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U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555

Subject: McGuire Nuclear Station
Docket Numbers 50-369 and -370
Catawba Nuclear Station
Docket Numbers 50-413 and -414
Supplementary Information Relative to
Topical Report BAW-10173; Boron Dilution Analysis

By letter dated February 20, 1991, the NRC staff transmitted the Safety Evaluation Report (SER) for Topical Report BAW-10173. The SER imposed 5 conditions on the use of the Topical, and requested that Duke respond to these conditions. By letters of March 14, 1991 and April 25, 1991 responses were provided for these conditions. It has since been determined that calculations relative to the response for Condition number 4 (boron dilution recriticality times) contained incorrect assumptions regarding initial reactor coolant system volumes. The calculations have been redone and the revised response to Condition 4 is attached. We regret any inconvenience this may have caused.

If there are any questions, please call Scott Gewehr at (704) 373-7581.

Very truly yours,

M S Tuckman /RCF

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Catawba Units 1 and 2 Boron Dilution Accident Reevaluation
Safety Evaluation

1. Introduction

The boron dilution accident has been reanalyzed to support recent Catawba reload cores. These flows are currently being administratively controlled until a change to Technical Specification 3/4.3.3.12 is applied for and received.

Catawba Units 1 and 2 are equipped with a Boron Dilution Mitigation System (BDMS) which serves to detect uncontrolled dilution events in Modes 3-6 of plant operation and secure possible dilution flowpaths by automatic valve operation. The evaluation of dilution events in Modes 3-6 must demonstrate that the dilution will be terminated, either by the BDMS or by the operator, before criticality occurs. In the event that one or both train(s) of the BDMS is (are) inoperable in these modes, the flowrate of the Reactor Makeup Water System is limited to values which have been shown to allow adequate operator action time to terminate the dilution before criticality occurs. Reanalysis of the boron dilution event in Modes 3-5 shows a need to change the Technical Specification flowrates to the following values:

Mode	Old Value	New Value
3	200	150
4	80	150
5	80	75

2. Accident Evaluation

The following safety evaluation has been prepared to justify the revision in allowable flowrates during operation in Modes 3-5 with one train of the BDMS inoperable.

CVCS Malfunction that Results in a Decrease in the Boron Concentration in the Reactor Coolant (Presented in FSAR Section 15.4.6)

This ANS Condition II event is analyzed to show that adequate time exists to terminate a dilution event prior to loss of shutdown margin. Termination of a dilution event can result from actuation of the Boron Dilution Mitigation System (BDMS) in Modes 3-6 or by operator action following a high flux at shutdown alarm in case the BDMS is inoperable.

A reanalysis of the dilution events with the BDMS inoperable was performed to demonstrate that, given bounding assumptions made on flowrates from the Reactor Makeup Water System, conservative temperature differences between the diluted water source and the Reactor Coolant System, and conservative ratios of initial to critical boron concentrations, that the operator would have adequate time to terminate the dilution before criticality occurs. The ratios of initial to critical boron concentrations assumed in the safety evaluation for the different modes of operation are confirmed to be bounded during cycle specific evaluations. The flowrates used in the evaluations with the BDMS inoperable are chosen to ensure that the operator will have 15 minutes in which to terminate the dilution prior to criticality. The Technical Specification flowrates are conservatively chosen to ensure that the flowrate values used in the evaluations are not exceeded.

Results and Conclusions

The evaluation of the boron dilution accident shows that the operator will be able to terminate a dilution event in Modes 3-5 prior to recriticality and that all Standard Review Plan acceptance criteria for the boron dilution event are satisfied. FSAR markups based on the evaluation are attached.

No CHANGES
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Results

The results following the startup of an idle pump with the above listed assumptions are shown in Figures 15.4.4-1 through 15.4.4-5. As shown in these curves, during the first part of the transient the increase in core flow with cooler water results in an increase in nuclear power and a decrease in core average temperature. The minimum DNBR during the transient is considerably greater than the limit value.

Reactivity addition for the inactive loop startup accident is due to the decrease in core water temperature. During the transient, this decrease is due both to the increase in reactor coolant flow and, as the inactive loop flow reverses, to the colder water entering the core from the hot leg side (colder temperature side prior to the start of the transient) of the steam generator in the inactive loop. Thus, the reactivity insertion rate for this transient changes with time. The resultant core nuclear power transient, computed with consideration of both moderator and Doppler reactivity feedback effects, is shown on Figure 15.4.4-1.

The calculated sequence of events for this accident is shown on Table 15.4.1-1. The transient results illustrated in Figures 15.4.4-1 through 15.4.4-5 indicate that a stabilized plant condition, with the reactor tripped, is approached rapidly. Plant cooldown may subsequently be achieved by following normal shutdown procedures.

15.4.4.3 Environmental Consequences

There would be minimal radiological consequences associated with startup of an inactive reactor coolant loop at an incorrect temperature. Therefore, this event is not limiting. The reactor trip causes a turbine trip and heat may be removed from the secondary system through the steam generator power relief valves or safety valves. Since no fuel damage is postulated to occur from this transient, the radiological consequences associated with this event would be less severe than the steam line break event analyzed in Section 15.1.5.

15.4.4.4 Conclusions

The transient results show that the core is not adversely affected. There is considerable margin to the limiting DNBR. Thus, no fuel or clad damage is predicted.

15.4.5 A MALFUNCTION OR FAILURE OF THE FLOW CONTROLLER IN A BWR LOOP THAT RESULTS IN AN INCREASED REACTOR COOLANT FLOW RATE

(Not applicable to Catawba).

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

15.4.6.1 Identification of Causes and Accident Description

Reactivity can be added to the core by feeding primary grade water into the Reactor Coolant System via the reactor makeup portion of the Chemical and Volume Control System. Boron dilution is a manual operation under administrative con-

trol with procedures calling for a limit on the rate and duration of dilution. A boric acid blend system is provided to permit the operator to match the boron concentration of reactor coolant makeup water during normal charging to that in the Reactor Coolant System. The Chemical and Volume Control System is designed to limit, even under various postulated failure modes, the potential rate of dilution to a value which, after indication through alarms and instrumentation, provides the operator sufficient time to correct the situation in a safe and orderly manner.

The opening of the reactor water makeup control valve provides makeup to the Reactor Coolant System which can dilute the reactor coolant. Inadvertent dilution from this source can be readily terminated by closing the control valve. In order for makeup water to be added to the Reactor Coolant System at pressure, at least one charging pump must be running in addition to a reactor makeup water pump.

The rate of addition of unborated makeup water to the Reactor Coolant System when it is not at pressure is limited by administratively limiting the output of the reactor makeup water pumps. Normally, only one reactor makeup water pump is operating while the other is on standby. With the RCS at pressure, the maximum delivery rate is limited by the control valve.

The boric acid from the boric acid tank is blended with primary grade water in the blender and the composition is determined by the preset flow rates of boric acid and primary grade water on the control board.

In order to dilute, two separate operations are required:

1. The operator must switch from the automatic makeup mode to the dilute mode.

2. The start button must be depressed.

Omitting either step would prevent dilution.

Information on the status of the reactor coolant makeup is continuously available to the operator. Lights are provided on the control board to indicate the operating condition of the pumps in the Chemical and Volume Control System. Alarms are actuated to warn the operator if boric acid or demineralized water flow rates deviate from preset values as a result of system malfunction.

~~A boron dilution is classified as an ANS Condition II event, a fault of moderate frequency. See Section 15.0.1 for a discussion of Condition II events.~~

The Boron Dilution Mitigation System (BDMS) uses two source range detectors to monitor the subcritical multiplication of the reactor core. An alarm setpoint is continually calculated as 4 times the lowest measured count rate, including compensation for background and the statistical variation in the count rate. Once the alarm setpoint is exceeded, each train of the BDMS will automatically shut off both reactor makeup water pumps, align the suction of the charging pumps to highly borated water from the RWST, and isolate flow to the charging pumps from the VCT. Since these functions are automatically actuated by the BDMS, no operator action is necessary to terminate the dilution event and recover the shutdown margin. Because of the averaging scheme used by the BDMS

to determine the count rate, there is a time delay or lag between the calculated output and the actual count rate. This time delay is a function of the initial, steady-state count rate. In order to maximize this time delay, a lower bound on the initial count rate of 1 cps is assumed.

A boron dilution is classified as an ANS Condition II event, a fault of moderate frequency. See Section 15.0.1 for a discussion of Condition II events.

15.4.6.2 Analysis of Effects and Consequences

Method of Analysis

To cover all phases of the plant operation, boron dilution during refueling, cold shutdown, hot shutdown, hot standby, startup, and power operation are considered in this analysis. ← insert from attached pages

Dilution During Refueling (Mode 6)

An uncontrolled boron dilution accident cannot occur during refueling as a result of a reactor coolant makeup system malfunction. This accident is prevented by administrative controls which isolate the Reactor Coolant System from the potential source of unborated water.

Valve NV230 in the CVCS will be locked closed during refueling operations. This valve will block the flow paths which could allow unborated makeup to reach the reactor coolant system. Any makeup which is required during refueling will be borated water supplied from the refueling water storage tank.

The most limiting alternate source of uncontrolled boron dilution would be the inadvertent opening of a valve in the Boron Thermal Regeneration System (BTRS). For this case highly borated RCS water is depleted of boron as it passes through the BTRS and is returned via the volume control tank. The following conditions are assumed for an uncontrolled boron dilution during refueling:

1. Technical Specifications require the reactor to be borated to a concentration of 2000 ppm at refueling. The critical boron concentration is conservatively estimated to be 1739 ppm.

2. Dilution flow is assumed to be the design output of both reactor makeup water pumps (300 gpm). This is assumed although normally neither the reactor makeup system nor the BTRS is operated at refueling conditions.

3. Mixing of the reactor coolant is accomplished by the operation of one residual heat removal pump.

4. A minimum water volume (3588 ft^3) in the RCS is used. This is the minimum volume of the RCS for residual heat removal system operation.

Modes 3-6 are analyzed with two different methods for two different purposes. First, with the BDMS assumed to be operable, the accident is analyzed to demonstrate that there is adequate time, without restrictions on the flow rates from potential dilution sources, for the BDMS to terminate the dilution prior to criticality. This time consists of two components: 1) the period required to stroke the valves manipulated by the BDMS and 2) the period required, once the unborated water source has been isolated, to purge the remaining unborated water from the piping leading to the RCS. Second, with the BDMS assumed to be inoperable, the accident is analyzed to demonstrate that there is adequate time, possibly with restrictions on the flow rates from potential dilution sources, for the operator to terminate the dilution prior to criticality. Since the BDMS is not used in Modes 1 and 2, the analysis of these modes is similar to the analysis of Modes 3-6 with the BDMS assumed to be inoperable, but without the restrictions on flow rates.

Alarm Function Which Initiates Mitigation

Mitigation of a boron dilution accident is not assumed to begin until an alarm has warned of the abnormal circumstances caused by the event. For Modes 3-6 with the BDMS operable, the alarm function is provided by the measured source range count rate exceeding the BDMS setpoint. For Modes 3-6 with the BDMS inoperable, the alarm function is provided by the source range high-flux-at-shutdown alarm exceeding its setpoint. For Mode 2 and for manual rod control during Mode 1, the alarm function is provided by the earliest reactor trip setpoint reached. Finally, for automatic rod control during Mode 1, the alarm function is provided by the alarm which occurs when the control rods reach their insertion limits.

Dilution Volume

A postulated dilution event progresses faster for smaller RCS water volumes. Therefore, the analysis considers the smallest RCS water volume in which the unborated water is actively mixed by forced circulation. For Modes 1-3, the Technical Specifications require that at least one reactor coolant pump be operating. This forced circulation will mix the RCS inventory in the reactor vessel and each of the four reactor coolant loops. The pressurizer and the pressurizer surge line are not included in the volume available for dilution in Modes 1-3. For normal operation in Mode 4, forced circulation is typically maintained, although the Technical Specifications do not require it. The volume available for dilution in Mode 4 is therefore conservatively assumed to not include the upper head of the reactor vessel, a region which has reduced flow in the absence of forced circulation, or the pressurizer and the pressurizer surge line. Since the Technical Specifications do require operability of all four steam generators during Mode 4, all four of the reactor coolant loops, in addition to the remainder of the reactor vessel, are included in the RCS volume available for dilution. For Modes 5 and 6, the reactor coolant water level may be drained to below the top of the main coolant loop piping, and at least one train of the Residual Heat Removal System (RHRS) is operating. The volume available for dilution in these modes is limited to the smaller volume RHRS train plus the portions of the reactor vessel and reactor coolant loop piping below the minimum water level (7.5 inches above the centerline of the hot and cold leg piping) and between the RHRS inlet and outlet connections. The

minimum water level used to calculate this volume is corrected for level instrument uncertainty.

Boron Concentrations

The Technical Specifications require that the shutdown margin in the various modes be above a certain minimum value. The difference in boron concentration, between the value at which the relevant alarm function is actuated and the value at which the reactor is just critical, determines the time available to mitigate a dilution event. Mathematically, this time is a function of the ratio of these two concentrations, where a large ratio corresponds to a longer time. During the reload safety analysis for each new core, the above concentrations are checked to ensure that the value of this ratio for each mode is larger than the corresponding ratio assumed in the accident analysis. Each mode of operation covers a range of temperatures. Therefore, within that mode, the temperature which minimizes this ratio is used for comparison with the accident analysis ratio. For accident initial conditions in which the control rods are withdrawn, it is conservatively assumed, in calculating the critical boron concentration, that the most reactive RCCA does not fall into the core at reactor trip. This assumption is also conservatively applied in Mode 3 when the initial condition is hot zero power. For colder conditions in Modes 3-5, emergency procedures for reactor trip with a stuck RCCA require that, prior to the initiation of the cooldown, the boron concentration be increased by an amount which compensates for any RCCAs not completely inserted.

Dilution Flow Rate

In the absence of flow rate restrictions, the dilution flow rate assumed to enter the RCS is greater than or equal to the design volumetric flow rate of both reactor makeup water pumps. In a dilution event, these pumps are assumed to deliver unborated water to the suction of the centrifugal charging pumps. Since the water delivered by these pumps is typically colder than the RCS inventory, the unborated water expands within the RCS, causing a given volumetric flow rate measured at the colder temperature to correspond to a larger volumetric dilution flow rate within the RCS. This density difference in the dilution flow rate is accounted for in the analysis. The above assumption on flow rate is also conservatively used for Mode 6, even though valve NV-230 in the Chemical and Volume Control System (CVCS) is locked closed during refueling. This valve blocks the flow paths which could allow unborated makeup to reach the RCS. Any makeup which is required during this mode is borated water supplied from the refueling water storage tank.

Results

The calculated sequence of events is shown in Table 15.4.1-1.

Dilution During Modes in which the BDMS is Required (Modes 3-6)

During Mode 6 an inadvertent dilution from the Reactor Makeup Water System is prevented by administrative controls which isolate the RCS from potential sources of unborated makeup water. The results presented in Table 15.4.1-1 for this mode are for an assumed dilution event, for which

no mechanism or flow path has been identified. For Modes 3-6 with the BDMS operable, the results presented in Table 15.4.1-1 show that there is adequate time to reach the BDMS alarm setpoint, stroke closed the valves to isolate the source of unborated water, and purge the unborated water already in the CVCS piping, before the shutdown margin is exhausted. For Modes 3-6 with the BDMS inoperable, the results presented in Table 15.4.1-1 show that, with limitations on flow rates from potential sources of unborated water, there is adequate time for the operator to determine the cause of the dilution, isolate the source of unborated water, and initiate reboration before the shutdown margin is exhausted. In accordance with Reference 11, adequate time is judged to be at least 15 minutes for Modes 3-5 and at least 30 minutes for Mode 6. The results presented in Table 15.4.1-1 are for the dilution flow rates which, assuming the boron concentration ratios are at the reload safety analysis limits, give exactly these operator response times. Flow rates are restricted, through Technical Specifications and administrative controls, to values which are less than these analyzed flow rates, thus in practice giving even longer operator response times. Additional margin is provided by the fact there is typically margin between the assumed boron concentration ratio for a given mode and the actual corresponding concentration ratio for the reload core.

Dilution During Cold Shutdown (Mode 5)

Conditions at cold shutdown require the reactor to be shut down by at least 1.0% Δk/k. The ratio of the 1.0% Δk/k shutdown boron concentration to the critical boron concentration is assumed to be the conservatively low value of 1.15. The following conditions are assumed for an uncontrolled boron dilution during cold shutdown:

1. Dilution flow is assumed to be the design output of both reactor makeup water pumps (300 gpm).

2. Mixing of the reactor coolant is accomplished by the operation of one residual heat removal pump.

3. A minimum water volume (3588 ft^3) in the RCS is used. This is the minimum volume of the RCS for residual heat removal system operation.

Dilution During Hot Shutdown (Mode 4)

Conditions at hot shutdown require the reactor to be shut down by at least 1.3% Δk/k. The ratio of the 1.3% Δk/k shutdown boron concentration to the critical boron concentration is assumed to be the conservatively low value of 1.15. The following conditions are assumed for an uncontrolled boron dilution during hot shutdown:

1. Dilution flow is assumed to be the design output of both reactor makeup water pumps (300 gpm).

2. Mixing of the reactor coolant is accomplished by the operation of one residual heat removal pump.

3. A minimum water volume (3588 ft^3) in the RCS is used. This is the minimum volume of the RCS for residual heat removal system operation.

Dilution During Hot Standby (Mode 3)

Conditions at hot standby require the reactor to have available at least 1.30% Δk/k shutdown margin. This mode of operation is analyzed both with and without the most reactive rod cluster control assembly (RCCA) stuck out of the core. The stuck rod case is assumed to occur immediately after a reactor trip and is therefore analyzed at no-load conditions. The case with no stuck rod is analyzed at 350°F which is conservative since this is the lowest permissible temperature in this mode. For both cases analyzed, the ratio of the 1.3% Δk/k shutdown boron concentration to the critical boron concentration is assumed to be the conservatively low value of 1.15. The following conditions are assumed in each case for a continuous boron dilution during hot standby:

1. Dilution flow is assumed to be the design output of both reactor makeup water pumps (300 gpm).

2. A minimum water volume (9029 ft^3) in the Reactor Coolant System is used. This corresponds to the active volume of the Reactor Coolant System while on natural circulation, i.e., the reactor vessel upper head and the pressurizer are not included.

Dilution During Startup (Mode 2)

Startup is a transitory mode of operation. In this mode the plant is being taken from one long term mode of operation, hot standby, to another, power operation. The plant is maintained in the startup mode only for the purpose of startup testing at the beginning of each cycle. During this mode of operation, the plant is in manual control, i.e., Tavg/rod control is in manual. All normal actions required to change power level, either up or down, require operator initiation. The Technical Specifications require a shutdown margin of 1.3% $\Delta k/k$ and four reactor coolant pumps operating. Additional conditions assumed are:

1. Dilution flow rate is a conservatively high charging flow rate (300 gpm) consistent with Reactor Coolant System operation at 2250 psia and 557°F.

2. A minimum RCS volume of 9800 ft^3. This is a conservative estimate of the active RCS volume, minus the pressurizer volume.

3. The HZP, ARI, N-1, critical boron concentration is assumed to be the conservatively high value of 1350 ppm, with a very conservative constant boron worth of 15.0 pcm/ppm.

Dilution During Power Operation (Mode 1)

With the unit at power and the Reactor Coolant System at pressure, the dilution rate is limited by the capacity of the charging pumps (analysis is performed assuming all charging pumps are in operation for manual rod control, 300 gal/min, although only one is normally in operation). For automatic rod control at power, a flow capacity of 300 gal/min is also assumed. The effective reactivity addition rate is a function of the reactor coolant temperature and boron concentration. Additional conditions assumed are:

1. A minimum RCS volume of 9800 ft^3. This is a conservative estimate of the active RCS volume, minus the pressurizer volume.

2. The reactivity insertion rate calculated is based on a conservatively high value for the expected boron concentration at power at which shutdown margin is lost (1150 ppm).

The operator is alerted to an uncontrolled reactivity insertion by an over temperature ΔT trip or by the rod insertion alarms depending on whether the plant is in manual or automatic rod control.

Results

The calculated sequence of events is shown in Table 15.4.1-1.

Dilution During Refueling (Mode 6)

During refueling, an inadvertent dilution from the Reactor Makeup Water System is prevented by administrative controls which isolate the RCS from the potential source of unborated makeup water.

The most limiting conditions for an inadvertent dilution from either the BTRS or the Reactor Makeup Water System occur with the RCS drained to 26" above the bottom ID of the reactor vessel inlet nozzles.

The results for Mode 6 indicate that there are 1.95 minutes available between the time the BDMS output exceeds the alarm setpoint and the shutdown margin is exhausted. A conservative response time of 25 seconds is assumed for the valves actuated by the BDMS to open or close. Therefore, this analysis demonstrates that there is sufficient time available (~1.5 minutes) for any remaining diluted water to be flushed from the charging lines and borated water from the RWST to be injected into the RCS prior to a loss of shutdown margin.

Dilution During Cold Shutdown (Mode 5)

While in cold shutdown, the RCS thermal conditions are maintained while operating on the Residual Heat Removal System (RHRS) with the RCS drained to 26" above the bottom ID of the reactor vessel inlet nozzles.

The results for Mode 5 indicate that there are 1.95 minutes available between the time the BDMS output exceeds the alarm setpoint and the shutdown margin is exhausted. A conservative response time of 25 seconds is assumed for the valves actuated by the BDMS to open or close. Therefore, this analysis demonstrates that there is sufficient time available (~1.5 minutes) for any remaining diluted water to be flushed from the charging lines and borated water from the RWST to be injected into the RCS prior to a loss of shutdown margin.

Dilution During Hot Shutdown (Mode 4)

The results for Mode 4 indicate that there are 1.95 minutes available between the time the BDMS output exceeds the alarm setpoint and the shutdown margin is exhausted. A conservative response time of 25 seconds is assumed for the valves actuated by the BDMS to open or close. Therefore, this analysis demonstrates that there is sufficient time available (~1.5 minutes) for any remaining diluted water to be flushed from the charging lines and borated water from the RWST to be injected into the RCS prior to a loss of shutdown margin.

Dilution During Hot Standby (Mode 3)

The results for Mode 3 indicate that there are 6.13 minutes available between the time the BDMS output exceeds the alarm setpoint and the shutdown margin is exhausted. A conservative response time of 25 seconds is assumed for the valves actuated by the BDMS to open or close. Therefore, this analysis demonstrates that there is sufficient time available (~5.7 minutes) for any remaining diluted water to be flushed from the charging lines and borated water from the RWST to be injected into the RCS prior to a loss of shutdown margin.

Dilution During Startup (Mode 2)

This mode of operation is a transitory mode to go to power and is the operational mode in which the operator intentionally dilutes and withdraws

control rods to take the plant critical. During this mode, the plant is in manual control with the operator required to maintain a very high awareness of the plant status. For a normal approach to criticality the operator must manually initiate a limited dilution and subsequently manually withdraw the control rods, a process that takes several hours. The plant Technical Specifications require that the operator determine the estimated critical position of the control rods prior to approaching criticality thus assuring that the reactor does not go critical with rods below the insertion limits. Once critical, the power escalation must be sufficiently slow to allow the operator to manually block the Source Range reactor trip after receiving P-6 from the Intermediate Range (nominally at 10^5 cps). To fast a power escalation (due to an unknown dilution) would result in reaching P-6 unexpectedly, leaving insufficient time to manually block the Source Range reactor trip. Failure to perform this manual action results in a reactor trip and immediate shutdown of the reactor, allowing sufficient time prior to a loss of shutdown margin for the operator to terminate the dilution event.

However, in the event of an unplanned approach or dilution during power escalation while in the startup mode, the plant status is such that minimal impact will result. The plant will slowly escalate in power to a reactor trip on the Power Range Neutron Flux Low Setpoint (nominally 25% RTP). After reactor trip, there is ~~at least 15.2 minutes~~ for operator action prior to a loss of shutdown margin to terminate the dilution.
adequate time (at least 15 minutes per Reference 11)

Dilution During Full Power Operation (Mode 1)

1. With the reactor in automatic control, the power and temperature increase from boron dilution results in insertion of the rod cluster control assemblies and a decrease in the shutdown margin. The rod insertion limit alarms (low and low-low settings) provide the operator with adequate time (~~of the order of 64.9 minutes~~) to determine the cause of dilution, isolate the primary grade water source, and initiate reboration before the total shutdown margin is lost due to dilution.
at least 15 minutes per Reference 11

2. With the reactor in manual control and if no operator action is taken, the power and temperature rise will cause the reactor to reach the overtemperature ΔT trip setpoint. ~~The boron dilution accident in this case is essentially identical to rod cluster control assembly withdrawal accident. The maximum reactivity insertion rate for boron dilution is approximately 1.64 pcm/sec and is within the range of insertion rates analyzed.~~ Prior to the overtemperature ΔT trip, an overtemperature ΔT alarm and turbine runback would be actuated. There is adequate time available (~~of the order of 47.0 minutes~~) after a reactor trip for the operator to determine the cause of dilution, isolate the primary grade water sources, and initiate reboration before the reactor can return to criticality.
at least 15 minutes per Reference 11

15.4.6.3 Environmental Consequences

There would be minimal radiological consequences associated with a Chemical and Volume Control System malfunction that results in a decrease in boron concentration in the reactor coolant. The reactor trip causes a turbine trip, and heat may be removed from the secondary system through the steam generator power relief valves or safety valves. Since no fuel damage occurs from this transient,

If the BDMS is inoperable, the secondary source of protection against a dilution event in Modes 3 through 6 is operation action. Longer response times are required to be assumed for such manual actions. When these longer response times are considered, it is necessary to restrict the flow rates from potential dilution sources. CNS

the radiological consequences associated with this event are less severe than the steam line break event analyzed in Section 15.1.5.

15.4.6.4 Conclusions

For Modes 1 and 2, the results presented above show that there is adequate time for the operator to manually terminate the source of dilution flow. Following termination of the dilution flow, the reactor will be in a stable condition. The operator can then initiate boration to recover the shutdown margin.

For Modes 3 through 6, the BDMS, as described in Section 7.6.2.4, is the primary source of protection against a dilution event. Even considering the conservative delays assumed in this analysis, the preceding results indicate that the BDMS will automatically terminate a dilution event in Modes 3 through 6 prior to a loss of shutdown margin.

15.4.7 INADVERTENT LOADING AND OPERATION OF A FUEL ASSEMBLY IN AN IMPROPER POSITON

15.4.7.1 Identification of Causes and Accident Description

Fuel and core loading errors such as can arise from the inadvertent loading of one or more fuel assemblies into improper positions, loading a fuel rod during manufacture with one or more pellets of the wrong enrichment, or the loading of a full fuel assembly during manufacture with pellets of the wrong enrichment will lead to increased heat fluxes if the error results in placing fuel in core positions calling for fuel of lesser enrichment. Also included among possible core loading errors is the inadvertent loading of one or more fuel assemblies requiring burnable poison rods into a new core without burnable poison rods.

Any error in enrichment, beyond the normal manufacturing tolerances, can cause power shapes which are more peaked than those calculated with the correct enrichments. There is a 5 percent uncertainty margin included in the design value of power peaking factor assumed in the analysis of Condition I and Condition II transients. The incore system of moveable flux detectors, which is used to verify power shapes at the beginning of cycle, is capable of revealing any assembly enrichment error or loading error which causes power shapes to be peaked in excess of the design value.

To reduce the probability of core loading errors, each fuel assembly is marked with an identification number and loaded in accordance with a core loading diagram. Before core loading, the fuel assemblies in the Spent Fuel Pool, designated for the next fuel cycle, will have the fuel assembly identification numbers and insert identification numbers checked. Following core loading, the fuel assembly identification numbers are again checked as final assurance that the core has been loaded properly.

The power distortion due to any combination of misplaced fuel assemblies would significantly raise peaking factors and would be readily observable with incore flux monitors. In addition to the flux monitors, thermocouples are located at the outlet of about one third of the fuel assemblies in the core. There is a high probability that these thermocouples would also indicate any abnormally high coolant enthalpy rise. Incore flux measurements are taken during the startup subsequent to every refueling operation.

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Table 15.4.1-1 (Page 2)

Time Sequence of Events for Incidents Which Cause

Reactivity and Power Distribution Anomalies

Accident	Event	Time (sec.)
Startup of an Inactive Reactor Coolant Loop at an Incorrect Temperature	Initiation of pump startup	1.0
	Power reaches P-8 trip setpoint	13.4
	Rods begin to drop	13.9
	Minimum DNBR occurs	15.0
CVCS Malfunction that Results in a Decrease in the Boron Concentration in the Reactor Coolant		
1. Dilution during refueling	Dilution begins	0
	BDMS setpoint is exceeded	633
	Criticality occurs	750
2. Dilution during cold shutdown	Dilution begins	0
	BDMS setpoint is exceeded	633
	Criticality occurs	750
3. Dilution during hot shutdown	Dilution begins	0
	BDMS setpoint is exceeded	633
	Criticality occurs	750
4a. Dilution during hot standby (w/o stuck rod)	Dilution begins	0
	BDMS setpoint is exceeded	1520
	Criticality occurs	1887
4b. Dilution during hot standby (w/stuck rod)	Dilution begins	0
	BDMS setpoint is exceeded	1520
	Criticality occurs	1887

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1a. Dilution during power operation (manual rod control)	Dilution begins	-
	Reactor trip setpoint reached	0
	Operator terminates dilution	<1039
1b. Dilution during power operation (automatic rod control)	Dilution begins	-
	Rod insertion limit alarm setpoint reached	0
	Operator terminates dilution	<1618
2. Dilution during startup	Dilution begins	-
	Reactor trip setpoint reached	0
	Operator terminates dilution	<1039
3a. Dilution during hot standby (BDMS operable)	Dilution begins	0
	BDMS setpoint reached	1237
	Dilution source isolated	1262
	Borated water reaches core	<1523
3b. Dilution during hot standby (BDMS inoperable)	Dilution begins	0
	High-flux-at-shutdown alarm setpoint reached	1816
	Operator terminates dilution	<2716
4a. Dilution during hot shutdown (BDMS operable)	Dilution begins	0
	BDMS setpoint reached	1359
	Dilution source isolated	1384
	Borated water reaches core	<1681
4b. Dilution during hot shutdown (BDMS inoperable)	Dilution begins	0
	High-flux-at-shutdown alarm setpoint reached	1816
	Operator terminates dilution	<2716
5a. Dilution during cold shutdown (BDMS operable)	Dilution begins	0
	BDMS setpoint reached	739
	Dilution source isolated	764
	Borated water reaches core	<885

Table 15.4.1-1 (Page 3)

Time Sequence of Events for Incidents Which Cause

Reactivity and Power Distribution Anomalies

5.	Dilution during startup	Power range low setpoint reactor trip due to dilution	0
		Criticality occurs (if dilution continues after trip)	912
6.	Dilution during full power operation		
	a. Automatic reactor control	Operator receives low-low rod insertion limit alarm due to dilution	0
		Shutdown margin lost (if dilution continues after trip)	3894
	b. Manual reactor control	Dilution begins	0
		Reactor trip setpoint reached for overtemperature ΔT	1074
		Shutdown margin is lost (if dilution continues after trip)	3894

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	Accident	Event	Time (sec.)
5b.	Dilution during cold shutdown (BDMS inoperable)	Dilution begins	0
		High-flux-at-shutdown alarm setpoint reached	1816
		Operator terminates dilution	<2716
6a.	Dilution during refueling (BDMS operable)	Dilution begins	0
		BDMS setpoint reached	1024
		Dilution source isolated	1049
		Borated water reaches core	<1267
6b.	Dilution during refueling (BDMS inoperable)	Dilution begins	0
		High-flux-at-shutdown alarm setpoint reached	3441
		Operator terminates dilution	<5241