Periodic remaining life evaluation program of PWR Pressurizer surge line concerning thermal stratification effect

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Contents

- Thermal Stratification Research and Measurement for Surge Line In China
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The Phenomenon and Results of Thermal Stratification

Thermal stratification is the result of:

- Horizontal piping line with a slight height difference between its two ends;
- Two different types of fluid (hot and cooler) with an extremely slow fluid velocity inside the piping line.

Owing to the difference in densities between the hot water and the relatively cooler water, the warmer lighter water tends to float on the cooler heavier water and then thermal stratification happens.
Thermal stratification in the surge line causes two effects:

- Extra global bending of the pipe compared with that predicted in the original design
- Potentially reduced fatigue life of the piping due to the global and local stresses resulting from stratification and striping.
Surge Line Thermal Stratification Research and Measurement (3/15)

The Requirements of Nuclear Authorities

Surge Line Thermal Stratification Research and Measurement (4/15)

- Surge Line Thermal Stratification Research Program Based on 300MWe PWR NPP
  - Temperature monitoring for thermal stratification of Surge line

The program was established in 1998. Take the advantages of the construction and preservice tests of PC Project I, we carried out temperature measurement of its surge line, and significant thermal stratification was observed.
Surge Line Thermal Stratification Research and Measurement (5/15)
Surge Line Thermal Stratification Research and Measurement (6/15)

◆ Design and operating transients modification

The following work was to develop transients applicable to the related NPPs which include the effects of stratification. The transients were developed based on the originally established design transients and were refined through the use of monitoring results, plant operating procedures, operator interviews and applicable data or experience of similar NPPs. The similarities rely on the surge line layout, the plant operating procedures and the piping and support configurations.
Surge Line Thermal Stratification Research and Measurement (7/15)

- Design and operating transients modification

- Normal & Upset Transients
  - Heat-up & Cool down
  - Transients Except for Heat-up & Cool down
    - Heat-up
      - $\Delta T$ and Occurrence of I/O Transients
    - Cool down
      - $\Delta T$ and Occurrence of Fluctuation Transients
    - I/O Transients
    - Fluctuation Transients
  - 50% of Heat-up transients
Analysis of thermal stratification effects on surge line

We studied the methods and computer programs to account for the global bending stresses, local stresses and thermal striping stresses caused by surge line thermal stratification.
Surge Line Thermal Stratification Research and Measurement (9/15)

- Data base for temperature monitoring and evaluation results

A computer program which is based on database was developed to preserve, manage and analyze the monitoring results.
Surge Line Thermal Stratification Research and Measurement (10/15)

temperature difference versus time
Surge Line Thermal Stratification Research and Measurement (11/15)

Temperature versus time
Surge Line Thermal Stratification Research and Measurement (12/15)

Load Case: Cool-down
Date: Dec. 20th
Time: 0:06:00

Temperature distribution
Surge Line Thermal Stratification Research and Measurement (13/15)

Function:

- To show the temperature distribution and stratification at any specified time for all monitoring sections.

- To categorize stratification cycles using the rainflow cycle counting method. And delta T change range and its relating occurrences can be provided.

- To provide a database for all monitoring results.
### Surge Line Thermal Stratification Research and Measurement (14/15)

#### 降温过程各截面出现的温度范围及相应的出现次数

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Surge Line Thermal Stratification Research and Measurement (15/15)

With the increasing accumulation of transient data, this program could play an important role in the life assessment of the pressurizer surge line.
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (1/11)

The transformation of the purpose of fatigue life assessment for the surge line

- As one of the important parts of primary loop, surge line plays a significant supporting role to the whole LTO of primary loop due to its thermal stratification loads.
- Originally, we studied surge line thermal stratification to account for its effects on design fatigue usage factor for the purpose of licence application.
- Presently, we studied surge line thermal stratification to account for its effects on the used life and the remaining life for the purpose of LTO.
■ Thermal Transient load sets for fatigue analysis
  ◆ Based on the design transients, there are many types of normal operating transients, test transients, upset transients and spray operating transients
  ◆ Each has its own relating stratification case, especially for plant heatup and cooldown conditions
  ◆ Accordingly, the load sets need to be categorized and combined in order to not only reduce the complexity of calculation and analysis, but also to reflect the effect of different type of load sets on the fatigue analysis result.
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (3/11)

- Key parameters for transient load sets categorizing
  - Temperature difference and its change rate
  - Pressure difference
  - Temperature & pressure distribution
  - Flow rate
  - Average temperature of each section
  - Top-to-bottom temperature difference of each section
  - Hot-to-cold interface position
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (4/11)

Key parameters of the transient load sets were selected based on their effects on the range of stress change, and sensitivity analysis for each parameter were performed to help the categorizing and combination.
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (5/11)

■ Analysis model

◆ Global bending caused by stratification
  ➢ The temperature distribution of the pipe section can be classified as three components: average distribution, linear distribution and non-linear distribution. They cause different types of stress on the section according to the definitions of ASME code.
  ➢ The linearly distributed temperature will cause the global bending of the surge line.
  ➢ The impact of the global bending on the pipe is analyzed using ANSYS computer program.
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (6/11)

◆ Mathematical model for analysis of global bending
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (7/11)

◆ Analysis of local stress
The local stress caused by the hot-to-cold interface on the pipe cross-section due to thermal stratification was calculated assuming a step change hot to cold.

◆ Thermal striping stress
The thermal striping stress due to the turbulence in the hot-to-cold stratification layer was also considered taking into account of the attenuation of thermal striping potential. And the comment and R&D results in the IAEA-TECDOC-1361 was also used for reference.
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (8/11)

- Fatigue analysis of the surge line
  - The integrated reactor coolant loop model is used to perform the fatigue analysis of the surge line and its nozzles.
  - Piping stress analysis computer program (PIPE 728) is used to construct the model and perform the analysis.
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (9/11)

Analysis model
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (10/11)

- Fatigue analysis of tee model
  A combination of line element model and 3D solid structure model is used to analyze the surge line hot leg tee connection
Fatigue analysis and life assessment of Surge Line for the purpose of LTO (11/11)

Evaluation of the results

- Pressurizer surge line fatigue evaluation was accomplished according to the ASME III NB-3650
- From the result of the fatigue analysis, it can be find that the normal operating transients including heatup and cooldown provide a comparatively small contribution to the usage factor, although the significant thermal stratification transients are observed.
- On the contrary, some upset transients with very conservative assumptions of the stratified temperature provide a comparatively large contribution to the usage factor
3 Conclusion (1/1)

- SNERDI has helped two owners (300MWe PWR NPP) to establish the temperature monitoring system for the Pressurizer surge line.

- For the fatigue life evaluation, the categorizing and combination of the thermal transient load sets based on the analysis of the selected key parameters of the transients are useful to find the important types of transient who contribute significantly to the analysis result.

- A database and the relating computer program is developed to preserve, manage and analyze the monitoring results, and design transient is modified and the operating transients can be refined.
Further work on surge line AMP

- Selection of control points (tee, nozzle, elbow etc.)
- Detail analysis of transient load sets key parameters
- Establishment of an online transient parameter collecting, recording and analysis system
- Fatigue life assessment
  - Approximate calculation based on DATABASE
  - Detail analysis based on recording data
Further Work (2/2)

- Surge line AMP endue further work on the topic of thermal stratification
  - More detail record of operation and ISI
  - More accurate analysis of thermal fatigue loads including those caused by thermal stratification
    - Modification of the mathematical model
    - Improvement of the computer program
    - Adoption of new technology
Thank You Sincerely