June 30, 2008

MEMORANDUM TO: Jimi T. Yerokum, Chief
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Division of Systems Analysis
Office of Nuclear Regulatory Research

FROM: Robert O. Hardies, Chief **/RA/**
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SUBJECT: INTERFACING SYSTEM LOSS-OF-COOLANT ACCIDENT FAILURE CONDITIONS

This memorandum is in response to a request made by Mr. Robert Prato of your branch to estimate more realistic failure conditions associated with the failure of secondary side piping assuming that precursor failure of the associated primary side isolation valves occurs. This scenario is known as an Interfacing System Loss-of-Coolant Accident (ISLOCA). The failure conditions of interest for an ISLOCA include both the likelihood of a secondary-side rupture due to overpressurization and the break size resulting from this overpressurization. Specifically, Mr. Prato requested an estimation of the likelihood that the break size is equivalent to a double-ended guillotine break (DEGB). This request was made to support the analysis of such failures for the Surry Nuclear Power Plant (Surry) as part of the State-of-the-Art Reactor Consequences Analysis (SOARCA).

This memorandum provides a brief summary of ISLOCA research, describes an approach that could be used to estimate ISLOCA failure probabilities, identifies conditions that would diminish the likelihood of a DEGB, and outlines an approach for a more rigorous determination of break sizes. Alternative break size assumptions that can be used in SOARCA to evaluate risk sensitivity to break size in lieu of a rigorous analysis are also provided.

Several generic safety issues dating back at least to 1980 have addressed ISLOCAs. In the early 1990's, Idaho National Laboratory (INL) led a research program to evaluate the risk associated with ISLOCAs. NUREG/CR-5928 summarizes the results of this research program and provides a screening method and procedures for performing an ISLOCA analysis. A screening and bounding analysis was used to demonstrate that the design margins available in boiling water reactor (BWR) systems preclude the possibility of an overpressure-induced rupture. The risk is higher for pressurized water reactor (PWR) plants and several plant specific and bounding analyses were performed to quantify the risk and possible ISLOCA consequences. As part of this analysis, screening estimates of passive system leak and/or rupture probabilities were developed in NUREG/CR-5862 to evaluate the susceptibility of secondary-side tanks, heat exchangers, filters, pumps, valves, flanged components, and pipes to failure due to overpressurization.

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The current SOARCA analysis of the Surry plant assumes that the conditional probability of a secondary-side pipe rupture due to primary-side overpressurization is 1. It is possible to determine more realistic rupture probabilities using the approach developed in the INL research program. The following information is needed to conduct such an analysis. The overpressurization magnitude must be known. If pressure losses in the system to be analyzed have been estimated, a more realistic magnitude of the overpressurization pulse can be determined. Alternatively, the system design pressure could be applied if no losses are conservatively assumed. The piping thickness, general corrosion allowance, and material properties must also be known or assumed to perform the analysis. This information, along with assumptions used to describe uncertainty in each of these parameters, can be used to develop a conditional rupture probability.

One important caveat is that this approach presumes that the pipes do not contain significant defects that may lead to failure at lower burst pressures than for pipes which are largely unflawed. This assumption is reasonable for piping systems which are made with seamless pipe, have no circumferential welds, and are inspected to ensure that the general corrosion allowances have not been exceeded. Piping systems that contain circumferential welds, are uninspected, or made from cast austenitic or carbon steels are more likely to violate this assumption. The specific materials, inspection history, and operating history should be evaluated for these types of systems to determine if the INL approach is applicable.

However, as in the SOARCA analysis, the conditional rupture probability can be conservatively assumed to be 1 and the preceding considerations are moot. If pipe rupture does occur, the size of the rupture determines the plant system risk calculated as part of the SOARCA analysis. The rupture size is first a function of the rupture orientation; the rupture could be either circumferentially or axially oriented. The most conservative analysis would assume that the rupture is circumferentially-oriented and forms a DEGB.

However, if the following conditions are met, the likelihood of a circumferentially-oriented failure, and hence a DEGB is expected to be small.

1. No significant circumferential defects (greater than 10% of the thickness) exists. This assumption is more likely met if the pipe is seamless and contains no circumferential welds within the sections of interest;
2. The bending and thermal stresses within the pipe are substantially lower (less than 50%) than the overload pressure stresses. If bending and thermal stress are of the same order of magnitude as the overload stresses and act in the axial direction, the pipe could fail via a circumferentially-oriented rupture which could progress to a DEGB. A systems-based analysis could be used to estimate these loads for the Surry plant using either operational information or information provided as part of a submittal to credit leak-before-break in order to satisfy General Design Criterion (GDC) 4;
3. The piping line is not subject to flow-accelerated corrosion (FAC) degradation to an extent that a circumferential failure mode becomes preferential; and
4. No other forms of degradation exist (e.g., microbiologically-enhanced corrosion, erosion/corrosion, etc) that could degrade the pipe wall thickness at a preferential location.

A review of the specific system would be needed to determine if these conditions are met. However, if these conditions are met and circumferentially-oriented failure, and DEGB, can be reasonably precluded, the pipe rupture will be axially-oriented and failure will be governed by the hoop stresses. This failure mode is most commonly called a fish-mouth type fracture. If a fish-mouth fracture occurs, the rupture size is expected to be less than a DEGB.

The specific break size distributions for either a circumferentially or axially-oriented rupture could only be predicted using a detailed dynamic fracture analysis which treats model and parameter uncertainty associated with key variables. The analysis would require fracture resistance properties for the material, general static loading information, the temporal history associated with the overpressurization transient and other active loading transients (e.g., thermal), piping geometry and support information, and boundary constraint information. Targeted experiments would also be recommended to confirm the numerical studies for more-simplified, benchmark problems and also possibly to address some of the uncertainties. Such an analysis is possible, but it would represent a state-of-the-art study with respect to piping structural integrity prediction.

Lacking a specific analysis, it is reasonable to assume that different break sizes could occur and then model the consequences associated with a break of a certain size. The proposal to evaluate the consequences associated with assumed break sizes up to a DEGB appears reasonable in light of the assumptions, uncertainties, and complicated analysis required to refine these break size estimates. It is recommended that a DEGB be assumed initially and then smaller breaks should be considered to examine the sensitivity of the results to the ISLOCA size. A break size with 66% of the area of a DEGB was used in initial SOARCA sensitivity studies. This is a reasonable alternative break size to consider. Other break sizes could be chosen based on the differences in the consequences associated with each break size. For instance, if the risk or consequence associated with a DEGB and a 66% break size are similar, it would be illustrative to model smaller break sizes, potentially to determine the break size at which the risk becomes less significant or inconsequential. If the risks associated with DEGB and a 66% break are quite different, it would be illustrative to examine larger break sizes to determine when the risk becomes unacceptable.

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