U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 15.4.6 CHEMICAL AND VOLUME CONTROL SYSTEM MALFUNCTION THAT RESULTS IN A DECREASE IN BORON CONCENTRATION IN THE REACTOR COOLANT (PWR)

REVIEW RESPONSIBILITIES

Primary - Reactor Systems Branch (RSB)

Secondary - None

I. AREAS OF REVIEW

Unborated water can be added to the reactor coolant system, via the chemical volume and control system (CVCS), to increase core reactivity. This may happen inadvertently, because of operator error or CVCS malfunction, and cause an unwanted increase in reactivity and a decrease in shutdown margin. The operator must stop this unplanned dilution before the shutdown margin is eliminated. Since the sequences of events that may occur depend on plant conditions at the time of the unplanned moderator dilution, the review includes conditions at the time of the unplanned dilution, such as refueling, startup, power operation (automatic control and manual modes), hot standby, and cold shutdown.

The review of postulated moderator dilution events considers causes, initiating events, the sequence of events, the analytical model, the values of parameters used in the analytical model, and predicted consequences of the event.

The sequence of events described in the applicant's safety analysis report (SAR) is reviewed by both the RSB. The RSB reviewer concentrates on the need for the reactor protection system and the operator action required to secure and maintain the reactor in a safe condition. The RSB review of SRP Section 6.3 covers the systems for emergency injection of borated cooling water.

The analytical methods are reviewed by RSB to ascertain whether the mathematical modeling and computer codes have been previously accepted by the staff. If a referenced analytical method has not been previously reviewed, the reviewer initiates a generic evaluation of the new analytical model.

Rev. 1 - July 1981

The predicted results of moderator dilution events are reviewed by RSB to assure that the consequences meet the acceptance criteria given in subsection II of this SRP section. Further, the results of the transients are reviewed to ascertain that the values of pertinent system parameters are within ranges expected for the type and class of reactor under review.

In addition, the RSB will coordinate the other branches' evaluations that interface with the overall review of the system as follows: The Instrumentation and Control Systems Branch (ICSB) reviews the instrumentation and control aspects of the sequence described in the SAR to confirm that reactor and plant protection and safeguards controls and instrumentation systems will function as assumed in the safety analysis as part of its primary review responsibility for SRP Sections 7.2 through 7.5. The Chemical Engineering Branch (CMEB) reviews the functional and operational characteristics and potential failure modes of the CVCS as part of its primary review responsibility for SRP Section 9.3.4. The RSB reviewer makes use of this review to evaluate initiating causes and the expected sequence of events. The Core Performance Branch (CPB) reviews the values of the reactivity parameters used in the analyses as part of its primary review responsibility for SRP Section 4.3 and also performs, upon request, additional analyses related to these accidents for selected reactor types as part of its primary review responsibility for SRP Sections 4.2 and 4.4.

For those areas of review identified above as being reviewed as part of the primary review responsibility of other branches, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP section of the corresponding branch.

II. ACCEPTANCE CRITERIA

The RSB acceptance criteria are based on meeting the relevant requirements of the following regulations:

A. General Design Criterion 10 (Ref. 2), as it relates to the reactor coolant system being designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during normal operations including anticipated operational occurrences.

B. General Design Criterion 15 (Ref. 3), as it relates to the reactor coolant system and its associated auxiliaries being designed with appropriate margin to assure that the pressure boundary will not be breeched during normal operations including anticipated operational occurrences.

C. General Design Criterion 26 (Ref. 4), as it relates to the reliable control of reactivity changes to assure that specified acceptable fuel design limits are not exceeded, including anticipated operational occurrences. This is accomplished by assuring that appropriate margin for malfunctions, such as stuck rods, are accounted for.

The general objective of the review of moderator dilution events is to confirm that either of the following conditions are met:

1. The consequences of these events are less severe than the consequences of another transient that results in an uncontrolled increase in reactivity and has the same anticipated frequency classification.

2. The plant responds to the events in such a way that the criteria regarding fuel damage and system pressure are met and the dilution transient is terminated before the shutdown margin is eliminated.

Specific criteria necessary to meet the relevant requirements of GDC 10, 15, and 26 are as follows:

1. Pressure in the reactor coolant and main steam systems should be maintained below 110% of the design valves. (Ref. 1)

2. Fuel cladding integrity shall be maintained by ensuring that the minimum DNBR remains above the 95/95 DNBR limit for PWRs and the CPR remains above the MCPR safety limit for BWRs based on acceptable correlations (see SRP Section 4.4).

3. An incident of moderate frequency should not generate a more serious plant condition without other faults occurring independently.

4. An incident of moderate frequency in combination with any single active comonent failure, or single operator error, shall be considered and is an event for which an estimate of the number of potential fuel failures shall be provided for radiological dose calculations. For such accidents, the number of fuel failures must be assumed for all rods for which the DNBR or CPR falls below those values cited above for cladding integrity unless it can be shown, based on an acceptable fuel damage model (see SRP Section 4.2), that fewer failures occur. There shall be no loss of function of any fission product barrier other than the fuel cladding.

5. If operator action is required to terminate the transient, the following minimum time intervals must be available between the time when an alarm announces an unplanned moderator dilution and the time of loss of shutdown margin:

   a. During refueling: 30 minutes.

   b. During startup, cold shutdown, hot standby, and power operation: 15 minutes.

The applicant's analysis of moderator dilution events should be performed using an acceptable analytical model. Should unreviewed analytical methods be proposed, these methods must be evaluated by the staff. For new generic methods, the reviewer initiates an evaluation.

All of the following plant initial conditions should be considered in the analysis: refueling, startup, power operation (automatic control and manual modes), hot standby, and cold shutdown.

The parameters and assumptions used in the analytical model should be suitably conservative. The following values and assumptions are considered acceptable:

(i) For analyses during power operation, the initial power level is rated output (licensed core thermal power) plus an allowance of 2% to account for power measurement uncertainty.

(ii) The boron dilution is assumed to occur at the maximum possible rate.

(iii) The core burnup and corresponding boron concentration are selected to yield the most limiting combination of moderator temperature coefficient, void coefficient, Doppler coefficient, axial power profile, and radial power distribution. This will usually be the beginning-of-life (BOL) condition.

(iv) All fuel assemblies are installed in the core.

(v) A conservatively low value is assumed for the reactor coolant volume.

(vi) For analyses during refueling, all control rods are withdrawn from the core.

(vii) For analyses during power operation, the minimum shutdown margin allowed by the technical specifications (usually 1%) is assumed to exist prior to the initiation of boron dilution.

(viii) For each event analyzed, a conservatively high reactivity addition rate is assumed taking into account the effect of increasing boron worth with dilution.

(ix) Conservative scram characteristics are assumed, i.e., maximum time delay with the most reactive rod held out of the core.

III. REVIEW PROCEDURES

The procedures below are used during both the construction permit (CP) and operating license (OL) reviews. During the CP review, the values of system parameters and setpoints used in the analysis will be preliminiary in nature and subject to change. At the OL review, final values should be used in the analysis, and the reviewer should compare these to the limiting safety system settings included in the proposed technical specifications.

The descriptions of moderator dilution transients presented in the SAR are reviewed by RSB regarding the occurrences leading to the initiating events. The sequence of events, from initiation until a stabilized condition is reached, is reviewed to ascertain:

1. The extent to which normally operating plant instrumentation and controls are assumed to function. Particularly important are the alarms which alert the operator to the unplanned boron dilution.

2. The extent to which the plant and reactor protection systems are required to function.

3. The credit taken for the functioning of normally operating plant systems.

4. The operation of engineered safety systems that is required.

5. The extent to which operator actions are required.

6. The appropriate margin for malfunctions, such as stuck rods are accounted for.

The RSB reviewer confirms that analyses are included for a boron dilution incident occurring during each of the following plant initial conditions: refueling, startup, power operation (automatic control and manual modes), hot standby, and cold shutdown. The refueling condition should consider cases when the reactor vessel head is removed and the coolant is drained to the elevation of the hot leg piping. For each such incident reviewed, all possible causes must have been considered by the applicant and justification presented that the cause selected for analysis is the one that allows the operator the least time to take corrective action.

With the aid of the EICSB reviewer, the timing of the initiation of those protection, engineered safety, and other systems needed to limit the consequences of each boron dilution incident to acceptable levels is reviewed. The RSB reviewer compares the predicted variations of system parameters with various trip and system initiation setpoints. The ICSB reviewer evaluates automatic initiation, actuation delays, possible bypass modes, interlocks, and the feasibility of manual operation where the SAR states that operator action is needed or expected.

To the extent deemed necessary, the RSB reviewer evaluates the effects of single active failures of systems and components that may affect the course of the transient. This phase of the review uses the system review procedures described in the standard review plans for Chapters 5, 6, 7, 8, and 9 of the SAR. In particular, the redundancy of alarms that alert the operator to the unplanned dilution is confirmed.

The mathematical models used by the applicant to evaluate core performance and reactivity status are reviewed by RSB to determine if these models have been previously found acceptable by the staff. If not, a generic review of the model proposed by the applicant is initiated.

The values of system parameters and initial core and system conditions used as input to the model are reviewed by RSB. Of particular importance are the reactivity coefficients and control rod worths used by the applicant. The justification provided by the applicant to show that the selected core burnup condition, boron concentration, and rod worths yield the minimum margins is evaluated. CPS is consulted regarding the values of the reactivity parameters used in the applicant's analysis. These values are reviewed by CPB under SRP Section 4.2. The value of core reactivity as a function of time following each incident analyzed is confirmed by comparision with an acceptable analysis performed for another plant, by comparison with staff calculations for typical plants done by CPB on request, or by independent calculations by the RSB reviewer.

The assumed dilution flow rates are reviewed, taking into consideration the system parameters which act to limit the flow. The reviewer examines the flow-limiting equipment characteristics provided by the applicant to justify his flow rate assumptions; e.g., if the flow is limited by the charging pump capacity, the assumed flow is compared with the flow for all charging pumps acting at full capacity. If some lesser value of flow is assumed, such as not all pumps operating, or flow limited by a valve, justification must be provided. EICSB is consulted concerning any interlocks for which credit is taken.

The results of the analyses are reviewed and compared to the acceptance criteria presented in subsection II of this SRP regarding the time available for the operator to take corrective action. The variations with time during the transient of important parameters are compared to those predicted for other similar plants to see that they are within the range expected. Parameters of particular

importance are core reactivity, boron concentration, rate of addition of unborated water, power level, core pressure, and minimum departure from nucleate boiling ratio (DNBR).

IV. EVALUATION FINDINGS

The reviewer verifies that the SAR contains sufficient information and his review supports the following kinds of statements and conclusions which should be included in the staff's safety evaluation report:

> Various chemical and volume control system (CVCS) malfunctions which could lead to an unplanned boron dilution incident have been reviewed. The malfunctions that allow the operator the shortest time for corrective action have been analyzed starting from plant conditions of startup, power operation (automatic and manual), hot standby, cold shutdown, and refueling. These events were evaluated by the applicant using a mathematical model that has been previously reviewed and found to be suitably conservative. The results of the analyses of these events showed that the operator has ___ minutes to take corrective action if a boron dilution incident occurs during refueling and ___ minutes if at power. In the latter case the most severe transient results in a minimum departure from nucleate boiling ratio (DNBR) of ____ and reactor coolant and main steam system pressures of less than 110% of design.

The staff concludes that the analysis for the decrease in reactor coolant boron concentration event is acceptable and meets the requirements of General Design Criteria 10, 15 and 26. This conclusion is based on the following:

1. The applicant has met the requirements of GDC 10 with respect to demonstrating that the specified acceptable fuel design limits are not exceeded for this event. This requirement has been met since the results of the analysis showed that the thermal margin limits (MDNBR for PWRs) are satisfied as indicated by SER Section 4.4.

2. The applicant has met the requirements of GDC 15 with respect to demonstrating that the reactor coolant pressure boundary limits have not been exceeded for this event. This requirement has been met since the analysis showed that the maximum pressure in the reactor coolant and main steam systems did not exceed 110% of the design pressure.

3. The applicant has met the requirements of GDC 26 with respect to demonstrating that the control rod system has the capability of overcoming the effects of boron dilution events during reactor operation. The applicant has demonstrated the fulfillment of these requirements by showing that under the postulated accident conditions, and with appropriate margins for stuck rods, the specified acceptable fuel design limits are not exceeded.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for comlying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission Regulations.

VI. REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Power Plant Components," Article NB-7000, "Protection Against Overpressure," American Society of Mechanical Engineers.

2. 10 CFR Part 50, Appendix A, GDC 10, "Reactor Design."

3. 10 CFR Part 50, Appendix A, GDC 15, "Reactor Coolant System Design."

4. 10 CFR Part 50, Appendix A, GDC 26, "Reactivity Control System Redundancy and Capability."