3.9 Variable Reactivity and Shutdown Margin

Applicability

This specification applies to the permissible excess reactivity and the required worths of the reactivity control systems.

Objective

To assure that the reactor can be safely shut down at any time.

Specification

The reactor shall not be made critical unless:

1. the reactor can be made subcritical using shim blades by at least 1% $\Delta K/K$ from the cold, Xe free critical condition with the most reactive operable blade and the regulating rod fully withdrawn.
2. no less than five shim blades are operable, and any inoperable blade is at the operating position or higher.
3. the time from initiation of a scram signal to 80% of full insertion is less than 1.0 sec for each control blade.
4. the D_2O reflector dump time is less than twice the initial measured value.

After initial measurements of control blade and regulating rod reactivity worths, the reactor shall not be made critical unless:

5. the total, available, positive reactivity of any control elements connected to an automatic controller, other than those covered by Specification 6.4, shall be worth less than 1.8% $\Delta K/K$.
6. the maximum controlled reactivity addition rate is no more than 5×10^{-4} $\Delta K/K/sec$.

7. the reactivity worth of the D_2O reflector dump is greater than the reactivity worth of the most reactive shim blade.

8. shim blades and/or the regulating rod may be connected to automatic controllers within the limitation of Specification 3.9-5 above. Only one shim blade may be withdrawn at a time.

9. The nuclear safety system shall be separate from any automatic controller.

Definitions

1. The "cold xenon free critical" MIT Reactor is defined as a critical configuration in which

   a. the average H_2O and D_2O temperature in core and reflector are 10°C.

   b. no fission product xenon exists in the reactor.

   c. the reactor is loaded for the beginning of an operating period.

   d. variable reactivity effects such as sample changes that may occur under normal operation shall be in their most positive reactive state.

2. Variable reactivity refers to the changes which may occur or vary during operation. It will include xenon, fuel burnup (for one or more operating cycles), sample changes made in operation, and changes in experiments during operation.

3. "Initiation of scram signal" in the case of the process system scrams is the time at which the true value of the parameter reaches its scram setting. For the nuclear channels, a signal simulating the chamber output will be used in place of the true value.

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4. The total available positive reactivity of any control elements connected to an automatic control system is the positive reactivity beyond the critical condition that could be inserted if the control elements were fully withdrawn.

5. The word "separate" means that the output of an instrument used in the safety system will not be influenced by interaction with the control system. For example, a signal derived from an instrument that forms part of the safety system would not be transmitted to the control system unless first passed through an isolation device.

Basis

As a general philosophical basis, the following struck rod criterion is complied with at this reactor: "It should be impossible for a reactor to be made critical in its most reactive situation on the withdrawal of a single rod. Conversely, it should always be possible to shut down the reactor with one rod stuck in its outermost position. If it is possible that rods or mechanisms might interact so that several could be stuck in the out position, then the number of rods included in the stuck rod criterion should be increased accordingly." (Ref. 3.9-1, p. 677)

Operation of the reactor with only five control blades presents no safety problem if Specification 3.1 on the core power distribution is met. In such operation, Specification 3.9-1 will require that the excess reactivity over cold Xe-free critical condition be less than the worth of the four least reactive shim blades, and with only five blades operating allows one blade to fail to drop while still completely shutting the reactor down.

Specification 3.2 and Section 15.2 of the SAR show that the power transient that will result from a reactivity step of 1.8% $\Delta K/K$ will not cause damage to the fuel integrity. Reactivity insertions due to a malfunction of an automatic controller would be in the form of ramps. Given that the nuclear safety system is separate from any automatic controller, that safety system would stop any transient resulting from a ramp long before the results would be as severe as a step insertion of 1.8% $\Delta K/K$.

The requirement that the nuclear safety system be separate from any automatic controller means that the ability of that safety system to perform its intended function will not be compromised. The total available positive reactivity of any control elements connected to an automatic controller is limited to less than 1.8% $\Delta K/K$.

The additional independent capability for reactivity control provided by the D_2O reflector dump gives added assurance that the reactor can be made subcritical under an adverse condition of fuel loading or control blade malfunction.

The scram time of a control blade shall be all the elapsed time between the initiation of the trip signal to 80% insertion of the control blade from the fully withdrawn position. In Section 15 of the SAR, it is shown that a scram delay of one second will not result in any damage to the reactor fuel.

The D_2O reflector dump time shall not exceed twice the initial measured value. If the reflector takes more than that time to dump, this would indicate the dump valve is not functioning properly or that some other abnormal condition has developed and should be repaired.

The control blade and regulating rod speeds are designed to limit the reactivity addition rate to less than 5×10^{-4} $\Delta K/K$/sec. This value is conservatively within the range of reactivity insertion rates normally accepted for reactor operation. Control systems in this range give ample margin for proper human response during approach to critical and power operations. In the event of an accidental continuous insertion of reactivity at this maximum rate, the response of the reactor safety system period and level trips will adequately protect the reactor.

Reference

3.9-1 Thompson, T.J. and J.G. Beckerley (Eds.), The Technology of Nuclear Reactor Safety, Vol. I, The MIT Press, Cambridge, Mass. (1964).

6.4 Closed-Loop Control Systems

Applicability

This specification applies to systems for the closed-loop control of the reactor exclusive of those automatic controllers covered by Specification 3.9. (Note: The reactivity restrictions contained in Specification 6.1-1 do not apply to experiments performed under this Specification, #6.4.)

Objective

To assure that the reactor can be safely shut down at any time.

Specification

1. Shim blades and/or the regulating rod may be connected to a closed-loop controller provided that the overall controller is designed so that the control of reactor power will always be feasible at either the desired termination point of any transient or at the maximum allowed operating power. Only one shim blade shall be withdrawn at a time.
2. Each proposed closed-loop controller shall require a documented safety analysis and approval by the MIT Reactor Safeguards Committee (MITRSC) or, if authorized by the MITRSC, by its Standing Subcommittee.
3. The nuclear safety system shall be separate from any closed-loop controller.
4. A period trip set at or longer than 20 seconds shall be operable whenever any closed-loop controller is in use. This trip shall transfer control to manual and sound an alarm.
5. The operability of the period trip is to be tested prior to use of any closed-loop controller during any week that a closed-loop controller is to be used.

Definitions

1. A reactor together with specified control mechanisms is defined as constituting a system that is "feasible to control" if it is possible to transfer the system from a given power level and rate of change of power to a desired, steady-state power level without overshoot, or conversely, undershoot. (Note: If a deviation band is specified about the desired power level, then the term "without overshoot" means that there will be no overshoot beyond the permitted deviation.)
2. The word "separate" means that the output of an instrument used in the safety system will not be influenced by interaction with the control system. For example, a signal derived from an instrument that forms part of the safety system would not be transmitted to the control system unless first passed through an isolation device.

Basis

The requirement that a closed-loop controller be designed so that control will always be feasible at the desired termination point of any transient insures that there will be no power overshoots, or conversely, undershoots other than those permitted by specified deviaiton bands, if any. The reactor period can be made rapidly infinite if the total reactivity, both that added directly by the control mechanisms and that present indirectly from feedback effects, is maintained less than the maximum available rate of change of reactivity divided by the effective, one-group decay constant. Physically, if the reactivity is so constrained, then, by reversal of the direction of motion of the specified control mechanism, it will be possible to negate the effect of the reactivity present and make the period infinite at any time during the transient. This condition, the absolute reactivity constraint, is unnecessarily restrictive. A less stringent constraint may be written that specifies that there be sufficient time available to eliminate whatever reactivity is present beyond the amount that can be immediately negated by reversal of direction of the designated control mechanism before the desired power level is attained. This condition is the sufficient reactivity constraint. Being an inequality, this constraint is not a control law. Its function is to review the decision of whatever control law is being used and, if necessary, override that decision. Provided that the net reactivity is always restricted to that permitted by the sufficient constraint, it should always be possible to halt a power increase at the desired termination point by merely reversing the direction of absorber travel. Therefore, adherence to this constraint means that no automatic control action should ever result in a challenge to the nuclear safety system. Additional information is given in Reference 6.4-1.

The requirement that each proposed closed-loop controller require a documented safety analysis and approval by the MITRSC or, if authorized by the MITRSC, by its Standing Subcommittee insures that the design of each controller will be carefully reviewed and that necessary off-line testing will be performed.

The requirement that the nuclear safety system be separate from any closed-loop controller means that the ability of that safety system to perform its intended function will not be compromised.

The existence of a trip that will transfer control to manual should the period become equal to or shorter than 20 seconds will provide a safety factor set more conservatively than the nuclear safety system. The signal used for this trip is separate from the nuclear safety system and is not processed by the closed-loop controller. This assures that the capability of the trip signal to perform its intended function will not be compromised.

Reference

6.4-1 Bernard, J.A., "Development and Experimental Demonstration of Digital Closed-Loop Control Strategies for Nuclear Reactors," Ph.D Thesis, MIT, May 1984.

Appendix B

SAR Revision #32

1. Attached is SAR revision #32.

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Summary of SAR Changes - SR #0-84-12

Page #	Changes
3.3.2-3	Section 3.3.2.1.6 rewritten to reflect change in Technical Specification #3.9-5
7.1.9-1	Section 7.2 change to reflect use of boron-impregnated stainless steel blades. (This completes a previous change made earlier.)
7.2-1	Modifies section 7.2 to include variable speed motors in the control system and shim blades in the automatic control system. Corrects typographical error in last line of page.
7.3-1	Changes wording to reflect use of constant or variable speed motors. Adds paragraph listing modes of control.
7.4-2	Changes frequency of building leak test from biannual to annual which is as specified in the Technical Specifications. Adds specification for damper leak test.
	Changes frequency of emergency cooling flow test to annual which is as specified in the Technical Specifications. Delineates specification for the test.
7.4-3	Changes frequency of calibration of reactor outlet temperature switches to annual which is as specified in the Technical Specifications. Deletes word bimetallic since capillary switches are used.
10.6c	New page.
10.6d	" "
10.8c	" "
10.8d	" "
10.31b	" "
10.32	Adds reference 10.1.6-1.

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situation on the withdrawal of a single rod. Conversely, it should always be possible to shut down the reactor with one rod stuck in its outermost position. If it is possible that rods or mechanisms might interact so that several could be stuck in the out position, then the number of rods included in the stuck rod criterion should be increased accordingly." (Ref. 3.3.2.1.4-1, p. 677)

3.3.2.1.5 The maximum controlled reactivity addition rate shall be no more than 5×10^{-4} $\Delta K/K/sec$. The maximum control blade and regulating rod control speeds shall be chosen to conform to this reactivity limitation.

The value of 5×10^{-4} $\Delta K/K/sec$ is conservatively within the range of reactivity insertion rates normally accepted for reactor operation. Control systems in this range give ample margin for proper human response during approach to critical and power operations. In the event of an accidental continuous insertion of reactivity at this maximum rate, the response of the reactor safety system period and level trips will adequately protect the reactor.

3.3.2.1.6 The total available positive reactivity of any control elements connected to an automatic controller other than those described in section 10.1.6 shall be worth less than 1.8% $\Delta K/K$. The reactivity that could be inserted due to the full withdrawal beyond the critical position of the control elements connected to an automatic controller is limited to 1.8% $\Delta K/K$ because (1) a step insertion of 1.8% $\Delta K/K$ will not cause damage to the fuel integrity by the resulting power transient and (2) a malfunction of an automatic controller would result in a ramp reactivity insertion which would be less severe than a step insertion of the same magnitude. (Refer to sections 15.2 and 3.3.2.1.5 of the SAR respectively.)

3.3.2.1.7 A backup scram capability shall be provided by provisions for dumping the D_2O reflector. The reactivity worth of such a dump shall be greater than the reactivity effect of the most reactive shim blade.

The additional independent capability for reactivity control gives added assurance that the reactor can be made sub-critical under any adverse condition of fuel loading or control blade malfunction.

a) Minor scram pushbutton at the control console and medical therapy control panel. During actuation of the minor scram, the magnets de-energize, blades drop and the blade mechanisms run in automatically.

b) Major scram pushbuttons at the control console and outside the containment in the utilities room. During actuation of the major scram, the magnets de-energize, blades drop, drive mechanisms run in, the D_2O reflector partially dumps, the ventilation stops and the building containment is sealed.

c) Manual (or automatic) scrams associated with experiments may be included as required.

7.1.9 Building Containment Isolation

As a protection against the release of airborne radioactive effluent from the building in excess of approved limits, redundant particulate and gaseous (plenum) radiation monitors continually monitor the containment ventilation exhaust. If any of these monitors exceed the set point the ventilation dampers seal and any positive pressure can be exhausted through the building pressure relief system, as described in 5.2.2.

These radiation monitors are provided with both high and low trips. Any failure which causes the reading to decrease to the low trip sounds an alarm. Loss of electrical power to the monitors will close the dampers and seal the building. The readings are usually recorded hourly by the reactor operator, and any deviation from normal operation would be noted. The ventilation trip action is tested before each startup (Table 7.4.2). If the main dampers do not close within ten seconds after a high effluent monitor alarm, the auxiliary dampers are closed automatically as shown in Fig. 7.3a.

7.2 Control System

The control system of the MITR consists of six boron-impregnated stainless steel shim blades, one aluminum clad cadmium regulating rod and their associated control circuits.

The control system is designed to give adequate control blade movement in both rate and distance. This design allows smooth and stable power control during reactivity changes including xenon transients, fuel burnup, temperature coefficient, sample changes, shutters, etc.

The control system contains the following features: drive in-limits, drive out-limits, subcritical position stop (shim blades only), constant or variable speed drive, withdrawal of only one shim blade at a time, automatic control of the regulating rod and/or shim blades, and automatic rundown provision.

The in-limit and out-limit circuits of the seven drive mechanisms stop the drive motors and prevent them from being driven beyond their physical limits. In case of failure of the microswitches, the mecnanisms are driven through a shear pin that prevents excessive force on any absorber.

The subcritical position interlock circuit is incorporated for the following reasons:

a) to maintain the shim bank programmed at a uniform height during approach to criticality,

b) to establish a level, below the critical height, to which individual shim blades can be withdrawn in one step,

c) to provide a convenient reference point at which the operator can pause to make a complete instrument check before bringing the reactor critical.

After all six shim blades are at the subcritical position, the manual control pushbutton is momentarily depressed to close the interlock to allow the blades to be withdrawn to the critical position.

During special tests, the subcritical position circuit can be bypassed by a spring loaded pushbutton that must be manually held depressed during the entire test. If this pushbutton is released, all withdrawal motion stops.

The shim blades and regulating rod may be withdrawn at either constant speed or variable speed subject to an upper limit such that the maximum controlled reactivity addition rate is not exceeded. The shim blades are moved by use of a selector switch which limits motion to a single blade. The regulating rod may be withdrawn simultaneously with the selected shim. The shims must be withdrawn individually but they can be inserted simultaneously by use of the All Rods In pushbutton. There are two possible modes of operation: manual and automatic. Regarding automatic control, two approaches are used. First, the reactivity associated with the control elements attached to an automatic controller may be limited as described in section 3.3.2.1.6 of the SAR. Second, the design of the controller may be required to meet certain criteria as discussed in section 10.1.6 of the SAR.

In order to ensure that the regulating rod does not reach in-limit of operation, i.e. (the inability to control positive variable reactivities automatically) the automatic rundown circuit is incorporated. When the regulating rod, on automatic control, is driven into its "near in-limit" position a visual alarm and buzzer alert the operator and also energize a 30 second time delay relay. The operator must reset the automatic rundown within the 30 second time limit. The operator would then insert the shims while withdrawing the regulating rod some distance above the "near in" position. If the operator fails to reset the automatic rundown circuit and does not reshim within the specified time, the delay relay will close and the selected shim blade will be driven in, thus reducing reactor power.

7.3 Startup Interlock System

To ensure that all flow systems are operating properly and that building containment is normal, a startup interlock system must be satisfied in addition to the scram conditions listed above before rods can be withdrawn at startup. The startup interlock system consists of the following interlocks:

1) all control blades must be fully inserted
2) H_2O must be overflowing from the core tank
3) D_2O must be overflowing from the reflector tank
4) Building ΔP must be more negative than -0.1" of H_2O
5) (Deleted)

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Table 7.4-1

ROUTINE SURVEILLANCE TESTS

	Test	Frequency	Specification
1)	Building leak test including Vent. Damper leak test	Annual	< 1% building vol/day at 2 psig. Light test normal
2)	Neutron level channels calibration	Annual	Detector circuits and plateau characteristics normal
3)	Period channels calibration	Annual	Detector circuits and plateau characteristics normal, indicated period correct ± 10%
4)	Safety channel response and blade drop time	Annual	≤ 1.0 sec
5)	Reflector dump time test	Annual	Normal
6)	Exhaust damper closure time test	Annual	Less than transit time for effluent air from plenum monitor to exhaust damper. Auxiliary damper automatic closure <10 sec
7)	Primary H_2O outlet temperature detector and recorder calibration	Annual	± 2°C
8)	Primary H_2O flow calibration	Annual	± 100 gpm
9)	Ventilation dampers inspection	Semiannual	Normal
10)	Plenum monitor source check	Quarterly	Normal
11)	Stack monitor source check	Quarterly	Normal
12)	Particulate monitor source check	Quarterly	Normal

Table 7.4-1 (Continued)

Test	Frequency	Specification
13) Water monitor source check	Quarterly	Normal
14) Area monitors source check	Quarterly	Normal
15) New building penetration leak test	When installed	To pass leak test (see Section 5.1.2.4)
16) Building pressure relief filters	Annual	Pass specification on efficiencies given in Section 5
17) Emergency Cooling Flow Test	Annual	$\geq$ 10 gpm per nozzle
18) Withdraw permit circuit isolation test	Semiannual	No electrical connection to any other circuits
19) Shield coolant flow calibration	Annual	$\pm$ 20 gpm
20) Reactor outlet temperature switches	Annual	$\pm$ 2°C

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10.1.6 Closed-Loop Control Systems

This section describes systems for the closed-loop control of the reactor power exclusive of those automatic controllers described in Section 3.3.2.1.6 of the SAR.

10.1.6.1 Description

The closed-loop controllers considered here have in common that they constitute a class of systems that are "feasible to control". The term "feasible to control" means that these controllers must be capable of transfering the reactor from a given power level and rate of change of power to a desired, steady-state power level without overshoot, or conversely, undershoot. (Note: If a deviation band is specified about the desired power level, then the term "without overshoot" means that there will be no overshoot beyond the permitted deviation.) This property can be attained by designing the controller so that the net reactivity is limited. Two constraints may be used. These are the "absolute" and "sufficient" reactivity constraints.

The equations of reactor dynamics show that the rate of change of reactor power depends on both the net reactivity and the rate of change of reactivity. This fact, coupled with the fact that the rate of change of reactivity is, under non-scram conditions, finite means that adjustments in the reactivity must be preplanned if power overshoots are to be avoided. The reactor period can be made rapidly infinite if the total reactivity, both that added directly by the control mechanisms and that present indirectly from feedback effects, is maintained less than the maximum available rate of change of reactivity divided by the effective, one-group decay constant. Physically, if the reactivity is so constrained, then, by reversal of the direction of motion of the specified control mechanism, it will be possible to negate the effect of the reactivity present and make the period infinite at any time during the transient. This condition, the absolute reactivity constraint, is unnecessarily restrictive. A less stringent constraint may be written that specifies that there be sufficient time available to eliminate whatever reactivity is present beyond the amount that can be immediately negated by reversal of direction of the designated control mechanism before the desired power level is attained. This condition is the sufficient reactivity constraint. Being an inequality, this constraint is not a control law. Its function is to review the decision of whatever control law is being used and, if necessary, override that decision. Provided that the net reactivity is always restricted to that permitted by the sufficient constraint, it should always be possible to halt a power increase at the desired termination point by merely reversing the direction of absorber travel. Therefore, adherence to this constraint means that no automatic control action should ever result in a challenge to the nuclear safety system. Additional information is given in Reference 10.1.6-1.

10.2.5 Conditions for Closed-Loop Control Experiments

This section describes the conditions for closed-loop control experiments exclusive of those automatic controllers described in section 3.3.2.1.6 of the SAR.

10.2.5.1 Experiment Conditions

The following four conditions must be met during any experiments using the closed-loop controller:

1. Shim blades and/or the regulating rod may be connected to a closed-loop controller provided that the overall controller is designed so that the control of reactor power will always be feasible at either the desired termination point of any transient or at the maximum, allowed operating power. Only one shim blade shall be withdrawn at a time.
2. The nuclear safety system shall be separate from any closed-loop controller.
3. A period trip set at or longer than 20 seconds shall be operable whenever any closed-loop controller is in use. This trip shall transfer control to manual and sound an alarm.
4. The operability of the period trip is to be tested prior to use of any closed-loop controller during any week that a closed-loop controller is to be used.

The purpose of the first condition is to insure that power overshoots will be unlikely. The second condition assures that the capability of the nuclear safety system to perform its intended function will not be compromised. The third and fourth conditions provide an additional reliable safety factor set more conservatively than the trips associated with the nuclear safety system. The use of this trip in effect limits the excess reactivity that can be present.

10.3.6 Closed-Loop Controllers

This section describes the envelope within which experiments can be performed using closed-loop controllers exclusive of those automatic controllers described in section 3.3.2.1.6 of the SAR.

10.3.6.1 Experimental Envelope

The use of closed-loop controllers must be accompanied by a period trip that transfers control to manual. This trip limits the excess reactivity that could be inserted while on closed-loop control. However, because the experiment conditions do not contain an explicit limit on the available reactivity associated with the controller, any number of control elements may be connected to a closed-loop controller. Thus, one class of experiments that can be studied are those involving multiple control elements.

A second class of experiments that may be studied are those involving novel control strategies. These would be performed by using a two-tier structure. The lower or first level of the controller would use a new control strategy and would be allowed to control the reactor power at some fraction of full power. The decisions made at this first level would be reviewed by a second tier having the property of feasibility of control. This second level would intervene if a decision of the first level could result in the attainment of a power level in excess of the allowed operating power.

REFERENCES

10.1-1 "Final Hazards Summary Report to the ACRS on a Research Reactor for the Massachusetts Institute of Technology" MIT-5007, January 1956.

10.1.3-1 "Medical Facility", Submitted to the USAEC on March 21, 1958.

10.1.6-1 Bernard, J.A., "Development and Experimental Demonstration of Digital Closed-Loop Control Strategies for Nuclear Reactors," Ph.D Thesis, MIT, May 1984.

10.3.4-1 Ziebold, Thomas O., "MIT Reactor Cryogenic Facilities, Technical Specifications", MITR-CF-2, March 1968 (revised May 1968). Filed with USAEC on June 7, 1968.

10.3.4-2 Thompson, T.J., Letter to Dr. Peter A. Morris, June 26, 1968.