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# REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

## REGULATORY GUIDE 2.2

## DEVELOPMENT OF TECHNICAL SPECIFICATIONS FOR EXPERIMENTS IN RESEARCH REACTORS

### A. INTRODUCTION

Paragraph 50.34(b)(4) of 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that each application for an operating license provide a final analysis and evaluation of the design and performance of structures, systems, and components of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility. Section 50.36 of 10 CFR Part 50 requires that each such application also include proposed technical specifications derived from the analyses and evaluation performed for the safety analysis report (SAR).

This guide describes information that should be included in proposed technical specifications for experiments in research reactors. It identifies considerations that should be addressed in the evaluation of experimental programs as well as considerations that should be addressed to define limits and other requirements to be included in the technical specifications. It is expected that the guidelines delineated here will be adapted, as required, to specific features and characteristics of individual research reactors.

### B. DISCUSSION

Each safety analysis report (SAR) contains a description of the proposed experimental program and safety analyses for each type of experimental facility proposed. It includes descriptions of and safety analyses for permanently installed facilities such as beam tubes, thermal columns, hydraulic or pneumatic tube systems, and other types of capsule irradiation facilities, and movable experimental facilities (in some types of reactors) which accommodate placement of shells, tubes, trays, baskets, or other guiding or positioning devices in or adjacent to the reactor core. Safety analyses for special modes of reactor system or component use to accommodate individual, repetitive, or multiple experiments should also be provided. These can include such categories as reactor pulsing, use of reactor coolant or fuel as gamma radiation sources, or use of fuel in subcritical arrays separated from the core.

The design, construction, and placement of each experimental facility should be analyzed for inherent safety questions that exist apart from experiments accommodated therein. In addition, for each experimental facility and mode of reactor system or component use, the descriptions and safety analyses should address the types and scopes of experiments intended to be performed.

The purposes of presenting such safety analyses are (1) to demonstrate that the experimental program as envisioned at the time of presentation of the SAR can be carried out without undue risk to the public health and safety, (2) to demonstrate the technical ability to carry out the kind of safety analyses which is expected to be done on a continuing basis throughout the evolution of the experimental program, (3) to establish bases against which unreviewed safety questions can be measured pursuant to paragraph (c) of §50.59, and (4) to develop subject matter appropriate for inclusion in technical specifications.

Safety in research reactor experimentation requires that consideration be given to any feature of the design or conduct of an experiment, including intended functions and possible malfunctions, which can create, directly or indirectly, a radiological exposure hazard. Safety analyses for experiments should consider (1) any

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interaction of an experiment with the reactor system that has the potential for breaching any primary barrier to fission product release from fuel, (2) any interaction of an experiment with the reactor system that could adversely affect any engineered safety features or control system features designed to protect the public from a fission product release, (3) any inherent feature of an experiment that could create beams, radiation fields, or unconfined radioactive materials, and (4) any potentially adverse interaction with concurrent experimental and operational activities.

A variety of specific technical factors, considered against the foregoing criteria, can give rise to safety problems as follows:

1. Factors in experiments which could cause a breach in any of the fission product barriers.

a. Reactivity effects as a result of placement or removal of an experiment or of motion of material within the experiments due, for example, to forced or natural convection of fluids, phase changes, chemical or radiolytic dissociation, or mechanical instability.

b. Thermal effects on fuel which alter local heat generation or heat transfer rates as a result of neutron flux perturbations, gamma heating, electrical heating, or alteration of coolant temperature or flow by experiment components or failure thereof due to heating, radiation degradation, or radiolytic dissociation.

c. Mechanical forces on fuel cladding arising from the manipulation of experimental components, from tools used for such manipulation, from thermal stress, vibration, or shock waves, or from missiles arising from functioning or malfunctioning experiments.

d. Chemical attack, including corrosion, resulting from the use in or escape of materials into the fuel environment or accelerated corrosion due to elevated temperatures.

2. Factors in experiments which could adversely affect engineered safety features or control system features.

a. Neutron flux perturbations affecting calibrations of safety channels and/or rod worths.

b. Mechanical forces adversely affecting shielding or confinement arising from causes as in 1.c. above.

c. Radiation fields or radioactive releases from experiments which can mask the performance of an operational monitoring system intended for the detection of fission product releases at early stages.

d. Physical interference by experiment components with reactor system components such as control or safety rods or physical displacement of reactor system shielding.

3. Factors in experiments which could create radiological risks due to radiation fields or unconfined radioactive material.

a. Use of materials which are or become chemically unstable or highly reactive or are subject to buildup of temperature or pressure, e.g., pressure buildup in special beam port plugs.

b. Irradiation of finely divided solids, liquids, or gases which are readily airborne if inadequately confined.

c. Degradation or failure of materials intended to confine experiments, e.g., by radiation decomposition of nonmetallic capsules, weld failures, gasket failures, excessive internal heat generation, or inadequate cooling.

d. Degradation or failure of vent systems or filter installations or inadequate shielding thereof.

e. Degradation or failure of safety-related instruments or control devices on experiments.

f. Mechanical instability resulting in unintended movement of an experiment relative to its shielding, e.g., by faulty stacking of lead brick, by exceeding floor-loading capabilities, or by capsules becoming buoyant in water.

g. Use of inadequate devices for shielding and handling experiment components or capsules following irradiations.

4. Factors relating to interactions with other experiments or with operational activities.

a. Reactivity effects of concurrent motion occurring in two or more experiments.

b. Potentially adverse interactions resulting from the use of common electric circuits and supplies and common portions of fluid systems such as manifolds for cooling water, vent, or drain systems.

c. Physical interference by experiments with patterns of operational activity which could impede or prevent a safety or emergency function, e.g., blocking of access routes.

d. Creation of industrial hazards such as the generation or release of toxic or noxious materials which could impair the ability of operators to perform necessary reactor safety functions.

e. Special modes of reactor operation such as pulsing, abnormal occurrences in reactor operation, or reactor accidents which could trigger failures in experiments.

The proposed technical specifications that are relevant to experiments in research reactors should (1) have bases relating to safety considerations as required by §50.36(a), (2) address subject areas that are clearly under the direct control of the licensee, and (3) fall under the categories of limiting conditions for operation, surveillance requirements, design features, or administrative controls, as specified in §50.36. Situations may arise in which the safety analyses of some unique experiments establish the need to consider the effects of such experiments on the safety limits and limiting safety system settings for reactor operation.

Technical specifications should provide reasonable flexibility to perform experiments, install new experimental facilities, or change or remove from use facilities previously described. Proposed technical specifications should address safety-oriented considerations, as distinct from functional or end-use descriptions of experimental programs. On the other hand, all safety considerations implicit in each individual experiment proposed must be enumerated and evaluated to determine whether or not they fall within the safety analysis for reactor operation presented in the SAR. In addition the proposed experiment should be evaluated in detail and its execution controlled so as to reduce any radiation dose to plant personnel and the public to the lowest practicable level.

## C. REGULATORY POSITION

The safety-oriented considerations from which technical specifications for experiments should be developed include (1) the physical conditions of the design and conduct of experiments, (2) the materials content of experiments, and (3) the administrative controls employed to evaluate, authorize, and carry out experiments. The material that follows is organized according to the above three considerations, but it is not intended that this be the only format acceptable for use for proposed technical specifications. The definitions of certain terms used in this section are given in Appendix A.

### 1. Physical Conditions

#### a. Reactivity Effects

From a safety standpoint, the principal concern is that associated with a net positive reactivity effect, whether it is caused by the insertion of an experiment having a positive reactivity effect or by the removal of an experiment having a negative reactivity effect. Credit may be taken for the operation of the reactor safety system and engineered safeguards systems provided (1) they have been designed to standards and criteria establishing very high reliability, such as ANSI N42.7 (IEEE-279), (2) adequate quality assurance was provided in their construction and is provided during operation, and (3) it can be shown that they can function independently of the assumed experiment failure mode. All proposed transients should be analyzed to assure that a safety limit would not be exceeded.

(1) Every experiment should be evaluated for its static reactivity worth and its potential reactivity worth.

(2) The potential reactivity worth of each secured removable experiment should be less than that value of reactivity which, if introduced as a positive step change, could result in a transient that would be likely to lead to doses in any restricted or unrestricted area in excess of the limits set forth in 10 CFR Part 20.

(3) The magnitude of the potential reactivity worth of each unsecured experiment should be less than that value which, if introduced as a positive step change in reactivity, would cause a violation of a safety limit or of the minimum shutdown margin.

(4) The rate of change of reactivity of any unsecured experiment, any movable experiment, or any combination of such experiments introduced by intentionally setting the experiment(s) in motion relative to the reactor should not exceed the capacity of the control system to provide compensation.

(5) The sum of the magnitudes of the static reactivity worths of all unsecured experiments which coexist should not exceed the maximum value of potential reactivity worth authorized for a single secured removable experiment or the minimum shutdown margin, whichever is less.

#### b. Thermal-Hydraulic Effects

(1) Every experiment should be evaluated for its actual and potential thermal effects on reactor components and coolant. Normally, this evaluation should be made for the reactor at the extremes of its operating margin, as defined by limiting safety system settings.

(2) Experiments should be designed to prevent the negation of any flux peaking or reactor coolant flow considerations that have been used to define or are implicit in the safety limits for the reactor. Coolant flow considerations should include potential blockage or redistribution and potential phase changes in liquid coolant.

(3) The surface temperature of the material which bounds or supports any experiment should not exceed the lowest of the following, where applicable:

(a) the saturation temperature of liquid reactor coolant at any point of mutual contact.

(b) a temperature conservatively below that at which the corrosion rate of the boundary material at any surface would lead to its failure, or,

(c) a temperature conservatively below that at which the strength of the boundary material would be reduced to a point predictably leading to failure.

#### c. Mechanical Stress Effects

(1) Every experiment should be evaluated with respect to the storage and possible uncontrolled release of any mechanical energy.

(2) Experiments involving a potential for creating objects with substantial momentum (missiles) should be oriented in such a way as to minimize the probability of damage to the reactor system.

(3) Materials of construction and fabrication and assembly techniques utilized in experiments should be so specified and used that assurance is provided that no stress failure can occur at stresses twice those anticipated in the manipulation and conduct of the experiment or twice those which could occur as a result of unintended but credible changes of, or within, the experiment.

(4) Prototype testing under experiment conditions should be employed to demonstrate the ability to withstand failure.

## 2. Material Content of Experiments

Certain kinds of materials which may be used in experiments possess properties with significant safety implications. Limitations on the amounts of such materials can limit the consequences of experiment failures. The material content of every experiment should be analyzed and limited according to the classifications given below.

### a. Radioactive materials

(1) The radioactive material content, including fission products, of any singly encapsulated experiment should be limited so that the complete release of all gaseous, particulate, or volatile components from the encapsulation will not result in doses in excess of 10% of the equivalent annual doses stated in 10 CFR Part 20. This dose limit applies to persons occupying (1) unrestricted areas continuously for two hours starting at time of release or (2) restricted areas during the length of time required to evacuate the restricted area.

(2) The radioactive material content, including fission products, of any doubly encapsulated or vented experiment should be limited so that the complete release of all gaseous, particulate, or volatile components from the encapsulation or confining boundary of the experiment could not result in (1) a dose to any person occupying an unrestricted area continuously for a period of two hours starting at the time of release in excess of 0.5 rem to the whole body or 1.5 rem to the thyroid or (2) a dose to any person occupying a restricted area during the length of time required to evacuate the restricted area in excess of 5 rem to the whole body or 30 rem to the thyroid.

(3) For purposes of applying the above considerations, a single-mode nonviolent failure of the encapsulation boundary that releases all radioactive material into the immediate environment of the experiment or to the reactor building, as appropriate, should be assumed. The analysis should establish the most probable trajectory of the material, if any, into restricted and unrestricted areas. Credit for natural consequence-limiting features such as solubility, absorption, and dilution and for installed features such as filters may be taken provided each such feature is specifically identified and conservatively justified by specific test or physical data or well-established physical mechanisms. In addition, with respect to installed features, credit taken for their effectiveness should depend on the adequacy of the related quality assurance procedures undertaken, including the extent to which surveillance tests simulate the conditions to be met in practice. If assumptions regarding atmospheric dilution are involved, they should not be less conservative than those used in the analysis of Design Basis Accidents.

Irradiation of fissionable materials, excluding the fissionable material content of fuel element assemblies described in the technical specifications, should be deemed an unreviewed safety question unless a specification meeting the above criteria and its related safety analysis have been approved by the Commission. With respect to other radioactive materials, specifications and safety analyses should be submitted that are representative of experiments with either the highest inventory of radioactive material, or the highest probability for failure that could result in the escape of such material into restricted and unrestricted areas. In addition, records should be generated and maintained to allow for review to demonstrate that the radioactive material content of each individual experiment does not exceed that allowed by the stated criteria.

These considerations should not be interpreted (1) to permit or encourage any unnecessary intentional releases of radioactive materials to unrestricted areas, or (2) to relieve the obligation to minimize and control radiation doses in restricted areas.

### b. Trace Elements and Impurities

A reasonable effort should be made to identify in advance of an experiment trace elements or impurities whose activation products may represent the dominant radiological hazard.

### c. High-Cross-Section Materials

Nuclides possessing high thermal neutron absorption cross sections should be identified and limited with respect to their quantity or method of inclusion in individual experiments in order to control reactivity or thermal effects within the limitations specified.

### d. Highly Reactive Chemicals

The inclusion of explosive materials in experiments constitutes an unreviewed safety question unless such usage has been reviewed and approved by the Commission, except that amounts up to 25 milligrams of TNT equivalent may be irradiated or stored inside the reactor confinement system in accordance with regulatory position C.1.c.

### e. Corrosive Chemicals

A list should be prepared identifying materials which are chemically incompatible with the reactor system from the viewpoint of corrosion and which should be excluded from any experiments or the use of which is subject to special scrutiny and control. This list should be provided to all who use the reactor.

### f. Radiation-Sensitive Materials

The evaluation of each experiment should include an assessment of the consequences of physical or chemical changes in the material content as a result of its presence in a radiation environment, particularly for nonmetallic materials.

Effects to be considered include the alteration or degradation of mechanical properties due to radiation-induced decomposition, e.g., of plastics or polymers, and radiolytic generation of excessive gas pressure or explosive gas mixtures.

**g. Flammable or Toxic Materials**

Procedures control should incorporate mechanisms for handling and limiting the quantities of highly flammable or toxic materials used in experimental programs or used in the reactor room.

**h. Cryogenic Liquids**

The inclusion of cryogenic liquids within the biological shield of a research reactor would constitute an unreviewed safety question unless such usage has been reviewed and approved by the Commission.

**i. Unknown Materials**

No experiments should be performed unless the material content, with the exception of trace constituents, is known.

**3. Administrative Controls of Experiments**

**a. Internal Authorization**

**(1) Evaluation by Safety Review Group**

(a) No experiment should be performed without review and approval by a technically competent Safety Review Group or Committee. Repetitive experiments with safety considerations in common may be reviewed and approved as a class.

(b) Criteria for review of an experiment or class of experiments should include (1) applicable regulatory criteria, including those in 10 CFR Part 20 and the technical specifications and (2) in-house safety criteria and rules which have been established for facility operations, including those which govern requirements for encapsulation, venting, filtration, shielding, and similar experiment design considerations, as well as those which govern the quality assurance program required under § 50.34.

(c) Records should be kept of the Safety Review Group's review and authorization for each experiment or class of experiments.

**(2) Operations Approval**

(a) Every experiment should have the prior explicit written approval of the Licensed Senior Operator in charge of reactor operations.

(b) Every person who is to carry out an experiment should be certified by the Licensed Senior Operator in charge of reactor operations as to the sufficiency of his knowledge and training in procedures required for the safe conduct of the experiment.

**b. Procedures for Active Conduct of Experiments**

(1) Detailed written procedures should be provided for the use or operation of each experimental facility.

(2) The Licensed Operator at the console should be notified just prior to moving any experiment within the reactor area and should authorize such movement.

(3) Each experiment removed from the reactor or reactor system should be subject to a radiation monitoring procedure which anticipates exposure rates greater than those predicted. The results of such monitoring should be documented.

**c. Procedures Relating to Personnel Access to Experiments**

(1) There should be a documented procedure for the control of visitor access to the reactor area to minimize the likelihood of unnecessary exposure to radiation as a result of experimental activities and to minimize the possibility of intentional or unintentional obstruction of safety.

(2) There should be a written training procedure for the purpose of qualifying experimenters in the reactor and safety-related aspects of their activities, including their expected responses to alarms.

**d. Quality Assurance Program**

There should be a Quality Assurance Program covering the design, fabrication, and testing of experiments, including procedures for verification of kinds and amounts of their material contents such as those described in regulatory position C.2.

## APPENDIX A

## DEFINITIONS

1. **Experiment** An experiment, as used herein, is any of the following:
   a. An activity utilizing the reactor system or its components or the neutrons or radiation generated therein;
   b. An evaluation or test of a reactor system operational, surveillance, or maintenance technique;
   c. An experimental or testing activity which is conducted within the confinement or containment system of the reactor; or
   d. The material content of any of the foregoing, including structural components, encapsulation or confining boundaries, and contained fluids or solids.

2. **Experimental Facility**—An experimental facility is any structure or device which is intended to guide, orient, position, manipulate, or otherwise facilitate a multiplicity of experiments of similar character.

3. **Explosive Material**—Explosive material is any solid or liquid which is categorized as a Severe, Dangerous, or Very Dangerous Explosion Hazard in "Dangerous Properties of Industrial Materials" by N. I. Sax, Third Ed. (1968), or is given an Identification of Reactivity (Stability) index of 2, 3, or 4 by the National Fire Protection Association in its publication 704-M, 1966, "Identification System for Fire Hazards of Materials," also enumerated in the "Handbook for Laboratory Safety" 2nd Ed. (1971) published by The Chemical Rubber Co.

4. **Movable Experiment**—A movable experiment is one which may be inserted, removed, or manipulated while the reactor is critical.

5. **Potential Reactivity Worth**—The potential reactivity worth of an experiment is the maximum absolute value of the reactivity change that would occur as a result of intended or anticipated changes or credible malfunctions that alter experiment position or configuration.

   The evaluation must consider possible trajectories of the experiment in motion relative to the reactor, its orientation along each trajectory, and circumstances which can cause internal changes such as creating or filling of void spaces or motion of mechanical components. For removable experiments, the potential reactivity worth is equal to or greater than the static reactivity worth.

6. **Removable Experiment**—A removable experiment is any experiment, experimental facility, or component of an experiment, other than a permanently attached appurtenance to the reactor system, which can reasonably be anticipated to be moved one or more times during the life of the reactor.

7. **Secured Experiment**—Any experiment, experimental facility, or component of an experiment is deemed to be secured, or in a secured position, if it is held in a stationary position relative to the reactor by mechanical means. The restraining forces must be substantially greater than those to which the experiment might be subjected by hydraulic, pneumatic, buoyant, or other forces which are normal to the operating environment of the experiment, or by forces which can arise as a result of credible malfunctions.

8. **Static Reactivity Worth**—As used herein, the static reactivity worth of an experiment is the absolute value of the reactivity change which is measurable by calibrated control or regulating rod comparison methods between two defined terminal positions or configurations of the experiment. For removable experiments, the terminal positions are fully removed from the reactor and fully inserted or installed in the normal functioning or intended position.

9. **Unsecured Experiment**—Any experiment, experimental facility, or component of an experiment is deemed to be unsecured if it is not and when it is not secured as defined in 7. above. Moving parts of experiments are deemed to be unsecured when they are in motion.