TU ELECTRIC

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10CFR50.36

William J. Cahill, Jr.
Group Vice President

April 30, 1993

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

SUBJECT: COMANCHE PEAK STEAM ELECTRIC STATION (CPSES)
DOCKET NOS. 50-445 AND 50-446
SUBMITTAL OF LICENSE AMENDMENT REQUEST 93-001
REANALYSIS OF INADVERTENT BORON DILUTION EVENT

REF: NRC letter from Thomas A. Bergman to William J. Cahill Jr., dated June 8, 1992, issuing Amendment 10 to Facility Operating License No. NPF-87

Gentlemen:

Pursuant to 10CFR50.90, TU Electric hereby requests an amendment to the CPSES Unit 1 Operating License (NPF-87) and CPSES Unit 2 Operating License (NPF-89) by incorporating the attached changes into the CPSES Units 1 and 2 Technical Specifications. These changes apply equally to CPSES Units 1 and 2.

The proposed changes replace the requirements associated with the Boron Dilution Mitigation System (BDMS) in the CPSES Unit 1 and 2 Technical Specification with alarms, indicators, procedures and controls to assure proper resolution of potential boron dilution events. Attachment 2 provides a detailed description of the proposed changes, a safety analysis of the changes, and TU Electric's determination that the proposed changes do not involve a significant hazards consideration. Attachment 3 provides the affected Technical Specification pages from the operating licenses, marked-up to reflect the proposed changes. The proposed changes in this license amendment request include revisions to the technical specifications (the removal of the BDMS); the addition of alarms and indicators; a change to the normal plant lineup; and procedural enhancements. All of these changes

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with the exception of the revisions to the technical specifications can be implemented under the provisions of 10CFR50.59 upon completion of an evaluation which concludes that an unreviewed safety question is not involved. However, because all these changes relate to an alternate method of addressing postulated boron dilution events, the changes are presented to the NRC for approval in a single package.

TU Electric requests approval of this proposed license amendment by June 10, 1993, with implementation of the technical specification changes to occur within 15 days after NRC approval. The remainder of the changes are to be completed prior to startup following the next refueling outage for each unit. The following compensatory actions will be in effect until all changes associated with this license amendment request are complete:

1) Within 4 hours of entry into MODES 3, 4 or 5 from MODES 1, 2 or 6, (and once per every 14 days thereafter while in MODES 3, 4 or 5), TU Electric will verify (unless startup is in progress) that either valve CS-8455 or valves CS-8560, FCV-111B, CS-8439, CS-8441, and CS-8453 are closed and secured in position; or

2) Following entry into MODES 3, 4 or 5 from MODES 1, 2 or 6, each crew of Control Room Staff will receive a briefing to discuss the type of reactivity changes that could occur during a dilution event; the indication of a dilution event; and the actions required to stop dilution, commence immediate boration and establish the required shutdown margin. For extended shutdowns, this briefing will be repeated for each crew prior to resumption of control room duties following an off duty period which exceeds 7 days. During time periods when this option is used, source range will be monitored for indication of unexplained increasing counts and inadvertent boron dilution every fifteen (15) minutes In addition, within 4 hours of entering MODE 5, TU Electric will ensure that only one Reactor Makeup Water Pump per unit (dilution source) is aligned to the supply header.

This implementation schedule will allow resolution of the temporary technical specification change authorized by Amendment 10 to NPF-87 prior to its expiration date which is June 25, 1993. The schedule and compensatory measures also assure that a level of safety commensurate with the safety evaluation enclosed in the referenced letter is maintained until all changes are completed.

In accordance with 10CFR50.91(b), TU Electric is providing the State of Texas with a copy of this proposed amendment.

Should you have any questions, please contact Mr. Bob Dacko at (214) 812-8228.

Sincerely,

William J. Cahill, Jr.

By: C. L. Terry
C. L. Terry
Vice President of Nuclear Engineering and Support

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Attachments:
1. Affidavit
2. Description and Assessment
3. Affected Technical Specification page (NUREG-1468)

Enclosures:
1. NSAC-183, "Risk of PWR Reactivity Accidents During Shutdown and Refueling", December 1992
2. Generic Letter 85-05
3. NUREG 0800 "Standard Review Plan", Section 15.4.6 Revision 1
4. CPSES FSAR Section 15.4.6 through Amendment 88

c - Mr. J. L. Milhoan, Region IV
Mr. B. E. Holian, NRR
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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

In the Matter of	)	
	)	
Texas Utilities Electric Company	)	Docket Nos. 50-445
	)	50-446
(Comanche Peak Steam Electric	)	License Nos. NPF-87
Station, Units 1 & 2)	)	NPF-89

AFFIDAVIT

C. L. Terry being duly sworn, hereby deposes and says that he is Vice President of Nuclear Engineering and Support for TU Electric, the licensee herein; that he is duly authorized to sign and file with the Nuclear Regulatory Commission License Amendment Request 93-001; that he is familiar with the content thereof; and that the matters set forth therein are true and correct to the best of his knowledge, information and belief.

C. L. Terry
Vice President of Nuclear
Engineering and Support

STATE OF TEXAS)
)
COUNTY OF DALLAS)

Subscribed and sworn to before me, on this 30 day of APRIL 1993.

Donald R. Woodlan
Notary Public

ATTACHMENT 2 TO TXX-93098

Description and Assessment

DESCRIPTION AND ASSESSMENT

I. BACKGROUND

Technical Specification 3/4.3.1, "Reactor Trip System Instrumentation", requires that the boron dilution flux doubling circuitry be operable in Modes 3, 4 and 5. The flux doubling circuitry is part of the Boron Dilution Mitigation System (BDMS) which was developed to detect and mitigate an inadvertent boron dilution event in Modes 3, 4 and 5 before a complete loss of shutdown margin occurs. The system detects a boron dilution event by monitoring the output of the source range neutron flux detectors to determine if the neutron flux has doubled over a prescribed time period. When a dilution event is detected, the BDMS isolates known dilution paths and aligns the charging pump suction to the refueling water storage tank so that any additional makeup will result in boration of the reactor coolant.

As a result of a review of the analyses for the licensing basis boron dilution event, it was identified that the inverse count rate ratio (ICRR) and the flux multiplication setpoint used in the analyses were not bounding for CPSES. As a result, the licensing basis boron dilution event analysis which shows that the BDMS will prevent a return to critical, is not applicable.

By letter TXX-92116 dated February 28, 1992, TU Electric proposed an amendment to the CPSES Unit 1 Technical Specifications to remove the boron dilution flux doubling requirements. Although the NRC did not approve the proposed amendment as a permanent change, the NRC did approve it as a temporary change, along with additional compensatory administrative requirements, to allow sufficient time to further research the issue and identify a long term solution. The temporary change expires for Unit 1 six months following the initial cycle 3 criticality and for Unit 2 six months following the initial cycle 1 criticality. The initial cycle 3 criticality for Unit 1 (December 25, 1992) was achieved prior to initial criticality for Unit 2. Therefore the temporary change expires first for Unit 1 on June 25, 1993, and needs to be addressed before that date. After that date, it may become necessary to obtain a Waiver of Compliance for operation in Modes 3, 4 and 5.

On December 15, 1992, TU Electric, three other utilities with similar BDMS designs, and Westinghouse met with the NRC to discuss an approach for mitigating a boron dilution event without the use of the BDMS which was consistent with the guidance provided in Standard Review Plan (SRP) Section 15.4.6. By letter dated February 8, 1993, the NRC indicated that the proposed approach was feasible.

Alternate potential solutions, such as relocating detectors, refining methods used to determine the ICRR, and attempts to reduce instrument error have not produced a satisfactory resolution. Therefore, this license amendment request, based on the approach presented in the December 1992 meeting, is hereby submitted.

II. DESCRIPTION OF TECHNICAL SPECIFICATION CHANGE REQUEST

The proposed changes revise Technical Specification 3/4.3.1, Reactor Trip System Instrumentation, to remove reference to the source range boron dilution flux doubling instrumentation and its associated action statement, surveillance and implementation footnotes. The specific changes are listed below:

- Table 3.3-1, Reactor Trip System Instrumentation - Delete reference to item 6b, concerning the operability of the Boron Dilution Flux Doubling instrumentation and its related footnote.

- Table 3.3-1, Table Notations - Delete Table Notation "h" concerning blocking flux doubling signals during startup and its related footnote.

- Table 3.3-1, Action Statements - Delete Action Statement 5.2 and its related footnote.

- Table 4.3-1, Reactor Trip System Instrumentation Surveillance Requirements - Delete Source Range, Neutron Flux Trip Actuating Device Operational Test R(12) and its related footnote.

- Table 4.3-1, Table Notations - Delete the portion of Table Notation (9) concerning the quarterly verification of Boron Dilution Alarm Setpoint. Also delete Table Notation (12) concerning the 18 month Surveillance Requirement of the Boron Flux Doubling circuitry and the Boron Dilution footnote.

III. ANALYSIS

A number of enhancements will be performed to the plant hardware and operations. These include:

- Installation of two additional high level alarms on the volume control tank, with alarm setpoints lower than the current high-high VCT level alarm, for improved instrumentation reliability and timeliness in identifying a potential dilution event.

- Revision to the normal operating mode of the letdown divert valve from "AUTO" to "VCT". This change enhances operator awareness during planned dilution events and eliminates the potential for masking an inadvertent dilution during routine plant operations.

- Installation of an alarm on the letdown divert valve to annunciate when the valve is not in the "VCT" position to heighten operator awareness of the potential for a dilution event during and following planned plant evolutions.

- Revisions to operating procedures to heighten operator awareness during evolutions that potentially impact boron dilution and to include the new alarms and indications for timely event recognition as well as the necessary actions required to terminate the event.

- Revisions to plant operating procedures to require the operation of at least one reactor coolant pump in MODES 3, 4 and 5 or have a valve in the flow paths of potential boron dilution sources closed or under administrative control. This change supports the revised analysis of the inadvertent boron dilution event which takes credit for the mixing volume associated with the operation of a reactor coolant pump in MODES 3, 4 and 5.

The enhancements described above have no impact on any event other than boron dilution. The physical modification, such as the addition of alarms and position indication, will be implemented in accordance with existing plant criteria. Because the alarms and indication only provide information and do not affect operations, they cannot adversely impact other events. The position of the letdown divert valve only affects the path for letdown flow. The flowpath selected for letdown does not affect any safety analyses. Thus the operational change to make "VCT" the normal operating mode has no safety impact. The procedural changes heighten the awareness of potential dilution events or provide alarm responses to mitigate potential dilution events. As such, these changes enhance the response to boron dilution events but have no other safety impact. The procedural requirement for reactor coolant pump operation or boron dilution path isolation/control in MODES 3, 4 and 5 enhances the plant operators' response to a boron dilution event. Running with at least one reactor coolant pump operating in MODES 3, 4 and 5 is already allowed by technical specifications. Thus there is no impact on safety. Isolating the dilution sources in MODES 3, 4 and 5 also has no safety impact. None of the accident analyses take credit for

these sources in the mitigation of the accident. When plant evolutions require dilution of the reactor coolant system, the process is administratively controlled and closely monitored by the operator.

As noted above, the BDMS alone could not be shown to prevent the plant from returning to critical following a boron dilution event. With the enhancements listed above, sufficient time is provided for the plant operators to take the necessary action to prevent a return to critical. The BDMS itself has no impact on any other event. Thus the portion of the change deleting the BDMS from the technical specifications has no other impact on safety.

The BDMS flux multiplication alarm will be retained as a plant design feature to provide the plant operators a diverse method for identifying a potential dilution event.

Appendix A provides a detailed Safety Analysis of the postulated inadvertent boron dilution event in MODES 3, 4 and 5 using the revised analytical methodology discussed with the NRC at the December 15, 1992 meeting. With this revised method, it is recognized that the Chemical and Volume Control System (CVCS) and the Reactor Coolant System (RCS) form a closed system, and mass imbalances which may affect the RCS may be detected in the CVCS. The analysis demonstrates that positive indication of a boron dilution event occurrence is provided to the operator and that sufficient time is available to perform all requisite activities necessary to terminate the event prior to the loss of all shutdown margin. Indications available to the operator include the Volume Control Tank water level indications and alarms, as well as other diverse backup indications and alarms (such as the source range flux multiplication alarm).

Cycle specific boron dilution event analyses will show that the event will be terminated before there is a complete loss of shutdown margin and that operator action will not be credited in the analyses until at least 15 minutes after the alarm which announces the inadvertent dilution (30 minutes when in the refueling mode). Such analyses have been successfully completed based on the enhancements discussed above, for CPSES Unit 1 Cycles 3 and 4 and CPSES Unit 2 Cycle 1.

Discussions provided in NSAC-183 and Generic Letter (GL) 85-05 indicate that an unmitigated boron dilution event is self limiting, due to inherent core reactivity feedback mechanisms, and no fuel damage is expected. For plants under licensing review, the NRC, in GL 85-05 required that protection be provided by meeting the Standard Review Plan (SRP) criteria. As discussed in Appendix A, the proposed change is consistent with the SRP guidance, and therefore, the level of protection also continues to be adequate. Thus, the consequences of the event are not significantly affected by the proposed changes.

IV. SIGNIFICANT HAZARDS CONSIDERATION DETERMINATION

TU Electric has evaluated whether or not a significant hazards consideration is involved with the proposed changes by focusing on the three standards set forth in 10CFR50.92(c) as discussed below:

Does the proposed change:

1. Involve a significant increase in the probability or consequences of an accident previously evaluated?

   The only event potentially impacted by the proposed change is the inadvertent boron dilution event. The discussion of the probability and consequences of an inadvertent boron dilution event at CPSES is provided in FSAR Section 15.4.6. Primarily, the proposed changes revise the method of detecting and mitigating the event. The only aspect of the changes that impact the potential causes of an inadvertent boron dilution event is the increased requirement to isolate potential dilution sources in MODES 3, 4 and 5. As a result, the overall probability of the event is slightly decreased.

   The alternate methods to detect and mitigate this event achieve the same basic goal as the originally proposed BDMS - to prevent a return to critical during an inadvertent dilution event. Because the BDMS as installed could not be shown to always be successful and the proposed change results in a design that does prevent a return to critical, the proposed change represents an improved response to the event. Thus it can be concluded that there is no increase in the consequences of a postulated boron dilution event.

2. Create the possibility of a new or different kind of accident from any accident previously evaluated?

   The revisions to plant procedural requirements to either operate a reactor coolant pump or to isolate/control potential dilution sources does not create the potential for a new or different kind of accident because these new requirements are configurations which have always been allowed. Similarly, the new normal position for the letdown divert valve does not create a new or different accident because the new normal position has always been an allowed position. The other procedural changes only increase the plant operators' awareness of potential boron dilution problems or provide the steps needed to respond to available indications and alarms to mitigate the potential event. As a result, these procedural changes do not create the possibility of a new or different kind of accident.

The proposed changes also include addition of new redundant VCT high level alarms and a new alarm indicating that the letdown divert valve is not in the "VCT" position. Because the alarms are passive, they do not create the possibility of a new or different kind of accident.

3. Involve a significant reduction in a margin of safety?

The design criterion and margin of safety for the previous BDMS was that the dilution event is terminated prior to the loss of all shutdown margin. The same criterion will be met following the implementation of the proposed changes. Therefore there is no reduction in the margin of safety.

Based on the above evaluations, TU Electric concludes that the activities associated with the above described changes present no significant hazards consideration under the standards set out in 10CFR50.92(c) and, accordingly, a finding by the NRC of no significant hazards consideration is justified.

V. ENVIRONMENTAL EVALUATION

TU Electric has evaluated the proposed changes and has determined that the changes do not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any effluent that may be released offsite, or (iii) a significant increase individual or cumulative occupational radiation exposure. Accordingly, the proposed changes meet the eligibility criterion for categorical exclusion set forth in 10CFR51.22(c). Therefore, pursuant to 10CFR51.22(b), an environmental assessment of the proposed changes is not required.

VI. REFERENCES

1. NUREG 1468, "Technical Specifications, CPSES Units 1 (and) 2", February 1993.

2. NUREG 0800, "Standard Review Plan", Section 15.4.6

3. Generic Letter 85-05, "Inadvertent Boron Dilution Events" January 31, 1985

4. NRC letter to Utility Subgroup on Boron Dilution from L. Raynard Wharton, dated February 8, 1993

5. NSAC-183, "Risk of PWR Reactivity Accidents During Shutdown and Refueling"

6. CPSES FSAR through Amendment 88

APPENDIX A

SAFETY ANALYSIS OF THE POSTULATED
INADVERTENT BORON DILUTION MODES
MODES 3, 4 AND 5

Pages 1 thru 32

Safety Analysis of the Postulated
Inadvertent Boron Dilution Event
Modes 3, 4, and 5

Table of Contents

I. Introduction and Background

The Inadvertent Boron Dilution event is considered in the licensing basis of Comanche Peak Steam Electric Station. This event is postulated to be initiated by a malfunction in the Chemical Volume and Control System (CVCS) which results in a decrease in the boron concentration of the Reactor Coolant System. The possibility of this event is considered for all modes of normal plant operation.

Several recent studies have been performed concerning the risk associated with inadvertent boron dilution events, particularly during shutdown and refueling. Among the most recent is NSAC-183 (December 1992), "Risk of PWR Reactivity Accidents During Shutdown and Refueling". Several conclusions of this report are relevant to the analysis of the inadvertent boron dilution event:

1) Due to their self-limiting nature, gradual boron dilution events are not expected to cause core damage, even if they are unmitigated.

2) No inadvertent criticalities have resulted from any of the gradual boron dilution events that have occurred to date.

3) The frequency of gradual boron dilution events reported at commercial nuclear plants in the United States has declined significantly in recent years. (The frequency of an inadvertent criticality from a boron dilution event is expected to be less than 1E-4 per reactor year.)

Previously, the mitigation of the inadvertent boron dilution event in those operation modes in which the reactor is subcritical (Modes 3, 4, and 5) relied on the detection of the subcritical multiplication. As the RCS boron concentration is reduced through dilution, the shutdown margin is eroded and, the subcritical multiplication factor approaches unity. Inadvertent dilutions in Mode 6 (refueling) are precluded through administrative controls.

For the analysis of this event in Modes 3, 4, and 5, subcritical multiplication is predicted through the use of an Inverse Count Rate Ratio (ICRR) curve. Traditionally, a generic, empirically-determined ICRR curve has been used to represent the subcritical multiplication seen by the source range neutron detectors. However, the cycle-specific ICRR curve is very sensitive to the location of the neutron source relative to the source range excore neutron detectors and also to the burnup of the fuel assemblies between the source and the detectors. This sensitivity makes the propriety of the generic ICCR curve to a specific core configuration difficult to demonstrate. With current analysis tools, the prediction of the source range detector response for a cycle-specific core configuration is not practical.

In the typical analyses of the inadvertent boron dilution event provided by Westinghouse for CPSES, the Boron Dilution Mitigation System (BDMS) is relied upon to detect an inadvertent boron dilution and to initiate actions to terminate the dilution. Analytically, operation of this system is simulated by predicting the time of "flux doubling" as seen by the source range neutron detectors (predicted through the use of the ICRR curve). With the use of the generic ICRR curves, the maximum flux multiplication setpoint which can be supported is approximately 2.1 - 2.3. However, the uncertainties associated with the BDMS flux multiplication setpoint are relatively large (on the order of ±30% span). The large uncertainties require that the flux multiplication setpoint be reduced from the typical analysis value of 2.0 to a Technical Specification value of ≈1.4. At CPSES, the "background" flux multiplication is nearly 1.3; thus, a flux multiplication setpoint of ≈ 1.4 is not practical from the standpoint of normal plant operations.

Because of these considerations, it is not feasible to demonstrate the adequacy of the BDMS for a particular core configuration prior to plant startup. Thus, an alternative approach has been developed. This approach is based on the detection of mass imbalances in the CVCS, which is unaffected by the previously described uncertainties. With the exception of initial and critical boron concentrations, this approach is insensitive to reload-dependent parameters. Because the values of important parameters can be predicted prior to plant start, this approach also allows for the performance of reload safety evaluations in accordance with 10CFR50.59.

II. Regulatory Basis

The inadvertent boron dilution event is analyzed to demonstrate compliance with several of the General Design Criteria described in 10CFR50, Appendix A. The NRC has developed the Standard Review Plan, NUREG-0800, Revision 2 (SRP) which provides specific guidance as to how compliance with the General Design Criteria may be demonstrated.

Even though recent studies have reported the expected frequency of occurrence of an inadvertent criticality from a gradual dilution event as ≈ 1.E-4 per reactor year, the inadvertent boron dilution event is classified as an ANS Condition II event, an event of moderate frequency in accordance with ANSI N-18.2, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants". ANS Condition II occurrences include incidents beyond normal plant operation, any one of which may occur during a calendar year of operation.

Consistent with the SRP, Section 15.4.6, the relevant General Design Criteria are GDCs 10, 15, and 26. Compliance with these GDCs is demonstrated by ensuring that the following specific criteria are satisfied:

1) The pressures in the RCS and main steam system are maintained below 110% of the design values.

2) Fuel cladding integrity shall be maintained by ensuring that the minimum DNBR remains above the 95/95 DNBR limit.

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 component failure shall be considered.

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.

For the present purposes, this definition is modified to require that the required operator action time interval extends from the time when an alarm announces an unplanned moderator dilution to the time when the corrective actions must be initiated in order to prevent a complete loss of shutdown margin.

For some events, particularly those events involving low dilution flow rates or small deviations in the boron concentrations, the time between the initiation of the event and the time at which the shutdown margin becomes completely eroded may be relatively large. Therefore, in addition to the guidance provided in Item 5, a third acceptance criterion for operator action times will be introduced:

c. The minimum time between the initiation of the event and the loss of shutdown margin: 30 minutes.

Although not specifically required for an ANS Condition II event, the inadvertent boron dilution event is currently analyzed to demonstrate that the event is terminated prior to the time the shutdown margin is completely eroded. If it is demonstrated that the reactor remains subcritical, there will be no power, pressure, or temperature excursions which could challenge the RCS and main steam system pressure limits, the minimum DNBR limits, nor lead to a more serious plant condition. Therefore, further demonstration of compliance with Items 1, 2, and 3 is not required, provided that it is shown that the shutdown margin is not completely eroded, thereby ensuring that the reactor remains subcritical.

III. Event Description

In the following discussions, the valve numbers are specific to CPSES.

One of the principal means of positive reactivity insertion to the core is the addition of unborated, primary grade water from the Reactor Makeup Control System (RMCS) into the RCS through the reactor makeup portion of the CVCS. Boron dilution with these systems is a manually initiated operation requiring close operator surveillance and is performed in accordance with strict administrative controls which limit the rate and duration of the dilution. A boric acid blend system is available to allow the operator to match the makeup boron concentration to that of the RCS during normal charging.

The principal means of causing an inadvertent boron dilution event are the opening of the RMCS control valves and the failure of the blend system, either by controller or mechanical failure. The CVCS and RMCS are designed to limit, even under various postulated failure modes, the potential rate of dilution to values which, with indication by alarms and instrumentation, will allow sufficient time for operator response to terminate the dilution. An inadvertent dilution from the RMCS may be terminated by closing the primary water makeup control valve. The expected sources of an inadvertent dilution may be terminated by closing isolation valves in the CVCS; i.e., LCV-112B and C (see Figure III-1); other sources are isolated by normally closed, manual valves. The lost shutdown margin may be regained by opening the isolation valves to the Refueling Water Storage Tank (RWST); i.e., LCV-112D and E, to allow the addition of highly borated water into the RCS.

Generally, to intentionally initiation a dilution, the operator must perform two distinct actions:

1) Switch the RMCS control of the makeup from the automatic makeup mode to the dilute or alternate dilute mode, <u>and</u>

2) Turn the RCS makeup actuation handswitch to the "start" position.

Failure to carry out either of the above actions prevents initiation of dilution.

In addition, during normal operation, the operator may add borated water to the RCS by blending boric acid from the boric acid storage tanks with unborated, primary grade water. The makeup controller will then limit the sum of the boric acid flow rate and primary grade water flow rate to the blended flow rate after turning the RMCS makeup actuation handswitch to the "start" position (i.e., the controller regulates the unborated, reactor makeup water flow rate).

An inadvertent boron dilution may be initiated by a failure in the Reactor Makeup Control System which results in either a reduction in the boric acid flow rate from the boric acid storage tanks, or an increase in the flow rate of unborated water from the Reactor Makeup Water Storage Tank (RMWST).

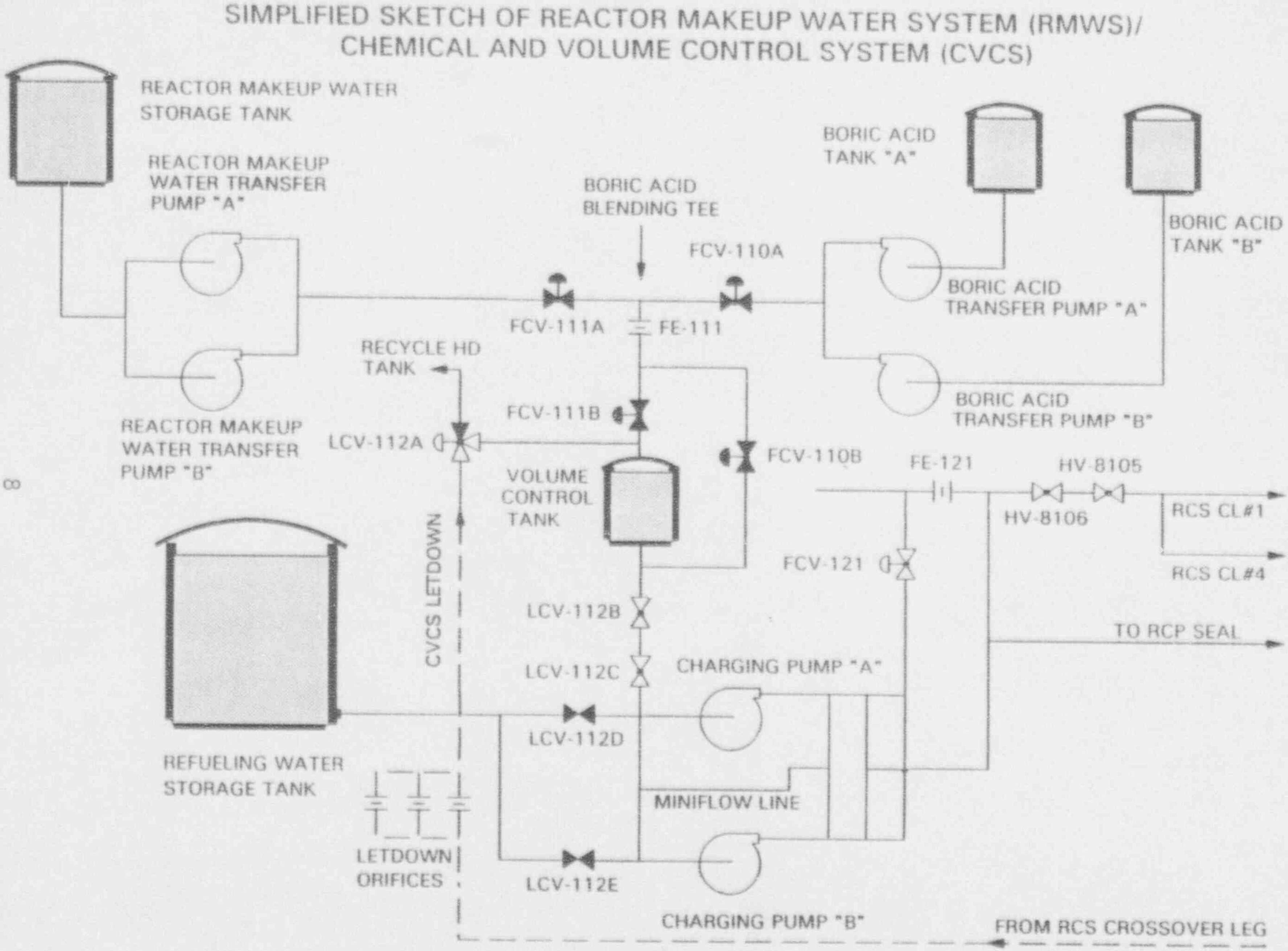


Figure III-1 Simplified schematic of the CVCS/RMCS

IV. Description of RMCS Design & Operation

The RMCS consists of a group of instruments arranged to provide a manually pre-selected makeup composition to the charging pump suction or the volume control tank (VCT). The RMCS control functions are to maintain the desired fluid inventory in the VCT and to adjust the reactor coolant boron concentration.

Under normal plant operating conditions, the RCS letdown is routed to the VCT. A three-way diversion valve (LCV-112A) is provided which may be used to divert letdown to the Recycle Holdup Tank (RHT). At CPSES, this valve is normally in the manual "VCT" mode. For planned plant evolutions performed in accordance with approved procedures, the letdown divert valve may be placed in "AUTO" (i.e., the valve will modulate to divert a certain amount of the letdown flow to the Recycle Holdup Tank), or in the manual "RHT" mode. The VCT level controller controls the operation of the letdown divert valve when in AUTO. The reactor operator controls the valve position in the manual RHT mode. In these modes, the operation of the letdown divert valve (by either automatic or manual control) would act to prevent the VCT water level from exceeding the high VCT water level alarm setpoint. Upon loss of air or electric signal, the letdown divert valve fails to the VCT position.

The control switches required to initiate a boron dilution are located on the main control board. At CPSES, two switches are provided: one mode selector switch for Off/Borate/Manual/Auto/Alternate Dilute/Dilute; and one makeup control switch for Stop/Neutral/Start.

The manual mode allows for addition of blended flow into the RWST or the spent fuel pools. While in this mode, makeup to the RCS is precluded.

The automatic makeup mode of operation of the RMCS provides a blended boric acid solution, pre-set to match the boron concentration in the RCS. The automatic makeup controller operates on demand signals from the VCT level controller. Under normal plant operating conditions, the mode selector switch is set in the "Automatic Makeup" position and the boric acid and total makeup flow controllers are set to provide the same concentration of borated water as contained in the RCS. The mode selector switch must be in the correct position and the controller energized by prior manipulation of the "Start"

switch. A pre-set low level signal from the VCT level controller causes the automatic makeup control action to start the selected reactor makeup water pumps, start the boric acid transfer pumps, open the makeup stop valve to the outlet of the VCT (FCV-110B), and position the reactor makeup water and boric acid flow control valves (FCV-111A and FCV-110A, respectively). The flow controllers automatically set the boric acid and reactor makeup water flows to the pre-set rates.

Makeup addition to the charging pump suction header via the outlet to the VCT causes the water level in the VCT to rise. At the pre-set high level point, the boric acid transfer pump stops; the reactor makeup water and boric acid flow control valves close; and the makeup stop valve closes. This operation may be terminated manually at any time by actuating the makeup stop.

The dilute mode of operation permits the addition of a pre-selected quantity of reactor makeup water at a pre-selected flow rate to the RCS. The reactor operator sets the mode selector switch to "Dilute", the total makeup flow controller setpoint to the desired flow rate, the total makeup batch integrator to the desired quantity and actuates the makeup start switch. The start signal causes the makeup control to start a selected reactor makeup water pump, open the reactor makeup stop valve to the VCT inlet (FCV-111B) and open the makeup water flow control valve. The makeup water is injected through the VCT spray nozzle and through the VCT to the charging pump suction header. When the pre-set quantity of reactor makeup water has been added, the batch integrator causes and the reactor makeup water flow control valve to close. This operation may be terminated manually at any time by actuating the makeup stop.

The alternate dilute mode of operation is similar to the dilute mode except a portion of the dilution water flows directly to the charging pump suction (through FCV-110B) and a portion flows into the VCT (through FCV-111B) before flowing to the charging pump suction. This mode of operation is used when intentionally diluting the RCS in order to minimize the delay caused by diluting the VCT before the RCS can be diluted. When the pre-set quantity of reactor makeup water has been added, the batch integrator closes the reactor makeup water flow control and reactor makeup stop valves to the inlet and outlet of the VCT. This operation may be terminated manually at any time by actuating the makeup stop.

The borate mode of operation permits the addition of a pre-selected quantity of concentrated boric acid solution at a pre-selected flow rate to the RCS. The operator sets the mode selector switch to "borate", the concentrated boric acid flow controller setpoint to the desired flow rate, the concentrated boric acid batch integrator to the desired quantity and actuates the makeup start switch. The concentrated boric acid is added to the charging pump suction header. The total quantity added in most cases will be so small that it will have only a minor effect on the VCT level. When the pre-set quantity of concentrated boric acid solution has been added, the batch integrator causes the boric acid transfer pump to stop and both the concentrated boric acid flow control and makeup stop valves to the VCT inlet to close. This operation may be manually terminated at any time by actuating the makeup stop.

V. Detection of an Inadvertent Boron Dilution Event in Modes 3, 4, and 5

The inadvertent boron dilution event is assumed to be initiated through a malfunction in the Reactor Makeup Control System or by operator error. Several indications and alarms are provided in the RMCS design for the monitoring of proper system operation. The available alarms and indications include:

- boric acid flow indication and deviation alarm,
- audible clicks from the boric acid totalizer (flow integrator),
- boric acid flow strip chart recorder,
- total makeup blended flow indication and deviation alarm,
- audible clicks from the total makeup blended flow totalizer,
- total makeup blended flow strip chart recorder, and
- high charging flow, and
- Centrifugal charging pump, boric acid transfer pump, and reactor makeup control system pump status lights.

Several potential RMCS failures will result in an increase in the VCT water level and pressure. The available alarms are the VCT high pressure, VCT high water level, and VCT high-high/full divert to RHT alarms.

Other diverse indications of an ongoing inadvertent boron dilution event are provided by the Nuclear Instrumentation System. The available indications and alarms include:

- High source range neutron flux at shutdown alarm,
- Indicated and recorded source range neutron flux rate count rate and startup rate,
- Audible source range neutron flux count rate, and
- At CPSES, source range neutron flux-multiplication alarm.

VI. Inadvertent Boron Dilution Event Scenarios

The inadvertent boron dilution event is assumed to be initiated by a malfunction in the Reactor Makeup Control System. A failure modes and effects analysis is provided below for each of the significant modes of RMCS operation with a focus on those malfunctions which result in either a reduction in the boric acid flow rate from the boric acid storage tanks, or an increase in the flow rate of unborated water from the RMWST. It is assumed that the CVCS and RMCS valve positions correspond to their normal alignments. The scenarios described below are initiated by a postulated malfunction; no additional single failure is assumed.

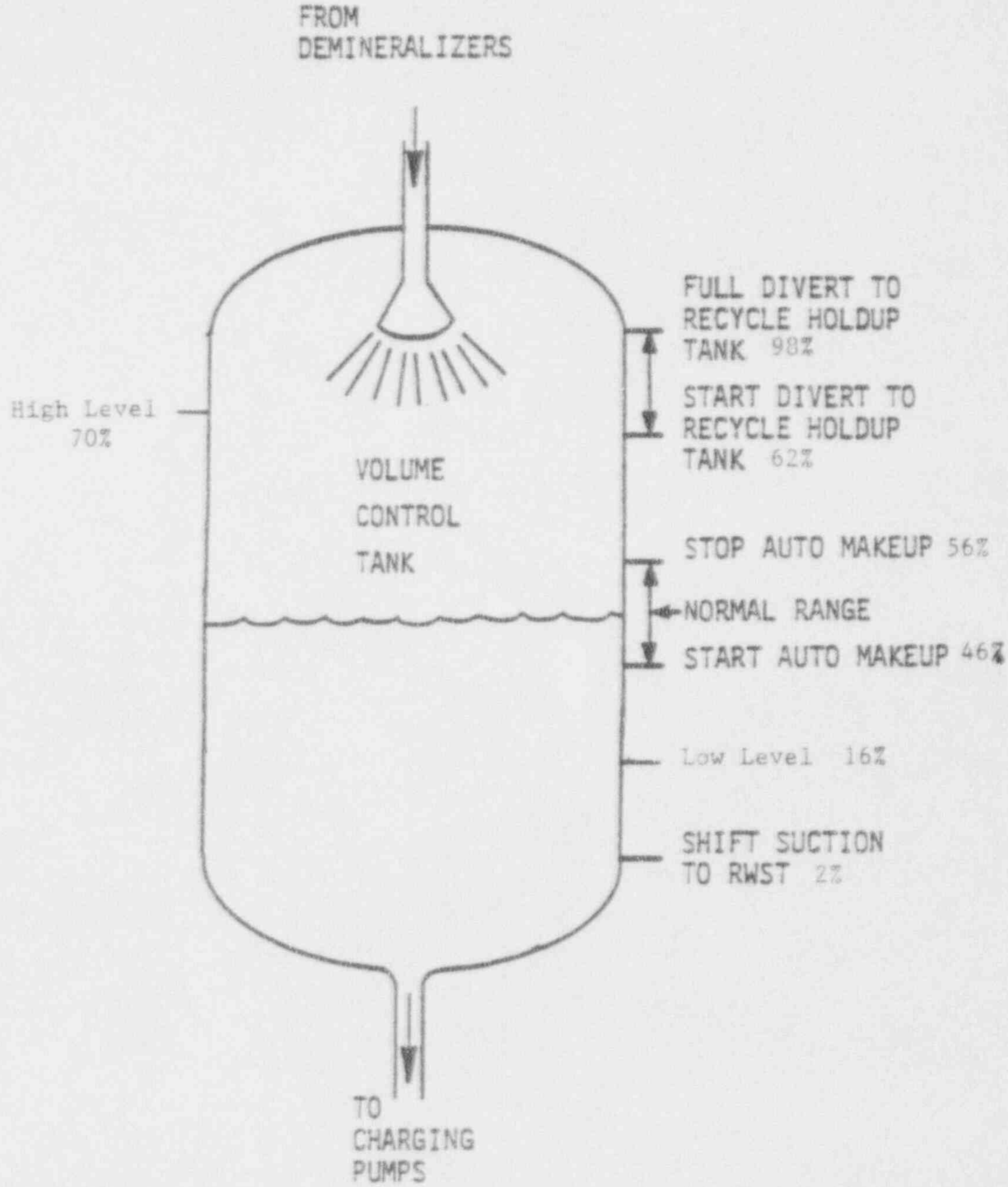
Potential inadvertent dilutions from sources other than through the RMCS (e.g., the Boron Thermal Regeneration System or Boron Recycle System) are precluded during normal operations by at least one and usually several closed manual valves. Because operations of these systems are plant evolutions performed in accordance with approved procedures and require a significant level of reactor operator interaction with the plant; these dilution scenarios are not considered further.

Automatic Operation

In this mode, the reactor operator manually sets the RMCS controller to provide the same concentration of borated water as contained in the RCS. The total makeup flow is initiated by the VCT water level controller when the VCT water level falls below the "start auto makeup" setpoint (see Figure VI-1). The flow is terminated when the VCT water level rises above the "stop auto makeup" setpoint. In this mode of operation, the potential malfunctions which could affect the inadvertent boron dilution event are:

a) Concentrated boric acid flow is less than required.
b) Reactor makeup flow is greater than required.
c) Due to operator error or calibration errors or instrument drift, the makeup water boron concentration is less than the RCS boron concentration.
d) Total makeup flow is not terminated at the "stop auto makeup" setpoint.

Figure VI-1 VCT Water Level Setpoints



Individually, potential malfunctions a, b and c could result in the addition of dilute water into the VCT and subsequently, the RCS. However, in the absence of an additional failure, the dilution would be limited to the volume of water between the "start auto makeup" and "stop auto makeup" VCT water level setpoints.

A malfunction which results in the continuation of total makeup flow to the VCT after the "stop auto makeup" setpoint has been exceeded would eventually result in a VCT high pressure or VCT high water level alarm. However, in the absence of an additional failure, no dilution would occur, because the boron concentration of the makeup would be the same as the RCS boron concentration.

Dilute and Alternate Dilute Operation

In these modes, the reactor operator intentionally injects a pre-selected quantity of reactor makeup water at a pre-selected flow rate to the RCS. These are planned dilutions, performed in accordance with approved plant procedures. The postulated malfunctions of importance to the inadvertent boron dilution event analysis are the malfunction of the RMCS to limit the flow rate of the reactor makeup water or the malfunction of the totalizer (integrator) to terminate the dilution when the requisite amount of reactor makeup water has been added. The proper operation of the totalizer would offset any failure to control the flow rate.

Borate Operation

In this mode, the reactor operator intentionally injects a pre-selected quantity of concentrated boric acid solution at a pre-selected flow rate to the RCS. There is no blending with reactor makeup water to form a more dilute boric acid solution; hence, there is no possibility for an inadvertent boron dilution event in this mode.

Design Basis Scenario

The design basis scenario for the inadvertent boron dilution event is that scenario which results in a continuous dilution at the highest dilution rate. As may be inferred from the previous discussions, only operation in the automatic and dilute/alternate dilute modes can result in inadvertent boron dilutions. In the scenarios described below, a single failure is assumed in addition to the initiating malfunction.

Because operation in the dilute/alternate dilute modes is by definition a planned plant evolution, the reactor operators are expecting a specific response in accordance with their training. It is expected that any malfunctions which occur would be immediately observed, resulting in timely operator action to mitigate the dilution. The CVCS alarms previously described are available for the detection of inadvertent dilutions. In addition, diverse alarms for the Nuclear Instrumentation System are available to assist the reactor operators in the detection of a potential malfunction. Procedural guidance is also provided to the operators concerning methods of terminating unplanned moderator dilutions. Hence, inadvertent dilutions in these modes of operation will not be considered in the development of the design basis scenario.

Any malfunction in the RMCS, while in the automatic mode of operation, coupled with an additional, single active failure, could result in the continuous injection of nearly pure water into the RCS. In order to bound all combinations of two failures (initiating malfunction plus additional single failure), the design-basis scenario for the inadvertent boron dilution event is defined to be:

1) The plant is initially at steady-state conditions, with the CVCS and RMCS valve positions in their normal alignment, which implies that the letdown divert valve is in the "VCT" position.

2) The initiating malfunction in the RMCS results in the delivery of the maximum amount of reactor makeup water (equal to maximum charging flow rate alarm) at the lowest boron concentration (0 ppm boron).

3) A single failure in the VCT level controller which results in the continuation of the dilution flow, even after the "stop auto makeup" setpoint is exceeded.

4) High VCT water level alarm provides the first alarm indicating that a boron dilution may be in progress.

5) The reactor operators are allocated 15 minutes to diagnose the event and initiate actions to isolate dilution sources and initiate re-boration. The operator response time is assumed to extend from the time when the high VCT water level is annunciated until the operator initiates corrective actions.

VII. Equipment Qualification

The following information is specific to CPSES. Recall that the inadvertent boron dilution event in Modes 3, 4, and 5 is an ANS Condition II event. As a result of this event, no automatic Reactor Trip System or Engineered Safety Features Actuation System actuations are required for event detection, termination, or mitigation. No adverse containment environments are generated.

The normal charging and letdown portions of the Chemical Volume and Control System, as well as the Reactor Makeup Control System, are "control grade" systems. The power supplies for the level, pressure and flow instrumentation are derived from Class 1E inverters. With the exception of the VCT water level channels, none of the CVCS/RMCS alarms previously mentioned are redundant. All transmitters associated with the CVCS and RMCS are subjected to periodic calibrations.

The valves required for termination of the dilution and subsequent reboration and the centrifugal charging pumps are powered from Class 1E power supplies.

VIII. Method of Analysis

For the analytical evaluation of this event, hand calculations are used to determine the periods of time required to move water at known flow rates to dilute known masses of water and to fill known volumes. Variations in the flow rates over time are smeared into constant average values. Changes in the water level in the VCT will generate alarms when setpoints are exceeded. Maximum or minimum values are assumed for flows, volumes, and boron concentrations as appropriate to effectively bound the most conservative average values. The analysis is performed over the entire range of RCS temperatures from 557°F to 68°F in order to ensure that the most conservative combinations of RCS coolant density, critical boron concentration, and shutdown margin are evaluated. The results of this analysis will demonstrate that at least 15 minutes is available for the reactor operator to initiate corrective actions in order to prevent the complete loss of shutdown margin from the time the high VCT water level alarm is generated.

RCS leakage and control system anomalies can affect the volume of water in the RCS and in the CVCS. This analysis conservatively bounds those effects by assigning a bounding steady-state mismatch value to the flows which affect the VCT water level.

Model Limitations and Assumptions

1) The RCS volume remains constant. The water level in the pressurizer does not change. Reactor operators set charging and letdown to maintain a constant system volume during steady state operations if automatic systems are not available. Small deviations of RCS mass during the dilution event can result from charging and letdown flow mismatches. A flow mismatch term is included to account for these small deviations.

2) The RCS and CVCS combine to form a closed system. Dilution water may enter the system boundary, but no water leaves the boundary. The small values of RCS leakage during operating modes can be accommodated by the flow mismatch term. All changes to the system volume are assigned to the VCT. Any addition of water to the RCS results in a change in VCT volume without changing the volume of water in any other system.

3) All dilutions occur at a constant rate. The RCS dilution is modeled as a step change from zero gpm to a constant dilution rate. The maximum dilution rate is considered.

4) The Net Operator Response Time begins only after the high VCT water level alarm is reached, and it ends at the time when operator action would no longer prevent criticality. System delays for valve manipulations and purging diluted pipes with boric acid reduce the Net Operator Response Time.

5) The subsystem temperatures are selected in such a way as to minimize the available mixing mass and maximize the dilution mass flow rate. The RCS mass is evaluated at operating MODE temperature boundaries; i.e., 557°F, 350°F, 200°F, and 68°F. The CVCS/RMCS fluid is evaluated at 45°F. Maximizing the density of the CVCS/RMCS and minimizing the density of the RCS act to increase the dilution rate.

6) The RCS temperature remains constant. The small fluctuations in RCS temperature during steady-state operations can be accommodated with the flow mismatch term.

7) The reactor is shutdown and the initial boron concentration is sufficient to meet the minimum shutdown margin required for each particular mode of operation, in accordance with the plant Technical Specifications.

8) It is assumed that the most reactive rod is stuck out of the core.

9) A conservatively low value for the Reactor Coolant System volume is assumed. This volume includes the reactor vessel, loop piping, reactor coolant pumps, and steam generator tubes. The volumes of the reactor vessel upper head, the pressurizer, the pressurizer spray and surge lines, the CVCS, and the Residual Heat Removal System are not included. The volumes are based on cold metal dimensions, with no allowance for thermal expansion of the volumes.

10) All times in core lifetime are considered. Generally, BOL is limiting due to the higher boron concentrations which maximize the dilution rate.

As described in Section VI, the design basis inadvertent boron dilution event is assumed to be initiated from normal steady-state conditions with all CVCS and RMCS valves in their normal positions for the shutdown modes of operation. In this state, all letdown is eventually returned to the VCT. The event is assumed to be initiated when the RMCS initiates auto makeup, based on the VCT water level at the "start auto makeup" setpoint. The initiating event is assumed to be a malfunction in the RMCS which results in the delivery of dilute (0 ppm boron) water into the charging pump suction. This dilute fluid is then injected into the RCS through the normal charging flow path. An additional failure in the VCT water level controller is assumed such that the dilution continues after the VCT water level has risen above the "stop auto makeup" setpoint.

Even though it is likely other alarm functions will have annunciated, it is assumed that the reactor operator is first made aware of the RMCS malfunction when the high VCT water level alarm annunciates. To terminate the event and initiate re-boration, the reactor operator must re-align the suction of the charging pumps from the VCT to the RWST. The dilute water in the CVCS lines must be purged before the borated water from the RWST enters the RCS, terminating the event. In the analysis of this event, it must be demonstrated that following receipt of the high VCT water level alarm, the reactor operator has at least fifteen minutes in which to initiate the re-alignment of the charging pump suction from the VCT to the RWST prior to the time that the shutdown margin is completely eroded. The actual time available for reactor operator response is referred to as the "Net Operator Response Time."

<u>Variables</u>

All variables used in the hand calculations are defined in Table VIII-1. Variables are defined in three types: (1) Input: a physical parameter fixed by the operating characteristics of the plant, (2) Property: determined from steam tables, and (3) Calc: a calculation result determined by algebraic combinations of the inputs and properties. A "conservative direction" has been assigned to the inputs. The conservative direction minimizes the time between the alarm annunciation and the loss of shutdown margin. This assumption, in turn, minimizes the available time interval for operator action. All other conservative directions are selected based on how the time interval available for operator action is affected. Because all properties are extracted directly from the 1967 ASME steam tables, no conservative direction is applied.

Table VIII-1
Definition of Variables

Type	Variable	Definition	Conservative Direction
Input	VRCS - ft^3	RCS Mixing Volume	Low
Input	TRCS - °F	Initial Temperature of RCS Mixing Volume	High
Property	vRCS - ft^3/lbm	Specific Volume of Water in VRCS	
Input	VVCT - ft^3	Volume of VCT between "start auto makeup" and "high VCT water level" alarm setpoints, plus uncertainties	High
Input	TVCT - °F	VCT/CVCS Purge Volume Temperature	Low
Property	vVCT - ft^3/lbm	Specific volume of water in VCT/Purge Volume	
Input	VPURG - ft^3	CVCS Purge Volume	High
Input	QCHRG -gpm	Charging Flow	High
Calc	tPURG - min	Purge time of charging line	
Input	QMIS - gpm	Mismatch flow: Net Letdown minus Net Charging	Most negative
Input	QDIL - gpm	Dilution flow rate	High
Input	BCRIT - ppm	Critical boron concentration	High
Input	BRCS - ppm	Initial boron concentration	Low
Calc	tFILL - min	Time to fill VVCT	
Calc	tCRIT - min	Time to dilute from BRCS to BCRIT	
Input	tSWAP - min	Total time of VCT/RWST swapover	High
Calc	tOP15 - min	Net Operator Response Time	

Inputs and Properties

RCS Mixing Volume (VRCS): This volume corresponds to the number of cubic feet of water which becomes diluted during the transient. This volume includes the reactor vessel, hot legs, cold legs, reactor coolant pumps, and steam generator tubes. It does not include the reactor vessel head, the CVCS, the Residual Heat Removal System, the pressurizer, or the pressurizer spray and surge lines. The volumes are based on cold metal dimensions; i.e, the thermal expansion at elevated temperatures is neglected. An allowance for plugging of 10% of the steam generator tubes is provided.

The entire mixing volume of the RCS can be included if at least one reactor coolant pump is operating. The proposed Technical Specification changes for CPSES will preclude boron dilutions, except under strict administrative controls, unless at least one reactor coolant pump is operating.

Initial Temperature of the RCS Mixing Volume (TRCS): This temperature is used to determine the density and mass in VRCS. The temperature is dependent on the specific operational mode under consideration.

Specific Volume of Water in VRCS (vRCS): This parameter is the saturated water specific volume at TRCS. The temperature is dependent on the specific operational mode under consideration.

Volume of VCT between Start Auto Makeup and High VCT Water Level Setpoints (VVCT): This parameter is the number of cubic feet of water required to actuate a high VCT water level alarm assuming the transient begins from just below the "start auto makeup" setpoint. Uncertainty allowances of ±5% of span are provided, thereby increasing the total difference in the setpoints by 10% span.

Charging Temperature (TVCT): This parameter is the temperature of the water in the purge volume and is used to determine the density and mass of the purge fluid. In order to maximize the dilution, the temperature is set to the conservatively low value of 45°F. This temperature is also assumed for the VCT and the letdown. Lower temperatures are not expected during normal operations.

Specific Volume of Water in VPURG (vVCT): This parameter is the saturated water specific volume at TVCT.

Purge Volume (VPURG): This parameter corresponds to the number of cubic feet of diluted water which must be purged from the charging system piping before the more heavily borated water from the RWST reaches the cold leg. This volume is required to extend from the check valve downstream of the RWST isolation valves to the injection point of the charging flow into the RCS. However, for conservatism in the CPSES analysis, this volume is increased to include the volume of pipes and components upstream of the RWST check valve back to the RWST supply line isolation valves (LCV-112D and E) and the volume upstream of the VCT/RWST tee back to the VCT isolation valves (LCV-112B and C). Because the effect of the purge volume is to delay the injection of boron into the cold leg, it is conservative to use a maximum purge volume for a particular plant condition.

Charging Flow Rate (QCHRG): This parameter is set equal to the sum of the seal injection and normal charging flow rates. All of the charging flow is assumed to enter the RCS mixing volume. This flow is limited on the high side to 150 gpm by the alarm limits for this parameter. A +5% uncertainty allowance for the flow instrumentation is provided.

Flow Mismatch (QMIS): This term is used to account for all of the effects which would invalidate the constant RCS volume or mass assumption. Small control system fluctuations or temperature changes could result in a mismatch between the charging and letdown flow rates, and small RCS leaks could also increase the need for charging. Because these mismatches could affect the VCT level, it is necessary to explicitly account for them. QMIS is defined by:

$$QMIS \equiv \text{Letdown (gpm)} - \text{Charging (gpm)}$$

The value of QMIS will conservatively be set to -22 gpm. The 22 gpm penalty is based on 12 gpm RCP seal return leakage allowance and 10 gpm for control system uncertainties and system leakage. (Note that the reactor coolant pump seal leakoff is returned to the CVCS downstream of the VCT.) A 10 gpm control system bias is considered to be easily detectable, as it would result in an increase in the pressurizer water level of ≈ 15% span over a 30 minute period. A negative value of QMIS will result in a decreasing VCT water level, which would act to delay the high VCT water level alarm expected if dilution flow was filling the VCT.

Dilution Flow Rate (QDIL): This parameter is the rate at which water flows into the charging pump suction from a diluted water source. The most limiting value of QDIL is always less than or equal to the charging flow rate. If QDIL is greater than the charging flow rate, then the VCT water level would change faster without resulting in a more rapid RCS dilution. The RCS dilution rate is limited by the value of the charging flow rate, QCHRG. For this reason, QDIL must always be less than or equal to QCHRG. A larger dilution rate is conservative; hence, QDIL will be assumed to be equal to QCHRG.

Critical Boron Concentration (BCRIT): The value of this parameter is calculated on a cycle-specific basis. A conservatively large value maximizes the dilution rate. The core conditions correspond to the critical, zero power, all rod inserted except for the most reactive rod, which is assumed to be fully withdrawn (ARI, N-1) condition. These values are calculated at 557°, 350°, 200°, and 68°F. The highest value over the cycle life is used. Uncertainties associated with the critical boron calculation are applied in accordance with the shutdown margin calculational methodology.

Initial RCS Boron Concentration (BRCS): The value of this parameter is calculated on a cycle-specific basis. The core conditions correspond to the ARI, N-1 condition which just meets the Technical Specification shutdown margin value for a particular operational mode. These values are calculated at 557°, 350°, 200°, and 68°F. The time in cycle lifetime is consistent with the BCRIT calculation. Uncertainties associated with the critical boron calculation are applied in accordance with the shutdown margin calculational methodology.

Total Time of Valve Swapover (tSWAP): This parameter is the sum of the opening time of the RWST isolation valves and the closing time of the VCT isolation valves. Due to the valve stroke times, this value is 25 seconds (0.417 minutes).

Calculated Variables

The calculated variables can be expressed in terms of the inputs and properties defined in the previous section.

Purge Time of the Charging Line (tPURG): The value of this parameter is the period of time from the end of the valve swapover to the time that borated water from the RWST enters the RCS. tPURG is defined by the following equation:

$$tPURG = \frac{VPURG}{QCHRG} * 7.4805\ \text{gal/ft}^3$$

Time to Fill VVCT (tFILL): The value of this parameter is the period of time required to increase the net volume of the RCS and CVCS by the amount VVCT. The time required to fill the VCT is affected by both the dilution flow rate and by the charging/letdown flow mismatch.

tFILL can be defined by the following equation:

$$tFILL = \frac{VVCT}{\{(QDIL + QMIS) \div 7.4805\ gal/ft^3\}}$$

<u>Time to Dilute from BRCS to BCRIT (tCRIT):</u> This parameter is defined as the period of time to dilute VRCS from the shutdown margin concentration to the critical concentration. When the charging flow rate is greater than the dilution flow rate, then the water from the VCT can affect the charging line boron concentration. This calculation does not consider the benefits of the additional mixing volumes provided by the VCT or the CVCS piping in the letdown streams. tCRIT is dependent upon the dilution flow rate and the density corrected volume of VRCS only. If QCHRG $\geq$ QDIL, then tCRIT can be defined by the following equation.

$$tCRIT = (VRCS/QDIL) \cdot (vVCT/vRCS) \cdot (7.4805\ gal/ft^3) \cdot \ln(BRCS/BCRIT)$$

<u>Net Operator Response Time (tOP15):</u> This parameter is the period of time from the high VCT water level alarm to the last opportunity for the operator to actuate the valve swap-over. tOP15 can be defined by the following equation:

$$tOP15 = tCRIT - tFILL - tSWAP - tPURG.$$

The only cycle-specific term in the above equation is tCRIT. Hence, tOP15 may be expressed in the following form:

$$tOP15 = K_1 \ln(BRCS/BCRIT) - K_2.$$

The event acceptance criterion is satisfied if tOP15 $\geq$ 15 minutes. The above equation may be re-arranged to give:

$$\frac{BRCS}{BCRIT} \geq e^{((15\ min\ +\ K2)/K1)}, \text{ or}$$

$$\frac{\dfrac{BRCS}{BCRIT}}{e^{((15\text{ min} + K2)/K1)}} \geq 1 \qquad \text{Eqn. VIII-1}$$

where:

$$K_1 = \frac{(VRCS)}{QDIL} \cdot \frac{(vVCT)}{vRCS} \cdot (7.4805\ \text{gal/ft}^3)\text{, and}$$

$$K_2 = \left(\frac{VVCT}{\{(QDIL + QMIS) \div 7.4805\}}\right) + \frac{(VPURG)}{QCHRG} \cdot (7.4805) + tSWAP$$

The left hand side of Equation VIII-1 is referred to as the boron concentration limit ratio and forms the basis for evaluating the acceptability of a core reload design for this event.

IX. CPSES Analysis Inputs and Results

The following values of the previously defined input and property parameters are applicable to CPSES Units 1 and 2.

Table IX-1
CPSES Values

Type	Variable	Definition	Value
Input	VRCS - ft^3	RCS Mixing Volume	8700
Input	TRCS - °F	Initial Temperature of RCS Mixing Volume	*
Property	vRCS - ft^3/lbm	Specific Volume of Water in VRCS	*
Input	VVCT - ft^3	Volume of VCT between "start auto makeup" and "high VCT water level" alarm setpoints, plus uncertainties	87.27
Input	TVCT - °F	VCT/CVCS Purge Volume Temperature	45
Property	vVCT - ft^3/lbm	Specific volume of water in VCT/Purge Volume	.016021
Input	VPURG - ft^3	CVCS Purge Volume	85.19
Input	QCHRG -gpm	Charging Flow	157.5
Input	QMIS - gpm	Mismatch flow: Net Letdown minus Net Charging	-22
Input	QDIL - gpm	Dilution flow rate	157.5
Input	BCRIT - ppm	Critical boron concentration	*
Input	BRCS - ppm	Initial boron concentration	*
Input	tSWAP - min	Total time of VCT/RWST swapover	0.417

* Cycle/Temperature Specific Value

Substituting the values in Table IX-1 into Equation VIII-1, the following expression is obtained:

$$\frac{\frac{BRCS}{BCRIT}}{e^{(3.6678 * vRCS)}} \geq 1 \qquad \text{Equation IX.1}$$

For CPSES Unit 1, Cycle 3, the temperature dependent initial and critical boron concentrations are shown in Table IX-2. Note that for CPSES Unit 1, the required shutdown margin in Modes 3 and 4 is 1.6% $\Delta k/k$ and 1.3% $\Delta k/k$ for Mode 5. For CPSES Unit 2, Cycle 1, the relevant boron concentrations are based on the required shutdown margin of 1.3% $\Delta k/k$ for all modes of operation. For demonstration purposes, the CPSES Unit 1, Cycle 4 boron concentrations include a 1.3% $\Delta k/k$ shutdown margin for all modes, even though the requirement for Modes 3 and 4 is 1.6% $\Delta k/k$.

The values presented below are representative of the beginning-of-cycle conditions. For these core configurations, BOC was evaluated to be limiting for this event.

Table IX-2

CPSES Unit and Cycle-Specific Boron Concentrations

Unit/Cycle	557°F		350°F		200°F		68°F	
	BRCS	BCRIT	BRCS	BCRIT	BRCS	BCRIT	BRCS	BCRIT
CPSES 1, Cycle 3	1204	1042	1329	1194	1340	1215	1337	1240
CPSES 1, Cycle 4	1562	1414	1647	1523	1665	1549	1671	1561
CPSES 2, Cycle 1	747	659	873	792	952	873	1013	934

Again, substituting the values in Table IX-2 into Equation IX.1, the following CPSES-specific results are obtained.

Table IX-3

CPSES Analysis Results
Modes 3, 4, and 5

RCS Temperature	557°F	350°F	200°F	68°F
vRCS (ft^3/lbm)	.021974	.017988	.016634	.016047
$e^{(3.6678*vRCS)}$	1.084	1.068	1.063	1.061
Unit 1, Cycle 3 Limit Ratio	1.066	1.042	1.038	1.016
Unit 1, Cycle 4 Limit Ratio	1.019	1.012	1.011	1.009
Unit 2, Cycle 1 Limit Ratio	1.046	1.032	1.025	1.023
Ratio Acceptance Limit	≥1.000	≥1.000	≥1.000	≥1.000

From Table IX-3, it may be observed that the limit ratio is greater than the value of the acceptance limit for Moes 3, 4, and 5, indicating that the reactor operators have greater than 15 minutes in which to perform the actions required to terminate an inadvertent boron dilution event before the shutdown margin is completely eroded.

Other Considerations

The design basis analysis previously described is initiated from a steady-state condition. Allowances for normal fluctuations in RCS temperature and small RCS leakage paths have been provided. The maximum dilution rate has been considered. These analysis assumptions are consistent with the design basis analysis currently presented in the Section 15.4.6 of the Final Safety Analysis Report and with the guidance provided in the Section 15.4.6 of the Standard Review Plan, NUREG 0800, Revision 1.

There are other plant evolutions which are not obviously bounded by the scenario described above. For small dilution flow rates, the time required to fill the VCT to the high VCT water level setpoint may be greater than the time required to dilute the RCS to the critical condition; however, the total time available for operator action can be shown to exceed 30 minutes. Alarms available to alert the reactor operator of a potential inadvertent boron dilution event include the concentrated boric acid flow and total makeup flow deviation alarms. The alarms generated by the Nuclear Instrumentation System, or the available trend recorders may be of more use to aid the reactor operators in the identification of an inadvertent boron dilution event for these slow dilution cases.

During the planned plant heatup and cooldown transients, the CVCS and RMCS may not be in their normal alignments. However, these evolutions are transitions between stable plant states and are performed in accordance with approved procedures. Strict administrative controls are in place which require significant operator interaction with the plant. In accordance with their training, the reactor operators are expecting specific responses during the evolutions and deviations from the norm receive additional attention.

During a plant heatup, water from the RCS is expelled from the closed RCS/CVCS system into the Recycle Holdup Tank. The dilution sources are typically isolated during this mode of operation in order to minimize the liquid radwaste processing above the letdown flow already being diverted to the RHT. If, through operator error, a dilution mechanism was introduced, the letdown divert valve would not be in the "VCT" mode; hence, the high VCT water level alarm function is not an appropriate alarm for use in the detection of an inadvertent boron dilution event. However, the total makeup flow and concentrated boric acid flow rate deviation alarms remain useful, and the Nuclear Instrumentation System continues to provide diverse alarms and indications of inadvertent reactivity changes.

Prior to performance of a plant cooldown, the RCS is borated to that concentration required to maintain the shutdown concentration at the target temperature. During the cooldown itself, the mismatch between the charging and letdown flow rates is fairly large, as additional fluid is injected into the RCS to compensate for shrinkage. This exceptionally large mismatch between the charging and letdown flow rates may be sufficient to mask certain indications of an inadvertent boron dilution. However, the total makeup flow and concentrated boric acid flow rate deviation alarms remain useful, and the

Nuclear Instrumentation System continues to provide diverse alarms and indications of inadvertent reactivity changes. In addition, cooldowns are performed with the reactor trip breakers open; hence, the assumption that the most reactive rod is withdrawn from the core is not necessary. Consideration of this assumption alone is sufficient to compensate for all cooldown scenarios allowed within the context of the plant technical specifications.

X. CPSES-Specific Actions Required for Implementation

The revised analytical methodology for the inadvertent boron dilution event is based on the premise that certain plant-specific activities will be completed prior to implementation. These activities are:

- Installation of an alarm on the letdown divert valve (LCV-112A) which will annunciate when the valve is not in the "VCT" mode. The VCT mode is defined as the normal mode; hence, the annunciator window will be dark during normal operations.

- Installation of redundant alarms for high VCT water level. The analysis is based on the assumption that a new VCT water level alarm function will be created. The setpoint for this function (70% span) is credited in the analysis, and is lower than the current high-high VCT water level alarm (98% span) and greater than the "stop auto makeup" setpoint (56% span).

- Alarm procedures for the CVCS alarms will be enhanced to alert the reactor operators to the possibility of an inadvertent boron dilution event.

- Administrative controls will be implemented which preclude the dilution events unless at least one reactor coolant pump is operating.

XI. Summary

The original analysis of the inadvertent boron dilution event for Modes 3, 4, and 5, described in FSAR Section 15.4.6, was based on the operation of the Boron Dilution Mitigation System. Since that analysis was developed, concerns have been identified which render the BDMS of little use from an accident analysis standpoint. Thus, a revised analytical methodology for the inadvertent boron dilution event has been developed.

With this revised method, it is recognized that the Chemical and Volume Control System and the Reactor Control System form a closed system, and mass imbalances which affect the RCS may be detected in the CVCS. Numerous alarms functions in the CVCS have been identified which will provide indication to the reactor operators of a potential inadvertent boron dilution event. The Nuclear Instrumentation System also provides several diverse alarms to assist the reactor operators in the detection of such an event.

Using the revised analysis methodology, an analysis of the event has been performed for Comanche Peak Steam Electric Station, Unit 1 (Cycles 3 and 4) and Unit 2 (Cycle 1). Compliance with event-specific acceptance criteria, selected to be consistent with the guidance of the Standard Review Plan, has been demonstrated for these core configurations.