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Materials Reliability Program: Second International Conference on Fatigue of Reactor Components

July 29–August 1, 2002
Snowbird Ski and Conference Center
Snowbird, Utah

Technical Report

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REPORT SUMMARY

This proceedings contains information presented at the Second International Conference on Fatigue of Reactor Components held 31 July–1 August, 2002, in Snowbird, Utah. This second conference, again sponsored by EPRI, the Organisation for Economic Co-Operation and Development (OECD), Nuclear Energy Agency/Committee on the Safety of Nuclear Installations (NEA/CSNI), and the U.S. Nuclear Regulatory Commission (NRC), provided a forum for the technical discussion of fatigue issues that affect the integrity and operation of light water reactor components.

Background
Fatigue is a primary degradation mechanism affecting nuclear power plant components worldwide. The effective management of fatigue is important to the continued safe operation of plant components during present operation and as plants consider long-term operation. In 2000, the EPRI Materials Reliability Program (MRP) organized the first conference in this series to bring together international experts to discuss significant fatigue issues affecting nuclear plant operations, share common experiences, and identify outstanding technical issues. The breadth of international efforts underway in this area dictated that future conferences be held to report research results and discuss relevant issues. The second conference in this series, again organized by the EPRI MRP, was held 29–31 July in Snowbird, Utah. Additionally, a one-day workshop on flaw growth in austenitic and nickel-based materials was held on 1 August. Cosponsorship of the conference was provided by the OECD NEA/CSNI, and the U.S. NRC.

Objectives
- To provide a forum for the technical discussion of fatigue issues that affect the integrity and operation of light water reactor components
- To share common experiences regarding fatigue of reactor components in order to ensure continued safe operation
- To identify common areas of interest to foster future international research/collaboration activities

Approach
The conference was organized in a series of technical presentation and group discussion sessions focused on the following fatigue-related topics:

- Thermal fatigue
- Environmental fatigue
- Fatigue monitoring/evaluation

- Codes and standards
- General fatigue issues

The conference was structured to directly benefit utility and plant managers, as well as system, materials, structural integrity, licensing, and maintenance/repair engineers. The discussion/panel sessions were structured to foster open discussion among participants in relevant fatigue issues.

Results

Approximately 60 fatigue experts, representing 8 countries, participated in the second conference. Strong representation was made by nuclear operators, vendors, regulatory agencies, research and development organizations, and other experts. Following the technical presentations, a summary panel session was held to discuss key technical issues identified during the conference. As a result of these discussions, conclusions were developed with the consensus of the conference participants. Based on the degree of technical exchange that occurred and the quality of information provided during the conference, the participants recommended that another conference on this topic be held in 18–24 months.

EPRI Perspective

Fatigue management is an important aspect of the continued safe operation of plant components. Periodic discussion of fatigue-related issues in an international forum allows the sharing of common experiences and fosters international collaboration in the resolution of fatigue issues. Future conferences in this series will continue to be a major forum for the discussion of plant component fatigue issues.

Keywords

Thermal fatigue
Environmental fatigue
Fatigue management
Life-cycle management

CONFERENCE SUMMARY

2nd International Conference on Fatigue of Reactor Components
29–31 July, 2002
Snowbird Ski & Conference Center
Snowbird, Utah

Following the technical presentations, a panel session was held to discuss key technical issues identified during the conference. As a result of these discussions, the following conclusions were developed with consensus of the conference participants.

Thermal Fatigue

1. Stronger U.S. utility participation in OECD and NEA/CSNI is encouraged regarding thermal fatigue technical issues.

2. Similar efforts are underway by several organizations worldwide to understand the fundamental mechanisms associated with thermal fatigue and predict component susceptibility. Data sharing and collaboration are encouraged for the benefit of all organizations.

3. International knowledge regarding the phenomena associated with thermal fatigue is progressing. Results of these studies should be incorporated into aging management programs, including in-service inspection (ISI) programs.

4. Consideration should be given to the assessment and screening of Class 2 piping systems for thermal fatigue.

5. International data efforts indicate that a change in the high-cycle end of the thermal fatigue mean data curve in the appropriate design code may be warranted. Generation of additional data beyond 10^6 cycles is recommended. This may also warrant a revision to fatigue evaluation procedures.

6. Fatigue usage factor is not necessarily a good indicator of component degradation.

Environmental Fatigue

1. The effect of flow rate on environmental fatigue for carbon/low-alloy steels has been shown by several organizations. Additional data are needed to characterize the effect for stainless steel materials.

2. The effect of flow rate should be considered in environmental fatigue evaluations.

3. International studies indicate that threshold conditions are necessary for environmental fatigue to occur.

4. Development of a new fatigue design (S-N) curve that incorporates environmental effects is not recommended.

5. For consideration of environmental effects, the present preferred approach is an application of an environmental factor, F_{en}.

6. Clarification of applicable environmental fatigue threshold parameters is needed, especially when the notion of "moderate" environmental effects is considered.

7. Fatigue analysis procedures (including design curves) should not be revised without a thorough understanding of all relevant effects:

    a. Applicability of load-controlled data was questioned; strain-controlled data are preferred.

    b. Clarification of surface finish effects.

8. The measurement and reporting of water conductivity and electro-chemical potential (ECP) associated with environmental fatigue tests in boiling water reactor (BWR) environments are encouraged.

9. Further reconciliation between operating experience and laboratory/component/structural data is recommended.

10. A more detailed evaluation of temperature/strain relationship in transient analysis (for example, the modified rate approach applied in Japan) should be considered for potential application.

Fatigue Monitoring/Evaluation

1. Fatigue transient monitoring (both globally and locally) is an important tool for fatigue aging management that should be implemented as early in plant life as practical.

2. Evaluation and assessment of data integrity are critical factors in the successful interpretation of fatigue transient monitoring results.

3. Advanced methods for material condition monitoring are being developed and show promise for the successful monitoring of fatigue. Further development is encouraged.

4. An overall integrated approach is critical to successful fatigue management of relevant structures. Training of plant personnel is an important aspect of any integrated approach.

5. Additional discussion of fatigue evaluation of welds is recommended in future conferences.

Codes & Standards (American Society of Mechanical Engineers [ASME] Section XI)

1. Improved in-service inspection (ISI) probability of detection (POD) is an important aspect in reducing component inspection frequency in flaw tolerance analyses.

2. The crack aspect ratio of propagating flaws has been shown through analytical studies to vary as a function of transient.

3. Multiple crack initiations may also need to be considered in a flaw tolerance evaluation.

4. da/dN information is needed for austenitic stainless steels.

28

FATIGUE EVALUATION OF A BWR FEEDWATER NOZZLE USING AN ON-LINE FATIGUE MONITORING SYSTEM

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FATIGUE EVALUATION OF A BWR FEEDWATER NOZZLE USING AN ON-LINE FATIGUE MONITORING SYSTEM

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Abstract

In 1994, the safe end of the feedwater nozzle of the Santa María de Garoña Nuclear Power Plant reactor pressure vessel was replaced. Since this is the most critical location of the vessel with respect to thermal fatigue, it was decided to monitor the fatigue usage of this nozzle through the installation of a fatigue monitoring system.

This paper summarizes the fatigue usage results obtained from the fatigue monitoring system, from its original installation up to present-day, and a comparison of the results to the design basis fatigue estimates. First, a comparison is made between the calculations included in the stress report of the nozzle and the calculations performed by the fatigue monitoring system in order to demonstrate the conservative methodology employed in the fatigue monitoring system. Then, the comparison is extended to actual plant transients. The conclusion is reached that the design basis fatigue evaluation of the vessel includes a high degree of conservatism compared to actual fatigue usage accumulation.

1.- INTRODUCTION

The Santa María de Garoña Nuclear Power Plant (SMG) is a third-generation Boiling Water Reactor (BWR-3) designed by General Electric (GE) in the late 1960s. The plant started commercial operation in 1971, its rated thermal power is 1,381 MWt, and its rated electrical power 460 MWe.

One of the most critical components of the plant is the Reactor Pressure Vessel (RPV). The SMG RPV is a 188" diameter by 726" height cylinder with a hemispherical bottom head and a removable hemispherical top head. The vessel was fabricated by the Rotterdam Dockyard Company (RDM) from low alloy steel (LAS) material. The design pressure and temperature are 1,250 psi and 575ºF, respectively. Rated normal full power operating pressure is 1,000 psi with an associated operating temperature of 545ºF.

The systems of the plant that need to interchange fluid with the RPV, either in normal operation or for safety purposes, are connected to the RPV through nozzles at different

per-event fatigue usage is multiplied by the 2,600 occurrences specified in the design basis, more than 95% of the total fatigue usage (U = 2.037) is obtained. The main reason for the low number of occurrences for this event is because the operators at SMG have been trained to avoid its occurrence.

6.- CONCLUSIONS

The higher estimation of the fatigue usage calculated for design basis transients with FPro, compared to the fatigue usage reported in the design basis stress report for the monitored safe end location, demonstrates that the methodology used by the fatigue monitoring system installed for the SMG RPV FDW nozzles is conservative. The main factors that justify this conservatism are: (i) the method of calculating and combining the individual stresses at the location of interest, (ii) the conservative grouping or "binning" of the stress cycles into discrete ranges, and (iii) the application of a conservative reduction factor to the ASME fatigue curve.

The fatigue usage computed by FPro for actual transients during a period of 7.75 years is significantly lower than the fatigue usage calculated for the equivalent design basis transients and than the allowable value of 1.0 specified in the ASME Code. Two reasons that contribute to this reduction are: (i) the sequence of occurrence of the transients is not the "worst case" sequence typically postulated in traditional design basis evaluation, and (ii) the observed transients, although very similar in shape to the design ones, are in general significantly less severe than the design basis definitions specified in the DS.

The most important factor that justifies the installation of the SMG fatigue monitoring system is the resulting projected number of system cycles. The number of cycles projected based on FPro evaluation is in all cases significantly lower than the number of cycles specified in the DS. This difference is especially significant for event #16, which is the primary contributor to the total design basis fatigue usage of the monitored component.

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