Fatigue Aging Management Reconciliation of 40-Year Transients for 60-Year Application

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ABSTRACT

This paper discusses a program developed by Westinghouse Electric Company that investigates and then qualifies existing 40-year design transients for 60 years of operations. The program is designed to provide a solid foundation establishing that the current design transients are conservative, and that they can be used without modification as the basis for 60 years of operations. Three areas of investigation are performed. The first area of investigation is an independent review of past operations. The review identifies and classifies plant transients from plant historical records. For the second area of investigation, experts from Westinghouse review the current transient and fatigue cycle counting program. The purpose is to determine the overall effectiveness of the transient and fatigue cycle counting program in identifying and tracking fatigue-significant events. Strengths and weaknesses of the program are identified and recommendations for improvement are made. The third and final investigation is an analysis of the data collected in the first and second parts, with respect to the frequency and severity of actual transients. The investigation analyzes the frequency of past events, projects them into the future, and compares results to the existing design frequency limits. The analysis also characterizes the severity of the actual plant transients with respect to the design assumptions. This is done to insure that, on an event-by-event basis, the design events are conservative enough to envelop the actual events. Finally, an overall conclusion is formulated and presented. In addition, the paper discusses the limitations in the scope of the work described.

INTRODUCTION

License renewal can allow owner/operators of nuclear power plants to extend operations and, as a result, increase their return on investment. This, however, is only true if the costs of the license renewal effort can be maintained within reasonable limits. One activity that can help reduce the license renewal costs is to show that the current design basis Time Limited Aging Analyses (TLAAs) that qualify the primary equipment are adequate to cover plant operations for up to 60 years, and hence do not require any revisions. To this end, Westinghouse has established a program that systematically investigates the feasibility of qualifying original design transients to support plant license extension to 60 years of operation. The qualification program relies on three areas of investigation: identification and classification of past operations, evaluation of the effectiveness of the plant transient and fatigue cycle counting program, and frequency and severity analysis of the transients identified. The initial task is to assemble the current design basis transient set and design frequency of occurrences for all of the major NSSS equipment. This is to be accomplished on a component specific basis, due to the inherent differences in the design parameters for the various RCS equipment.

It is suggested that the initial equipment scope be limited to the following primary system equipment:

Reactor vessel pressure boundary and internals
Primary loop piping
Pressurizer vessel
Reactor coolant pump pressure boundary
Steam generators
Control rod drive mechanisms

Explicitly excluded from consideration are the pressurizer lower head, pressurizer surge and spray nozzles, pressurizer surge and spray lines, charging lines and associated charging nozzles, and all branch lines subject to NRC Bulletin 88-08 loading conditions. These locations experience transients that are too complex to be adequately measured by the methods applied in this investigation. As a result, distinct qualification programs are required for each of these equipment locations.

ASSEMBLING THE CURRENT LICENSING BASIS TRANSIENTS

The current licensing basis transients consist of those transients and frequencies of occurrence that were originally postulated during the plant design. The basis also includes transients identified based on industry experience and regulatory mandates, as well as any modifications to the transients as a result of plant operating history. The design basis transients are assembled on a component specific basis, using information from sources such as: original component equipment and design specifications, plant Technical Specifications, FSAR, and input from the respective component designers. Other sources to consider are thermal upratings and the plant's cycle counting procedure. Review and analysis of this documentation provides assurance that the current design basis transient set is conservative and comprehensive for use in the evaluation of plant operations, and subsequently as the basis for 60 years of operation. The following issues are addressed:

- The transients identified represent the complete set of design transients.
- Design transients and frequencies of occurrence are presented on a component specific basis, which facilitates assessing the impact of any transient at the component level.
- Differences in the design transients (i.e., in process parameters and the number of occurrences) are identified and reconciled.

One application of this method resulted in the identification of a number of differences in design parameters, including:

- Differences in the number of cycles analyzed for a particular transient, either between two sister units or among available equipment specifications and documentation
- Differences in the transients and number of design cycles identified between two units for the same equipment
- Differences in the process parameters identified among the various equipment specifications for the same design transient.

DETERMINING THE ACTUAL PLANT TRANSIENTS

To determine the actual plant transients, a comprehensive cross section of available information should be selected for detailed review. Internal and external documentation and site interviews of plant personnel should all be considered. The following data sources are considered essential for this effort:

Reactor Trip Reports

Reactor trip reports should be reviewed for the purpose of identifying the following information:

Date and Time of Reactor Trip
Initial power level prior to Reactor Trip
Cause of Reactor Trip
System responses during and after trip
Changes in process parameters after the trip

Plant Cycle Counting Procedure and Associated Reports

The plant's cycle counting procedure, associated reports, and supporting data can be used to identify specific transients, as well as periods of plant operations where transient activity may have occurred. This information can be used only after a thorough review of the plant's cycle counting procedure and process confirms the effectiveness of the program.

Test Procedures and Reports

In conjunction with interviews conducted with site personnel, Westinghouse recommends a review of a cross section of the plant's test procedures and reports. Particular interest should be given to tests that affected primary system pressure, including steam generator pressure tests and primary pressure tests.

Licensee Event Reports

A comprehensive review of all plant Licensee Event Reports (LERs) is performed to identify events that have the potential to impact the fatigue of primary components (i.e., any event that affected RCS system temperature and pressure). The purpose is to identify any fatigue significant events that might not have been captured as part of the plant's transient cycle counting procedures, reactor trip reports, or other plant documentation. This review is a critical element in evaluating the effectiveness of the plant's cycle counting program.

Plant Data

An invaluable source for confirming analysis assumptions is actual plant data. Actual plant parameter data can be collected by plant personnel digitally from the plant computer and used for detailed analysis. The type of data can provide details of the following plant operations:

- Plant heatup and cooldown. Among all of the plant transient maneuvers, heatup and cooldown operations generally have the greatest impact on component fatigue. Representative plant data allows the evaluation of the relative severity of actual heatup and cooldown transients in comparison with the original design.
- Unit loading and unloading. Based on the number of design cycles relative to actual occurrences of this transient, it may be possible to exempt the unit loading and unloading transients from the cycle counting, provided that both the frequency and severity of the unit loading and unloading transients are bounded by design.

Interviews with Plant Personnel

Interviews with plant personnel are performed to verify that operating practices are consistent with or bounded by the design assumptions. Westinghouse has developed a written questionnaire to be completed by site personnel prior to conducting the interviews. The questionnaire, though originally designed in 1989 for a Westinghouse Owners Group (WOG) program on pressurizer surge line stratification, continues to provide clarification of operating practices, particularly in the area of plant heatup and cooldown maneuvers. The majority of the information collected on heatup and cooldown practices is from written responses to this questionnaire. Areas addressed in the site interviews and in the questionnaire include:

- Heatup and cooldown practices including Reactor Coolant Pumps and Residual Heat Removal operations
- Pressurizer spray operations
- Pressurizer steam bubble formation and collapse
- Feedwater operations
- Charging and letdown operations
- Occurrences of safety injection
- Knowledge of any unusual events

Interviews with plant test engineers would concentrate on the following areas:

- Primary side pressure and leak tests
- Secondary side pressure and leak tests

The interview with plant engineers responsible for transient classification and fatigue cycle counting should concentrate on the following areas:

- The cycle counting process
- The criteria to identify transients
- Transient classification
- Heatup and Cooldown cycle counting, including criteria for classification of partial heatup and cooldown cycles

EVALUATING THE CURRENT CYCLE COUNTING PROGRAM

Westinghouse has personnel who are qualified to review the overall effectiveness of site procedures that are used to identify and track transient cycles. Their reviews assess the ability of the procedures to accurately identify and classify plant transients, the effectiveness of the transient classifications, the strength and detail of the supporting documentation, and the supporting technical basis for the program. The goal of this investigation is to establish that the site procedure meets the following requirements:

- The procedure accurately identifies and classifies plant transients.
- The transients and the design frequency of occurrence are consistent with or conservative relative to the design basis.
- The transient classifications reflected in the procedure are effective. That is, the procedure advocates an effective and consistent method for categorizing, counting and tracking plant transients.
- Supporting documentation is adequate, and includes sufficient strength and detail.
- A technical basis exists for the cycle counting program.

Westinghouse evaluates the cycle counting procedure using the criteria identified in Table 1. During the review, the strengths and weaknesses of the procedure, as well as recommendations for enhancement, are identified and discussed with the utility.

Table 1 Criteria for Evaluating Cycle Counting Process and Procedures

General criteria
Procedure clearly states purpose of cycle counting and describes its significance
Procedure clearly defines its scope (i.e., applicable equipment and any notable exceptions)
Procedure identifies references, resources, and records that are needed
Procedure identifies monitoring frequency
Transient Identification Procedure:
Accurately reflects all design basis transients and their respective design frequencies of occurrence.
Accurately (or conservatively) describes the applicable process parameters in terms of upper and lower limits and rates that assure all fatigue significant events are captured and addressed.
Includes a section on policy, that describes the action to be taken or method to be applied, to classify transients that lie outside the identified bounds in process parameters.
Transient Counting Procedure:
Identifies total design cycles applicable to all design basis transients.
Identifies design cycles on a component specific basis or points to a basis document that identifies component specific cycles.
Provides a clear, repeatable method for counting transients in a consistent manner.
Identifies actual design cycles for all design basis transients.
Identifies a limit (i.e., as a percentage of total number of design cycles) and a course of action to be taken when actual transient cycles are approaching design cycles.
Design Basis Document:
Identifies all design basis transients applicable to the plant.
Identifies design transients applicable to specific components.
Describes the applicable transients in terms of upper and lower design limits and design rates of change in the process parameters.
Reconciles differences in design parameters.
Identifies and provides justification for transients that have been excluded from the counting procedure.
Identifies any conservatism to be applied in the cycle counting procedure relative to the design basis (e.g., upper and lower limits to be used, rates of change, or frequencies of occurrence).
Identifies how and when updates to the basis document should be made and how changes should be incorporated into cycle counting procedure.

Strengths, Weaknesses, and Recommendations to the Cycle Counting Program

The effectiveness of a manual cycle counting procedure is very dependent on the proficiency of the responsible engineer in executing the procedure. First and foremost, the responsible engineer must maintain in-depth information for each transient cycle counted, and keep the cycle/event information organized and readily available. Having this information organized and readily available makes reviews and assessments much easier to complete, and supports verification activities. Second, the documentation should identify plant policy and administrative requirements of the cycle counting program. This includes issues such as responsible personnel, frequency of monitoring and reporting requirements. As an example of the latter, the policy section should identify actions to be taken by the responsible engineer when the number of cycles approaches the design limit. Third, the documentation should clearly identify the process parameters to be monitored on a component specific basis. For example, the supporting definition criteria for some transients use both magnitude and rates of changes in temperature to characterize the thermal portion of the transient. The consideration of both rate and magnitude is the proper way to interpret thermal events that act on thick-walled components.

Finally, the cycle counting program should have a well-documented technical basis. The basis documentation should accurately identify and justify the transients to be counted and the criteria by which they are counted. Similarly, certain design transients can be recommended for exemption from cycle counting, provided adequate information supporting their exemption exists. A low frequency of occurrence relative to the design frequency, coupled with less severe plant response relative to the design transient response, is a good reason for exempting a design transient from cycle counting. While such transients are expected to occur in the future, their accumulation rates are so low that they would never reach the design limit. The technical basis document should provide justification for exemption.

Westinghouse has found that typical weaknesses of manual cycle counting procedures are in the areas of applicability, policy, authorized personnel, training requirements, equipment scope, monitoring frequency, record requirements, transient limitations, event significance, and technical basis documentation.

ANALYZING THE TRANSIENT DATA

One of the first steps in the data analysis is to show that the actual frequency of occurrence of the design basis transients is bounded by the frequency assumed in the original design. The severity of the actual plant transients in comparison with the severity of the design basis transients must also be addressed. This comparison is performed to demonstrate that, on an event-by-event basis, the design events are conservative enough to envelop the actual events.

In general, the actual number of transient occurrences may be determined based on a review of the cycle counting report, in conjunction with reactor trip reports, plant LERs, reports of abnormal occurrences, test procedures, and interviews with plant personnel. During these reviews, information gathered at the site is compared to the transients identified in the cycle counting report. It is important to show that the method of counting and assigning transient events to the appropriate design transient category is performed in a consistent and conservative manner, and is thus appropriate for use as the sole resource for certain transient frequencies (e.g., small step increase/decrease transients, large load rejection transients).

A composite list of actual plant transients should be generated for each unit from all of the sources used. Certain transients, such as steady state fluctuations, feedwater cycling at hot standby, and boron concentration equalization, may not be included in the composite list. Westinghouse has developed a technical basis for exempting each of these transients from the cycle counting processes.

60-Year Cycle Projections

After establishing the total number of transients for each unit, the next task is to conservatively project the frequency of occurrence of future transients. The goal is to demonstrate that the current design transient set is applicable to 60 years of operation. This is accomplished by projecting the anticipated occurrences for 60 years of operation, based on actual occurrences to date. The result can be used to demonstrate that the frequency and severity of the 40-year design basis transients bound 60 years of operation.

Data for each of the following transients should be analyzed to determine a reasonable, yet conservative, projection of future occurrences.

- 10% step decrease from full power
- 10% step increase from full power
- Large step load decrease from full power
- Plant heatup
- Plant cooldown
- Pressurizer cooldown
- Loss of load
- Loss of offsite power
- Partial loss of flow
- Reactor trip from full power

In general, to predict the number of cycles to 60 years, it should be assumed that the plant will experience at least the mean number of occurrences of each transient per year. However, this may not be true for all transients; some transients may need to be treated differently. For plant heatup, plant cooldown and pressurizer cooldown transients, using the data for all years of operation to date may result in overly conservative predictions. Therefore, the mean frequency on a per-year basis can be derived from more recent operating history (e.g., last ten years of operation) and used as the basis for determining future cycles.

Similarly, the frequency of occurrence of reactor trips may be shown to be high at the beginning of life, compared to a much lower frequency after the plant has operated for a number of years. It can be estimated that the number of trips in the middle of life would continue to be similar to those that have occurred during recent plant operating history. At the end of life, it is conservative to assume that the number of trips would increase due to failure of components due to aging. Therefore, reactor trip cycle projections for the time interval between the current year of operation and 50 years of operation are typically derived from the last ten years of operations. Between 50 and 60 years, a trip rate based on the first ten years of operation may be assumed. It should be noted that this conservative modeling ignores any measures adopted by the utility to incorporate preventative maintenance as part of an aging management plan. Therefore, these projections in no way imply that more failures will actually occur.

The transients listed above do not represent the entire set of transients in the plant design basis. More importantly, they represent the entire set of actual past transients as classified by a typical detailed review. The data analysis can show that the mean frequency of occurrence provides the most reasonable, yet conservative, prediction of future cycles. Using all years of operation to date provides a very conservative prediction of future cycles, because generally the plant experiences a greater number of transients during the early years of operation.

Where the actual number of occurrences is approaching the design frequency, and the actual frequency can be controlled, the actual number of occurrences can be judged to be limited to the design value. Obviously, it would be necessary to perform an evaluation or analysis to justify an additional number of occurrences of these transients. Upset condition transients that have not occurred to date may be anticipated to not occur in the future. Therefore, the projected number of cycles is reasonably assumed to be zero.

Severity Analysis

It is not sufficient to simply count occurrences of actual transients, project them for sixty years of operation, and then compare that number to the design basis cyclic limits. That, by itself, does not prove the validity of the assumption that the original design transient set is adequate for sixty years of operation. It must also be shown that, on a transient-by-transient basis, the design transient is more severe than the actual transients experienced. This can actually become a very complex task when dealing with long and convoluted plant operations like plant heatup and cooldown that do not follow the design assumption.

The purpose of the severity analysis is to show that the original design transient assumptions are severe enough to bound the operating events. Note that the intent of the design basis transients is to bound not just specific operations, but a wide range of possible events with varying ranges of severity in temperature, pressure and flow. Thus, if a plant event does not meet the design criteria, based on sequence of operations, a suitable classification should be assigned which bounds the severity of the actual transient. In this manner, it is possible that every event can be classified within the design basis.

For example, a review of reactor trip reports may indicate that there were several instances in which the RCS experienced cooldown below the design parameters following a reactor trip. This represents a change from initial cold leg temperature that is more severe than design assumptions. It may be possible to reclassify the event as a loss of offsite power event, which includes a severe cooldown. It is possible that this practice can be used to classify all events experienced by the plant within the original design transient set. However, if an actual plant transient cannot be classified under any of the design basis transients, then some reconciliation is necessary to address the impact of frequency and severity on fatigue for each event found.

One area of investigation that requires special attention is plant heatup and cooldown operations. Most plants' heatup and cooldown operations incorporate several ramps and hold points. This is in contrast to the design heatup transient, which reflects a constant ramp increase in temperature between cold shutdown and no load conditions. The ramps and holds occur several times during the heatup maneuver. Similarly, the actual cooldown transient is performed such that several hold points follow ramp decreases in RCS temperature between no- load and cold shutdown conditions.

There is a common concern that the original design heatup and cooldown transients do not adequately bound the additional thermal stress cycles produced by these "stop and go" operations. Without further evaluation, it cannot be determined if the long term effects of these hold points would contribute more fatigue usage to the cumulative usage factors for the RCS components beyond the design cycles of the single-ramp transients. Westinghouse has developed an efficient parametric method of evaluation to address this issue.

Most of the remaining transients experienced by the plant can all be qualified by direct comparison to the design transient assumptions. A partial listing of the types of transients that fall into this category follows:

Loading/Unloading at 5% of Full Power per Minute
10% Step Load Increase/Decrease of Full Power
Large Step Decrease with Steam Dump
Reactor trip
Loss of Load without Immediate Turbine Trip or Reactor Trip
Partial Loss of Flow
Loss of off site power
Inadvertent Auxiliary Spray
Primary Side Pressure Tests
Secondary Side Pressure Tests

CONCLUSIONS

The program described in this paper investigates and then qualifies existing 40-year design transients for 60 years of operations. The program is designed to provide a solid foundation establishing that the current design basis transients are conservative and applicable, without modification, as the basis for 60 years of operation. This foundation is established based on independent review of past operations, expert review of the current transient and fatigue cycle counting program, and frequency and severity analysis of the data collected in the first and second parts. The operations review identifies and classifies actual plant transients. The expert review assesses the effectiveness of the cycle counting program based on its strengths and weaknesses, and provides recommendations for improvement. The results of the frequency and severity analysis provide a comprehensive comparison of projected plant transients against the existing design frequency limits. Application of this program will demonstrate that, on an event-by-event basis, the design events are conservative enough to envelop the actual events during the extended operating period.