TECHNICAL SPECIFICATIONS

1 Introduction

1.1 Purpose and Scope

This document constitutes the technical specifications (TS) for the Missouri University of Science and Technology Research Reactor facility (License No. R-79). This document uses the guidance provided in American National Standards Institute/American Nuclear Society (ANSI/ANS) 15.1, "The Development of Technical Specifications for Research Reactors," issued 1990 [1].

The TS represent the agreement between the licensee and the U.S. Nuclear Regulatory Commission (NRC) on administrative controls, equipment availability, and operational parameters.

Specific limitations and equipment requirements for safe reactor operation and for handling abnormal situations, typically derived from the safety analysis report (SAR), are called specifications. These specifications represent a comprehensive envelope for safe operation. This document lists only those operational parameters and equipment requirements directly related to preserving that safe envelope.

Included are the specifications and the bases for the TS. The bases provide the technical support for the individual TS and are included for information purposes only. They are not part of the specifications and do not constitute limitations or requirements to which the licensee must adhere.

1.2 Definitions

administrative controls—those organizational and procedural requirements that are established by the NRC and/or the facility management.

ALARA—as low as reasonably achievable.

channel—the combination of sensor, line, amplifier, and output devices that are connected for the purpose of measuring the value of a parameter.

channel calibration—an adjustment of the channel such that its output corresponds with acceptable accuracy to known values of the parameter that the channel measures. Calibration shall encompass the entire channel, including equipment actuation, alarm, or trip, and shall be deemed to include a channel test.

channel check—a qualitative verification of acceptable performance by observation of channel behavior or by comparison of the channel with other independent channels or systems measuring the same variable.

channel test—the introduction of a signal into the channel to verify that it is operable.

Commission—the U.S. Nuclear Regulatory Commission (or NRC).

configuration—the specific arrangement of specific fuel elements and control rods in the grid plate to constitute a reactor core.

confinement—a closure on the overall facility that controls the movement of air into it and out through a controlled path.

control rod—a device fabricated from neutron-absorbing material that is used to establish neutron flux changes.

core—the general arrangement of fuel elements and control rods.

critical—when the effective multiplication factor (k_{eff}) of the reactor is equal to unity.

direct supervision—in visual and audible contact.

excess reactivity—that amount of reactivity that would exist if all reactivity control devices were moved to the maximum reactive condition from the point where the reactor is exactly critical ($k_{eff} = 1$).

experiment—any apparatus, device, or material installed in or near the core or that could conceivably have a reactivity effect on the core and that itself is not a core component or experimental facility.

experimental facility—any structure or device associated with the reactor that is intended to guide, orient, position, manipulate, or otherwise facilitate a multiplicity of experiments of similar character.

explosive material—any solid or liquid that is categorized as a "severe," "dangerous," or "very dangerous" explosion hazard in *Sax's Dangerous Properties of Industrial Materials* [2], or that is given an Identification of Reactivity (Stability) index of 2, 3, or 4 by the National Fire Protection Association in its publication 704-M, *Identification System for Fire Hazards of Materials* [3], or that is enumerated in the *CRC Handbook for Laboratory Safety* [4], published by the Chemical Rubber Co.

fueled experiment—any experiment that contains uranium-235, uranium-233 or plutonium-239 in greater than trace quantities, not including the normal reactor fuel elements.

grid plate—the structural member that supports the fuel elements.

licensee—the Board of Curators of the University of Missouri.

limiting condition for operation (LCO)—the lowest functional capability or performance level of equipment required for safe operation of the facility [5].

limiting safety system settings (LSSSs)—settings for automatic protective devices related to those variables having significant safety functions. Where an LSSSs setting is specified for a variable on which a safety limit has been placed, the setting shall be so chosen that an automatic protective action will correct the abnormal situation before a safety limit is exceeded [5].

measured value—the value of a parameter as it appears on the output of a channel.

mode—when the reactor is positioned as close as possible to the thermal column, it is in the T mode, and when it is moved away from the thermal column and reflected by water, it is in the W mode.

moveable experiment—an experiment that is intended to be moved in or near the core or into and out of the reactor while the reactor is operating.

operable—a component or system that is capable of performing its intended function.

operating—a component or system that is performing its intended function.

protective action—the initiation of a signal or the operation of equipment within the reactor safety system in response to a variable or condition of the reactor facility having reached a specified limit.

reactivity limits—those limits imposed on reactor core excess reactivity, based on a reference core condition.

reactivity worth of an experiment—the maximum absolute value of the reactivity change that results from the experiment being inserted into or removed from its intended position.

reactor facility—that portion of the reactor building that constitutes the confinement but that does not include the front office area.

reactor operating—whenever the reactor is not secured or shut down.

reactor operator—an individual who is licensed to manipulate the controls of the reactor.

reactor rundown—a situation in which control rod drives automatically insert control rods into the core.

reactor safety systems—those systems, including their associated input channels, that are designed to initiate automatic reactor protection or to provide information for initiation of manual protective action.

reactor secured—whenever the following occurs:

1) Either there is insufficient moderator available in the reactor to attain criticality, or there is insufficient fissile material present in the reactor to attain criticality under optimum available conditions of moderation and reflection, or

2) The following conditions exist:

   a) the minimum number of neutron-absorbing control devices are fully inserted or other safety devices are in shutdown position, as required by the TS, and

   b) the console key switch is in the off position, and the key is removed from the lock, and

   c) no work is in progress involving core fuel, core structure, installed control rods, or control rod drives, unless they are physically decoupled from the control rods, and

   d) no experiments are being moved or serviced that have, on movement, a reactivity worth that exceeds the maximum value allowed for a single experiment, or one dollar, whichever is smaller.

reactor shutdown—when the reactor is subcritical by at least one dollar in the reference core condition with the reactivity worth of all installed experiments included.

reference core condition—reactivity condition of the core when it is at 20 degrees Celsius (C) (68 degrees Fahrenheit (F)) and the reactivity worth of xenon is negligible ($<0.22\%\ \Delta k/k$).

regulating rod—a low reactivity-worth control rod used primarily for fine control to maintain an intended power level. Its position may be varied either by manual control or by the automatic servo-controller.

reportable occurrence—any of the conditions described in Section 6.7.2 of these specifications.

safety channel—a measuring or protective channel in the reactor safety system.

safety limits—limits on important process variables that are found to be necessary to reasonably protect the integrity of certain physical barriers that guard against the uncontrolled release of radioactivity [5]. (The principal physical barrier is the fuel cladding.)

scram time—the elapsed time between reaching a limiting safety system setpoint and the time when a control rod is fully inserted.

secured experiment—any experiment, experimental facility, or component of an experiment that 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 may normally be subjected.

senior reactor operator—an individual who is licensed to direct the activities of licensed reactor operators. Such an individual is also a reactor operator. A senior reactor operator is also referred to as a senior operator.

shall, should, and may—the word "shall" is used to denote a requirement; the word "should" to denote a recommendation; and the word "may" to denote permission, which is neither a requirement nor a recommendation.

shim/safety rods—high-reactivity-worth, boron-containing control rods used primarily to provide coarse reactor control. They are connected electromagnetically to their drive mechanisms and have scram capabilities.

shutdown margin—the minimum shutdown reactivity necessary to provide confidence (1) that the reactor can be made subcritical by means of the control and safety systems, starting from any permissible operating condition with the maximum-worth scrammable rod and any nonscrammable control rod in their fully withdrawn positions and (2) that the reactor will remain subcritical without further operator action.

startup source—a spontaneous source of neutrons that is used to provide a channel check of the startup (fission chamber) channel.

surveillance time intervals—

2-year (interval not to exceed 30 months)
annually (interval not to exceed 15 months)
semiannually (interval not to exceed 7½ months)
quarterly (interval not to exceed 4 months)
monthly (interval not to exceed 6 weeks)
weekly (interval not to exceed 10 days)
daily (must be done during the working day)

true value—the actual value of a parameter.

unscheduled shutdown—any unplanned shutdown of the reactor caused by actuation of the reactor safety system, operator error, equipment malfunction, or a manual shutdown in response to conditions that could adversely affect safe operation, not including shutdowns that occur during testing or checkout operations.

2 Safety Limits and Limiting Safety System Settings

2.1 Safety Limits

Applicability: This specification applies to the temperature of the fuel cladding.

Objective: To ensure that the integrity of the fuel cladding is maintained to guard against an uncontrolled release of fission products.

Specification: The safety limit shall be on the temperature of fuel element cladding, which shall be 510°C (950°F).

Bases: The blister temperature of the aluminum alloy used for cladding in the fuel element fabrication is about 527°C (981°F). To maintain the fuel element integrity, the cladding temperature must not exceed 510°C (950°F). The maximum cladding temperature associated with full-power (200 kilowatts (kW)) operations is only about 90°C (194°F). Furthermore, calculations show that cladding temperatures associated with a reactor power of 4.5 megawatts would be only about 140°C (284°F), still well under the safety limit.

2.2 Limiting Safety System Settings

Applicability: This specification applies to the setpoints for the safety channels monitoring reactor thermal power, P.

Objective: To ensure that automatic protective action is initiated to prevent the maximum fuel cladding temperature from exceeding the safety limit.

Specifications: The LSSS shall be on reactor thermal power, P, which shall be no greater than 300 kW, or 150% of full power.

Bases: Reactor cooling is provided by natural convection in the reactor pool. Therefore, the only parameter that can be used to limit the fuel cladding temperature is the reactor power. The SAR (Section 4.6) shows that, at a reactor power of 300 kW, the maximum cladding temperature is well below 105°C (221°F). This temperature is much lower than the temperature at which fuel element damage could occur. Therefore, an extremely large safety margin exists between the limiting safety system setpoint and the safety limit.

3 Limiting Conditions for Operation

3.1 Reactor Core Parameters

Applicability: These specifications apply to the reactivity condition of the reactor and the reactivity worths of control rods and experiments.

Objectives: To ensure that the reactor can be operated safely and that it can be shut down at all times.

Specifications: The reactor shall not be operated unless the following conditions exist:

1) The maximum excess reactivity for reference core conditions with secured experiments and experimental facilities in place shall be no more than 1.5% $\Delta k/k$.

2) The minimum shutdown margin under reference core conditions with secured experiments and experimental facilities in place, and with the highest worth control rod and the regulating rod fully withdrawn, shall be no less than 1.0% $\Delta k/k$.

3) The excess reactivity limit (Section 3.1(1)) and shutdown margin limit (Section 3.1(2)) may be temporarily exceeded following a core configuration change under the following conditions:

    a) reactor power is limited to 2 kW,

    b) reactor operations are limited to the measurement of excess reactivity, control rod worths, and shutdown margin, and

    c) the reactor is immediately shut down upon discovery of excess reactivity or shutdown margin being in violation of the limits specified in Section 3.1(1) or Section 3.1(2). In such an instance, a core configuration change shall be implemented with the intent of meeting the limits specified in Section 3.1(1) and Section 3.1(2).

4) The reactor shall be operated only when all lattice positions internal to the active fuel boundary are occupied by a fuel element, a control rod fuel element, or an experimental facility.

5) The regulating rod shall be worth no more than 0.7% $\Delta k/k$ in reactivity.

Bases:

1) A sufficient excess reactivity is needed to provide for temperature effect override, xenon override, and operational and experimental flexibility. The limit of 1.5% $\Delta k/k$ on excess reactivity is to ensure that the operational characteristics of a reactor core are those analyzed in the SAR. Chapter 13 of the SAR shows that a stepwise reactivity insertion of 1.5% $\Delta k/k$ does not adversely affect the health and safety of the public and the reactor staff.

2) The minimum shutdown margin provides assurance that the reactor can be shut down from any operating condition and remain shut down after cool down and xenon decay, even if one control rod should become stuck in the fully withdrawn position.

3) This specification provides for operational flexibility during measurements of excess reactivity and shutdown margin.

4) This specification precludes the possibility of having an internal vacancy into which a fuel element could be inadvertently inserted.

5) Since the regulating rod is used for automatic control, it is prudent to limit its reactivity worth to less than the delayed neutron fraction, so that a prompt neutron criticality cannot inadvertently be caused by its total withdrawal.

3.2 Reactor Control and Safety Systems

3.2.1 Reactor Control Systems

Applicability: This specification applies to the instrumentation that must be operable for safe operation of the reactor.

Objective: To require sufficient control information and automatic protective signals to be available to the operator to ensure safe operation of the reactor.

Specification: The reactor shall not be operated unless the channels described in Table 3.1 are operable. Values listed are the limiting setpoints. For operational convenience, the actual setpoints may be on more restrictive values.

Table 3.1 Control Channels		
Channel	**Setpoint**	**Function**
Linear Power Demand	120%	Rundown
Low Compensating Ion Chamber Voltage	80%	Rundown
Reg. Rod on Insert Limit in Auto	Not Applicable	Rundown
Reactor Power	120%	Rundown
Reactor Period	15 s	Rundown
Radiation Area Monitors (RAMs)[1]	20 mrem/hr	Rundown[1]
Core Inlet Pool Water Temperature	135°F	Rod Withdrawal Prohibit
Startup Count Rate[1]	2 cps	Rod Withdrawal Prohibit[1]
Reactor Period[1]	30 s	Rod Withdrawal Prohibit[1]
Recorder Off	Not applicable	Rod Withdrawal Prohibit

Bases: The 120% reactor power rundown provides an additional layer of protection designed to prevent the LSSS (150% power) from being reached. The 15-second reactor period rundown provides an additional layer of period protection and prevents the reactor from reaching the scram setpoint of 5 seconds described in Table 3.2. The 20 millirem/hour (mrem/hr) rundown for the RAMs provides for reactor shutdown in the unusual event that radiation levels at any of three gamma RAM locations reaches the setpoint. The core inlet pool water temperature rod withdrawal prohibit provides protection to keep the demineralizer resins below their suggested temperature limit of 60 °C (140 °F). The startup interlock, which requires a neutron count rate of at least 2 counts per second before the reactor is operated, ensures that sufficient neutrons are available for proper operation of the startup channel, and for a controlled approach to criticality. The 30-second reactor period rod withdrawal prohibit establishes a reasonable and conservative limit for normal operations. The recorder off rod withdrawal prohibit ensures that the strip chart recorders are on during reactor operations.

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1 These functions may be key bypassed at the reactor console by the Senior Operator on Duty as provided for in the Standard Operating Procedures.

3.2.2 Reactor Safety Systems

Applicability: This specification applies to the reactor safety system channels.

Objective: To stipulate the reactor safety system channels that must be operable to ensure that the LSSS are not exceeded during normal operation.

Specification: The reactor shall not be operated unless the safety system channels presented in Table 3.2 are operable. Values listed in the table are the limiting setpoints. For operational convenience, the actual setpoints may be on more restrictive values.

Table 3.2 Safety System Channels

Channel	**Setpoint**	**Function**
Manual Scram Button	Not applicable	Scram
Safety #1	300 kW	Scram
Safety #2	300 kW	Scram
Reactor Period	5 s	Scram
Bridge Motion	Not applicable	Scram
Loss of Coolant	4.88 m (16 ft) above core	Scram
Log N & Period Not Operative	Not applicable	Scram

Bases: The manual scram allows the operator to shut down the reactor if an unsafe or abnormal condition arises. Safety Channels #1 and #2 are provided to ensure that the power level is limited to protect against abnormally high fuel temperatures. The period scram is provided to ensure that the power level does not increase in a period of less than 5 seconds. The bridge motion scram shuts the reactor down in the event that the bridge is moved. The loss of coolant shuts the reactor down in the event of a loss of pool water. The Log N and Period Not Operative scram shuts the reactor down if the Log N and Period Channels are in a “not operative” condition.

3.2.3 Shim/Safety Rod Drop Times

Applicability: This specification applies to the time from the receipt of a safety signal to the time it takes for a shim/safety rod to drop from the fully withdrawn to the fully inserted position (free-drop time).

Objective: To ensure that the reactor can be shut down within a specified period of time.

Specification: The reactor shall not be operated unless the free-drop time for each of the three shim/safety rods is less than 1 second.

Bases: Shim/safety rod drop times as specified will ensure that the safety limit will not be exceeded in a worst-case delayed critical transient, which has been analyzed in Chapter 13, Section 13.1.6.2, of the SAR.

3.3 Coolant System

Applicability: This specification applies to the water in the reactor pool, which serves as the reactor coolant.

Objective: To ensure that adequate cooling is provided for the reactor core at all times and to ensure that there is sufficient biological shielding available. The objective of the water quality requirement is to minimize corrosion of the fuel element cladding and to minimize neutron activation of dissolved materials.

Specification:

1) The reactor shall not be operated unless the water level is at least 4.88 meters (m) (16 feet (ft)) above the core.

2) The resistivity of the pool water shall be greater than 0.2 megohm-cm as long as there are fuel elements in the pool. This requirement may be waived for a period of up to 3 weeks once every 3 years.

3) The minimum temperature of the reactor pool should be no less than 15.5 °C (60 °F) when the reactor is operated.

Bases:

1) This provision is primarily to ensure sufficient depth of water for shielding but also provides assurance that a natural convection flow path will be available.

2) Experience with water quality control at this and many other reactor facilities shows that maintenance within the specified limit provides acceptable control of the corrosion rate. (See

Chapter 5, Section 5.2 for further information.) The provision that allows this requirement to be temporarily waived is to supply operational flexibility in the unlikely event that the demineralizer becomes inoperable. The 3-week period should be sufficient to make repairs.

3) The reactor core has a negative moderator reactivity effect that provides an increase in excess reactivity when the reactor pool is at lower temperatures and lower reactivity at higher pool temperatures. Maintaining a minimum reactor pool temperature of 15.5 °C (60 °F) or greater will ensure that the excess reactivity will not significantly increase and that the shutdown margin will not decrease.

3.4 Confinement

Applicability: This specification applies to the capability of isolating the reactor facility from the unrestricted environment when necessary.

Objective: To minimize exposure to the public resulting from a potential release of airborne activity into the reactor facility and to be consistent with the ALARA principle.

Specification: Unless the reactor is secured, the truck door is to be closed and the ventilation intake and exhaust duct louvers operable or secured in a closed position.

Basis: This specification ensures that the reactor facility can be quickly isolated in case of an unexpected release of airborne radioactivity from the reactor or associated experimental facilities.

3.5 Ventilation System

Applicability: This specification applies to the ventilation fans and the associated intakes and exhausts.

Objective: To provide for normal building ventilation and the reduction of airborne radioactivity within the reactor bay during reactor operation.

Specification: A ventilation fan with a rated capacity of at least 127.4 cubic meters per minute (m^3/min) (4,500 cubic ft per minute) shall be turned on within 10 minutes after the reactor reaches full power.

Bases: Experience has shown that, during normal operation, this specification is sufficient to maintain radioactive gaseous effluents below the limits in Appendix B, "Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage," to Title 10, Part 20, "Standards for Protection Against Radiation," of the *Code of Federal Regulations* (10 CFR Part 20). Chapter 11, Section 11.1.1, of the SAR shows that releasing the air does not unduly expose the public. The 10-minute provision provides for operational flexibility.

3.6 Radiation Monitoring Systems and Radioactive Effluents

3.6.1 Radiation Monitoring Systems

Applicability: This specification applies to the gamma radiation area monitoring instrumentation.

Objective: To provide protection against excessive radiation levels for personnel in the reactor building.

Specifications: The reactor shall not be operated unless the constant air monitor (CAM) is operable and the RAMs, located at the reactor bridge, at the demineralizer, and in the basement experimental area, are operable. Table 3.3 specifies the approximate locations, setpoints, and functions. Values listed are the limiting setpoints. For operational convenience, the actual setpoints may be on more restrictive values.

The reactor may be operated with one or more of the RAM channels inoperable under the following conditions:

1) The period of operations with the RAM channel(s) inoperable does not exceed 1 week.

2) A portable gamma radiation instrument is placed in the same vicinity as the inoperable RAM detector(s), with a local audible alarm setpoint of 20 mrem/hr or less.

3) If the inoperable channel is the bridge RAM, the control room operator must be able to visually monitor the radiation level of the portable unit.

Table 3.3 Radiation Area Monitors

Location	**Setpoint**	**Function** [2]
CAM	1500 cpm	Alarm
Reactor Bridge	20 mrem/hr 50 mrem/hr	Rundown Building Evacuation
Demineralizer	20 mrem/hr	Rundown
Basement Experimental Area	20 mrem/hr	Rundown

[2] These functions may be key bypassed at the reactor console by the Senior Operator on Duty, as provided for in the Standard Operating Procedures.

Bases: The RAMs provide information to operating personnel about the radiation level above the reactor pool, at the demineralizer, and in the basement experimental area. They ensure that, in case of a failure of an experiment or a significant drop in the pool water level, the appropriate action can be automatically initiated.

Chapter 7, Section 7.4, of the SAR includes a detailed discussion of the rationale for the RAM detector locations, setpoints, and functions.

3.6.2 Radioactive Effluents

Applicability: This specification applies to radioactive effluents released from the reactor facility.

3.6.2(1) Airborne Effluents

Objective: To ensure that exposure to the public resulting from the routine release of radioactive airborne effluents will not endanger the health and safety of the public.

Specification: The activity of argon-41 released from the facility shall not exceed the limits of 10 CFR Part 20, Appendix B, Table 2.

Bases: Chapter 11 of the SAR includes the bases for this specification.

3.6.2(2) Liquid Effluents

Objective: To ensure that exposure to the public resulting from the release of radioactive liquid effluents will not endanger the health and safety of the public.

Specification: The activity of liquids released from the facility shall not exceed 10 CFR Part 20 limits.

Bases: Chapter 11 of the SAR includes the bases for this specification.

3.7 Experiments

Applicability: These specifications apply to experiments run in conjunction with the reactor.

Objectives: To ensure the reactor can be shut down at all times, that the reactor fuel will not be damaged, that the LCOs will not be exceeded, and that a malfunction of an experiment will not result in an undue radioactivity release to the environment.

3.7.1 Reactivity Limits

Specifications: The reactor shall not be operated unless the following conditions exist:

1) Experiments worth more than 0.4% Δk/k shall be:

   a) a secured experiment,

   b) inserted and removed with the reactor shut down, and

   c) inserted and removed from the reactor with a procedure approved by the Radiation Safety Committee (Committee).

2) The sum of the absolute values of all experiments shall be no greater than 1.2% Δk/k.

3) Experiments having moving parts shall not have a continuous insertion rate greater than +0.05% Δk/k per second. This requirement does not apply to the experiment's insertion into or removal from the core.

Bases:

1a) This limit prevents a moveable experiment from causing a large reactivity insertion into the operating reactor. Chapter 13, Section 13.1.6.2, of the SAR includes an analysis of this reactivity limit.

1b) To avoid accidentally inserting too much reactivity when the reactor is operating, such experiments are to be positioned or removed only when the reactor is shut down.

1c) A thorough Committee review of such a procedure provides assurance that such experiments will take reactor and personnel safety, as well as the environment, into proper account.

2) The total reactivity of 1.2% Δk/k places an acceptable upper limit on the worth of all experiments. This limit is lower than the reactivity for which an accident analysis was performed in Chapter 13, Section 13.1.2, of the SAR. This analysis showed that the maximum fuel cladding temperature would not exceed the safety limit, should an accident occur.

3) This specification allows certain reactor kinetics experiments to be performed, while it maintains constraint upon the rate of change of reactivity insertions. It is well within the envelope of the reactivity insertion rate that was analyzed in Chapter 13, Section 13.1.9. Results have shown that the health and safety of the public and the reactor staff would not be endangered in such an accident.

3.7.2 Materials

Specifications:

1) All materials to be irradiated in the reactor shall be either corrosion-resistant in reactor pool water or encapsulated within corrosion-resistant containers.

2) Explosive material shall not be allowed in or near the reactor unless specifically approved by the Committee. Experiments reviewed by the Committee, in which the material is potentially explosive, either while contained or if leaked from the container, shall be designed to prevent damage to the reactor core or to the control rods or instrumentation, and to prevent any changes in reactivity. Known explosives in an amount greater than 25 milligrams shall not be irradiated in or near the reactor core. In addition, the pressure shall be calculated or experimentally determined so that it will not cause the sample container to fail.

3) Fueled experiments shall not be allowed in or near the reactor unless specifically approved by the Committee. Fueled experiments in an amount that would generate a power greater than 25 W shall not be irradiated at the MSTR facility. Fueled experiments that generate more than 1 W power shall be irradiated in the reactor pool at least 4.88 m (16 ft) beneath the pool water surface. Fueled experiments that generate less than 1 W power may be irradiated anywhere in the facility. Fueled experiments shall be encapsulated to contain all fission products during irradiation. The encapsulation device shall be designed to prevent degrading of the device due to pressure and temperature of the fuel experiment.

4) Cooling shall be provided to prevent the surface temperature of an experiment being irradiated from exceeding the boiling point of the reactor pool water.

Bases:

1) The requirement concerning either corrosion-resistant materials or corrosion-resistant encapsulation provides assurance that irradiation samples will not contaminate the pool water.

2) Special case-by-case precautions must be taken before the irradiation of explosive materials will be allowed. The quantities are restricted to very small masses. Such irradiations would most likely be carried out at the far end of the beam tube or of the thermal column, in which case, the potential for core damage or reactivity changes would be very small.

3) Special case-by-case precautions must be taken before the irradiation of fueled experiments. The Committee must determine that none of the criteria listed in 10 CFR 50.59(c)(2) are met. Section 13.1.1 of the SAR addresses the impact of the failure of a fueled experiment.

4) Samples or containers irradiated in the pool are in contact with a large heat sink. However, to ensure that departure from nucleate boiling does not occur, adequate heat removal must be

provided.

3.7.3 Failure and Malfunction

Specifications: Experiments shall be designed so that they will not contribute to the failure of other experiments or core components, or cause other perturbations that may interfere with the safe operation of the reactor. Experiments shall be designed so that no credible reactor transient could cause the experiment to fail in such a way as to contribute to a reactor accident.

Bases: Experiments that could adversely affect proper operation of the control rods must be avoided. Control over the reactor core must be maintained, should an experiment fail.

4 Surveillance Requirements

Allowable surveillance time intervals shall not exceed the times shown in the definition in Section 1.2. The maximum intervals on surveillance frequencies are to provide operational flexibility and are not to be used to reduce frequency. The established frequencies are to be maintained over the long term.

Surveillance requirements (except those specifically required for safety when the reactor is shut down) may be deferred during reactor shutdown; however, they must be completed before reactor startup unless reactor operation is required for the performance of the surveillance. Such surveillance should be performed as soon as practicable after reactor startup.

4.1 Reactor Core Parameters

4.1.1 Excess Reactivity, Rod Worth, and Shutdown Margin Measurements

Applicability: This specification applies to the reactor core.

Objective: To ensure that the requirements of Section 3.1 are not violated.

Specifications: Following a change in core configuration, the following steps shall be performed:

1) A licensed operator shall visually confirm that all internal grid-plate positions are occupied before taking the reactor critical.

2) The excess reactivity of the core shall be measured. If the excess reactivity is found to be outside the limits specified in Section 3.1, the reactor shall be shut down and the core configuration changed with the intent of complying with the limits specified in Section 3.1. If the excess reactivity is found to be acceptable, then:

   a) the control rod worths shall be measured, and

b) the shutdown margin shall be determined.

3) The regulating rod worth shall be measured whenever the rod is installed in a new core configuration.

Bases:

1) Visual inspection of the reactor core is the most reliable way to ensure that all internal positions are occupied and that no space exists for rapid insertion of a fuel element (see Chapter 13, Section 13.1.2, of the SAR).

2) An experimental determination of the excess reactivity and shutdown margin is necessary to preclude operating the reactor without adequate shutdown capability.

3) The determination of the regulating rod worth is to make certain that its value does not exceed the delayed neutron fraction.

4.2 Reactor Control and Safety Systems

4.2.1 Shim/Safety Rods

Applicability: This specification applies to the surveillance requirements for the shim/safety rods.

Objectives: To ensure that the control rods are capable of performing their function and to establish that no significant physical degradation in the rods has occurred.

Specifications:

1) Shim/safety rod drop times shall be measured as follows:

   a) semiannually

   b) for a particular control rod, whenever the magnet assembly is disassembled or reassembled, or if the control assembly is moved to a new grid position

2) The shim/safety rods shall be visually inspected annually for pitting and cracking and whenever rod drop times exceed the LCOs (Section 3.2.3 of these specifications).

Bases:

1) Rod drop-time measurements are required to ensure the reactor can be quickly shut down.

2) The visual inspection of the shim/safety rods and measurement of their drop times are made

to determine whether they are capable of performing properly and to detect any gradual degradation in rod performance.

4.2.2 Safety Channels

Applicability: This specification applies to the surveillance requirements for the reactor safety system channels listed in Section 3.2.2.

Objective: To ensure that the reactor safety system channels are operable.

Specifications:

1) A channel test of each of the reactor safety system channels shall be performed before each day's operation or before each operation expected to extend more than 1 day, except for the bridge motion monitor and loss of coolant, which shall be done weekly.

2) A channel calibration of the reactor power range safety channel and period channel shall be performed annually.

3) The thermal power shall be experimentally verified annually.

Bases:

1) The daily channel tests will ensure that the safety channels are operable.

2) The annual calibration will correct for any long-term drift of the channels.

3) The annual verification of thermal power will correct for drift and ensure operation within the requirements of the license.

4.2.3 Maintenance

Applicability: This specification applies to the surveillance requirements following maintenance of control or safety systems.

Objective: To ensure that, after maintenance has been performed, a system is operable before it is used.

Specification: Following maintenance or modification of a control or safety system or component, the licensee shall verify that the system is operable, either before it is returned to service or during its initial operation.

Bases: The intent of the specification is to ensure that work on the system or component has been properly performed and that the system or component has been properly reinstalled or reconnected.

Correct operation of some systems, such as power range monitors, cannot be verified unless the reactor is operating. Operation of these systems will be verified during their initial operation following maintenance or modification.

4.3 Coolant System

Applicability: This specification applies to the surveillance of coolant water quality.

Objective: To ensure that water quality does not deteriorate over extended periods of time, even if the reactor is not operated.

Specifications:

1) The resistivity of the coolant water shall be measured at least once every 2 weeks when the reactor is operated.

2) If the reactor is not operated, conductivity shall be measured monthly.

Bases: Section 3.3 of these specifications establishes water quality requirements. This section ensures that the water quality is not permitted to deteriorate over extended periods of time, even if the reactor does not operate. The demineralizer resins should be regenerated to improve the water quality. If that is not sufficient, the resins should be replaced.

4.4 Confinement

Applicability: This specification applies to the surveillance requirements for confinement of the reactor bay.

Objective: To ensure that the closure equipment to the reactor bay is operable.

Specifications: A test shall be performed quarterly to ensure that the following equipment is operable or can remain permanently closed: bay door, ventilation inlet, and exhaust duct louvers, and the personnel security door.

Bases: Quarterly surveillance of this equipment will verify that the confinement of the reactor bay can be maintained, if confinement is needed.

4.5 Ventilation Systems

Applicability: This specification applies to the ventilation fans and associated closure devices.

Objective: The objective is to ensure that the ventilation fans and closure devices perform their functions satisfactorily.

Specification: Ventilation fans and intake/exhaust louvers shall be visually checked quarterly for proper operation.

Bases: Quarterly surveillance is to ensure proper exchange of air through the reactor facility to reduce the buildup of radioactive gases within the reactor bay.

4.6 Radiation Area Monitors and Radioactive Effluents

4.6.1 Radiation Area Monitors

Applicability: This specification applies to the gamma RAMs required in Section 3.6.1 of these specifications.

Objectives: To ensure that the RAMs are operating properly.

Specifications:

1) A channel check shall be performed on each gamma RAM channel daily before reactor startup.

2) Calibration of the RAMs shall be performed annually.

Bases: Adequate radiation control requires operable monitors, and experience has shown that an annual calibration of the monitoring systems is adequate to ensure their proper functioning within the specified limits.

4.6.2 Radioactive Effluents

4.6.2(1) Airborne Effluents

Applicability: This specification applies to the surveillance of the air in the reactor building while the reactor is operated.

Objective: To verify the method used to calculate the airborne effluents.

Specifications: An experimental verification of calculated release values shall be performed every 5 years and when a change in licensed power occurs.

Bases: This is to ensure that the airborne radioactive effluents will be properly accounted for. The basis for this specification is given in Chapter 11, Section 11.2.3.1, of the SAR.

4.6.2(2) Liquid Effluents

Applicability: This specification applies to the surveillance of liquid radioactive effluents.

Specifications: Before any release of a potentially radioactive liquid effluent, samples shall be drawn and analyzed.

Bases: This is to ensure that radioactive liquid effluents will be properly analyzed before being released to the unrestricted environment. The basis for this specification is given in Chapter 11, Section 11.2.3.3.

4.7 Experiments

Applicability: These specifications apply to the specific surveillance activities related to experiments.

Objectives: To make certain that all of the restrictions on experiments in Section 3.7 are met.

Specification: Samples to be irradiated and of experiments to be performed at the reactor shall be performed in accordance with properly prescribed procedures.

Bases: The preparation of samples and experiments by proper techniques ensures greater laboratory safety.

5. Design Features

Only those design features of the facility describing materials of construction and geometric arrangements, that if altered or modified would significantly affect safety and that are not included in Sections 2, 3, or 4 of the TS, are included in this section.

The SAR contains the details necessary for establishing criteria for the following TS.

5.1 Site and Facility Description

5.1.1 Location

The Nuclear Reactor Building is located on the east side of the Missouri University of Science and Technology campus near 14th Street and Pine Street in Rolla, MO.

5.1.2 Description

The reactor is housed in a steel-framed, double-walled building designed to restrict leakage. Air and other gases may be exhausted through vents in the reactor bay ceiling 9.1 m (30 ft) above grade. The Reactor Building's free volume is approximately 1700 m^3.

5.2 Reactor Coolant System

The reactor is cooled by natural convection of light water. The core is submerged in the reactor pool, ensuring a pathway for natural convection flow. The pool also serves as a heat sink, a neutron moderator and reflectors, and a radiation shield.

5.3 Reactor Core and Fuel

5.3.1 Core Configurations

Various core configurations that meet the requirements of Section 3.1 may be used to accommodate experiments.

5.3.2 Fuel Elements

1) Plate fuel elements of the MTR type are used. The overall dimensions of each element are approximately 7.6 × 7.6 × 91.4 centimeters (cm) (3 × 3 × 36 inches (in.)). The active length of fuel is approximately 24 in. and the fuel is clad in aluminum alloy. The fuel elements have 18 fuel plates joined to two side plates. The whole assembly is joined at the bottom to a cylindrical nose piece that fits into the core grid plate.

   The fuel meat is U_3Si_2 dispersed in an aluminum matrix and is enriched to approximately 20 percent U-235.

2) Control rod fuel elements are similar to the elements described in (1) with the exception that the center eight plates have been removed and have been replaced with guide plates so that the control rod cannot come in contact with the fuel plates.

3) Half-fueled elements have nine plates fueled with low-enriched uranium (LEU) (either the front ones or the rear ones, as appropriately marked) and nine dummy (or unfueled) plates.

4) An irradiation fuel element has six fuel plate positions left unoccupied (plate positions 11 through 16), plates 10 and 17 are unfueled, and all the others (1 through 9 and 18) are fueled.

5.3.3 Control Rods

1) Poison sections of the three shim/safety rods are stainless steel and initially contained approximately 1.5 percent natural boron. The rods' dimensions are 5.7 × 2.2 cm (2¼ × 7/8 in.) and are approximately 83.8 cm (33 in.) long.

2) The poison section of the regulating rod is a stainless steel oval-shaped tube, 25 in. long, has a wall thickness of 0.065 in., and is mechanically coupled to the rod drive.

5.3.4 Control Rod Drive Mechanisms

1) The shim/safety rod drives have a maximum vertical travel of 24 in. and a withdrawal rate of approximately 6 in. per minute. The shim/safety rods are magnetically coupled to the drive mechanisms and drop into the core, by gravity, upon a scram signal.

2) The regulating rod drive has a maximum vertical travel of 24 in. and a withdrawal rate of approximately 24 in. per minute. The regulating rod is mechanically coupled to its rod drive and does not respond to a scram signal.

3) Lights are provided on the operator's console to indicate the upper limit, lower limit, and shim range for each shim/safety rod.

5.3.5 Startup Source

A strong enough neutron source is available to satisfy the requirements of a count rate greater than 2 counts per second during a cold reactor startup.

5.4 Fissionable Material Storage

The fuel storage pit, which is located below the floor of the reactor pool and at the end opposite from the core, is capable of storing the complete LEU fuel inventory. The neutron multiplication factor of the fully loaded storage pit shall not exceed 0.9 under any conditions.

6 Administrative Controls

6.1 Organization

6.1.1 Structure

The Nuclear Reactor Facility is part of the Department of Mining and Nuclear Engineering of the Missouri University of Science and Technology. The organizational structure is shown in Figure 6.1.

6.1.2 Responsibility

The Chair of Mining and Nuclear Engineering is the individual responsible for the reactor facility's licenses (Level 1).

The Director Nuclear Reactor (DNR) is the contact person for the NRC and has overall responsibility for management of the facility (Level 2). The DNR shall have a minimum of 6 years of nuclear experience. The DNR shall have a Bachelor's (or higher) degree in engineering or science. Equivalent education or experience may be substituted for a degree. The degree may fulfill 4 years of the 6 years of nuclear experience required.

The Reactor Manager (Level 3) shall be responsible for the day-to-day operations and for ensuring that all operations are conducted in a safe manner and within the limits prescribed by the facility license and the provisions of the Committee. During periods when the Reactor Manager is absent, his responsibilities may be delegated to a senior reactor operator (Level 4).

The Reactor Manager shall have 3 years of nuclear-related experience. A maximum of 2 years of equivalent full-time academic training may be substituted for 2 of the 3 years of nuclear-related experience required. As soon as reasonably possible after being assigned to the position, the Reactor Manager shall obtain and maintain an NRC senior operator's license.

A health physicist who is organizationally independent of the Reactor Facility operations group, as shown in Figure 6.1, shall be responsible for radiological safety at the facility. The health physicist may also be the Radiation Safety Officer.

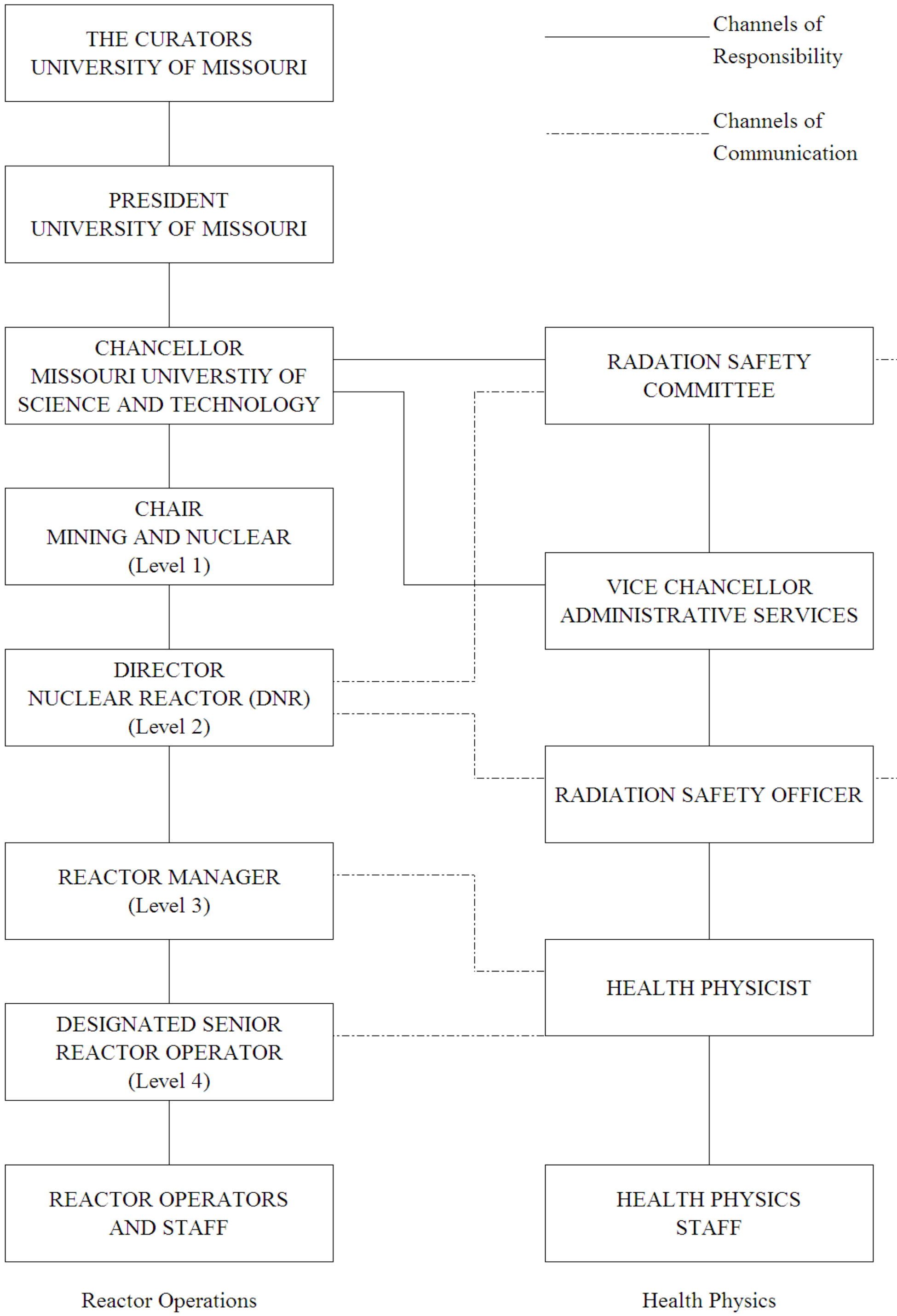

Figure 6.1 Organizational structure of the University of Missouri related to the Missouri S&T Nuclear Reactor Facility

6.1.3 Staffing

1) The minimum staffing when the reactor is not secured shall be:

   a) A certified reactor operator in the control room.

   b) A second designated person present at the reactor facility able to carry out prescribed written instructions. Unexpected absence for as long as 2 hours to accommodate a personal emergency may be acceptable, provided immediate action is taken to obtain a replacement.

   c) A designated senior reactor operator shall be readily available on call. "Readily available on call" means an individual who

      i) has been specifically designated and the designation is known to the operator on duty,

      ii) keeps the operator on duty informed of where he or she may be rapidly contacted and the phone number, and

      iii) is capable of getting to the reactor facility within a reasonable time under normal conditions (e.g., 30 minutes or within a 15-mile radius).

2) A list of reactor facility personnel by name and telephone number shall be readily available in the control room for use by the operator. The list shall include:

   a) management personnel
   b) radiation safety personnel
   c) other operations personnel

3) Events requiring the presence at the reactor facility of a senior reactor operator are:

   a) initial startup and approach to power
   b) all fuel or control-rod relocations within the reactor core region
   c) relocation of any in-core experiment with a reactivity worth greater than one dollar
   d) recovery from unplanned or unscheduled shutdown or significant power reduction

6.1.4 Training

When the reactor is being used for training purposes, the following conditions shall be met:

1) Students and trainees may operate the reactor under the direct supervision of a licensed reactor operator, provided the excess reactivity is less than 0.7% delta k/k.

2) Trainees may operate the reactor under the direct supervision of a senior reactor operator when the excess reactivity is equal to or greater than 0.7% delta k/k and less than 1.5% delta k/k.

6.1.5 Selection and Training of Personnel

The selection, training, and requalification of operations personnel shall meet or exceed the requirements of American National Standard for Selection and Training of Personnel for Research Reactors, ANSI/ANS-15.4 (1988), Sections 4-6. [6]

6.2 Review and Audit

A committee shall review and audit reactor operations to ensure that the facility is operated in a manner consistent with public safety and within the terms of the facility license. The committee shall be referred to as the Radiation Safety Committee (Committee); it shall report to the Chancellor of the campus and advise the Chair of Mining and Nuclear Engineering and the DNR on those areas of responsibility specified below.

6.2.1 Composition and Qualifications

The Committee shall be composed of at least five members, one of whom shall be the Radiation Safety Officer of the campus. No more than two members will be from the organization responsible for reactor operations. At least three members of the Committee shall collectively represent a broad spectrum of expertise in areas relating to reactor safety and research using radioisotopes. Qualified approved alternates may serve in the absence of regular members.

6.2.2 Charter and Rules

1) A quorum of the Committee shall consist of at least one-half of the voting members where the operating staff does not constitute a majority.

2) The Committee shall meet at least once each calendar year. Minutes of all meetings shall be disseminated to Committee members and to other responsible personnel, as designated by the Committee Chairman.

3) The Committee shall have a written statement, or charter, defining such matters as the authority of the Committee, the subjects within its purview, and other such administrative provisions as are required for the effective functioning of the Committee.

6.2.3 Review Function

As a minimum, the Committee shall:

1) Review, in accordance with 10 CFR 50.59, "Changes, Tests, and Experiments," untried

experiments and tests that are significantly different from those previously used or tested in the reactor, as determined by the DNR.

2) Review, in accordance with 10 CFR 50.59, changes to the reactor core, reactor systems, design features, or procedures that may affect the safety of the reactor.

3) Review new procedures.

4) Review all proposed amendments to the facility license and TS.

5) Review reportable occurrences and the actions taken to identify and correct the cause of the occurrences.

6) Review significant operating abnormalities or deviations from the normal performance of facility equipment that affect reactor safety.

This same Committee may have other responsibilities, for example, oversight of the campus byproduct materials license. The Committee may assign subcommittees to act on its behalf, provided that said subcommittees report all actions in writing.

6.2.4 Audit Function

The Committee will arrange for a knowledgeable and impartial individual (or individuals) to review reactor operations and audit the operational records for the following:

1) compliance with reactor procedures, TS, and license provisions
2) training and the requalification program
3) emergency plan
4) health physics
5) results of actions taken to correct deficiencies
6) experiments
7) security procedures

An impartial individual is one who is not directly affected by the findings or recommendations of the audit and has no reason to be biased concerning the review. These audits shall be performed annually.

6.3 Radiation Protection Program

The health physicist shall be responsible for implementing the radiation protection program at the reactor facility.

6.4 Operating Procedures

The reactor staff shall prepare and use written procedures for at least the items listed below. These procedures shall be adequate to ensure the safe operation of the reactor but should not preclude the use of independent judgment and action, should the situation require it.

1) startup, operation, and shutdown of the reactor

2) installation or removal of fuel elements, control rods, experiments, and experimental facilities

3) actions to be taken to correct specific and foreseen potential malfunctions of systems or components, including responses to alarms, suspected coolant system leaks, and abnormal reactivity changes

4) emergency conditions involving a potential or actual release of radioactivity, including provisions for evacuation, reentry, recovery, and medical support

5) preventive and corrective maintenance operations that could have an effect on reactor safety

6) periodic surveillance (including testing and calibration) of reactor instrumentation and safety systems

7) radiation control procedures, which shall be maintained and made available to all operations personnel

8) implementation of emergency and physical security plans

Substantive changes to the previous procedures shall be approved by the Committee and the DNR (Level 2) or designated alternates. Minor modifications to the original procedures that do not change their original intent can be made by the Facility Manager (Level 3) or higher but the modifications must be approved by the DNR (Level 2) or designated alternates within 14 days.

6.5 Experiments Review and Approval

The reactor staff shall perform a thorough review of all proposed experiments to ensure that they meet the requirements of Section 3.7 of these specifications.

Following the reactor staff review and approval, any proposed untried experiments will be forwarded to the Committee for its review. The DNR or designated alternate shall give approval in writing before the proposed untried experiment is initiated.

Substantive changes to previously approved experiments shall be made only after review by the Committee and approval in writing by the DNR or designated alternates.

6.6 Required Actions

6.6.1 Action To Be Taken in Case of a Safety Limit Violation

1) The reactor shall be shut down, and reactor operations shall not be resumed until authorized by the NRC.

2) The safety limit violation shall be promptly reported to the DNR.

3) The safety limit violation shall be reported to the NRC (see Section 6.7.2).

4) A safety limit violation report shall be prepared. The report shall describe the following:

   a) applicable circumstances leading to the violation including, when known, the cause and contributing factors

   b) effect of the violation upon reactor facility components, systems, or structures and on the health and safety of personnel and the public

   c) corrective action to be taken to prevent recurrence

5) The report shall be reviewed by the Committee, and any followup report shall be submitted to the NRC (see Section 6.7.2) when authorization is sought to resume operation of the reactor.

6.6.2 Actions To Be Taken in Response to Certain Occurrences

The following actions shall be taken if an event of the type identified in Sections 6.7.2(1)(b) or 6.7.2(1)(c) occurs:

1) Reactor conditions shall be returned to normal or the reactor shall be shut down. If it is necessary to shut down the reactor to correct the occurrence, operations shall not be resumed unless authorized by Level 2 or designated alternates.

2) The occurrence shall be reported to the DNR and to the NRC (see Section 6.7.2).

3) The occurrence shall be reviewed by the Committee at its next scheduled meeting.

6.7 Reports

6.7.1 Operating Reports

An annual progress report will be made by May 30 of each year to the NRC Document Control Desk that provides the following information:

1) A narrative summary of reactor operating experience, including the energy produced by the reactor or the hours the reactor was critical, or both.

2) The unscheduled shutdowns including, where applicable, corrective action taken to preclude recurrence.

3) Tabulation of major preventive and corrective maintenance operations having safety significance.

4) A summary of changes to the facility or procedures that affect reactor safety and performance of tests or experiments carried out under the conditions of 10 CFR 50.59 [6].

5) A summary of the nature and amount of radioactive effluents released or discharged to environs beyond the site boundary. The summary shall include, to the extent practicable, an estimate of individual radionuclides present in the effluent. If the estimated average release after dilution or diffusion is less than 25 percent of the concentration allowed, a statement to this effect is sufficient.

6) A summarized result of environmental surveys performed outside the facility.

7) A summary of exposures received by facility personnel and visitors, where such exposures are greater than 25 percent of those allowed.

6.7.2 Special Reports

1) If any one of the following events occurs, the licensee shall make a report describing the circumstances of the event by telephone to the NRC Headquarters Operations Center no later than the following working day, followed by a written report, submitted to the NRC Document Control Desk, within 14 days:

   a) violation of safety limits (see Section 6.6.1)

   b) release of radioactivity from the site above allowed limits (see Section 6.6.2)

   c) any of the following: (see Section 6.6.2)

      i) operation with actual safety-system settings for required systems less conservative than the LSSS specified in the TS

      ii) operation in violation of the LCOs established in the TS, unless prompt remedial action is taken

      iii) a reactor safety system component malfunction that renders or could render the reactor safety system incapable of performing its intended safety function unless the malfunction or condition is discovered during maintenance tests or periods of reactor shutdowns

[NOTE: Where components or systems are provided in addition to those required by the TS, the failure of the extra components or systems is not considered reportable, provided that the minimum number of components or systems (specified or required) performs the intended reactor safety functions.]

iv) an unanticipated or uncontrolled change in reactivity greater than one dollar (excluding reactor trips resulting from a known cause)

v) abnormal and significant degradation in reactor fuel or cladding, or both; coolant boundary; or containment boundary (excluding minor leaks), where applicable, that could result in exceeding prescribed radiation exposure limits of personnel or the environment, or both

vi) an observed inadequacy in the implementation of administrative or procedural controls such that the inadequacy causes or could have caused the existence or development of an unsafe condition with regard to reactor operations

2) A written report of the following shall be submitted within 30 days to the NRC Document Control Desk:

a) significant changes in the transient or accident analyses as described in the SAR
b) permanent changes in facility organization involving Level 1, 2, or 3 personnel

6.8 Records

Records may be logs, data sheets, or other suitable forms. The required information may be contained in single or multiple records, or a combination thereof.

6.8.1 Records To Be Retained for a Period of at Least Five Years

1) normal reactor facility operation (but not including supporting documents such as checklists and log sheets, which shall be maintained for a period of at least 1 year)

2) principal maintenance operations

3) reportable occurrences

4) surveillance activities required by the TS

5) reactor facility radiation and contamination surveys where required by applicable regulations

6) experiments performed with the reactor

7) fuel inventories, receipts, and shipments

8) approved changes in operating procedures

9) records of meeting minutes and audit reports of the Committee

6.8.2 Records To Be Retained for at Least One Requalification Cycle

Regarding retraining and requalification of licensed operations personnel, the records of the most recent complete requalification cycle shall be maintained.

6.8.3 Records To Be Retained for the Life of the Facility

1) gaseous and liquid radioactive effluents released to the environment
2) radiation exposures for all personnel monitored
3) updated, corrected, and as-built drawings of the facility

7 REFERENCES

[1] American National Standards Institute/American Nuclear Society, ANSI/ANS 15.1, “The Development of Technical Specifications for Research Reactors,” American Nuclear Society, LaGrange Park, IL (1990).

[2] *Sax’s Dangerous Properties of Industrial Materials*, Richard J. Lewis, Sr., Van Nostrand-Reinhold Co., New York, NY (1996).

[3] *Identification System for Fire Hazards of Materials,* Publication 704-M, National Fire Protection Association, Batterymarch Park, Quincy, MA (1980).

[4] *CRC Handbook for Laboratory Safety*, Norman V. Steere, Chemical Rubber Company, Cleveland, OH (1971).

[5] Title 10, Part 50, “Domestic Licensing of Production and Utilization Facilities,” of the *Code of Federal Regulations*, U.S. Government Printing Office, Washington, DC (Current).

[6] ANSI/ANS-15.4, “Selection and Training of Personnel for Research Reactors,” American Nuclear Society, LaGrange Park, IL (1988).