiers	1	2	3	4	5	6		
A								
B								
Total								
Posted op. 1								

Sigma amplifiers	# 1 safety		# 2 safety		# 3 safety		Period	
Heat to cath. st.								
B+ Unregulated.								
B+ Regulated								
B+ Current								
Power (meter)								

Condition of trouble monitors
Remarks

APPENDIX XIV

ORR WEEKLY CHECKS

Date

Check if "OK"		
______ 1.	Underwater lights check	
______ 2.	Secondary system supplies, check and reorder	
______ 3.	Pool tools check	
______ 4.	"Teletalk" communication system check	
______ A.	Room 307	
______ B.	Room 305	
______ C.	Room 303	
______ D.	Room 301	
______ E.	North side of pool	Clear contact must be established between the control and the point in question. The ability of the control room to contact each area should be tested as well as the reverse condition.
______ F.	South side of pool	
______ G.	Health Physics Office	
______ H.	Second floor, west	
______ I.	First floor, north	
______ J.	First floor, south	
______ K.	Subpile room	
______ L.	Outside subpile room door	
______ M.	Pipe tunnel	
______ N.	Reactor pump house	
______ O.	Reactor secondary pump house	
______ P.	F-2 control room	
______ Q.	Trane coolers	
______ 5.	PA system check (PA = public address)	
______ A.	Third level	
______ B.	Second level	
______ C.	Toilets in 3042 Building	
______ D.	First level	A man should be able to hear the PA clearly and distinctly in any and all of the locations listed. Calls should be made from all Operations Division microphones.
______ E.	Basement	
______ F.	Area outside northeast corner of building	
______ G.	Pump house	
______ H.	Storage tank area	
______ I.	Reactor heat exchanger area	
______ J.	Cooling tower area	
______ 6.	Run emergency gasoline pump one hour.	
______ 7.	Check the area for loose gas cylinders and compile a list of those for the log; give locations.	
______ 8.	Clean the two reactor models on the second floor southwest.	

APPENDIX XV

SAMPLE SCHEDULE

OUT

Date ________

Source	Pos.	Sample no.	Can or rabbit no.	Out sched.	Out actual	Material	Claimed
12 - 8							
8 - 4							
4 - 12							

Remarks:

SAMPLE SCHEDULE

IN

Date ___________

Source	Pos.	Sample no.	Can or rabbit no.	In sched.	In actual	Material	Claimed
12 - 8							
8 - 4							
4 - 12							
Remarks:							

APPENDIX XVI

ORR WEEKLY REPORT

	For week ending	
A. COOLING WATER (Items 1-4 measured at demineralizer inlet)	Reactor	Pool
1. Maximum pH and resistance for week		
2. Average pH and resistance for week		
3. Minimum pH and resistance for week		
4. Average gross gamma activity c/m/ml		
5. Date of last change of filters	East	
	West	
6. Average water temperature (°F)		
a. Exit		
b. Inlet		
c. ΔT		
B. REACTOR CONTROL SYSTEM (List changes, modifications, trouble, etc.)		

C. OPERATING DATA (From log book)	
MWh at end of week	
MWh at beginning of week	
MWh for week	
MWd for week	

Date	Day no.	Acc. energy -- MWh		Hours operated	Hours down	No. of shutdowns	
		Instrument	Heat			Scheduled	Unscheduled
Total							

D. DEMINERALIZER DATA

Column	Run No.	Date started/ ended	Total through-put in run (gallons)	Average c/m/ml		Average specific resistance and pH	
				Inlet	Outlet	Demineralizer influent	Demineralizer effluent
REACTOR							
N. cation							
N. anion							
N. mixed bed							
S. cation							
S. anion							
S. mixed bed							
POOL							
Cation							
Anion							

E. SHUTDOWNS

1. Scheduled

Date	Duration (h)	Remarks
Total hours		

2. Unscheduled

Date	Duration (h)	Remarks
Total hours		

3. Total downtime, scheduled and unscheduled ______ hours

F. FACILITY CHANGES

Facility	Date in	Date out	Nature of experiment	Sponsor

APPENDIX XVII

ORR SHUTDOWN SCHEDULE

Date of shutdown		Time
Date of startup		Time
Purpose of shutdown	☐ Refueling ☐ Isotopes ☐ Experiment ☐ End of cycle Other (specify)	
Method of shutdown	Setback to N_L from Reverse rod to 6 inches from Scram from	
Pool entry required	☐ Yes ☐ No	

ORR SHUTDOWN WORK SCHEDULE

Date

I. PREPARATION FOR SHUTDOWN

A. Prepare for pool entry if required.
  1. Cover floor and parapet with paper (not bridge).
  2. Provide supplies--gloves, shoe covers, etc.
  3. Provide radiation-detection instruments.
  4. Provide a radiation work permit ready for signature after a survey is made.

B. Prepare for refueling
  1. Relocate fuel elements in storage racks if necessary.
    a. Have all fuel to be used in reactor pool.
    b. Provide empty spaces as required.
  2. Prepare a fuel-transfer sheet for use during the actual transfer.

C. Prepare experiments for shutdown
  1. Turn HB-6 auto-off switch to "off" 10 minutes before shutdown.
  2. Contact experimenters if required. This will usually be unnecessary for scheduled shutdowns.

D. Prepare for isotope work
  1. Number the samples and place in the rack. Be sure that the samples are the proper size.
  2. Assemble the spare iodine assembly, and place it in the isotope platform rack position No.5.

E. Other preparations (specify)

II. SHUTDOWN

A. Shut the reactor down as specified above.

B. Observe the shim-rod drives for proper action during the scramming and recocking operation. Log any malfunctions and make necessary repairs. Remarks ______________________

C. Determine that both scram circuits are completed.

D. During the "cooling down" period

1. Check the magnet-release times.*
2. Check the drop currents on all magnets.*

E. Perform the test on the emergency cooling units according to attachment No. __________.*

F. Other special checks before water flow is stopped (specify)

G. Complete the shutdown checks in accordance with the check list attached.

H. Prepare the hydraulic-tube facility for pool entry if required by

1. Removing all samples.
2. Removing the facility from service (Close HT-1, then HT-5).

* Applies to end of cycle shutdown only, unless otherwise specified.

III. OPERATIONAL ACTIVITIES

A. Refueling

1. Reload the core in accordance with the attached reloading schedule
   beginning date ______________ time ______________
2. Transfer shim rods from B-4 and B-6 core position to the shimrod rack. Use a check sheet.*

   Note: The shim rods in core positions D-4 and D-6 at shutdowns will be transferred to B-4 and B-6, respectively, before startup.*
3. Leave core positions _____ and _____ free of shim rods for routine drive replacement. Use a check sheet for any rod movements necessary.*

B. Isotopes

1. Move the core pieces containing isotopes from positions ________________ to the designated storage positions on the isotope platform.
2. Perform work as outlined on the isotope schedule.
3. Inventory trays worked. F-full, MT-empty.
4. Prepare samples for shipment by: (Date) ______________ time __________

C. Iodine unit (CP-A3)

1. Remove and replace with a spare unit which is located in isotope platform rack position No.5.
2. Work the removed unit.
3. Prepare one cylinder for shipment by: (Date) ______________ time __________

Note: this shutdown schedule is continued on the next pate for end-of-cycle shutdowns.

* Applies to end-of-cycle shutdown only, unless otherwise specified.

APPENDIX XVIII

ORR SHUTDOWN CHECK LIST

Initial		Date
	1. Scram handle in "scram" position.	
	2. Key switch in "off" and key removed.	
	3. All rods in seat position and seat lights "on".	
	4. All rod-mode switches in "off" position.	
	5. Servo demand at N_L.	
	6. After 30-MW operation:	
	a. Continue normal circulation of reactor water for 30 min or until the temperature of the reactor water is equal to the pool temperature; i.e., 78°F < outlet temperature < 100°F.	
	b. Complete the "test" on emergency cooling units (end-of-cycle shutdowns only).	
	c. Unit No. 1 Unit No. 2 Unit No. 3 } Check to determine that DC motors turn the pumps after AC motors are stopped.	
	d. Unit No. 1 Unit No. 2 Unit No. 3 } "Charger-battery" disconnects closed. (The No. 1 and 2 disconnects should be opened if the shutdown is for a period greater than 8 hours.)	
	e. Unit No. 1 Unit No. 2 Unit No. 3 } "Battery-motor" disconnects opened.	
	7. Reactor secondary loop.	
	a. Fans in "off." b. Pumps in "off." c. Blow-down valves closed. d. Acid addition system "off."	
	8. Pool secondary loop.	
	a. Fan in "off." b. Pump in "off." c. Blow-down valve closed. d. Acid addition in "off."	
	9. Main pumps "off."	
	10. Shutdown pump "on."	
	11. Main pump test blocks removed.	
	12. Channel No. 1 Channel No. 2 } Log-N amplifiers on ground position.	
	13. No. 1 fission chamber inserted to give 20 cps No. 2 fission chamber inserted to give 20 cps	
	14. CRM speaker at poolside activated.	

APPENDIX XIX

ORR MECHANICAL MAINTENANCE RECORD

Date	Time	Shift

System

Component

Malfunction

Details of inspection

Details of repair

Radiation and contamination problems encountered

Craftsman who performed work	Craft foreman	Operations supervisor

APPENDIX XX

FUEL TRANSFER MEMO

From	Date
To	Shift

Source	Type units	No. units	Receiver	Remarks

APPENDIX XXI

SHIM ROD REMOVAL CHECK LIST

In preparation for this operation, the necessary tools should be checked, balcony cleared and roped off, the procedure for rod transfers (1.3.3f) reviewed, etc. Shift engineers must closely supervise all parts of operation and initial at completion of operation.

☐ 1. Assure that all seat lights are showing, and that drives are near lower limit and drive unit is in locked position. Assure that magnet current is off. Seat switch actuating lever should be checked to assure that the shim rod is actually resting on the seat switch actuating rod.

☐ 2. Raise both hold-down arms by catching bail of arm with a hook and tilting the arm east.

☐ 3. Remove the 4 fuel elements immediately (N, S, E, W) adjacent to the rod or rods to be moved. (This ensures subcriticality.)

☐ 4. Position bridge above core, winch on bridge above rod, with cable directly over rod.

☐ 5. Unlock safety hook and lower into tank. Engage fuel hook in round locking pin eye.

☐ 6. Lower safety hook to rod and engage in rod handle. Lock hook by lifting safety pin eye slightly and rotating counterclockwise. Remove auxiliary fuel hook.

☐ 7. Raise drives enough so that 3 reclutching prongs clear 3 studs. Unlock rod by rotating locking handle. Leave drive unlocked.

☐ 8. Station a man to watch the count rate recorder. Raise rod slowly about 1 foot until sure rod is unlocked and free of the drive.

☐ 9. Clear bridge and pool-side of unnecessary people. Make certain bridge can be moved.

☐ 10. Under radiation surveillance raise rod enough so that piston will clear top of tank. Move bridge west promptly, until rod can be lowered. Lower rod until radiation level tolerable.
______________ maximum reading mr/h.

☐ 11. Identify rod.

☐ 12. Move rod to storage location and place there.

☐ 13. Unhook from rod and complete transfer memo.

A rod that is replaced in core <u>must</u> be locked and checked by the crew putting it in the core.

Date	Engineer
Shift	Rods moved

APPENDIX XXII

SHIM ROD INSERTION CHECK LIST

In preparation for this operation, make sure the necessary tools are checked and available, the balcony cleared and roped off, the procedure for rod transfer (1.3.3f) reviewed, etc. Shift engineers must closely supervise all parts of operation and initial at completion of operation.

☐ 1. Assure that the 4 fuel elements (N, S, E, W) immediately adjacent to the rod have been removed, the rod drive is unlocked and near lower limit, the hold-down arms are raised.

☐ 2. Place shim-rod winch on bridge, so cable will be directly over the future position of the rod.

3. (a) Applies to irradiated rods.

☐ (1) Unlock safety hook and lower to rod. Engage in rod. Lock by lifting and turning latch eye counterclockwise.

☐ (2) Under radiation surveillance raise the rod from storage location. Identify rod.

☐ (3) Move bridge eastward. When near tank, raise rod under radiation surveillance enough to clear tank top. Immediately lower rod when above access flange until radiation subsides. Maximum reading ________ mr/h.

(b) Applies to unirradiated rods.

☐ (1) Assure that rod is secure in the carrier.

☐ (2) Engage locking hook of winch on rod and thread the special wire choker through the shim rod. Attach choker to crane hook and lift unit to vertical position. Remove carrier.

☐ (3) Raise rod, move over pool, and lower into water until winch supports the rod.

☐ (4) Remove the wire choker.

☐ 4. Position bridge so that rod is directly above the core position it will go in. Station a man to watch the count rate recorder while lowering rod.

☐ 5. Engage a fuel hook in the eye on the back of the hook to keep the rod from twisting while entering lower grid. The rod must hang vertically.

☐ 6. When the rod has entered the lower bearing properly, take the fuel hook off the safety hook. Continue lowering slowly until the rod is down and cable slacked. A seat light will show if drive was truly unlocked.

☐ 7. Send an operator to subpile room to lock the drive by rotating the locking handle.

☐ 8. The locking of the rod must be checked by lifting up gently on the rod with the winch. A small upward movement will indicate the rod is free to move between seat and cross. If the upward movement is not stopped by the cross, the rod is free and must yet be locked.

☐ 9. An additional check can be made by raising the drive 5 inches and noting that the rod now can be raised some 5 inches also. Run drives back down, and assure that the rod can no longer be raised.

☐ 10. Unlock safety hook from rod and remove.

Other fuel or rod movements may now be made.

A rod that is replaced in core <u>must</u> be locked and checked by the crew putting it in the core.

Date	Engineer
Shift	Rod moved and checked

APPENDIX XXIII

TOOL AND EQUIPMENT CHECK LIST FOR PERSONNEL WORKING IN AND/OR OVER ORR POOLS

Job	IN			OUT		
Name and/or item	Date	Time	By (Initial)	Date	Time	By (Initial)

APPENDIX XXIV

CURRENT PERSONNEL EXPOSURE RECORD

Cumulative Exposure Should Total _____ mr

HP Week No. _______
Date _______

Name	Cumulative Exposure	M	T	W	T	F	S	S	Remarks
Atkins									
Belitz									
Blauer									
Branam									
Brown									
Cagle									
Coleman									
Culbert									
Darr									
Daughtry									
Davis									
Fox									
Gaither									
Guinn									
Harper									
Hulen									
Hurt									
Jernigan									
Kennemore									
Kerby									
Klaus									
Lande									
Mc Bee									
Mc Reynolds									
Malone									
Nixon									
Owens									
Roy									
Schmollinger									

APPENDIX XXV

RADIATION WORK PERMIT

RADIATION WORK PERMIT (RWP)	Date and time From a.m. p.m. to a.m. p.m.	Extended by to a.m. p.m.	Work permit No. R 19173

Location & job description

RADIATION SURVEY DATA (To be filled in by Health Physics)								
Loc. Code	Specific location and distance from source	Type of radiation	mrem/h	Working time for ______ mrem	Contamination		Radiation survey	
					Type	Measurement	By	Date and time
A								
B								
C								
D								

INSTRUCTIONS*

HEALTH PHYSICS MONITORING REQUIRED: ☐ START OF JOB ☐ INTERMITTENT ☐ CONTINUOUS ☐ END OF JOB

Contact HP for survey before starting work in a new location		Provide assistance for removal of protective clothing	
Tape coveralls to gloves and footwear		Monitor breathing zone	
Check tools at end of job		Nasal smear required	
Check personnel at end of job		Bioassay sample required	
Timekeeping required		Do not work alone-standby observe required	

Remarks

PROTECTIVE EQUIPMENT AND MONITORING INSTRUMENTS

Cap			Coveralls (1 pair)		Shoe covers		Pocket meters	
Canvas hood			Coveralls (2 pairs)		C-zone shoes		Dosimeter	
Safety glasses		Gloves	Canvas		Rubbers		Film ring	
Eye shield			Leather		Rubber boots		Dose-rate alarm	
Half mask			Surgeon's		Plastic bootees		Dose alarm	
Assault mask			Plastic		Lab coat		Cutie pie	
Chemox mask			Rubberized canvas		Special film meter		GMS meter	
Air-line hood			Household rubber					
Air-line suit								

REGULAR APPROVALS	SPECIAL APPROVALS
Health Physics certification	Division Director
Supervision	H.P. Division Director
Supervision	Deputy Lab Director

*Only items checked (✓) apply (over)

1. Health Physics shall be present for line breaks or removal of shielding.
2. Notify Health Physics of any deviations from instructions and changes in working conditions. Timekeeping by ____________
3. Personnel survey is required when leaving contamination zones.
4. Return work permit to Health Physicist upon completion of job or expiration of permit. Dept. ____________

PERSONNEL AND EXTERNAL EXPOSURE CONTROLS						Planned exposure (mrem)	TIME RECORD							Estimated exposure (mrem)
Name	Dept.	P.R.No.	Location code	Dose rate used	Working time		Begin	End	Begin	End	Begin	End	Total time	

1. Radiation Work Permit is required* when:
   (a) expected dose is > 20 mrem to the body or 300 mrem to extremities for an individual during a single work assignment;
   (b) dose rate > 5 rem/h (total body);
   (c) airborne radioactivity is > $(MPC)_a$ for a 40-h week;
   (d) specified by divisional operating rules and procedures or by posted regulations.

2. Supplementary Time Sheet

To be used if extra space is needed for the timing of individuals into and out of an area, etc.

3. Special Approvals

(a) Dose Rate rem/hr (total body)

\>5 Division Director in charge of work area — Oral or written; noted and initialed on the permit by the person obtaining the approvals.
\>20 Above and Health Physics Division Director.
\>50 Above and Laboratory Deputy Director.

(b) Dose (total body)

\>60 mrem/day for nonoperating personnel, or >300 mrem/week for operating personnel — Division Director in charge of individual
\>1 rem — Above and Laboratory Deputy Director

4. Copies
   (a) The RWP must be posted or available at work site.
   (b) Health Physics maintains a copy for record and reference purposes.
   (c) A copy must be distributed to appropriate line supervision.

* Posted regulations may be used in lieu of an RWP for operating personnel under specified conditions. (See Regulation 3, Procedure No. 26, ORNL Health Physics Manual.)

APPENDIX XXVI

BACKGROUND SURVEY

Performed by	Reason	Date	Time

NOTE: This Survey is to be performed each Saturday and after the startup of the reactor at the beginning of a cycle. A survey meter (G-M Counter) shall be used for this Survey, with a Cutie Pie used when survey meter goes off scale.

		mr/h	
AREA		MAXIMUM BACKGROUND	PRE-SET LOCATION
1. POOLS			
a. East	TAKEN AT SURFACE NEAR POOL WALLS		
b. Center			
c. West			
d. Top of bridge			
e. Above hydraulic tube			
2. HOT CELL			
a. North cell			
1. Window			
2. Access holes (not including top of cell)			
3. Walls (up to height of 6 feet)			
b. South cell			
1. Window			
2. Access holes (not including top of cell)			
3. Walls (up to height of 6 feet)			
3. WALKWAYS			
a. Third level, South			
b. Third level, North			
c. Second level, South			
d. Second level, North			
e. Second level, West			
f. First level, South			
g. First level, East			
h. First level, North			
i. First level, West			
4. EXPOSED EXPERIMENTAL EQUIPMENT (PIPING, ETC.) ON 2nd. LEVEL BALCONY	NORTH		
	SOUTH		
5. FACILITIES			
a. North facility			
b. South facility			
c. HB-1			
d. HB-2			
e. HB-3			
f. HB-4	1		
	2		
g. HB-5			
h. HB-6			

	mr/h	
AREA	MAXIMUM BACKGROUND	PRE-SET LOCATION
6. BASEMENT:		
a. Pipe tunnel		
b. Sub-pile room door		
1. Near reactor bottom plug		
c. North walkway		
d. South walkway		
e. Pool heat exchanger area		
f. Beam hole plug storage area		
g. Degasifier		
1. Air separator		
2. Water tank		
h. Pneumatic tube laboratory		
i. Reactor north demineralizer		
1. Anion		
2. Cation		
3. Mixed bed		
j. Reactor south demineralizer		
1. Anion		
2. Cation		
3. Mixed bed		
k. Pool demineralizer		
1. Anion		
2. Cation		
7. PUMP HOUSE		
a. # 1 Pump cell		
b. # 2 Pump cell		
c. # 3 Pump cell		
d. Shutdown pump (electric) cell		
e. Emergency pump (gasoline) cell		
8. REACTOR HEAT EXCHANGER PIT		
a. Entrance		
b. North side of pit		
c. South side of pit		
9. REACTOR WATER ACTIVITY		
10. POOL WATER ACTIVITY		
11. SUMP COUNTS		
a. # 5 (Decay tank)	c/m/ml	
b. # 4E (Expansion pit)	c/m/ml	
c. # 4W (Expansion pit)	c/m/ml	
d. # 6 (3042)	c/m/ml	

APPENDIX XXVII

AIR SAMPLE DATA

Name	Phone	Bldg. No.	Date
Sample No.	Time From To		Results required Date Time
Location	Date counted		Counter operator
SPECIFY RESULTS DESIRED			

Type radio activity	Immediate count.				C_1			C_2				C_{11}	
	$T - T_0$ <4 hours				$T_1 - T_0$ >4 hours			$T_2 - T_1$ > 16 hours				LONG LIVED ACTIVITY	
	Date	Time	Counts	$\mu c \times 10^{-6}$	Date	T_1 Time	Counts	Date	T_2 Time	Counts	Hrs. T	Counts	$\mu c \times 10^{-6}$
α													
β													

Smear sample data in disintegrations per minute Give dpm only on smears over: ________ dpm Alpha ________ dpm Beta	Remarks

α	β	α	β	α	β	α	β	α	β
1		21		41		61		81	
2		22		42		62		82	
3		23		43		63		83	
4		24		44		64		84	
5		25		45		65		85	
6		26		46		66		86	
7		27		47		67		87	
8		28		48		68		88	
9		29		49		69		89	
10		30		50		70		90	
11		31		51		71		91	
12		32		52		72		92	
13		33		53		73		93	
14		34		54		74		94	
15		35		55		75		95	
16		36		56		76		96	
17		37		57		77		97	
18		38		58		78		98	
19		39		59		79		99	
20		40		60		80		100	

APPENDIX XXVIII

EXPERIMENT REVIEW QUESTIONNAIRE
for Experiments in the
ORR, OGR, and LITR

Questionnaire Completion Data	
Experiment Number	
Experiment Reference Number	
Research Person In Charge	
Research Division (Sponsoring)	
Reactor Facility	
Operations Technical Coordinator	
Duration of Experiment Program	
Date of Planned Insertion	
Date of Actual Insertion	
Operations Approval	
Experiment Review Committee Approval	
Disposition and Comments -	

This questionnaire has several closely related purposes:

1. It requests the experimenter to evaluate many basic problems and conditions which appear to be generally associated with in-reactor experiments, thereby reducing the possibility that some important basic factor will be overlooked in the experiment design.
2. It requests information needed for the following:
   a. Operations review of the experiment from all aspects including safety, operability, and compatibility with the reactor and other experiments.
   b. Experiment Review Committee review consisting primarily of a comprehensive hazards evaluation.
   c. To establish a central file of experiment information and operating histories.
3. It provides Reactor Operations personnel with information necessary to assure safe and efficient operation of the reactor when the experiment is in progress, and to permit valid evaluation of emergency conditions and the instigation of appropriate corrective action.

In essence, the experiment review questionnaire is a summary hazards report for the experiment. To serve this purpose it must contain a rather complete and detailed description of the experiment facility design and construction, as well as evaluations of the various experiments to be performed, and analysis of the functional characteristics of the entire system under the various sets of conditions to which it may be subjected. In addition, the probable results of all credible incidents such as reactor power excursions, loss of utilities, and equipment failure must be established. Safety procedures and/or equipment must be provided to prevent damaging accidents in cases where the above analyses indicate that hazardous conditions may develop or are inherently associated with the system.

In general, the experiment designer, or design group, will have necessarily accumulated all of the above outlined information in arriving at a final fixed experiment design, and it is hoped that this questionnaire may also be of some use as a guide or outline during the progressive stages of the experiment design.

The inadequacy of a single questionnaire for any of the experiments to be performed in any one of three greatly different reactors should be recognized. In a given experiment some of the information requested may not be applicable, while for others additional information will be required. In so far as possible these variations should be pointed out by the Reactor Operations representative at the time the questionnaire form is given to the experimenter. As the design develops, additional revisions in the questionnaire content may become necessary.

Section I

GENERAL INFORMATION

Please supply the following information:

A. Experiment Personnel: List below in the order to be contacted in the event of an emergency.

TABLE 1

Name	*	**	Office		Phone	
			Room	Bldg.	Business	Home

* Persons qualified to make technical decisions regarding the experiment.
** Persons qualified to operate the experiment.

B. Charge Code: ____________________
(Charges for reactor space will be billed to this code until further notice is received.)

C. Manning of Experiments will be:

Continuous? ____________

Other? Explain ____________________

D. Special Assistance Desired From Operations Personnel: (State the nature and extent of assistance desired.)

E. Special Requirements of the Reactor During:

1. Power Level Changes (start-ups, shutdowns, adjustments)

2. The Operating Cycle - ____________________

3. Shutdowns (scheduled end of cycle) ____________________

F. Health Physics Services Required: ____________________

G. Hot Cell Usage Planned: (State briefly the following)

1. Nature of the work to be performed.

2. Anticipated frequency of use.

3. Estimated time required per operation.

H. Building and Other Space Requirements For:

1. Instruments

2. Personnel

3. Outside (state usage)

4. Other

I. Flux Desired:

1. Thermal Neutrons ____________________ $\frac{\text{Neutrons}}{\text{cm}^2\text{-sec}}$

2. Fast Neutrons (state energy range) ____________________ $\frac{\text{Neutrons}}{\text{cm}^2\text{-sec}}$

3. Gamma Photons (state energy range) ____________________ $\frac{\text{Photons}}{\text{cm}^2\text{-sec}}$

J. Flux Measurements to be Made: (State which, how, and by whom.)

____

K. Disposal: (What will be the final disposal of the in-reactor section of the facility tube and experiment assemblies.)

L. Utilities Required:

TABLE 2

	Property	AC	DC	Emergency*	Other
Electrical power	Volts				
	Amps				
	Power				
Water		Process	Demineralized	Reactor	Pool
	Pressure (psig)				
	Flow (gpm)				
Compressed Air		Plant Supply	Emergency Supply	Other	
	Pressure (psig)				
	Flow (scfm)				
Steam	Pressure (psig)				
	Quantity (lb/min)				
Drains		Process**	Warm	Hot	
	Flow (gpm)				
Off-Gas Capacity		Normal	Emergency	Other	
	Negative Press (in. H_2O)				
	Flow (cfm)				

* Designate the source of emergency power.

** In the ORR the process and warm drains are the same.

Section II

EXPERIMENT FACILITY DESCRIPTION

A. Objective of Experiment Facility Test Program:

B. Mechanical Construction of Facility:

1. Provide a layout sketch showing the amount and location of floor space to be used.

2. Provide a flow diagram showing the functional relation of the system mechanical components. This should include numbers and sufficient nomenclature for later reference in description.

3. Describe each major mechanical component and special design feature (e. g. pumps, filters, heat exchangers, double containment, automatic withdrawal mechanisms).

4. List in Table 3 the design, test, and operating limits and ranges of all of the system mechanical components and materials that are important in assuring the safety of personnel, the reactor, or the experiment as affected by temperature, pressure, mechanical loads, etc.

TABLE 3

Component or Material	Temperature			Pressure			Other		
	Design	Test	Oper.	Design	Test	Oper.	Design	Test	Oper.

5. Attach copies of detailed mechanical drawings, and material and component specifications.

Section III

EXPERIMENT ASSEMBLY DESCRIPTION

This refers to the assembly or system of materials to be irradiated including containers, insulation, etc., as distinguished from the experiment facility which includes instruments, external shielding, motors, pumps, access tubes into the core, etc.

A. Objective of the Experiment:

B. Supply a sketch showing the experiment assembly components, coolant passages, thermocouple locations, and other pertinent information.

C. Describe the experiment assembly and the operating conditions.

Section IV

MATERIALS

A. Supplementary

List all materials (such as acid, caustic, highly flammable, toxic, or otherwise potentially hazardous materials) to be used in conjunction with the experiment.

TABLE 4.

Material	Use	Maximum Inventory	Type and Location of Storage

B. Materials to be Irradiated

List the type and quantity of all materials to be located within the reactor. List separately the facility materials and experiment assembly materials (if applicable). If these are itemized in work sheet or other compact form, attach copies and give reference to them below.

TABLE 5

Facility		Experiment	
Material	Quantity	Material	Quantity

Section V

THERMODYNAMICS

In making the thermodynamic analysis two cases should in general be distinguished:

1. The experiment facility contains components located in an operating reactor, but contains no experiment assembly or test materials.

2. The experiment facility contains an experiment assembly or test materials located in an operating reactor.

In addition to this distinction analysis of cases 1 and 2 above should include consideration of the following conditions.

1. Normal design operating conditions with the reactor at full power.
2. Reactor power level constant at 120% of nominal full power.
3. Loss of experiment coolant flow and:
   (a) The reactor continues to operate at full power.
   (b) The reactor is shut down as prescribed by safety circuits.
4. The reactor is brought from zero to 120 % of full power in 90 seconds.

A. For each of the two cases (1 and 2 of first paragraph) describe all material flow paths.

B. Attach (in work-sheet or other suitable form) calculations and/or data to establish the following information for all cases and conditions described above.
1. Fluid temperatures, pressures, and velocities.
2. Temperatures of heat transfer surfaces.
3. Heat fluxes through heat transfer surfaces.
4. Heat generation rates.
5. Heat to be dissipated by or discharged to the reactor water, pool water, and off-gas system.

The following tables are included for use in tabulating requested information in cases where they are applicable.

TABLE 6

Fluid Conditions:

Fluid	Point Reference*	Physical Form	Temp.	Press.	Velocity	
					lb/min	ft/min

* Use numbers given on flow diagrams to indicate the point in the system where the flow conditions apply.

Heat Generation Rates and Operating Temperatures

If this information is attached in work sheet (or other) form, please indicate this and give reference to its location in this questionnaire.

TABLE 7

Heat Generating* Element (Name & Location)	Surface		Heat Generation (kW)			
	Temp. °F	Heat Flux (watts/ft²)	Fission	Gamma	Other	Total kW

* Refer to the functional sketch and use the nomenclature given there to specify names and locations of heat generating components.

Heat Dissipation (kW), or Discharge to:

TABLE 8

Heat Receiver		Heat Received (kW)
Reactor Water		
Pool Water		
Drains	Process	
	Warm	
	Hot	
Off-Gas System		

Section VI

REACTIVITY EFFECTS

1. The experiment facility in-reactor components (exclusive of the experiment assembly and/or test materials).

2. Collapsible voids and materials contained by the experiment facility in-reactor components (exclusive of the experiment assembly and/or test material), which could be replaced by reactor cooling water upon failure of the facility in-reactor containment.

3. The experiment assembly and/or test materials.

4. Any in-reactor materials and/or components that will be in motion during reactor operation.

Section VII

RADIOACTIVITY

Attach (in work sheet or other compact form) calculations and/or experimental data to provide the following information for the normal and maximum credible cases.

A. The quantity and types of radioactivity which might be distributed throughout the system.

B. The external radioactive source which must be provided with biological shielding.

C. The radioactive sources strength to be shielded during removal of the experiment facility access tube, or other component.

D. The radioactivity to be removed by any clean-up systems such as charcoal traps.

E. Personnel exposure (direct and ingested dose) resulting from complete rupture of the containment system.

F. Radioactivity Effluent to Disposal Systems:

RADIOACTIVE WASTE DISPOSAL*

TABLE 9

Nuclei	Discharge Rates (curies/day)			Disposal System (Off-gas, hot drain, etc.)
	Number	Normal	Emergency (Maximum)	
Kr	85			
	89			
	87			
	88			
Xe	133			
	135			
I	131			
	133			
	135			
Sr	89			
	90			
Ce	144			
Ru	103			
Ba	140			
Others				

* List values for the specific nuclei indicated. Group other activity.

Section VIII

SHIELDING

A. External Biological: Provide the following material and information.

1. Layout sketch showing the location and space to be occupied by the external biological shielding.

2. Sketch of the installation showing the effective shield thickness and geometry.

3. Describe the material, design, and constructional features. Include absorption coefficients and other pertinent data for special or new materials.

B. Removal and Transport Shields

1. *Sketch showing dimensions, cavity shapes and sizes, shutter operation, etc.*

2. Describe the method of transport. List safety factors for lugs, handles, etc., for lifting the shield.

3. Attach copies of shielding calculations for non-standard or special shields.

Section IX

INSTRUMENTATION AND CONTROLS

A. Provide a layout sketch showing the location of instruments, and the space to be occupied.

B. Provide a functional or flow diagram.

C. Include copies of detailed wiring diagrams and specifications of the instrumentation and controls.

D. Using Table 10 identify each instrument and control channel.

E. If any instrument component, or its associated circuity, does not conform to the I & C recommendations explain the variation and the circumstances requiring it.

F. Establish the reliability of any *developed* or special equipment. Attach the supporting information or fill in below.

INSTRUMENTS AND CONTROLS IDENTIFICATION

TABLE 10

Property or Condition Being Monitored	Sensing Element Type Location	Type of Monitor	Action Required (State Conditions For)			
			Alarm	Setback	Scram	OTHER (Turn off heaters, pressure relief)

G. List for each safety instrument channel acceptable spare sensing elements (e. g. thermocouples) which may be substituted in the event of failure, and describe the provisions and procedures for making these changes.

H. Describe the methods and procedures for restoring normal operation following the failure of a safety instrument. This should include a suitable system for blocking out the instrument safety connections so that reactor operation may be resumed, and the failed instrument can be replaced or repaired.

I. Indicate by an asterisk (*) those instruments in Table 10 that are required for safety when no experiment assembly and/or materials are contained by the facility.

Section X

PROCEDURES

Describe briefly in outline form the procedures to be used in performing the following operations. Estimate the time requirements for each operation.

A. Installation and removal of the experimental facility in-reactor components.

B. Installation and removal of the experiment assembly and/or test materials.

C. Sampling, experiment position adjustments, etc.

D. Describe briefly the provisions and/or procedures to prevent the escape of radioactive materials into the building during the performance of the above operations.

E. Instrumentation pre-start or checkout operations.

Section XI

HAZARDS

Evaluate all recognized personnel and reactor hazards associated with the experiment.

APPENDIX XXIX

EXPERIMENT INFORMATION

Date	Checked by

EXPERIMENT LOCATION	Reactor	Date inserted	Facility
Expected duration of experiment			
Brief description of experiment			
WHOM TO NOTIFY IN CASE OF TROUBLE			

Name	Business phone	Home phone

Special startup instructions
What to do in the event of an accidental shutdown
What services (gas, steam, casks, etc.) are required for this experiment
What to do in the event of power failure
Notify experimenter before scheduled shutdowns?

Special check or readings to be made

POSSIBLE TROUBLES

Signal response	Caused by	What to do
Alarm only		
Alarm and setback		
Alarm and scram		

Any other instructions

APPENDIX XXX

EXPERIMENT STATUS CHANGE REQUEST

	Date
Requester	
Experiment identification	
Change(s) requested	
Reason for change	
CHANGE(S) APPROVED BY	
Operations	
Experimenter	
Other	
CHANGE(S) COMPLETED BY	
Name	
Division	Date

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