UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
LONG ISLAND LIGHTING COMPANY	)	Docket No. 50-322 O.L.
(Shoreham Nuclear Power Station, Unit 1)	)	

DIRECT TESTIMONY OF MARC W. GOLDSMITH

ON BEHALF OF SUFFOLK COUNTY REGARDING

SUFFOLK COUNTY CONTENTION NO. 4 - WATER HAMMER

April 13, 1982

SUMMARY OUTLINE OF SUFFOLK COUNTY

CONTENTION 4 - WATER HAMMER*

Pressure pulses, known as water hammers, have the potential to damage or weaken piping systems at Shoreham, including those classified as safety-related. LILCO has made some efforts, primarily through design activities and procedure development, to minimize the possibility of water hammer at Shoreham. However, one important means to minimize this phenomena has received insufficient attention. Preoperational and startup tests at other BWR Mark II plants could provide important data, if integrated into the Shoreham test program, which would help to avoid or minimize this phenomena at Shoreham. Notwithstanding the availability of such data and the obvious relevance to safe operation of Shoreham, LILCO and NRC staff have done little to incorporate these data into the Shoreham program. Since water hammer is an unresolved generic safety issue, testing is an important part of assuring that appropriate measures are taken to minimize the potential for water hammer events. LILCO should be required to acquire these data and utilize them in development of its startup and operating procedures as a necessary prerequisite to compliance with the GDC.

Exhibits*

1. NUREG-0606, Vol. 3, No. 4, November 16, 1981, pgs. 10-14.

2. NUREG-0582, July 1979, pgs. 3-11 to 3-14.

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*/ ASLB Memorandum and Order, March 15, 1982, p. 30.

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REGARDING SUFFOLK COUNTY CONTENTION 4 -

WATER HAMMER

Q Please state your name, address and occupation.

A My name is Marc W. Goldsmith, and my business address is 400-1 Totten Pond Road, Waltham, Massachusetts. I am President of Energy Research Group, Inc. I have prepared this testimony. A statement of my qualifications has been separately provided to this Board.

The purpose of this testimony is to address Suffolk County Contention 4 on Water Hammer which reads as follows:

> Suffolk County contends that LILCO has not demonstrated adequate assurance of the operability of safety-related piping to prevent or withstand the effects of water hammer because the Company has not considered the start-up experience at similar BWR plants. Therefore, Shoreham safety-related piping (e.g. ECCS, Reactor Decay Heat Removal Systems) does not meet 10 CFR 50, Appendix A, GDC 1, 31, and 46.

I. Background: The Meaning and Importance of Water Hammer

The term water hammer encompasses a multitude of different actions that cause pressure pulses in piping that could damage pipes and equipment. In nuclear power plants, as in conventional power plants, there are many mechanisms that initiate water hammer events. Severe water hammer may occur: following pump startup or valve opening if the discharge lines are partially empty; in partially empty lines that are designed as full discharge lines; due to the rapid opening and closing of valves; during water entrainment in steam lines; by a sudden change in a valve position; from the mixing of subcooled water and steam; from slug impact due to rapid condensation; and, finally, due to pump startup, stopping and seizure with full lines.[1/] Although these mechanisms for initiating water hammer are different, the dynamics of the liquid motion and the associated dynamic loadings

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1/ In NUREG-0606, February 19, 1982, the listed causes of water hammer at nuclear power plants were "such causes as rapid condensation of steam pockets, steam-driven slugs of water, pump startup with partially empty lines, and rapid valve motion." NUREG-0606, p. 10. See Exhibit 1.

are similar. These events cause sudden flow and pressure changes which result in the propagation of pressure pulses that can result in significant dynamic loads when the liquid fronts reach restrictions or directional changes in the piping.

Between 1971 and 1978 there were approximately one hundred reported incidents of water hammers in LWRs.[2/] More than half of these water hammer events occured at BWRs. Water hammer (or steam hammer) events in BWRs can involve the RHR system, ECC systems, containment spray, service water, feedwater and steam lines. Several incidents have resulted in piping and valve damage. Exhibit 2 to this testimony, identifies fifty-four BWR water hammer events recorded between 1971 and 1978. Only three of these incidents resulted in no damage. Most of these events occured during plant operation. Water hammer events have also occured during plant startup.

For example, in one European G.E. BWR Mark II plant similar to Shoreham, serious water hammer damage was discovered on RHR pump delivery lines during RHR system startup operations. The water hammer damaged ten snubbers by either bending or partly releasing them. Consequently, the second division of the RHR-LPCI system was declared inoperable.[3/]

2/ The NRC reports that between 1971 and February 1982, there were more than 200 water hammer incidents. NUREG-0606, p. 10. See Exhibit 1.

3/ Further data on this European event are not yet available because the Staff considers detailed data to be proprietary. The witness urges the Board to find a means to make these potentially significant data available to LILCO.

The NRC has stated in NUREG-0582 that the overall frequency of water hammer events is unnecessarily large and that steps in design and in plant operation should be pursued with the goal of reducing the event frequency. Water hammer is considered by the NRC to be a generic unresolved safety issue (Task A-1). Therefore, ". . .in 1977 the NRC staff initiated a review of reported water hammer events and of the potential for occurrence of water hammer in all fluid systems that could have an impact on plant safety. The objectives of the review were to identify the causes of water hammer events that could affect reactor safety and to recommend further staff actions needed to reduce the likelihood of such events."(NUREG-0582, July 1979) Most of the recommendations developed during their review are scheduled to be implemented under Task Action Plan A-1, "Water Hammer", which is scheduled to be completed in June 1983. Until unresolved generic safety issues are resolved by the NRC, the Staff is expected to review such issues on an individual plant basis during licensing. The Shoreham SER Apperdix B, page B-7, identifies the measures taken at Shoreham during design to minimize the probability of water hammer. However, the SER is incomplete because it does not consider the importance of prior testing experience in mitigating water hammer.

II. Discussion

Past BWR water hammer events should be viewed as serious and all reasonable precautions should be taken to prevent water hammer events at Shoreham.

Other BWR Mark II plants have or will soon have pre-operational or start-up data pertinent to water hammer experience. These data, as well as data from other LWR's, should be reviewed by LILCO to determine whether any implications exist for Shoreham and whether any remedial action could be taken to prevent water hammer events at

Shoreham.[4/] Since there are multiple causes of water hammer, preoperational and startup testing programs provide an important check on plant design features, and on procedures used to minimize water hammer. This type of data is now being obtained at plants of similar design to Shoreham but is not being integrated into the Shoreham testing program or procedures by LILCO.

While water hammer is a generic unresolved issue, it does not appear that preoperational or startup data from other plants has been incorporated in the NRC's safety review of Shoreham or in LILCO's preoperational or startup program. Information readily and easily obtainable (e.g. the recent European Mark II plant water hammer event) is not being used to prevent a water hammer or used in the licensing review to assure all appropriate efforts are taken to minimize a potential occurrence of water hammer at Shoreham.

GDC number 1 entitled "Quality Standards and Records" requires that

> . . .structures, systems, and components important to safety shall be designed, fabricated, erected and tested to quality commensurate with the importance of the safety functions to be performed.

Good engineering testing practices of safety-related water systems require assurance that pipe movement effects are tested for and assurance derived concerning the systems' ability to withstand transients. The Shoreham testing program does not integrate previous BWR Mark II experience to assure that the piping in the new Mark II containment configuration is appropriately tested to assure the design performs safely. Thus, it is concluded that GDC 1 is not satisfied.

4/ Certainly the Mark II experience at the European reactor would appear directly pertinent to Shoreham.

GDC number 31 entitled "Fracture Prevention of Reactor Coolant Pressure Boundary" states:

> The reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.

GDC number 31 is not met at Shoreham because there is no assurance of a sufficient pressure boundary margin relative to the stresses on water systems during postulated accident conditions. Testing to assure that the boundary behaves in a non-brittle manner and that the probability of rapidly propagating failures is minimized cannot be shown as being adequately considered during and after a water hammer event. Indeed, the probability of water hammer events at Shoreham has not been minimized as a result of the lack of integration of previous transient stress experience into Shoreham's preoperational piping vibration test program.

Finally, GDC number 46 entitled "Testing of Cooling Water System" states:

> The cooling water system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and the performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation for reactor shutdown and for loss-of-coolant accidents, including operation of applicable portions of the protection system and the transfer between normal and emergency power sources.

GDC 46 is not met because the appropriate pressure and functional testing has not been adequately determined. The dynamic pressure loads that could result from a water hammer event could be better characterized by more rigorous testing. A more appropriate pressure test at Shoreham could be derived from previous test experience at similar plants. Better assurance of the structural leaktight integrity of components following a water hammer event could also be obtained from similar plant experiences. The structural integrity of piping is dependent on fatigue cycling which could occur as a result of water hammer and without appropriate test knowledge, more water hammer could occur than is necessary. Therefore, GDC number 46 is not met at Shoreham.

The following efforts and analysis were performed to check the adequacy of LILCO's actions to minimize the potential for water hammer at Shoreham.

1. The Stone & Webster design guideline (EMTG-24-0 - Flow Transient Loads for Piping System Design) relative to dynamic effects on water systems piping, which includes the design criteria for water hammer, was requested and reviewed;
2. LILCO operations personnel were interviewed to determine whether startup procedures for the main steam lines (SP 22.001.01, Rev. 1 - Startup-Cold Shutdown to 20 PCT and SP 23.116.01, Rev. 0 - Main and Auxiliary Steam) were appropriate to minimize the possibility of water hammer; and,
3. Systems such as the keep fill system and high point vents (FSAR Response 212.59) were evaluated to determine that design measures were taken to minimize water hammer based on past water hammer occurrences.

During this evaluation, it became clear that no efforts were being made to incorporate prior experience or preoperational and startup testing at other Mark II containment plants to assure that experience as it related to water hammer would be incorporated in the Shoreham startup procedures or in the Shoreham design. The concern thus remains that the incorporation of experience from events occuring during the startup operation or preoperational testing in other plants might prevent or minimize a water hammer event from occurringat Shoreham. The weakening resulting from such unnecessary water hammer events could lead to further problems within those piping systems.

A logical sequence of events exists which LILCO should have followed during engineering design to minimize water hammer. This sequence includes the following procedures:

1. Check for causes of failures which have occurred in the past due to water hammer;
2. Design piping systems to avoid these past failures, e.g. design the ECCS to be kept filled;
3. Modify design or procedures based on operating experience; e.g. main steam line warm-up;
4. Check new designs via pre-operational, startup or other tests.

LILCO has designed Shoreham's safety-related piping system for dynamic loadings and established operating procedures that it believes will minimize water hammer. However, these efforts are incomplete because according to the Responses of LILCO to Suffolk County Interrogatories and to Suffolk County Second Set of Interrogatories, pages 16-20, dated March 26, 1982, and LILCO's Further Response to Suffolk County Interrogatories, dated 4/9/82, LILCO has made no commitment to monitor water hammer occurrences during startup at other similar BWR plants and use that

experience at Shoreham. LILCO also has not made any commitments to contact engineering or other personnel at other General Electric BWR Mark II plants to determine if any water hammer problems arose during their pre-operational testing or low power testing. Other BWR Mark II plants have or will soon have pre-operational or start-up data pertinent to water hammer experience. These data should be reviewed by LILCO to determine whether implications exist for Shoreham and whether any remedial action could be taken to prevent water hammer events at Shoreham.5/

There is also no assurance that the NRC's Safety Evaluation Report review with respect to water hammer at Shoreham is either complete or adequate. In appendix B.5 of the Shoreham Safety Evaluation Report, the NRC states:

> Although water hammer can occur in any light water reactor and approximately 118 actual and probable events have been reported in boiling water reactors as of September 1979, none have caused major pipe failures in a boiling water reactors such as Shoreham and none have resulted in the offsite release of radioactivity.

This SER statement clearly understates the problem. In NUREG-0606, the Staff notes that there have been instances of water hammer causing piping and valve damage. NUREG-0606, p. 10. Even if no pipe failure or offsite releases have been caused, a significant safety concern does clearly exist -- a concern which the SER does not adequately address.

5/ In LILCO's Further Response to Suffolk County Interrogatories dated April 9, 1982, LILCO states that it has not evaluated any problems identified at other General Electric BWR Mark II plants, but that it "is considering such evaluations."

LILCO could clearly do far more to address the water hammer problem. In addition to review of data from other plants, it is interesting to note the plans of Commonwealth Edison at the LaSalle plant. Commonwealth Edison has committed to a pipe vibration monitoring program including visual inspections. As noted in the LaSalle SER (NUREG-0519), both high and moderate energy piping and instrument lines within the containment will be monitored and inspected "to identify any excessive vibration that will result in fatigue failures." (NUREG-0519 LaSalle Safety Evaluation Report, March 1981, pg. 3-19). The LaSalle program is a rigorous effort to monitor water hammer effects. A similar program should be established at Shoreham and LILCO should inquire about data acquired in the LaSalle program.

Therefore, unless both LILCO and the NRC review and evaluate startup and pre-operational testing experience at Mark II BWR plants similar to Shoreham and from other LWR's, there is no assurance that Shoreham's safety-related piping meets 10 CFR 50, Appendix A, GDC 1, 31, and 46.

EXHIBIT 1

NUREG-0606, Vol. 3, No. 4

November 16, 1981, pgs 10-14

NUREG-0606
Vol. 3, No. 4
November 16, 1981

UNRESOLVED SAFETY ISSUES SUMMARY

AQUA BOOK

Manuscript Completed: November 1981
Date Published: December 1981

Prepared for: OFFICE OF NUCLEAR REACTOR REGULATION

Prepared by: OFFICE OF MANAGEMENT AND PROGRAM ANALYSIS
U.S. NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

WATER HAMMER (A-1)

AS OF WEEK ENDING NOVEMBER 16, 1981

KEY PERSONNEL

TASK MANAGER
ATTCK SEABIZ (DST) X24217

A.D. Barbig 11/27/81

MPA ANALYST
R. DERN X28130

TASK REVIEWERS

NAME	BRANCH
S. MCKAY	PTRB/DHFS
C. GRIMES	RSB/DSI

SCHEDULED COMPLETION

1978 ANNUAL REPORT 12 31 80

CURRENT 09 15 83

• PROBLEM DESCRIPTION

Since 1971 there have been over 200 incidents involving water hammers in BWRs and PWRs reported. The water hammers for steam hammers have involved steam generator feedrings and piping, the RHR system, ECC systems, and containment spray, service water, feed water and steam lines. The incidents have been attributed to such causes as rapid condensation of steam pockets, steam driven slugs of water, pump start-up with partially empty lines, and rapid valve motion. Most of the damage reported has been relatively minor, involving pipe hangers and restraints, however, there have been several incidents which have resulted in piping and valve damage.

Task Action Plan TAP A-1 subdivides resolution of this Unresolved Safety Issue (USI) into the following tasks:

Task 1 Water Hammer Summary Reports

Task 2 Resolution of Water Hammer Issue

Task 3 Water Hammer Position for Operating Reactors

Task 4 Water Hammer Safety Studies

Task 1 and 4 have been completed and the reports are on the network charts which follow. The near term position for operating reactors is to permit continued operation since, as noted above, damage attributed to water hammer has been relatively minor. The long term aspect of Task 3 is an integral part of the resolution of this issue.

Task 2 represents the resolution aspect of this USI and will result in the final resolution.

• RES INTERFACE INFORMATION

None

• ACRS INTERFACE INFORMATION

ACRS interest in the water hammer issue continues. A briefing to describe current efforts and proposed method of resolution is scheduled for December 1981.

• TECHNICAL ASSISTANCE CONTRACTS

Prior technical assistance, funded under FIN Nos. A6257 & A6251, was closed out in quarter III, FY 81. A new work order, FIN No. A6461, was established in quarter III, FY 81, for technical support directed at resolution of USI A-1. An acceptable work plan has been worked out with EG&G, and the attached network schedule reflects activities underway.

FIN NO.	CONTRACTOR	OBLIGATED	EXPENDED
# FY 81 A6461	EG&G Idaho	$120 000	$38 300

• POTENTIAL PROBLEMS

Delayed acquisition of plant or event data, related to water hammer occurrences being studied, could impact current schedule shown.

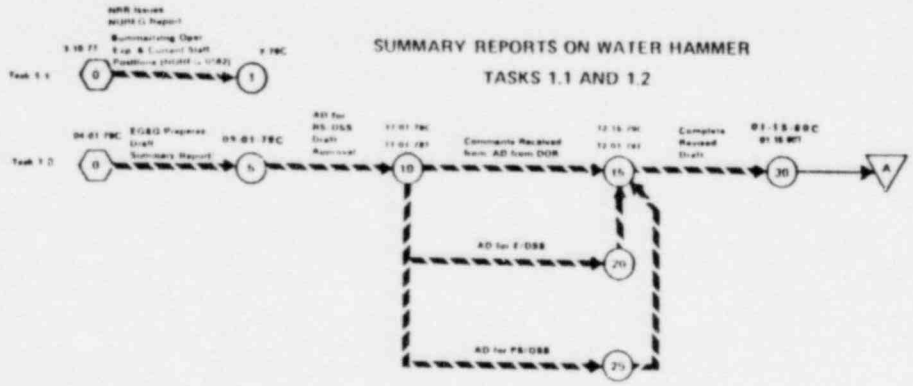
• STATUS SUMMARY

The concluding efforts and scheduled milestones for resolution of A-1 are shown in the attached schedule. Resolution will be based on evaluations of plant systems and operating procedures, severity of events experienced and attendant safety implications. It is postulated that guidelines and procedures will be developed which will minimize, or mitigate, water hammer events. The frequency of water hammer events reported has been low, and the incurred damage principally confined to pipe hangers and snubbers.

EG&G selected a subcontractor (QUADREX) in late Oct 1981 for assistance in evaluating plant systems, operating and maintenance procedures, and for development of guidelines for design and operation of safety systems to minimize the impact of water hammer events.

EG&G staff have updated the previous water hammer events report (CAAP TR 053) to include events into CY 1981. This report will serve as the data base for assessment of severity of water hammer occurrence, damage inflicted and to establish reactor system trends.

# INDICATES A CHANGE IN INFORMATION



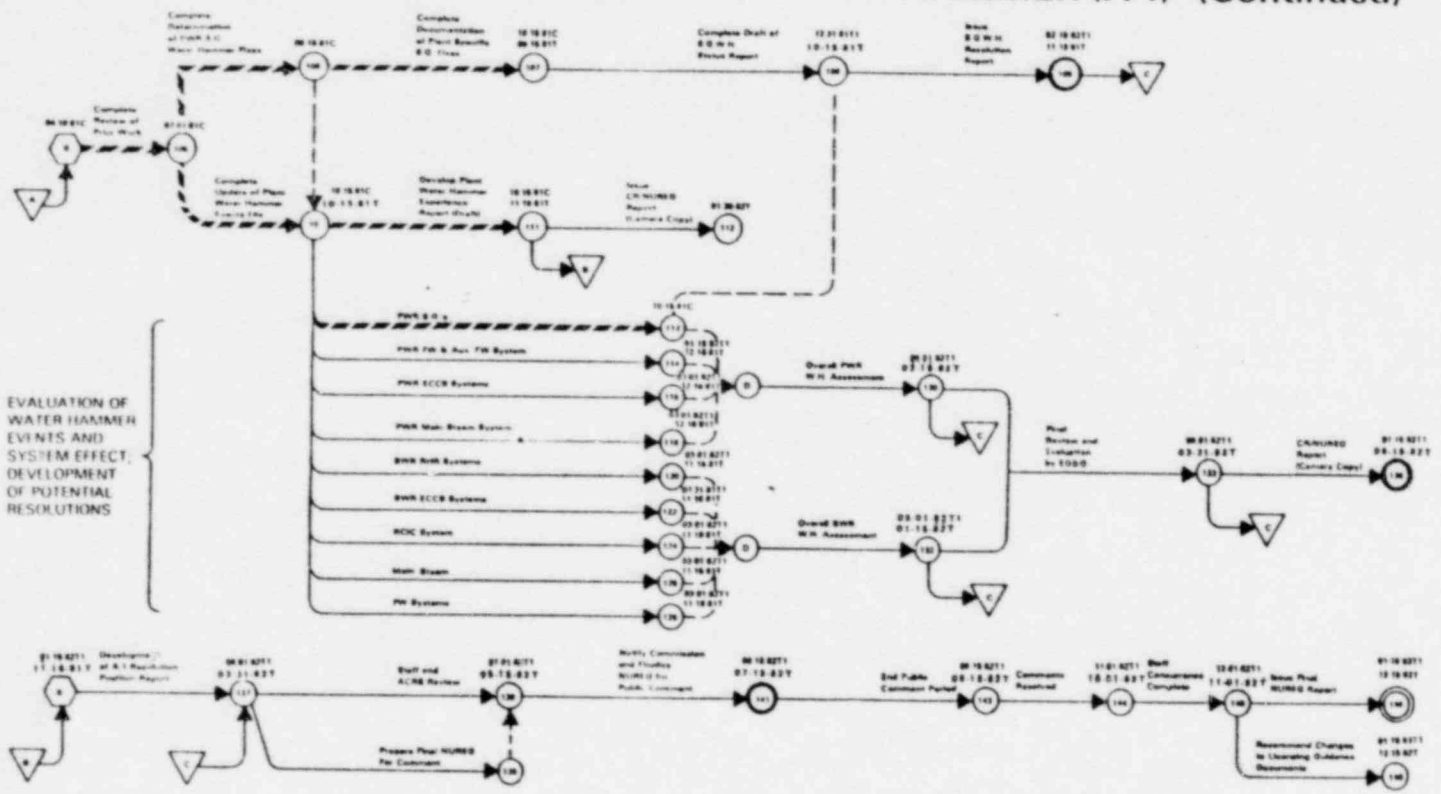
TASK 1 REPORTS

NUREG-0582, "Water Hammer in Nuclear Power Plants," July 1979

Chapman, R.L., "Water Hammer Studies," EG&G Interim Rpt., CAAP TR-983 (Rev. 1), July 1980 (Prepared for NRC Use)

NOTE: This is a preliminary activities network which is under review. Dates will be refined in the next Aqua Book update and will be dependent on establishing technical support contracts.

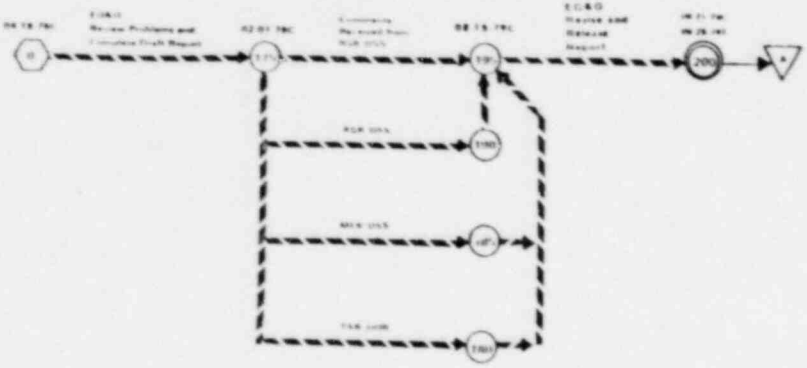
WATER HAMMER (A-1) (Continued)



LONG TERM POSITION
TASK 3.2

INCORPORATED IN SUBTASK 2.0

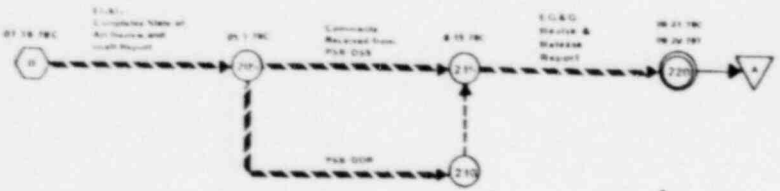
REVIEW AND EVALUATION OF POTENTIAL WATER HAMMER PROBLEMS
TASK 4.1



TASK 4.1 REPORT

Chapman, R. L., et al., "Review and Evaluation of Actual and Potential Water Hammer Events in Nuclear Plants," EG&G Interim Rpt. CAAP-TR-042 (Rev. 1), September 1979 (Prepared for NRC Use)

DEVELOPMENT OF CURRENT INFORMATION ON WATER HAMMER
TASK 4.2

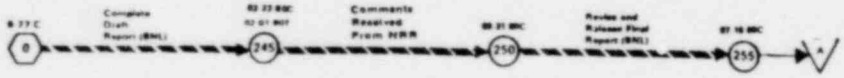


TASK 4.2 REPORT

Watkins, J.C., Berry, R.A., "A State of the Art Literature Review of Water Hammer," EG&G Interim Interim Rpt., RE A 70 044, April 1979 (Prepared for NRC Use)

WATER HAMMER (A-1)
Continued

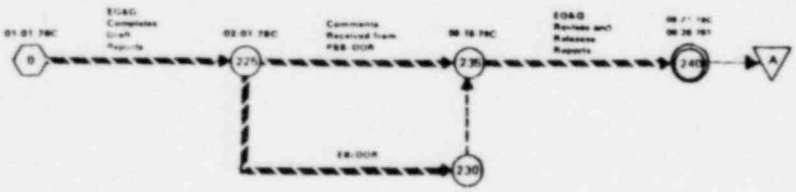
WATER HAMMER IN STEAM GENERATORS
TASK 4.3



TASK 4.3 REPORT

Bohn, P. et al., "An Evaluation of Condensation Induced Water Hammer in Pretreat Steam Generators," NUREG/CR-1966, September 1980

WATER HAMMER CALCULATIONS
TASK 4.4



TASK 4.4 REPORTS

Wiliamson, R.L., "An Analysis Tool for Predicting the Transient Hydrodynamics Resulting from the Rapid Filling of Voided Piping Systems," EG&G Interim Rpt. RE E 79-006, February 1979 (Prepared for NRC Internal Use)

Morton, D.S., "An Analytical Procedure for Performing Structural Analyses of Nuclear Piping Systems Subjected to Fluid Transients," EG&G Interim Rpt. RE E 79-013, February (Prepared for NRC Internal Use)

Dominic, F.N., "An Investigation of the Steam Void Collapse Water Hammer Initiating Mechanism," EG&G Interim Rpt. RE A 79-276, February 1979 (Prepared for NRC Internal Use)

Berry, R.A., "An Analysis Tool for Predicting Transient Hydrodynamics in Nuclear Piping Systems Containing Swing Check Valves," EG&G Rpt. RE A 79-261 (Rev. 2), September 1979 (Prepared for NRC Internal Use)

EVALUATE SAFETY SIGNIFICANCE OF WATER HAMMER SCENARIOS
TASK 4.5

TASK 4.5 REPORT

Bartell, R.F., "Supplemental Water Hammer Analysis and Review," EG&G preliminary Rpt. EGG-CAAP-5122, July 1980 (Prepared for NRC for Use as a Preliminary or Working Document)

EXHIBIT 2

NUREG-0582, July 1979, pgs 3-11 to 3-14

NUREG-0582

WATER HAMMER IN NUCLEAR POWER PLANTS

Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission

TABLE 3.2 OTHER WATER HAMMER EVENTS

Water Hammer Type	System	Plant	Reactor Type	Commercial Operation	Event Date	Damage
Pump Startup w/Inadvertently Voided Discharge Lines	RHR	Duane Arnold	BWR	02/01/75	04/06/77	Yes
	RHR	Hatch 1	BWR	12/31/75	12/15/74	Yes
	RHR	Quad Cities 1	BWR	02/18/73	04/04/72	Yes
	RHR	Brunswick 1	BWR	03/18/77	11/09/77	Yes
	RHR	Brunswick 2	BWR	11/03/75	09/05/75	Yes
	RHR	Brunswick 2	BWR	11/03/75	09/30/75	Yes
	RHR	Fitzpatrick	BWR	07/28/75	03/21/75	Yes
	RHR	Fitzpatrick	BWR	07/28/75	05/24/75	Yes
	RHR	Brunswick 2	BWR	11/03/75	09/30/75	No
	Core Spray	Dresden 2	BWR	06/09/72	03/29/71	Yes
	Core Spray	Dresden 2	BWR	06/09/72	07/11/76	Yes
	Core Spray	Dresden 3	BWR	11/16/71	11/27/74	Yes
	Core Spray	Duane Arnold	BWR	02/01/75	04/10/74	Yes
	Core Spray	Duane Arnold	BWR	02/01/75	02/11/77	Yes
	Core Spray	Oyster Creek	BWR	12/69	05/25/71	Yes
	SSI Discharge Line	San Onofre 1	PWR	11/01/68	10/20/73	Yes
	HPCI	Brunswick 2	BWR	11/03/75	03/24/78	---
	Emergency Equipment Cooling Water	Brown Ferry 1,2,3	BWR	08/01/74	------	---
				03/01/75	------	---
				03/01/77	------	---
	RHR Service Water	Fitzpatrick	BWR	07/28/75	04/10/74	Yes
	Service Water	Salem 1	PWR	06/30/77	1977	---
	Main FW	Oconee 3	PWR	12/16/74	------	Yes
	LPSI	Palisades 1	PWR	12/31/71	05/14/74	Yes
Expected Transients in Initially Empty Lines	Main Steam Safety Valve	Robinson	PWR	03/07/71	04/70	Yes
	Press. Relief Valve Discharge line	Surry 1	PWR	12/22/72	01/73	Yes

TABLE 3.2 OTHER WATER HAMMER EVENTS (Cont'd)

Water Hammer Type	System	Plant	Reactor Type	Commercial Operation	Event Date	Damage
Valve Opening, Closing and Instability	Main Steam	Arkansas 1	PWR	12/19/74	06/15/76	Yes
	Main Steam	Millstone 1	BWR	03/71	------	Yes
	Main Steam	Oconee 1	PWR	07/15/73	03/21/75	No
	Main Steam	Oconee 2	PWR	09/09/74	------	Yes
	Main Steam	Turkey Point 3	PWR	12/14/72	11/05/75	Yes
	Main Steam	Millstone 1	BWR	03/71	12/28/70	Yes
	Main Steam	San Onofre 1	PWR	01/01/68	01/14/74	Yes
	Main Steam	Oyster Creek 1	BWR	12/69	1971	Yes
	Main Steam	Dresden 2	BWR	06/09/72	09/28/71	---
	Main Steam	Pilgrim 1	BWR	12/72	07/24/72	Yes
	Main FW	Beaver Valley 1	PWR	10/01/76	12/27/76	Yes
	Main FW	Beaver Valley 1	PWR	10/01/76	11/05/76	Yes
	Main FW	Beaver Valley 1	PWR	10/01/76	01/05/77	Yes
	Main FW	Quad Cities 2	BWR	03/10/73	06/10/74	Yes
	Main FW	Quad Cities 2	BWR	03/10/73	08/12/75	Yes
	Main FW	Quad Cities 2	BWR	03/10/73	08/31/75	Yes
	Main FW	Turkey Point 3	PWR	12/14/72	------	No
	Main FW	Turkey Point 4	PWR	09/07/73	------	No
	Main FW	Pilgrim 1	BWR	12/72	01/06/76	Yes
	Main FW	Dresden 2	BWR	06/09/72	12/05/74	Yes
	Main FW	Dresden 2	BWR	06/09/72	02/18/76	Yes
	Main FW	Quad Cities 2	BWR	03/10/73	10/17/75	Yes
	Main FW	Dresden 3	BWR	11/16/71	06/23/74	Yes
	Main FW	Dresden 3	BWR	11/16/71	09/04/74	Yes
	Main FW	Oconee 1	PWR	07/15/73	------	No
	Main FW	Oconee 2	PWR	09/09/74	------	Yes
	Main FW	Oconee 3	PWR	12/16/74	------	Yes
	Main FW	Ginna	PWR	07/70	07/22/73	Yes
	Main FW	Millstone 1	BWR	03/71	12/26/74	Yes
	Main FW	Zion 1	PWR	12/31/73	06/20/76	No
	Main FW	Zion 2	PWR	09/17/74	03/18/75	Yes
	CVCS	Maine Yankee	PWR	12/28/72	06/02/77	No

TABLE 3.2 OTHER WATER HAMMER EVENTS (Cont'd)

Water Hammer Type	System	Plant	Reactor Type	Commercial Operation	Event Date	Damage
Check Valve Closure and Delayed Opening	Main Steam	Surry 1	PWR	12/22/72	10/05/73	Yes
	Main Steam	Surry 2	PWR	05/01/73	12/02/72	Yes
	Main Steam	Point Beach 2	PWR	10/01	04/08/73	Yes
	Cooling System for Reactor Auxiliaries	Calvert Cliffs 1	PWR	05/08/75	04/25/77	Yes
	Main Steam	Maine Yankee	PWR	12/28/72	12/02/72	No
	Recirculation Spray	Surry 1	PWR	12/22/72	11/29/74	Yes
	Containment Spray	Surry 1	PWR	12/22/72	12/27/74	Yes
	Recirculation and Containment Spray	Surry 2	PWR	05/01/73	12/27/74	Yes
	Core Spray	Millstone 1		03/71	04/17/78	Yes
Water Entrainment in Steam Lines	HPCI	Browns Ferry 1	BWR	08/01/74	10/14/72	Yes
	HPCI	Browns Ferry 1	BWR	08/01/74	04/14/74	Yes
	HPCI	Brunswick 2	BWR	11/03/75	08/30/76	Yes
	HPCI	Duane Arnold	BWR	12/01/75	06/11/74	Yes
	HPCI	Fitzpatrick	BWR	07/28/75	07/20/75	Yes
	HPCI	Fitzpatrick	BWR	07/28/75	07/28/75	Yes
	HPCI	Dresden 2	BWR	06/09/72	05/28/70	Yes
	RCIC	Browns Ferry 1	PWR	08/01/74	10/14/72	Yes
	Aux. FW Turbine	Palisades	PWR	12/31/71	------	Yes
	Aux. FW Turbine	Zion 1	PWR	12/31/73	06/16/74	Yes
	Isolation Condenser	Millstone 1	BWR	03/71	03/11/78	Yes

TABLE 3.2 OTHER WATER HAMMER EVENTS (Cont'd)

Water Hammer Type	System	Plant	Reactor Type	Commercial Operation	Event Date	Damage
Steam Bubble Collapse and Mixing of Subcooled Water Steam from Inter-connected systems	Plant Steam Heating System	Big Rock Point 1	BWR	03/29/63	10/31/77	No
	HPCI	Monticello	BWR	06/30/71	1972	Yes
	Main FW	Oconee 1	BWR	07/15/73	------	No
	RHR	Brunswick 1	BWR	03/18/77	03/18/77	Yes
	RHR	Brunswick 2	BWR	11/03/75	12/29/76	Yes
	RHR	Dresden 2	BWR	06/09/72	09/28/71	Yes
	RHR	Monticello	BWR	06/30/71	------	Yes
	SIS Accumulator	Surry 1	PWR	12/22/72	11/20/74	Yes
	SIS Accumulator	Surry 2	PWR	05/01/73	1974	Yes
	RHR	Brunswick 2	BWR	11/03/75	04/18/77	Yes
	HPCI	Brunswick 1	BWR	03/18/77	05/20/77	Yes
	Main FW	Zion 1	PWR	12/31/73	12/31/73	No
	Main FW	Rancho Seco	PWR	04/17/75	1974	Yes
	Steam Generator Blowdown Line	Haddam Neck 1	PWR	01/01/6	03/17/78	Yes
Pump Startup	HPCI	Browns Ferry 3	BWR	03/01/77	01/18/77	Yes
	RHR	Pilgrim 1	BWR	12/72	10/17/75	Yes
Not Identified	Steam Generator Blowdown Line	Indian Point 2	BWR	08/73	------	Yes
	RHR steam line	Brunswick 1	BWR	03/18/77	12/20/77	Yes