PSNH

Public Service of New Hampshire

New Hampshire Yankee Division

Wendell P. Johnson
Vice President

July 25, 1985
SBN-848
T.F. B7.1.2

United States Nuclear Regulatory Commission
Washington, D. C. 20555

Attention: Mr. George W. Knighton, Chief
Licensing Branch No. 3
Division of Licensing

References:
(a) Construction Permits CPPR-135 and CPPR-136, Docket Nos. 50-443 and 50-444
(b) USNRC Letter, dated September 30, 1981, "Acceptance Review of Application for Operating Licenses for Seabrook Station, Units 1 and 2," D. G. Eisenhut to W. C. Tallman
(c) "Safety Evaluation Report Related to the Operation of Seabrook Station, Units 1 and 2," NUREG-0896, March 1983
(d) PSNH Letter (SBN-432), dated January 25, 1983, "Open Item Response (SRP 15.4.6 Reactor System Branch)," J. DeVincentis to G. W. Knighton
(e) E. W. Hagen, "Evaluation of Events Involving Unplanned Boron Dilutions in Nuclear Power Plants," NUREG/CR-2798, ORNL/NSIC-208, July 1982

Subject: Response to SER Confirmatory Issue 40; Inadvertent Boron Dilution (15.4.6) - Final Response

Dear Sir:

As committed to in Reference (d), please find enclosed revised FSAR Section 15.4.6 (Attachment 1) and marked-up FSAR Section 7.6 (Attachment II) which demonstrates Seabrook Station's compliance with Section 15.4.6 of the Standard Review Plan (SRP) regarding inadvertent boron dilution events. This information will be incorporated into the FSAR by a future amendment.

Bounding dilution events for each operational mode were analyzed. This analysis and the results are discussed in Attachment I. The conclusion reached was that for each operational mode the elapsed time between the alarm/indication and potential loss of all shutdown margin meets the time intervals requirements of the SRP (i.e., sufficient time for operator action).

It should be noted that the analysis performed was based on a change to the control rod absorber material (i.e., using Ag-In-Cd in lieu of B_4C for the absorber material). This change will be incorporated into the FSAR by a

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future amendment. Any Technical Specification changes required from this analysis will be provided with Seabrook's proposed Technical Specifications which are scheduled for submittal by July 26, 1985. In order to further assist your review, it should also be noted that our responses to RAI Nos. 440.91 through 440.99 and 440.128 have been superseded, in part or whole, by the enclosed revision of FSAR Section 15.4.6.

Further, to justify credit for operator action in mitigating the consequences of inadvertent dilution, we supplemented existing indications and alarms with a Shutdown Monitor System. This monitoring system is described in Attachment II. This system provides a measure of conservatism above and beyond previous plant designs included in the Reference (e) study, wherein it was indicated that in each inadvertent boron dilution event, for plants without this system, the operations personnel had more than sufficient time to take corrective or mitigative action before the safety margin was seriously challenged. In light of this we believe that normal administrative controls are sufficient to assure satisfactory operation and maintenance of the Shutdown Monitor System.

This response fulfills the commitment we made in Reference (d). We do not plan to take any further action in regard to this issue except as described above and in Attachments I and II and, therefore, request your written notification by August 23, 1985, that the enclosed is acceptable.

Very truly yours,

Johnson
Wendell P. Johnson
Vice President

Enclosures

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SBN- 848

ATTACHMENT I

REVISED FSAR SECTION 15.4.6
(BORON DILUTION EVENT)

15.4.6 Chemical and Volume Control System Malfunction That Results in a Decrease in the 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 makeup water into the Reactor Coolant System (RCS) via the reactor makeup portion of the Chemical and Volume Control System (CVCS). A boric acid blend system is provided to permit the operator to match the boron concentration of reactor makeup water during normal charging to that in the RCS. 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. The CVCS 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 makeup water (RMW) control valve and one of the stop valves provides a flow path to the RCS, which can dilute the reactor coolant. Inadvertent dilution from this source can be readily terminated by closing the control valve. The rate of addition of unborated makeup water to the RCS when it is not at pressure is limited by the capacity of the RMW pumps. Normally, only one RMW pump is operating while the other is on standby. In order for makeup water to be added to the RCS at pressure, at least one charging pump must be running in addition to a RMW pump. With the RCS at pressure, the maximum delivery rate is limited by the capacity of the charging pumps, which is more limiting than the capacity of the RMW pumps.

Information on the status of the RMW is continuously available to the operator. Lights are provided on the control board to indicate the operating condition of the pumps in the CVCS. 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.

An additional source of unborated water which can dilute the reactor coolant is the Boron Thermal Regeneration System (BTRS). Borated RCS water is depleted of boron as it passes through the BTRS.

The combined dilution capability from the RMW System and the BTRS potentially represents the worst possible case for RCS boron dilution. However, the BTRS is excluded as a potential source of unborated water during refueling, cold shutdown, and hot shutdown. Technical Specifications require that this be redundantly accomplished by rendering the BTRS Chiller Compressor inoperable and bypassing the BTRS Regenerative Demineralizers. Thus, the limiting dilution flow rate during these three modes of operation is assumed to be the maximum flow capacity of the RMW System.

Regardless of the cause of a dilution event, numerous alarms and indications including a Shutdown Monitor System alarm will alert the operator to a potential loss of shutdown margin. The Shutdown Monitor System augments the source range nuclear instrumentation by monitoring for statistically significant increases in the excore neutron flux, as an indication of a potential return to criticality. Specifically, when the neutron count rate increases to 1.5 times the initial (or base) count rate, an alarm is generated. Further description of the Shutdown Monitor System is provided in Section 7.5.

The boron dilution event is classified as an ANS Condition II incident (a fault of moderate frequency) as defined in Section 15.0.1.

15.4.6.2 Method of Analysis

The method of calculating the time to lose all shutdown margin is briefly described below. If a boron mass balance is formed, the following relationship can be derived:

$$C(t) = C_o e^{-\alpha t}$$

$$\alpha = Q \rho_{DIL} / (7.481 \, V \, \rho_{RCS})$$

where:

$C(t)$ = time-dependent core boron concentration, ppm

C_o = initial core boron concentration, ppm

t = time after event initiation, minutes

Q = constant diluent volumetric flow rate, gpm

ρ_{DIL} = diluent density at 70°F, 62.3 lb/ft^3

ρ_{RCS} = density of RCS fluid, lb/ft^3

V = effective mixing volume within the RCS, ft^3

In this equation, the diluent (injection flow) is assumed to have zero boron content.

The above equation may be rearranged to calculate the time to loss of shutdown margin.

$$t_c = \frac{1}{\alpha} \ln (C_o / C_c)$$

where

C_c = critical boron concentration, ppm

From this equation, it is seen that the portion of the RCS available for mixing the incoming diluent affects the time to lose shutdown margin. The results of LOFT Experiment L6-6 on Boron Dilution(10) show that mixing occurs in volumes having sufficiently high fluid velocities. That is, velocities must be high enough to cause flow induced diffusion.

Fluid velocities in various RCS components were calculated for the limiting condition of one RHR pump operating with the RCS System full. Table 15.4-14 provides a comparison of the calculated velocities versus velocities required for flow induced diffusion taken from Reference 10. The LOFT L6-6 experiment scaling was based on a reactor which is nearly identical to Seabrook. So, the fluid velocities shown in Table 15.4-14 are applicable. The calculated steady-state velocities are greater than that required to induce boron diffusion. Moreover, the steady flow through the RCS loops assure that they are swept out and therefore participate in the mixing process. In conclusion, credit for mixing in the RCS loops is appropriate when the loops are full.

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

1. Dilution During Refueling

   The following conditions are assumed for an uncontrolled boron dilution during refueling:

   a. Technical Specifications require that a minimum of 2000 ppm be maintained during refueling. With a 50 ppm allowance for uncertainties, the initial boron concentration is assumed to be 1950 ppm.

   b. The maximum boron concentration to lose all shutdown margin is conservatively assumed to be 1286 ppm. This bounds the condition of All Rods Out (ARO), Beginning-of-Life (BOL), no xenon, and cold ($T \simeq 70^{\circ}F$).

c. Dilution flow is assumed to be the maximum capacity of the two RMW pumps (300 gpm) with 0 ppm water returning to the RCS. Technical Specifications require the BTRS to be incapacitated for this mode.

d. Mixing of the reactor coolant is accomplished by the operation of at least one residual heat removal pump.

e. A minimum water volume (4,336 ft^3) in the Reactor Coolant System is used. This is the minimum volume of the RCS for Residual Heat Removal System operation. The water in the reactor vessel is assumed to be drained such that the nozzles are half filled. The total volume consists of the reactor vessel volume up to the half filled nozzles, the hot and cold legs half filled, and the crossover piping between the steam generators and reactor coolant pumps. This is the volume required for RHR operation, but does not include the volume of the RHRS itself.

f. The density of RCS fluid is assumed to be 62.3 lb/ft^3 (cold).

2. Dilution During Cold Shutdown (With Filled Loops)

a. The maximum boron concentration required to lose all shutdown margin is conservatively assumed to be 805 ppm. This bounds the condition of All Rods In (ARI) less the highest worth assembly, BOL, no xenon, and cold ($T \simeq 70^{\circ}F$).

b. Technical Specifications require a minimum shutdown margin. The minimum boron concentration required to meet this shutdown margin is conservatively assumed to be 880 ppm.

c. Dilution flow is assumed to be identical to the refueling case, i.e., 300 gpm.

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

e. A minimum water volume of 10,147 ft^3 in the Reactor Coolant System is used. This corresponds to the total RCS volume without the pressurizer and surge line. It does not include the volume of the RHR System. Credit is taken for boron mixing in the RCS loops.

f. The density of RCS fluid is assumed to be 62.3 lb/ft^3 (cold).

3. Dilution During Cold Shutdown (With Drained Loops)

a. Technical Specifications require that 2000 ppm be maintained in this condition. With a 50 ppm allowance for uncertainties, the initial boron concentration is assumed to be 1950 ppm.

b. The maximum boron concentration required to lose all shutdown margin is identical to the case with filled loops, i.e., 805 ppm.

c. The assumed dilution flow rate is identical to the case with filled loops, i.e., 300 gpm.

d. Mixing of the reactor coolant is accomplished by operation of at least one residual heat removal pump.

e. A minimum water volume of 4,336 ft^3 in the Reactor Coolant System is used. This is the minimum volume of the RCS for Residual Heat Removal System operation as described under Dilution During Refueling.

f. The density of RCS fluid is assumed to be 62.3 lb/ft^3 (cold).

4. Dilution During Hot Shutdown

a. The RCS coolant is assumed to be 50°F subcooled (minimum) at a temperature of 350°F (maximum) so that a coolant density of 55.6 lb/ft^3 is used.

b. The maximum boron concentration required to lose all shutdown margin is conservatively assumed to be 747 ppm. This bounds the condition of 350°F, zero power, ARI less the highest worth rod, BOL, and no xenon.

c. Technical Specifications require a minimum shutdown margin. The minimum boron concentration required to meet this shutdown margin is conservatively assumed to be 828 ppm.

d. In this mode of operation, makeup to the RCS may be either from the Residual Heat Removal (RHR) pumps or the charging pumps depending on RCS pressure. In either case, the flow rate of unborated water would be limited by the capacity of the RMW pumps, i.e., 300 gpm.

5. Dilution During Hot Standby and Startup

For unplanned dilution events during these two operational modes, the operator may be alerted by any of several indications including a reactor trip or Shutdown Monitor alarm. For those scenarios in which the operator is alerted to the event by a reactor trip, the remaining time to lose all shutdown margin is bounded by the analysis of dilution during power operation in the next section. For those cases where the operator is alerted to the event by alarms other than a reactor trip, the time to lose all shutdown margin is bounded by the case analyzed below. For this bounding case, the reactor is assumed to be initially subcritical with all rods in less the highest worth rod and with the Technical Specification requirement for shutdown margin met using soluble boron.

a. The maximum boron concentration required to lose all shutdown margin is conservatively assumed to be 704 ppm. This bounds the condition of hot, zero power, ARI less the highest worth rod, BOL, and no xenon.

b. Technical Specifications require a minimum shutdown margin. The minimum boron concentration required to meet this shutdown margin is conservatively assumed to be 786 ppm.

c. Dilution flow is assumed to be limited to the capacity of two charging pumps (240 gpm) with the Reactor Coolant System at 2250 psia.

d. A minimum water volume (10,147 ft^3) in the Reactor Coolant System is used. This volume corresponds to the active volume of the Reactor Coolant System, minus the pressurizer and surge line volumes.

e. Mixing of the reactor coolant is accomplished by operation of the reactor coolant pumps.

f. The density of the RCS fluid is assumed to be 46.4 lb/ft^3 (557^oF and 2250 psia).

6. <u>Dilution During Power Operation</u>

a. The maximum boron concentration required to lose all shutdown margin is conservatively assumed to be 704 ppm. This bounds the condition of hot, zero power, ARI less the highest worth rod, BOL, and no xenon.

b. The minimum initial boron concentration is obtained by assuming full power, no xenon and control rods at their insertion limit. BOL conditions are assumed consistent with part (a) above. A conservative value for this condition is 786 ppm.

c. With the unit at power and the Reactor Coolant System at pressure, the assumed dilution rate is identical to the case for hot standby and startup, i.e., 240 gpm.

d. The Reactor Coolant System volume assumed (10,147 ft^3) corresponds to the active volume of the Reactor Coolant System excluding the pressurizer and surge line.

e. Mixing of the reactor coolant is accomplished by operation of the reactor coolant pumps.

f. The density of the RCS fluid is assumed to be 44.1 lb/ft^3 (588.5^{o}F and 2250 psia).

15.4.6.3 Results of Analysis

1. Dilution During Refueling

For dilution during refueling, the minimum time required for the shutdown margin to be lost is 45.1 minutes. The Shutdown Monitor System alarm or other alarms will actuate within 14.9 minutes. This will allow more than a half hour for the operator to prevent a loss of all shutdown margin.

2. Dilution During Cold Shutdown (With Filled Loops)

For dilution during cold shutdown with filled loops, the minimum time required for the shutdown margin to be lost is 22.5 minutes. The Shutdown Monitor System alarm or other alarms will actuate within 7.4 minutes. This will allow more than 15 minutes for the operator to prevent a loss of all shutdown margin.

3. Dilution During Cold Shutdown (With Drained Loops)

For dilution during cold shutdown with drained loops, the minimum time required for the shutdown margin to be lost is 95.7 minutes. The Shutdown Monitor System alarm or other alarms will actuate within 25.0 minutes. This will allow more than 15 minutes for the operator to prevent a loss of all shutdown margin.

4. Dilution During Hot Shutdown

For dilution during hot shutdown, the minimum time required to lose all shutdown margin is 23.3 minutes. The Shutdown Monitor System alarm or other alarms will actuate within 8.0 minutes. This will allow more than 15 minutes for the operator to prevent a loss of all shutdown margin.

5. Dilution During Hot Standby and Startup

For dilution during hot standby and startup, the minimum time required to lose all shutdown margin is 25.7 minutes. For this bounding case, the Shutdown Monitor System alarm or other alarms will actuate within 8.7 minutes. This will allow more than 15 minutes for the operator to prevent a loss of all shutdown margin.

6. Dilution During Power Operation

a. With the reactor in automatic control, the power and temperature increase from boron dilution results in insertion of the RCCAs and a decrease in the shutdown margin. The rod insertion limit alarms (low and low-low settings) provide the operator with a minimum of 24.4 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.

b. With the reactor in manual control, and no operator action, there will be a power and temperature increase. Depending on initial control rod position, either rod insertion limit alarms will occur, or the OTΔT trip will occur first. As with case (a) above, if the rod insertion limit is reached first, then the operator has a minimum of 24.4 minutes before the shutdown margin is lost. If the OTΔT trip occurs first, then this event is essentially identical to a RCCA bank withdrawal event. The maximum reactivity insertion rate for boron dilution at power is approximately 1.41 pcm/sec and is seen to be within the insertion rates analyzed for the bank withdrawal (see Section 15.4.2). Following the OTΔT trip or insertion limit alarms (whichever occurs first) the operator has a minimum of 24.4 minutes left before the shutdown margin is lost.

15.4.6.4 Radiological Consequences

No radiological consequences have been calculated for this postulated event since no fuel or clad damage is predicted.

15.4.6.5 Conclusions

The results presented above show that for all the operating modes, there is adequate time for the operator to terminate an unplanned boron dilution event prior to loss of all shutdown margin. Following termination of the dilution flow, the reactor will be in a stable condition with no fuel damage. The effect of increasing boron worth with dilution was taken into account for all cases analyzed. A conservatively low (most negative pcm/ppm) value was used. The calculated sequence of events for the limiting cases described above is shown in Table 15.4-1.

4. Barry, R. F. and Altomare, S., "The TURTLE 24.0 Diffusion Depletion Code", WCAP-7213-P-A, February, 1975 (Proprietary) and WCAP-7758-A (Non-Proprietary), February, 1975.

5. Barry, R. F., "LEOPARD, a Spectrum Dependent Non-Spatial Depletion Code for the IBM-7094", WCAP-3269-26, September, 1963.

6. Taxelius, T. G. (ed), "Annual Report - Spert Project, October, 1968, September, 1969", Idaho Nuclear Corporation IN-1370, June, 1970.

7. Liimataninen, R. C. and Testa, F. J., "Studies in TREAT of Zircaloy-2-Clad, UO - Core Simulated Fuel Elements", ANL-7225, January - June 1966, p. 177, November, 1966.

8. Risher, D. H., Jr., "An Evaluation of the Rod Ejection Accident in Westinghouse Pressurized Water Reactors Using Spatial Kinetics Methods", WCAP-7588, Revision 1-A, January, 1975.

9. Bishop, A. A., Sandberg, R. O. and Tong, L. S., "Forced Convection Heat Transfer at High Pressure After the Critical Heat Flux", ASME 65-Ht-31, August, 1965.

10. Adams, J. P. and Berta, V. T., "Quick-Look Report on LOFT Boron Dilution Experiment L6-6", EGG-LOFT-5867 (May, 1982).

TABLE 15.4-1
(Sheet 2 of 3)

Accident	Event	Time (sec.)
2. 3 pcm/sec reactivity insertion rate	Initiation of uncontrolled RCCA withdrawal	0
	Over-temperature ΔT reactor trip signal initiated	27.7
	Rods begin to fall into core	29.7
	Minimum DNBR occurs	30.1
c. Startup of an Inactive Reactor Coolant Loop	Initiation of pump startup	0.0
	Power reaches P-8 trip setpoint	10.2
	Rods begin to drop	12.2
	Minimum DNBR occurs	12.6
d. CVCS Malfunctions that Result in a Decrease in Boron Concentration in the Reactor Coolant		
1. Dilution during refueling	Dilution begins	0
	Operator isolates source of dilution; minimum shutdown margin occurs	2703
2. Dilution during cold shutdown (filled loops)	Dilution begins	0
	Operator isolates source of dilution; minimum shutdown margin occurs	1353
3. Dilution during cold shutdown (drained loops)	Dilution begins	0
	Operator isolates source of dilution; minimum shutdown margin occurs	5741

TABLE 15.4-1
(Sheet 3 of 3)

Accident	Event	Time (sec.)
4. Dilution during hot shutdown	Dilution begins	0
	Operator isolates source of dilution; minimum shutdown margin occurs	1399
5. Dilution during hot standby and startup	Dilution begins	0
	Operator isolates source of dilution; minimum shutdown margin occurs	1543
6. Dilution during power operation		
(a) Automatic reactor control	Dilution begins; rods are at insertion limit	0
	Operator isolates source of dilution; minimum shutdown margin occurs	1467
(b) Manual reactor control	Dilution begins; rods are at insertion limit	0
	Operator isolates source of dilution; minimum shutdown margin occurs	1467
e. Rod Cluster Control Assembly Ejection		
1. Beginning-of-Life, Full Power	Initiation of rod ejection	0.0
	Power range high neutron flux setpoint reached	0.041
	Peak nuclear power occurs	0.130
	Rods begin to fall into core	0.55
	Peak fuel average temperature occurs	2.29
	Peak heat flux occurs	2.32
	Peak clad temperature occurs	2.32

TABLE 15.4-14

SEABROOK RCS COMPONENT FLUID VELOCITIES AND BORON MIXING CHARACTERISTICS

Volume	Fluid Velocity(1)(3)	Velocity(3) Required for Full Mixing(2)
Hot Leg	$3.7\text{x}10^{-2}$	$1.5\text{x}10^{-3}$
Steam Generator Tubes	$1.5\text{x}10^{-2}$	$1.5\text{x}10^{-3}$
Pump Suction	$3.2\text{x}10^{-2}$	$1.5\text{x}10^{-3}$
Cold Leg	$4.1\text{x}10^{-2}$	$1.5\text{x}10^{-3}$
Core	$5.3\text{x}10^{-2}$	$1.5\text{x}10^{-3}$

NOTES

(1) Fluid velocities are calculated assuming all RCS pumps are off, only one RHR pump is on (3,000 gpm), and the RCS loops are full.

(2) These are minimum cyclic velocities required to induce sufficient boron diffusion for complete mixing in these volumes.

(3) Velocities are in meters/second.

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ATTACHMENT II

REVISED FSAR SECTION 7.6
(SHUTDOWN MONITOR)

Insert Section 7.6.10

for SI-V93 has been placed in "open", and then the key locked selector switch has been placed in "open".

~~7.6.10~~ 7.6.11 References

1. The Institute of Electrical and Electronic Engineers, Inc., "IEEE Standard: Criteria for Protection Systems for Nuclear Power Generating Stations," IEEE Standard 279 - 1971.
2. The Institute of Electrical and Electronic Engineers, Inc., "IEEE Trial-Use Criteria for the Periodic Testing of Nuclear Power Generating Station Protection System," IEEE Standard 338 - 1971.

7.6.10 Shutdown Monitor

The shutdown monitor measures the countrate from a neutron counting instrument. It performs a statistical time average of the neutron countrate and displays this average in the source range (from 0.1 counts per second (cps) to 10^4 cps). It also provides an alarm output to indicate a decrease in reactor shutdown margin when the neutron count rate increases by an amount equal to the preset alarm ratio. The shutdown monitor alarm setpoint is continuously recalculated and automatically reduced as the reactor is shut down and the neutron flux is reduced. When the neutron countrate achieves a steady value and then eventually increases, the alarm setpoint remains at its lowest value unless it is manually reset. An alarm will occur when the time averaged neutron countrate increases due to a reactivity addition to a value equal to the preset alarm setpoint. The response time for the alarm depends on the initial countrate and the rate of change of neutron flux. The preset alarm ratio is chosen to ensure an early alarm will occur during an inadvertent boron dilution event. Analysis of inadvertent boron dilution events is discussed in Section 15.4.6.

There are two redundant alarm channels. The alarm from one shutdown monitor channel is annunciated on the VAS and the alarm for the other channel is annunciated on a hardwired alarm on the main control board. Each shutdown monitor channel has its own associated neutron counting instrumentation. Both channels of neutron counting instrumentation are independent and are classified as IE equipment.