# Consequential Steam Generator Tube Rupture Program

## Background

The NRC and the nuclear power industry have expended considerable resources over the last two decades to better understand the safety implications and risk associated with consequential steam generator tube rupture (C-SGTR) events (i.e., events in which steam generator (SG) tubes leak or fail as a consequence of the high differential pressures or SG tube temperatures, or both, predicted to occur in certain accident sequences). Key activities included an assessment of temperature-induced creep-rupture of the reactor coolant system (RCS) components in the NUREG-1150 study entitled, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants, issued December 1990; a representative analysis of the potential for induced containment bypass by an ad hoc NRC staff working group in NUREG-1570, "Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture" issued in 1998, and recent thermal-hydraulic (T/H) analyses and risk analyses as part of the steam generator action plan (SGAP). Severe accident analyses performed as part of the state-of-the-art reactor consequence analyses (SOARCA) project provide additional insights into the likelihood and impact of subsequent failure of the reactor hot leg shortly following a C-SGTR event.

Prior investigations of a Westinghouse plant concluded that the contribution of C-SGTR events to the overall containment bypass frequency is at best at the same order of magnitude, if not lower than, the containment bypass fraction associated with other internal events for most pressurized-water reactors (PWRs). Thus, plant risk assessments should consider and monitor the risk associated with C-SGTR in a manner commensurate with its expected importance at each plant. Although important conclusions were made, these investigations identified certain limitations of scope, as well as a lack of thorough RCS component modeling with advanced simulation tools. It is important to address these limitations to advance our understanding of associated risks and to develop an enhanced risk assessment tool for C-SGTR events.

## Objectives

To close the technical gaps and to develop an enhanced risk assessment procedure for C-SGTR, the current RES program will attempt to fulfill the following objectives:

- Update computational fluid dynamics (CFD) and system code models for Combustion Engineering (CE) plants.
- Evaluate the impact of in-core instrument tube failures on natural circulation.
- Update SG flaw distributions.
- Complete structural analyses of CE and Westinghouse RCS components.
- Develop a user-friendly methodology for assessing the risk associated with consequential tube rupture and leakage in design-basis accidents and severe accident events.

- Conduct a reassessment of the conditional probabilities of C-SGTR based on updated flaw distributions and updated T/H analyses.
- Compile and summarize key research, building upon NUREG-1570 (work performed as part of SGAP activities.

**Approach**

**CE Thermal-Hydraulic and Severe Accident Analysis**

The updated modeling approach and lessons learned from these most recent Westinghouse plant predictions will be applied to a CE plant model in order to improve the T/H predictions. This effort will update the hot-leg flow and mixing model, as well as hot-leg thermal radiation modeling.

The CE CFD model will be updated to include a simplified upper plenum, hot leg, surge line, and the SG primary side. This model will be used to predict hot leg and inlet plenum mixing rates, as well as the variations in temperature of the flow entering the hottest tubes in the SG. The system code modeling effort will include the development of a MELCOR CE plant model which incorporates all of the lessons learned from the recent Westinghouse predictions completed in support of the SGAP. The modeling will also incorporate the updated CE CFD model predictions.

**Assess Impact of In-Core Instrument Tube Failures**

RES completed a study on the impact of the consequences of instrumentation tube failure during severe accidents, which is detailed in ERI/NRC-09-206, “Analysis of the Impact of Instrumentation Tube Failure on Natural Circulation During Severe Accidents” (ADAMS Accession No. ML100130402). This work assesses the impact of instrumentation tube failures for Three Mile Island, Unit 2 (TMI-2) (a Babcock & Wilcox (B&W) design with a once through SG), and Zion (a 4-loop Westinghouse design with a U-tube SG).

**Updated Steam Generator Flaw Distributions**

To assess the probability of an induced SGTR, detailed knowledge of the characteristics of SG tube flaws is needed with the tube temperature and stress profile during postulated accidents. For statistical analysis, flaw density distribution data as a function of size, shape, orientation, location, and type are needed. The potential for failure depends primarily on the upper tail of the size distribution (i.e., the most severe flaws) for a given flaw type and location. A verification process was used to confirm that the flaw distributions are consistent with operating experience for observed leakage rates.

A selected set of inspection reports is used to pool the observed SG tube flaw characteristics. This information is used to develop flaw distributions for wear and crack type flaws, which form the input to estimate C-SGTR behavior and probabilities using the C-SGTR calculator developed for this purpose.

**Structural Analysis of CE and Westinghouse RCS Components for Prediction of RCS Piping Failure**

RES structural analyses will build upon the latest T/H and severe accident analyses to include specific RCS components for Westinghouse and CE plants (e.g., hot-leg nozzle and hot leg-to surge line nozzle). The failure analysis will consider uncertainty resulting from the shape, size, and location of potential flaws in the RCS components.

RES plans to identify, characterize, and model relevant RCS nozzles to assess their potential for failure during severe accidents for Westinghouse and CE plants. Two-dimensional axisymmetric and three-dimensional models will be developed, addressing variables such as nozzle geometries and configurations, boundary conditions, loading conditions, fabrication effects, stress-corrosion cracking mitigations, and degraded conditions. These models will be used to determine the time to failure for each analyzed component and the associated sensitivity to loadings and flaw geometry. Because of the importance of incorporating uncertainty, RES will develop a semiempirical methodology, based on numerical experiments, to predict failure of critical RCS components. The resulting methodology is expected to be more conducive to the procedure adopted in the C-SGTR risk assessment method developed as part of the program.

**Simplified Method for Assessing the Risk Associated With C-SGTR**

In March 2009, RES provided the NRC's Office of Nuclear Reactor Regulation (NRR) with a report describing a method for assessing C-SGTR risk (ADAMS Accession No. ML083540412). RES intends to extend the methods described in this previous report to incorporate a number of enhancements. These enhancements will include consideration of the updated T/H conditions, SG flaw distribution, and RCS component analyses. Additionally, C-SGTR risk assessment methods described in previous NRC, Electric Power Research Institute (EPRI), and industry reports will be reviewed to identify useful insights and modeling approaches for use with the new simplified method. RES anticipates that the level of analysis in the new approach will be comparable to that of the previous RES C-SGTR risk report and the earlier NUREG-1570 study. Consistent with previous C-SGTR risk assessment work, the new simplified method will consider both pressure-induced and thermally induced SG tube failures.

**Reevaluation of C-SGTR Conditional Probabilities**

In support of SGAP, RES previously developed an SG tube failure probability calculation tool. RES plans to extend the framework and modeling approaches used in this tool, including pressure- and temperature-induced challenges. Consequently, this program will focus on further validation of the detailed modeling used in the calculator, extension of calculator capabilities, updates to basic data and parameters (including provisions for future data updates), improvements in calculator usability, and development of supporting documentation.

**Status**

RES has recently completed additional thermal-hydraulic and structural analyses for Combustion Engineering plant designs and is currently evaluating the risk implications of severe accident induced consequential steam generator tube ruptures (C-SGTRs) for these designs. Previous research efforts have focused on characterization of SG tube flaws, development of a calculation tool for assessing the timing of SG tube failure and failure of other portions of the reactor coolant system, and detailed analyses of Westinghouse plant designs. The staff is currently developing a comprehensive report that summarizes work that has been performed under this project.

**Deliverables**
RES anticipates completing a draft NUREG report on the project in late 2013, to be followed by a final NUREG report in 2014.

**For More Information**
Contact Raj Mohan Iyengar, RES/DE at 301-251-7907 or Raj.Iyengar@nrc.gov.