April 9, 1997

Mr. Ted C. Feigenbaum
Executive Vice President
c/o Mr. Russell Mellor
Director of Site Operations
Connecticut Yankee Atomic Power Co.
362 Injun Hollow Road
East Hampton, CT 06424-3099

SUBJECT: FINAL ACCIDENT SEQUENCE PRECURSOR ANALYSIS OF CONDITION AT HADDAM NECK

Dear Mr. Feigenbaum:

Enclosed for your information is a copy of the final Accident Sequence Precursor analysis of the potential operational condition at Haddam Neck reported in Licensee Event Report No. 213/95-010. The date of discovery was March 9, 1995, and the description of the event is: Multiple safety injection valves are susceptible to pressure locking. With the plant in a permanently shutdown status, this potential is no longer pertinent.

This final analysis (Enclosure 1) was prepared by our contractor at the Oak Ridge National Laboratory, based on review and evaluation of your comments on the preliminary analysis, comments received from the NRC staff and from our independent contractor, Sandia National Laboratories. Enclosure 2 contains our responses to your specific comments. In our review of your comments we employed the criteria contained in the material which accompanied the preliminary analysis. The results of the final analysis indicate that this was an accident sequence precursor for a condition existing in 1995.

Please contact me at (301) 415-1442, if you have any questions regarding the enclosures. We recognize and appreciate the effort expended by you and your staff in reviewing and providing comments on the preliminary analysis.

Sincerely,

Original signed by:

Morton B. Fairtile, Senior Project Manager
Non-Power Reactors and Decommissioning Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket No. 50-213
Enclosures: As stated
cc: See next page

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Morton B. Fairtile, Senior Project Manager
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Office of Nuclear Reactor Regulation

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Northeast Utilities Service Company

Haddam Neck Plant
Docket No. 50-213

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B.2 LER No. 213/95-010

Event Description: Multiple safety injection valves are susceptible to pressure locking

Date of Event: March 9, 1995

Plant: Haddam Neck

B.2.1 Event Summary

In preparation for the closeout of Generic Letter (GL) 89-10, personnel at Haddam Neck determined that the following motor-operated valves (MOVs) were potentially susceptible to pressure locking (Fig. B.2.1):

- Valves SI-MOV-861A, -861B, -861C and -861D (the HPSI admission valves),
- Valves SI-MOV-871A and -871B (the LPSI admission valves), and
- Valve SI-MOV-873 (the common LPSI isolation valve).

This analysis assumes the susceptible valves could impact the plant response to a large-break LOCA (LBLOCA). An increase in the core damage probability (CDP) during the time that the necessary conditions for pressure locking these valves exists is 4.7×10^{-6}. The nominal CDP for the same period is 2.1×10^{-6}. The uncertainty in the frequency of LBLOCAs and the uncertainty in the likelihood that the pressure locking conditions will exist contribute to the uncertainty in this estimate.

B.2.2 Event Description

On March 9, 1995, personnel at Haddam Neck determined that several safety injection (SI) valves were susceptible to pressure locking, which could preclude them from performing required safety functions following a postulated LOCA (Ref. 1 and 2).

Pressure locking occurs when the fluid in the valve bonnet is at a higher pressure than the adjacent piping at the time of the valve opening. The two most likely scenarios for elevating the pressure in the valve bonnet relative to the pressure in the valve system are given below.

1. Thermal pressure locking (or bonnet heatup) can occur when an incompressible fluid is trapped in the valve bonnet (e.g., during valve closure), followed by heating-up the volume in the bonnet. The bonnet heatup scenarios include heating the valve bonnet by an increase in the temperature of the environment during an accident, heat up due to an increase in the temperature of the process fluid on either side of the valve, etc. (Normal ambient temperature variation is not considered because it occurs over a long time period and pressure changes tend to be alleviated through extremely small amounts of leakage. Further, operating experience shows that normal temperature variations are not a source of pressure locking events.)

2. Hydraulic pressure locking (or pressure-trapping) can occur when an incompressible fluid is trapped in the valve bonnet, followed by depressurization of the adjacent piping prior to valve opening. Examples of hydraulic pressure locking scenarios include back-leakage past check valves, and system operating pressures that are higher than the system pressure when the valve is required to open.

Pressure locking is of concern because the pressure in the space between the two discs of a gate valve can become pressurized above the pressure assumed when sizing the valve's motor operator. This prevents the valve operator from opening the valve when required.

Thermal binding is a phenomenon where temperature changes of the valve internal components causes the valve stem to expand after closure. This results in a higher required opening thrust that may be above the opening thrust assumed when sizing the valve motor operator.

In 1990, plant personnel reviewed the potential of flexible wedge gate valves becoming pressure locked and thermally bound in response to the Institute of Nuclear Power Operations' significant operating events report (SOER) number SOER 84-7. As a result of these reviews, personnel implemented remedial measures consisting of procedural changes (stroking valves during plant heatup), analytical treatment of pressure locking effects, and limited testing of valves to address the high priority valves found subject to pressure locking and thermal binding.

In order to upgrade the quality of the documentation on pressure locking and thermal binding issues in preparation for the closeout of GL 89-10, personnel determined that several of the valves in the safety injection system were potentially subjected to pressure locking conditions that were more significant than previously concluded. According to plant personnel, the concern is the thermal pressure locking of the HPSI admission valves, the LPSI admission valves, and the common LPSI isolation valve (Ref. 3 and 4).

B.2.3 Additional Event-Related Information

NRC Information Notice (IN) 95-18 (Ref. 5), which addresses the Haddam Neck event, elaborates on the mechanisms of pressure locking:

> Pressure-locking may occur in flexible-wedge and parallel disk gate valves when fluid entrapped in the bonnet becomes pressurized and the actuator is incapable of overcoming the additional thrust requirements needed to overcome the increased friction resulting from the differential pressure on both valve disks from the pressurized fluid. IN 95-14 discusses several ways in which fluid may enter the valve bonnet . . . . These mechanisms represent potential common-cause failure modes that can render redundant trains of safety-related emergency core cooling systems incapable of performing their safety functions.

According to personnel at Haddam Neck, the pressure locking condition of concern for the HPSI admission valves, the LPSI admission valves, and the common LPSI isolation valve is thermal pressure locking. Hence, these valves are susceptible to becoming pressure locked if (1) water (the incompressible fluid) becomes

trapped in the bonnet during valve closure and (2) water in the valve bonnet becomes heated by an increase in the temperature of the environment or the process fluid on either side of these valves.

B.2.4 Modeling Assumptions

Personnel at Haddam Neck indicated that the failure mode of concern for the high-pressure and low-pressure safety injection valves is believed to be thermally-induced pressure locking, wherein water trapped in the valve bonnets may expand during plant heatup and prevent the valves from opening. This analysis assumes that valves SI-MOV-861A, -861B, -861C -861D and valves SI-MOV-871A, -871B could be unavailable because of pressure locking following a large-break LOCA, which would render LPSI and HPSI inoperable. The potential failure of valve SI-MOV-873 was not considered because its failure is only significant if valves SI-MOV-871A and -871B function correctly, which is assumed not to be the case.

The Haddam Neck *Individual Plant Examination* (IPE) (Ref. 6) indicates that LPSI will provide adequate makeup during a LBLOCA to prevent core damage. The simple event tree model used for this event (Fig. B.2.2) consists of a postulated LBLOCA initiating event with the success or failure of the following two modes of operation: LPSI and decay heat removal (DHR). Consistent with other ASP analyses, an annual LBLOCA frequency of 2.7×10^{-4}/yr was assumed (Ref. 7).

The significance of an unavailability such as this event is estimated in the Accident Sequence Precursor (ASP) Program in terms of the increase in CDP over the unavailability period, which is also referred to as the importance. Because a nonrecoverable failure of the HPSI admission valves and the LPSI admission valves will fail both high- and low-pressure injection, and injection is required following a large-break LOCA, the significance of the event can be estimated directly from the change in the probability of injection failure and the probability of a large-break LOCA in the unavailability period. The time interval during which the SI valves could have been inoperable is difficult to determine. This analysis assumes that the valves may have been unavailable for a total of 1 week during the prior year because once the pressure in the bonnet equalizes, pressure locking is no longer a concern. Hence, the temperatures on both sides of the valve equalizing and normal valve leakage will remove the susceptibility to pressure locking. Figure B.2.3 explores the impact of different assumptions regarding the duration of the time these valves are unavailable.

The CCDP associated with this event is estimated to be

$$\frac{2.7 \times 10^{-4}}{52} \begin{Bmatrix} \text{CCDP for a LBLOCA} \\ \text{in a 1-wk period} \end{Bmatrix} + \frac{8.2 \times 10^{-5}}{52} \begin{Bmatrix} \text{CCDP from the IRRAS} \\ \text{base case for 1-wk period} \end{Bmatrix}$$

$$= 6.8 \times 10^{-6} \begin{Bmatrix} \text{Total CCDP} \\ \text{in a 1-wk period} \end{Bmatrix}.$$

The importance for this event (CCDP - CDP) is estimated to be

$$6.8 \times 10^{-6} \begin{Bmatrix} \text{Total CCDP} \\ \text{in a 1-wk period} \end{Bmatrix} - \frac{8.2 \times 10^{-5}}{52} \begin{Bmatrix} \text{CDP from the IRRAS} \\ \text{base case for 1-wk period} \end{Bmatrix}$$

$$= \frac{2.5 \times 10^{-5}}{52} \left\{ \begin{matrix} \text{Representative base case} \\ \text{LBLOCA CDP} \end{matrix} \right\}$$

$$= 4.7 \times 10^{-6} \ \{\text{Importance}\}.$$

B.2.5 Analysis Results

An increase in the core damage probability (CDP) during the time that the necessary conditions for pressure locking these valves exists is 4.7×10^{-6}. The nominal CDP for the same period is 2.1×10^{-6}. The dominant core damage sequence for the event (sequence no. 3 on Fig. B.2.2) involves:

- a postulated large-break LOCA, and
- failure of low-pressure injection.

This estimate is based on estimated frequencies of large-break LOCAs. No large-break LOCAs have been observed to date, so there is substantial uncertainty associated with the frequency estimate. The CCDP estimate also is dependent on the assumption that the pressure-locking phenomenon would prevent the injection valves from opening during large-break LOCAs. This assumption is consistent with those made in the analysis reported in LER 213/95-010, but may be pessimistic.

B.2.6 References

1. LER 213/95-010, Rev. 0, "Pressure Locking of Safety Injection Valves," April 6, 1995.

2. LER 213/95-010, Rev. 1, "Pressure Locking of Safety Injection Valves," November 8, 1995.

3. Conference call with personnel from Haddam Neck, the NRC's Office for Analysis and Evaluation of Operational Data, and the Oak Ridge National Laboratory (ORNL), January 23, 1997.

4. Personnel communication between P. D. O'Reilly, U.S. NRC, and M. D. Muhlheim, ORNL.

5. Information Notice 95-18, "Potential Pressure-Locking of Safety-Related Power-Operated Gate Valves," U.S. Nuclear Regulatory Commission, March 15, 1995.

6. Haddam Neck Plant , *Individual Plant Examination*.

7. NUREG/CR-4674, Vol. 21, *Precursors to Potential Severe Core Damage Accidents: 1994, A Status Report*, Appendix H, U.S. Nuclear Regulatory Commission, December 1995.

8. *Final Safety Analysis Report*, Connecticut Yankee Atomic Power Company, Haddam Neck Plant.

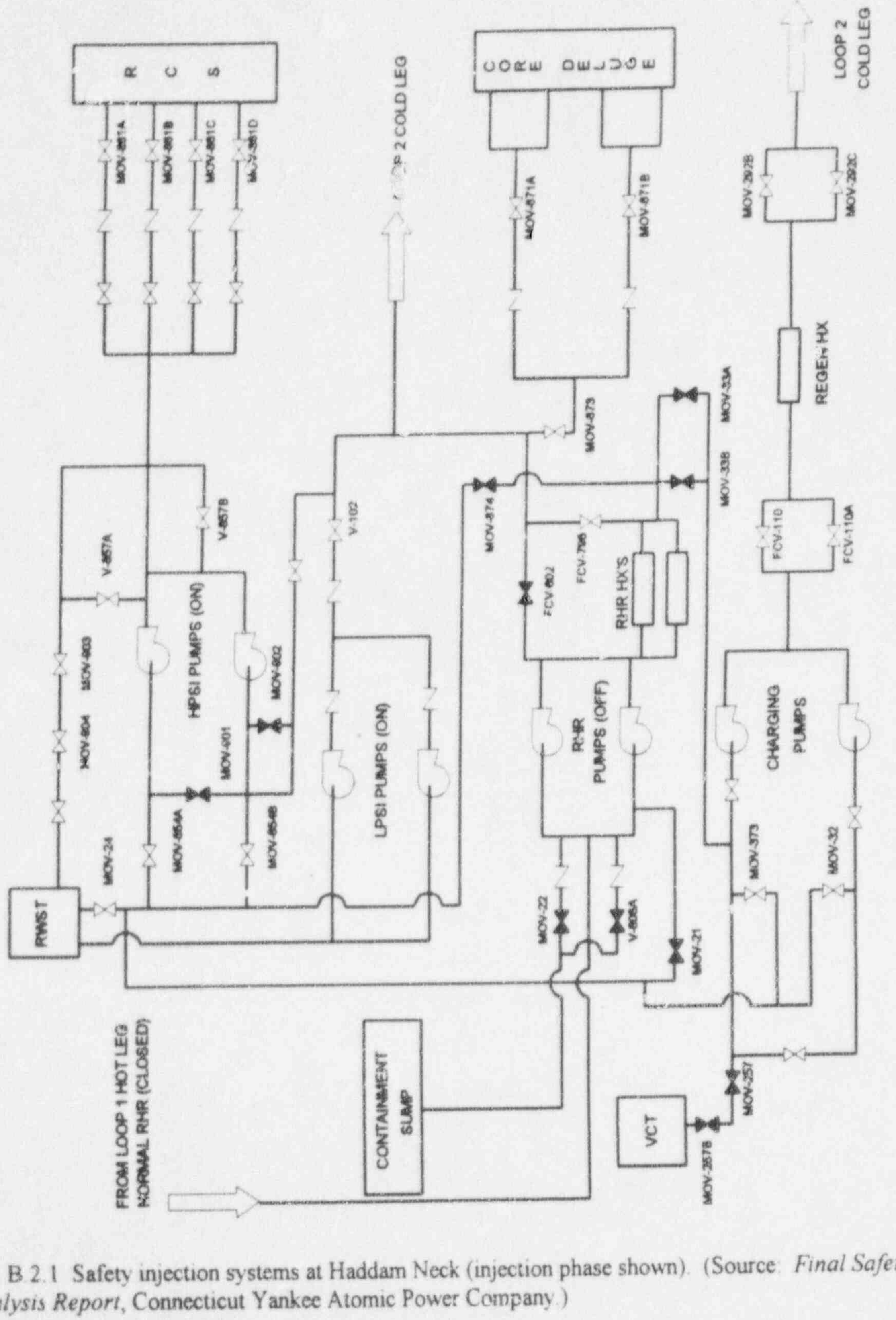

Fig. B.2.1 Safety injection systems at Haddam Neck (injection phase shown). (Source: *Final Safety Analysis Report*, Connecticut Yankee Atomic Power Company.)

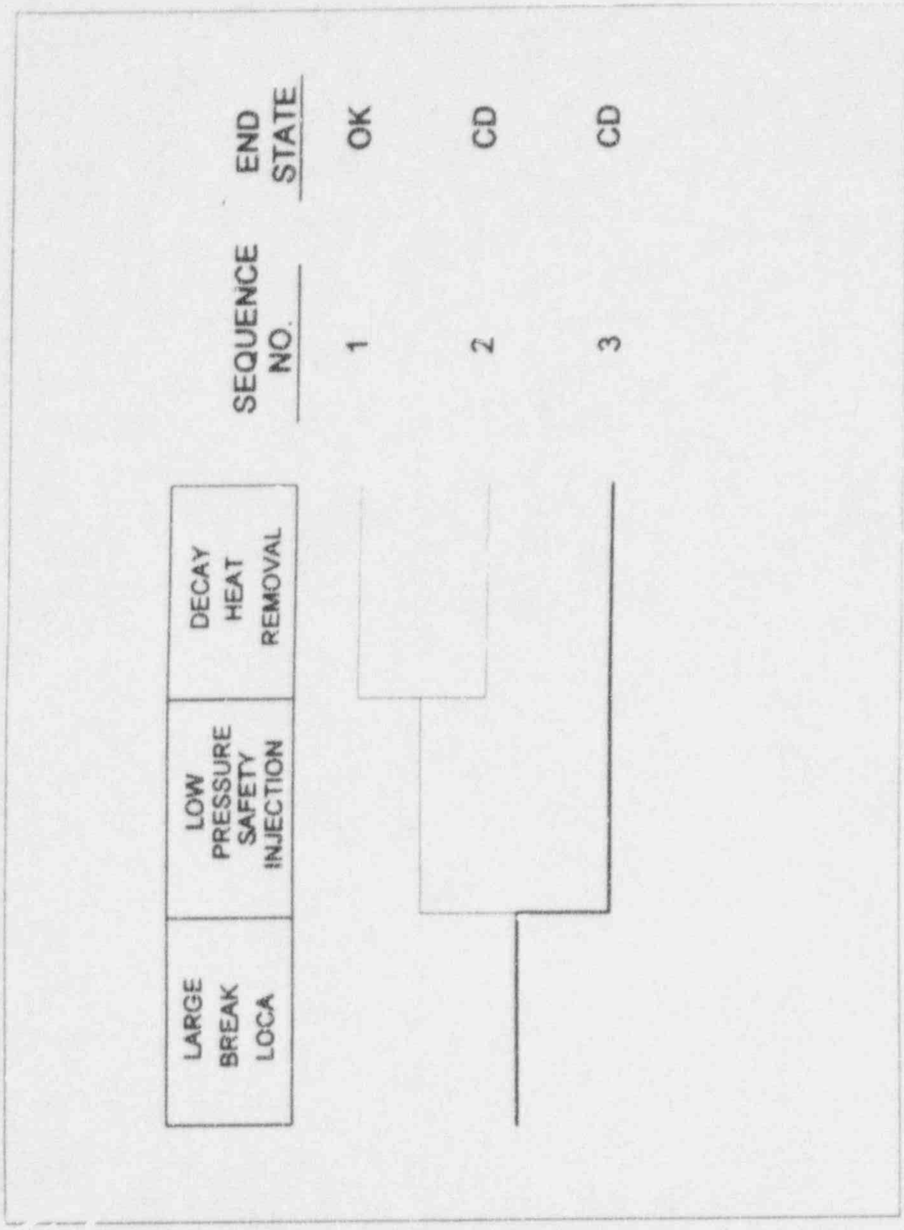

Fig. B.2.2. Dominant core damage sequence for LER No. 213/95-010.

F.2 LER No. 213/95-010

Event Description: Multiple safety injection valves are susceptible to pressure locking

Date of Event: March 9, 1995

Plant: Haddam Neck

F.2.1 Licensee Comments

Reference: Letter from T. C. Feigenbaum, Connecticut Yankee Atomic Power Company, to the U.S. Nuclear Regulatory Commission, transmitting "Haddam Neck Plant Comments on Preliminary Accident Sequence Precursor Analysis", letter no. 50-213-B15951, October 30, 1996.

Comment 1: Connecticut Yankee Atomic Power Company (CYAPCO) did not provide specific comments on the Accident Sequence Precursor analysis of event LER 213/95-010, but rather forwarded an assessment of the event performed by Northeast Utilities Services Company (NUSCO), which used different assumptions. Regarding the ASP analysis, Feigenbaum's letter states:

> CYAPCO believes that the ASP report is too conservative in estimating the conditional core damage probability. The NUSCO quantification assumed a conditional probability of valve failure other than 1.0. The basis for this assumption was provided in the LER as to why the valves would likely have functioned for a large break LOCA without loss-of-offsite power.

Response 1: Instead of commenting directly on the ASP analysis, the licensee for Haddam Neck submitted a report prepared by NUSCO: "An Analysis of the Risk Impact Due to Pressure Locking and Thermal Binding of CY ECCS MOVs". Because the ASP analysis and NUSCO's analysis could not be directly compared due to the different approaches taken to estimate the importance of pressure locking, a series of conference calls were held between personnel at ORNL, AEOD, and CYAPCO. Through these conference calls, sufficient information necessary to realistically estimate the likelihood that those valves susceptible to pressure locking would fail, given the existence of the conditions expected to cause pressure locking, was obtained. Consequently, the ASP analysis no longer assumes the conditional probability of valve failure to be 1.0. Although NUSCO's analysis and the ASP analysis still cannot be directly compared due to the different approaches taken to estimate the importance of pressure locking, the results should be comparable. An increase in the core damage probability (CDP) (an importance measure) during the time that the necessary conditions for pressure locking these valves exists is 4.7×10^{-6}. This compares to a change

of core damage frequency (CDF) calculated by NUSCO of 1.76×10^{-5}. Based on the ASP analysis, the nominal CDP for a 1-year period is 1.1×10^{-4}. This compares favorably with NUSCO's estimate of 1.3×10^{-4}. The uncertainty in the frequency of LBLOCAs and the uncertainty in the likelihood that the pressure locking conditions will exist contribute to the uncertainty in this estimate.