A POTENTIAL FOR WATER HAMMER

DURING THE RESTART OF RHR PUMPS

FOR BWR NUCLEAR PLANTS

by the

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NOTE: This report documents results of studies completed to date by the Office for Analysis and Evaluation of Operational Data with regard to a particular operating event. The findings and recommendations contained in this report are provided in support of other ongoing NRC activities concerning this event. Since the studies are ongoing, the report is not necessarily final, and the findings and recommendations do not represent the position or requirements of the responsible program office of the Nuclear Regulatory Commission.

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PREFACE

Water hammer is a term commonly used in the engineering field to des   a large unbalanced force being developed within a piping system. The force occurs as a result of abrupt changes of fluid states (e.g., pressure, temperature and flow rates). The magnitude of the water hammer force can vary in a wide range depending primarily on the rate of change of fluid states. The effect on the piping system ranges from simple pipe movements, piping support failures to permanent damages to the integrity of a piping system, in some cases, even resulting in a pipe rupture. Therefore, it is commonly known among conc ned engineers that consideration must be given to prevent water hammer in the design and operation of any fluid systems.

In the design and operation of a commercial nuclear power plant, water hammer is also viewed as an undesirable event since it could potentially affect the intended safety function of a fluid system in the event of a plant accident. Although extensive consideration has been given to prevent water hammers from occurring, a large number of them has occurred during the history of the commercial operation. Luckily, the magnitude of the water hammer has not reached a level to cause any pipe ruptures.

A recent review of water hammer events was performed by the Office for Analysis and Evaluation of Operational Data indicated that there might be certain scenarios o, operational sequences that could cause damaging water hammers. If allowed to occur, the magnitude of the water hammer force could be much larger than ever experienced in the present nuclear industry. Therefore, it is important to initiate a timely review to identify those scenarios (e.g., basic initiating mechanisms, design features, operating procedures, and single failures) that could result in severe and damaging water hammer events. Only with a proper understanding of the scenario, possible design or procedural changes can then be made to prevent the occurrence or minimize the consequences of the postulated water hammer.

Because of the concern of the potential for large damaging water hammer, AEOD has initiated a limited review of the situation. From this review, one such scenario was identified that involves the containment cooling mode of RHR operation for BWR nuclear plants. The result of findings along with recommendations is presented in this report.

1. INTRODUCTION

In recent years, licensees of operating reactors have reported a large number of water hammer events during commercial operation. Although most of these events resulted in little or no damage to the piping system pressure boundary integrity, there frequently has been damage to the pipe supports and attachments that could adversely affect the safe operation of certain safety systems in the event of a plant accident. As a result, the NRC initiated a study to review the water hammer events. The objective of the review was to identify the causes of water hammer events and, further, to recommend actions needed to reduce the likelihood of such events. The results of this review was published in NUREG-0582.

Because of the high frequency of water hammer operational events and their potential impact on the safety system operation, AEOD initiated its own limited review of the situation. The primary objective has been to assess certain scenarios or operational sequences that could result in conditions conducive to water hammer which, if allowed to occur, may impair the continued operation of a needed safety system.

A recent review of the RHR system for a typical BWR Nuclear Plant (Figure 1) has revealed one such event that involves the containment cooling mode of RHR operation during normal plant operation or following a postulated loss of coolant accident (LOCA). In such an event, conditions known to cause water hammer may result from an RHR pump stop and subsequent restart with an inadvertently voided system. A detailed description of the problem and results of the AEOD investigation of the event are presented below.

2. OPERATING EXPERIENCES

A review of information on water hammer events obtained primarily from Licensee Event Reports (LERs) indicates that water hammer has occurred in the operation of RHR systems while a portion of the discharge piping was not full of water. Below are some events that were reported by the licensees.

- Browns Ferry 1 reported two events that might be a result of water hammer in the torus spray line, that occurred on November 18, 1973 and May 14, 1974. The cause of water hammer could be water discharging into a partially drained line.

- Fitzpatrick-1 reported three water hammer events that occurred on April 10, 1974, March 21, 1975 and May 24, 1975. The cause of water hammer was determined to be RHR pump startup while the discharge piping was not full of water. As a result of this experience, a "keep full" system was later installed to prevent a recurrence of water hammer.

- Duane Arnold reported two water hammer events that occurred on January 31, 1977 and April 6, 1977. The cause of water hammer was determined to be an improper venting procedure such that the line was not completely filled with water when the RHR pump started.

From the above events, it is reasonable to conclude that water hammer may occur following pump startup if the discharge lines are voided or partially empty.

3. EVENT DESCRIPTION

Design of the containment cooling function of the RHR system calls for the RHR pumps to be aligned to pump water from the suppression pool through the RHR heat exchangers where cooling takes place by transferring heat to the RHR service water. The flow then returns to the suppression pool via the full flow test return line. If desired, the water pumped through the heat exchangers may be diverted to spray headers above the suppression pool and in the drywell. The spray flow directed to the pool will condense any bypassed steam and cool any noncondensable gases collected in the free volume above the suppression pool water. The spray in the drywell condenses any steam in the primary containment thereby lowering containment pressure and temperature.

A review of a typical RHR System arrangement (Figure 2) reveals that if the pump flow is inadvertently stopped during the containment cooling operation mode, it will result in rapid draining of the system because the discharge valves cannot be quickly closed. Voids and air pockets may also be generated in the system since a large section of the system including the RHR heat exchangers is situated above the suppression pool elevation. These conditions could induce water hammer if the RHR pump was subsequently restarted prior to proper venting and refilling of the system. However, damaging water hammer can be prevented if

(1) the RHR pump will not restart automatically (unless immediately) after its trip with the spray or test return valves open and

(2) the operator has prior knowledge about the potential for water hammer following a pump trip, and takes proper steps to vent and refill the system before manual pump restart.

To further assess the possibility of water hammer occurring in the RHR System, AEOD has performed a review of the RHR System design and associated operating instructions for a typical BWR system.

The review indicates that there are several possible operational modes of the RHR System, which could potentially lead to conditions conductive to water hammer.

4. FINDINGS

4.1 Suppression Pool Cooling Mode of RHR Operation

During either normal plant operation or following an accident, the operator can initiate the suppression pool cooling mode of RHR operation (without initiating containment spray) whenever necessary to maintain suppression pool water temperature. To do that, the operator aligns the RHR pumps to pump water from the suppression pool through RHR heat exchangers. After cooling takes place in the heat exchangers, the water returns to the suppression pool via the full flow test return line. If the pool cooling flow is stopped for any reason, rapid RHR system draining will occur and continue until the test return line valve closes or a system void forms with sufficient negative pressure. Although a "keep full" system is provided, it is not sized to maintain the RHR System filled during this high rate of drainage and it cannot fill the void unless the return line valve closes.

From the review of operating instructions, for a typical BWR plant, it is not clear that the operator has received adequate instruction regarding the potential for water hammer associated with the operation of the suppression pool cooling system. It appears possible that the operator may restart the pumps while the system is still voided thereby causing water hammer. To prevent water hammer, the operator must be warned not to restart the pumps until the system is refilled and vented.

There is a situation that may cause the pump to restart automatically. For example, in the event of a small LOCA, the containment pressure may stay high for a long period of time. During the event, the HPCI System may be called upon to maintain the reactor vessel water level while a portion or all of the RHR System may be aligned for suppression pool cooling. In case of a loss of normal power, the operating RHR pumps will be tripped immediately, but will be restarted automatically after a time delay on emergency diesel power if high containment pressure is present. The test return line valves remain "as is" during the power transfer. This automatic restart feature is needed to maintain the LPCI operation in a major LOCA, but it is undesirable during the suppression pool cooling mode of operation because the system can become partially voided.

4.2 Containment Spray Mode of RHR Operation

According to typical plant operating procedures, the containment spray system cannot be placed in service unless the LPCI mode of the RHR system has initiated and its requirements satisfied. However, if the containment pressure and temperature remain high following LPCI operation, the operator may choose to initiate the containment spray system by directing the RHR pump flow simultaneously to both of the drywell and torus spray headers. If the operating RHR pumps should then be tripped for any reason, the RHR system will be vented by the drywell spray line and drain rapidly through the torus spray header. A virtually unlimited drain will occur if the full flow test return line valve is also open. Since the operator has not been properly instructed about the above operational sequence, it is likely that he may attempt to restart the RHR pumps with a largely voided system thereby causing water hammer.

It is important to note that for events such as loss of coolant accident (LOCA) and loss of offsite power (LOP), capabilities of remotely venting and refilling the lines are not provided. If the RHR system should be drained during such events, the system may not be accessible for refilling and venting and, furthermore, such provisions are not on emergency power. If that were to occur, the reactor operator must take extra precautions to close all valves before restart and then reopen them slowly or face the consequences of damaging water hammer.

Following a LOCA, there is also a possibility that water hammer will occur automatically should a LOP occur while the containment spray system is running. This is because the RHR pumps are restarted automatically on emergency power shortly after the LOP if the containment high pressure signal exists.

5. CONCLUSION AND RECOMMENDATIONS

During the operation of the RHR containment cooling system in a BWR plant, conditions conducive to water hammer will occur if the operating RHR pumps are stopped for any reason without first closing all containment and torus spray and test return line valves. Water hammer could subsequently occur if the pumps were restarted either automatically or manually without proper measures being taken to assure that no voids have formed. The water hammer could be severe enough to hinder the continued operation of the affected RHR System when the system is most in need. If the water hammer force is large enough, there is also a potential threat to breach the containment integrity by overstressing the containment penetrations to the drywell and torus spray headers and the torus cooling line during the water hammer.

From the above discussion and review findings, it is apparent that operational conditions can exist that are precursor situations for water hammer; steps and corrective action should be taken to reduce it. Provided below are AEOD's recommendations that, if implemented, would help reduce the likelihood of RHR pump restart water hammer events and their potential impact on the continued operation of RHR systems for a BWR plant.

1. The operator should be specifically warned about the potential for water hammer during operation of RHR system in the suppression pool cooling and containment spray modes of operation.

2. Whenever the RHR pumps are tripped while in these modes of operation without first closing all associated discharge valves, the operator should not be permitted to restart the pumps until he ensures that the system is refilled and vented.

3. The refill and vent systems should be upgraded so that they can be appropriately operated from an environmentally acceptable location in the event of an inadvertent RHR pump trip during a LOCA or LOP.

4. Only one train of the RHR system should be used for containment cooling at one time, and remain isolated from the other train.

5. The licensee should develop an emergency startup procedure and appropriate hardware provisions so that, if needed, the operator can restartup the RHR System flow slowly enough to minimize the effect of water hammer in a partially voided system.

6. Consideration should be given to design modifications which eliminate the automatic restart of RHR pumps in the event of a LOCA or other emergencies followed by a LOP or other inadvertent pump trip situations while the containment cooling system is in operation. It might be shown that the probability of such situations is sufficiently small that they need not be considered.

AEOD believes that implementation of these recommendations is necessary. Failure to implement them can expose the RHR system to the risk of damaging water hammer which could adversely affect system operation when the system is most needed.

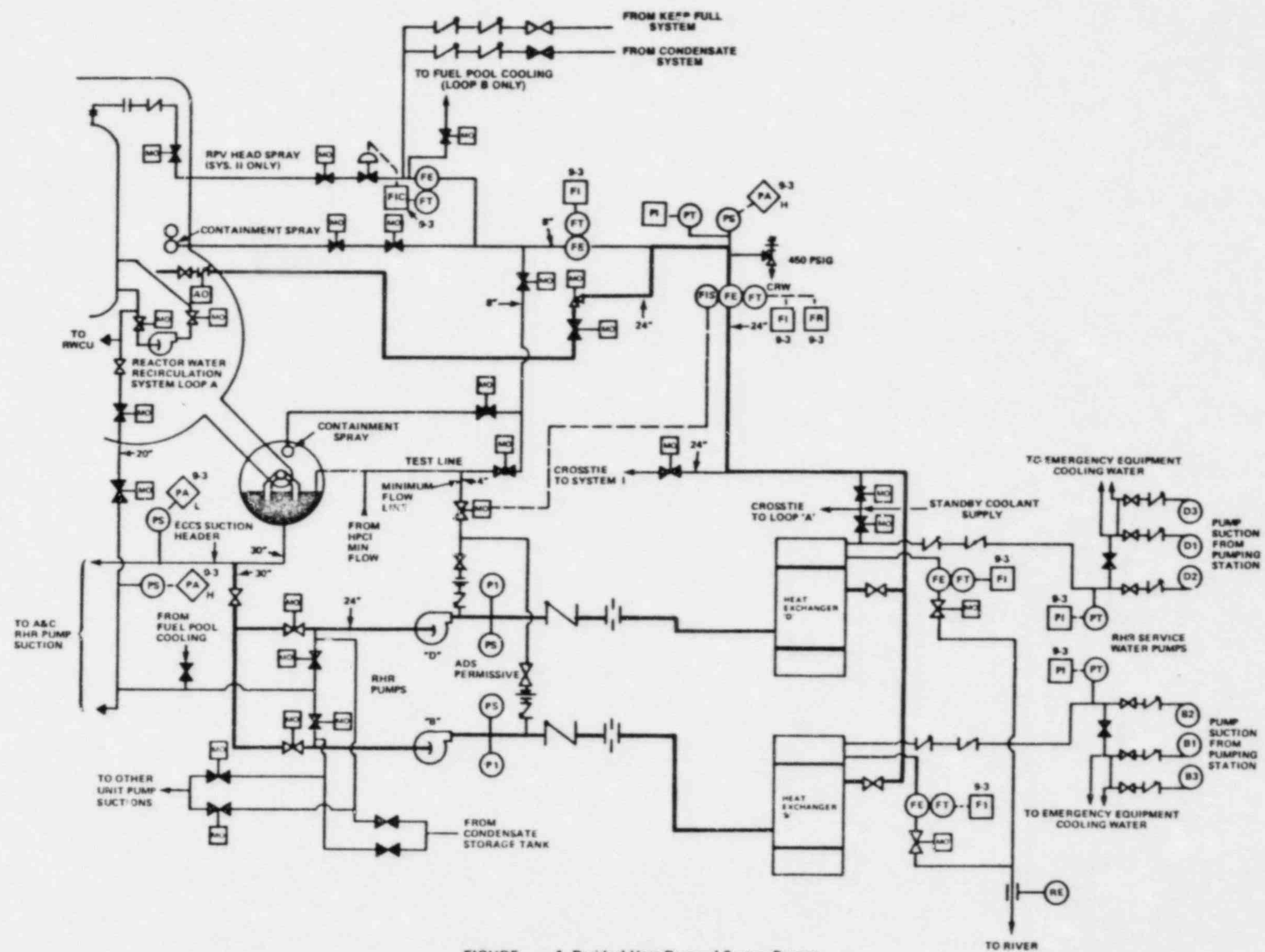

FIGURE 1 Residual Heat Removal System Process Flow Diagram

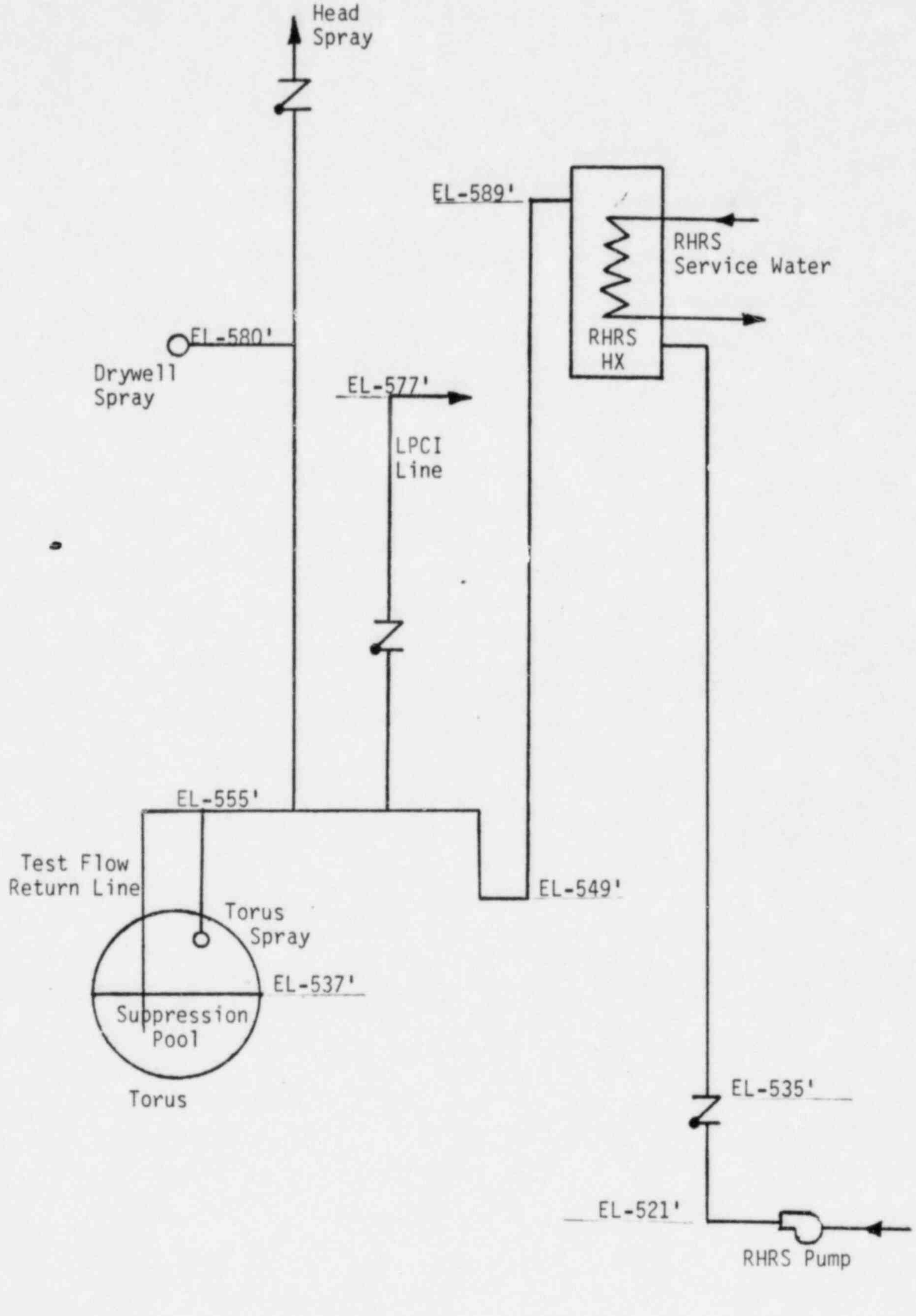

FIGURE 2 Typical Relative Location Of The RHR System Components