U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

BRANCH TECHNICAL POSITION 10-2

DESIGN GUIDELINES FOR AVOIDING WATER HAMMERS IN STEAM GENERATORS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of power conversion systems

Secondary - None

A. BACKGROUND

Plant operational experience has shown that top-feed steam generators containing feedwater spargers with bottom drain holes incur steam-condensation-induced water hammers. This type of water hammer has frequently occurred after the feedwater sparger was uncovered (due to some plant transient) and cold auxiliary feedwater flow was subsequently initiated. The initiation of the auxiliary feedwater flow into the steam generator produces a water slug in the sparger or feedwater piping, which is then accelerated by the unbalanced pressures produced by the condensation of a steam pocket in the line. The resultant impulse could be of a sufficient magnitude to cause damage to the steam generator internal components and feedwater systems piping. The most damaging of such water hammer incidents occurred at Indian Point No. 2 in 1973, where the water hammer loads resulted in rupture of a 46-cm (18-in) feedwater pipe and damage to the containment inner liner. The repeated occurrence of such water hammers and the potential severity of such flow instabilities resulted in the NRC engaging Creare, Inc., in 1976 to evaluate causes and effects, to develop recommendations for avoidance of top-feed steam generator water hammer, and to suggest design methods for minimizing associated dynamic loads.

Revision 4 - March 2007

The underlying causes of water hammer in top-feed steam generators were extensively studied by Creare, Inc., who reported findings and recommended design modifications to minimize or preclude such water hammer occurrence in NUREG-0291 (1977). These recommendations called for (a) use of J-tubes on the topside of the feed ring to minimize loss of water when uncovered, (b) early initiation of auxiliary feedwater to keep piping and feed ring full of water, (c) short horizontal FW pipe lengths at the SG nozzle to reduce magnitude of slug formation and impact, and (d) limiting FW recovery flow rates to less than 9.5 l/s per SG (150 gpm/SG) to minimize steam-water entrainment and subsequent formation of a water slug. The use of top discharge feed (i.e., tubes) makes flow-rate limits practical because the limit only has to be imposed until the piping is full, regardless of steam generator water level. The design and operational modifications were implemented by plants experiencing SG water hammer and appear to have essentially eliminated SGWH. NUREG-0918 details plant specific modifications which were made. In addition, experience sustains maintaining preoperational tests to verify the absence of SGWH.

More recently, Westinghouse and Combustion Engineering have introduced steam generators of the preheat type, wherein the majority of feedwater enters the steam generator at the bottom through a preheater section. The potential for condensation-induced water hammer in preheat steam generators was studied by BNL and reported in NUREG/CR-1606, "An Evaluation of Condensation-Induced Water Hammer in Preheat Steam Generators," June 1980. This report, citing the lack of definitive experimental and analytical results, recommended full-scale verification tests to demonstrate the absence of damaging water hammer in preheat steam generators and connecting feedwater piping (i.e., preoperational tests).

B&W steam generators, which are "once through" flow designs, have generally not reported water hammer occurrence. However, in May 1982, several B&W plants (following inservice inspection) reported damaged internal auxiliary feedwater headers and support structures. The cause was attributed to steam pocket collapse. The internal auxiliary feed ring design concept is similar to CE & W top-feed ring concepts which have experienced water hammer before corrective design measures were implemented. For these B&W plants, the OTSGs are being modified to return to the previous design using auxiliary feedwater injection manifolds which are external to the steam generator.

The staff believes that SGWH evidence and studies performed to date warrant the establishment of design guidelines for steam generators and the associated piping. Guidelines have been developed that may be used to reduce the probability of a damaging steam-condensation-induced water hammer, particularly for the Westinghouse and Combustion Engineering PWR designs which use top-feed steam generators.

B. BRANCH TECHNICAL POSITION

In CP and COL application reviews, the staff expects the applicant to provide the following design capability and verification:

Top-Feed Steam Generator Designs

To eliminate or reduce possible water hammer in the feedwater system:

1. Prevent or delay water draining from the feed ring following a drop in steam generator water level by means such as top discharge J-Tubes and limiting feed ring seal assembly leakage.

2. Minimize the volume of feedwater piping external to the steam generator which could pocket steam using the shortest possible (less than 2.1 m (7 ft)) horizontal run of inlet piping to the steam generator feed ring.

3. Perform tests acceptable to NRC to verify that unacceptable feedwater hammer will not occur using the plant operating procedures for normal and emergency restoration of steam generator water level following loss of normal feedwater and possible draining of the feed ring. Provide the procedures for these tests for approval before conducting the tests and submit the results from such tests.

4. Implement pipe refill flow limits where practical.

Preheat Steam Generator Designs

1. Minimize the horizontal lengths of feedwater piping between the steam generator and the vertical run of piping by providing downward turning elbows immediately upstream of the main and auxiliary feedwater nozzles.

2. Provide a check valve upstream of the auxiliary feedwater connection to the top feedwater line.

3. Maintain the top feedwater line full at all times.

4. Perform tests acceptable to NRC to verify that unacceptable feedwater hammer will not occur using plant operating procedures for normal and emergency restoration of steam generator water level following loss of normal feedwater. Also perform a water hammer test at the power level at which feedwater flow is transferred from the auxiliary feedwater nozzle to the main feedwater nozzle. The test shall be performed by pumping feedwater through the auxiliary feedwater (top) nozzle at the lowest feedwater temperature that the plant standard operating procedure (SOP) allows and then switching the feedwater at that temperature from the auxiliary feedwater nozzle to the main feedwater (bottom) nozzle by following the SOP. Submit the results of such tests.

Once Through Steam Generator (OTSG) Designs

1. Provide auxiliary feedwater to the steam generator through an externally mounted supply top discharge header.

2. Perform tests acceptable to NRC to verify that unacceptable feedwater hammer will not occur using the plant operating procedures for normal and emergency restoration of steam generator water level following loss of normal feedwater. Provide the procedures for these tests for approval before conducting the tests, and submit the results of such tests.

C. REFERENCES

1. Block, J. A., et al., "An Evaluation of PWR Steam Generator Water Hammer," NUREG-0291, June 1977.

2. Chapman, R. L., et al., "Compilation of Data Concerning Known and Suspected Water Hammer Events in Nuclear Power Plants," NUREG/CR-2059, May 1982.

3. Anderson, N. and Han, J. T., "Prevention and Mitigation of Steam Generator Water Hammer Events in PWR Plants," NUREG-0918, December 1982.

4. NUREG/CR - 1606, “An Evaluation of Condensation - Induced Water Hammer Inpreheat Steam Generators,” June 1980.