NRC FORM 658

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NUCLEAR REGULATORY COMMISSION

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DATE OF MEETING
11/28/2000

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Docket Number(s)	PROJECT NO. 669
Plant/Facility Name	EPRI
TAC Number(s) (if available)	
Reference Meeting Notice	11/14/00
Purpose of Meeting (copy from meeting notice)	TO DISCUSS STATUS OF EPRI MATERIAL RELIABILITY PROJECT ON ENVIRONMENTAL EFFECTS ON FATIGUE

NAME OF PERSON WHO ISSUED MEETING NOTICE	TITLE
L. N. OLSHAN	PROJECT MANAGER

OFFICE
NRR

DIVISION
DLPM

BRANCH
PD II-1

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EPRI MRP Fatigue ITG on Reactor Water Environmental Effects

Report To

US Nuclear Regulatory Commission

Washington, DC

November 28, 2000

Report Outline

I.	Opening Comments	Doug Walters, NEI
II.	Meeting Objectives & Expectations	Mike Robinson, DPC
III.	Background Information	Mike Robinson, DPC
IV.	Reactor Water Effects Project Plan & Schedule	Mike Robinson, DPC
V.	License Renewal Guidelines Document for Addressing Fatigue Reactor Water Effects	Art Deardorf, SIA
VI.	Environmental Effects Data Review	Dr. R Nickell
VII.	Technical Issue Resolution & Next Step	All
VIII.	Conclusion & Final Comments	

Meeting Objectives & Expectations

- Introduce MRP program on fatigue environmental effects
- Begin the process for NRC and industry to reach agreement on generic method(s) LR applicants can use for the management of the effects of a reactor water environment on the fatigue life of metal components
  - Document agreement in GALL/SRP and/or SER
- Establish open, on-going dialogue with NRC management & staff
- Obtain support and participation in future meetings between technical staffs and subject experts

Program Benefits

- Enhance the LR process
  - Achieve consistency on EAF issue among LR applicants
  - Fewer RAIs
  - Reduce amount of plant specific work

- Adoption of management method(s) by near term LR applicants and those yet to make the decision on LR

Background: MRP Fatigue Issue Task Group

- Approved by MRP Executive Group and Senior Reps 7/98
- Original ITG charter was thermal fatigue in small bore RCS attached piping and un-isolatable from the RCS
- Reactor water effects on fatigue life added to ITG scope in August, 2000
- Augumented ITG membership with other utility technical experts and industry experts to provide guidance on project activities
- Coordinate ITG activities with NEI License Renewal Working Group

MRP ITG on Fatigue Environmental Effects

Mike Robinson, Duke
Mike Davis, Duke
Bernie Van Sant, OPPD
Robin Dyle, SNC
Fred Polaski, Exelon
Charlie Griffin, CPL
Les Spain, Dominion
Raymond To, Entergy
Stan Rosinski, EPRI
James Laborde, SCE&G
Richard Rose, FP&L
Lee Rochino, RG&E
Alan Van Der Sluys

Greg Robison, Duke
Guy DeBoo, Exelon
Art Deardorff, SIA
Gary Stevens, SIA
Bob Nickell
Sumio Yukawa
Har Mehta, GE
Doug Walters, NEI
John Carey, EPRI
Todd Mielke, NMC
Glenn Gardner, NEU
Dave Peltola, DE&S

MRP Reactor Water Environmental Effects Program Plan

Reactor Water Environmental Effects

Program Goal:

Provide license renewal applicants with acceptable method(s) for the management of reactor water environmental effects on the fatigue life of metal components

Reactor Water Environmental Effects

Program Objectives:

- **NEAR TERM**: Provide license renewal applicants with guidance on industry and NRC acceptable aging management methods for consideration of reactor water effects
- **LONG TERM**: Through additional testing, data research, etc. provide a technical basis to ensure acceptable aging management programs are available

Program Plan Task Listing

- EF-1: License Renewal Guidelines for Addressing Fatigue Reactor Water Environmental Effects, Revision 0
- EF-2: Revise EPRI License Renewal Fatigue Environmental Effects Reports
- EF-3: Review and Evaluation Of Fatigue Environmental Effects Data
- EF-4: Fatigue Environmental Effects Tests
- EF-5: Appendix L Improvements
- EF-6: Fatigue Lead Plant Inspection Program and NDE Operating Experience
- EF-7: Fatigue Crack Frequency Re-Evaluation
- EF-8: International Fatigue Test Program
- EF-9: ASME Code Support
- EF-10: Revise EPRI/GE F_{en} Methodology Report
- EF-11: Fatigue Environmental Effects Technical Basis Document
- EF-12: Revision 1 to EF-1

EF-1: License Renewal Guidelines for Addressing Fatigue Reactor Water Environmental Effects, Revision 0

Description: This task assists near term LR applicants by providing accepted method(s) for addressing the reactor water effects issue and lays a consistent, agreed upon course of action leading to disposition of the issue in the future

Desired Outcome: A documented and agreed to approach that near term license renewal applicants can use or refer to for addressing the reactor water effects on the fatigue life of metal components

Schedule:

Submit draft to NRC: 12/08/00

Submit Rev. 0 document to NRC: 01/15/01

NRC approval: 03/15/01

EF-2: Revise EPRI License Renewal Fatigue Environmental Effects Evaluation Reports

Description: EPRI Reports TR-107515,110043,110356, and 107943 provide evaluations of fatigue reactor water effects at various PWR and BWR fatigue sensitive locations as identified in NUREG/CR-6260. Four primary issues have been raised on these reports by NRC.

- Issue #1, use of latest ANL data
- Issue #2, credit for moderate environmental effects
- Issue #3, strain threshold
- Issue #4, weighted-average strain rate (accepted by NRC)

Desired Outcome: Identify and address fatigue sensitive locations that require evaluation for license renewal thus permitting focused attention on locations where environmental effects warrant further review.

Schedule: Start: 03/15/01 Complete: 07/15/01

EF-3: Review and Evaluation of Fatigue Environmental Effects Data

Description: This task performs a critical review and assessment of available world wide data on laboratory environmental effects testing. The data review will focus on specific environments and loading conditions utilized during lab testing programs, assess applicability of lab conditions to actual plant operating environments and loading conditions, and assess the relevance and applicability of the lab data to actual plant operating conditions.

Desired Outcome: Guidance in clarifying impact of and necessary industry action to manage the effect of reactor water environment on fatigue life. This task identifies additional testing that may be required and addresses the issues of data scatter, flow rate, applicability of lab data, etc.

Schedule: In progress Complete: June 2001

EF-4: Fatigue Environmental Effects - Fatigue Testing

Description: This task performs additional testing identified by EF-3 with selected testing conditions, material type, test environment, specimen configuration, loading conditions, etc to facilitate assessment of the effects of the reactor water environment

Desired Outcome: Additional testing results that enhance the understanding of the reactor water effects

Schedule: Start: 01/01/01 Complete: 12/31/02

EF-5: ASME Section XI Appendix L Improvements

Description: Appendix L to ASME Section XI introduced a damage tolerance procedure to assess the serviceability of fatigue sensitive components. This task reviews current Appendix L procedure requirements and recommends changes to the procedure

Desired Outcome: Proposed revisions to Appendix L. NRC acceptance of the revised Appendix L flaw tolerance method as an accepted fatigue management option for LR.

Schedule: In Progress Complete: 12/31/01

EF-6: NDE Experience/Lead Plant Inspections

Description: The PNNL study (NUREG/CR-6674) suggests a high probability of cracking at fatigue sensitive locations due to reactor water effects. This task collects, analyzes, and interprets existing industry NDE results of fatigue sensitive locations.

Desired Outcome: NDE operating experience to determine applicability of PNNL predictions. Information that can be used in deciding the appropriate means to manage reactor water effects.

Schedule: Start: 01/01/01 Complete: 12/31/02

EF-7: Fatigue Crack Frequency Re-Evaluation

Description: The PNNL study (NUREG/CR-6674) was performed to assess potential significance of EAF on plant safety (CDF) using conservative and bounding assumptions. This task will recalculate the cumulative probability of through wall pipe cracking due to EAF for a few controlling component locations by using more realistic information in pc-PRAISE calculations

Desired Outcome: Revised estimates of cumulative through wall fatigue cracking probabilities that are significantly lower than the probabilities reported in the PNNL studies

Schedule: Start: 01/01/01 Complete: 12/31/01

EF-8: International Fatigue Test Program

Description: Both EDF and the Japanese utilities are funding research on reactor water environmental effects. EDF tests are being performed by GE in Schenectady, NY and the Japanese testing by IHI, MHI, and possibly others.

Desired Outcome: Access to EDF and Japanese test data and test facilities.

Schedule: Start: 01/01/01 Complete: 12/31/02

EF-9: ASME Code Support

Description: Significant efforts are underway in the ASME Code for possible incorporation of reactor water effects into various operating plant criteria, including S/N design curves and Appendix L. EPRI sponsored research and this project inputs are relevant to ongoing Code activities

Desired Outcome: Work with ASME Code committees to effect changes to the ASME Code

Schedule: Ongoing

EF-10: Revise EPRI/GE F_{en} Methodology Report

Description: First released in '95, TR-105759 provided recommended procedure for incorporating reactor water effects into existing ASME Section III component fatigue analyses. This task will update the EPRI report to reflect influence of new data, changes to F_{en} methodology, environmental threshold values, etc

Desired Outcome: The outcome will be a revision to TR-105759 to reflect recent reactor water environmental data, threshold values, and F_{en} equations that are consistent with latest Argonne publications

Schedule: TBD

EF-11: Fatigue Environmental Effects Technical Basis Document

Description: This task compiles and evaluates the results of Tasks 1-10

Desired Outcome: A document that provides the technical basis and justification for addressing environmental effects on fatigue

Schedule: Completion: 3/31/03

EF-12: License Renewal Guidelines for Addressing Fatigue Reactor water Environmental Effects, Revision 1

Description: This task provides a revision to Task EF-1 to reflect changes that will/may occur as new data and information are developed.

Desired Outcome: Identification of acceptable aging management options for fatigue which adequately address reactor water environmental effects for the license renewal term

Schedule: Start: 01/01/03 Complete: 06/30/03

MRP FATIGUE ITG ON REACTOR WATER ENVIRONMENTAL EFFECTS

Guidelines Document and Assessment Methodology

Art Deardorff
Structural Integrity Associates

NRC/MRP/NEI Meeting

November 28, 2000

OBJECTIVES OF GUIDELINES

- **Provide Guidance for License Renewal Applicants**

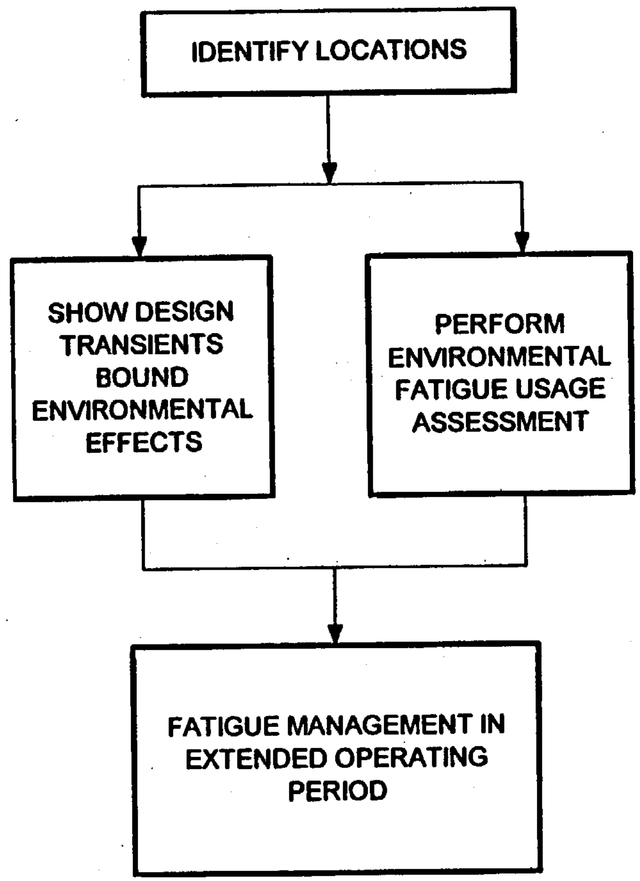
- **Define Various Approaches to Manage Potential Effects of Reactor Water Environment**

- **To Minimize the Plant-Specific Work Necessary for Considering Reactor Water Environmental Effects**

GUIDELINES DOCUMENT OUTLINE

- Introduction
- Background
- License Renewal Approach
  - Overview
  - Evaluation of environmental effects
  - Managing fatigue in license renewal period
  - B31.1 plants
- Conclusions
- Appendices
  - Assessment of NUREG/CR-6260 results
  - PVRC evaluation recommendations
  - Moderate environmental effects
  - Demonstration that transient severity bounds environmental effects

OVERVIEW OF APPROACH



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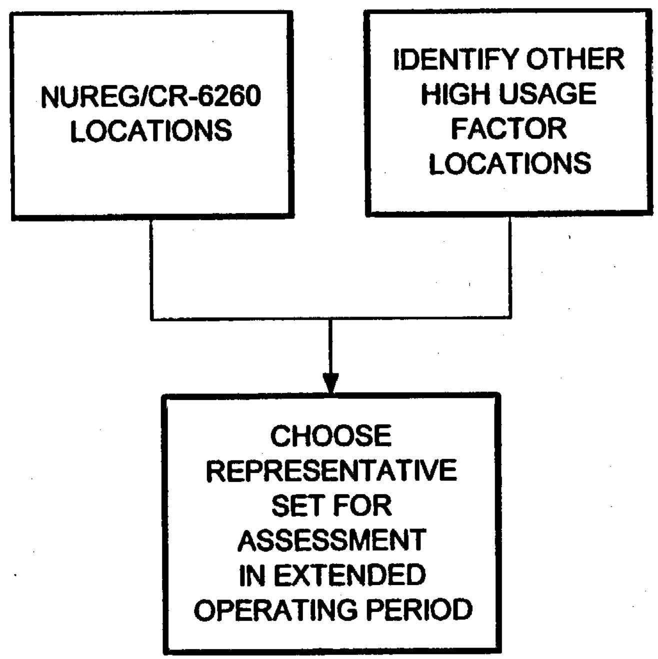
IDENTIFICATION OF LOCATIONS FOR EVALUATION



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IDENTIFICATION OF LOCATIONS

- **Locations to Consider**
  - Identify those locations expected to have high usage factors (including reactor water environmental effects)
    - NUREG/CR-6260 set
    - Other plant-specific locations

- **Objective**
  - Establish set of locations (6-10) to track in extended operating period

IDENTIFICATION OF LOCATIONS FOR EVALUATION

- **Locations Chosen Should be Diverse:**
  - Components/Geometry/Materials
  - Loading conditions
  - Environment
- **Excluding Locations from Consideration**
  - Excess conservatism in fatigue analysis methods
  - Location has similar materials, loading conditions, geometry, or environment to another selected location
  - Assessment of environmental effects shows that effect will be small
- **After this Review, the Identified Locations Require Detailed Assessment**

ENVIRONMENTAL FATIGUE ASSESSMENT

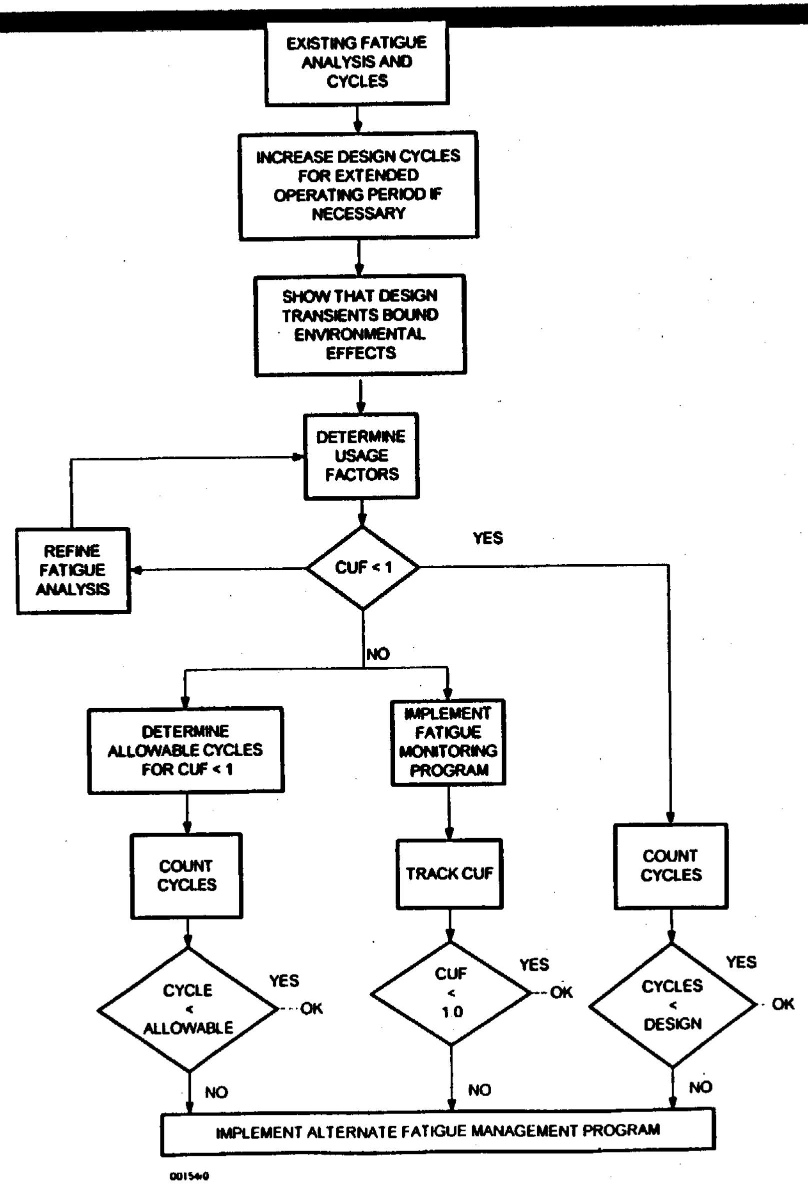
- Two Methods Provided
  - Show transient severity bounds environmental effects
  - Recalculate CUF using environmental factors

- Methods are Different but Include Similar Elements

ASSESSMENT OPTIONS FOR EACH LOCATION

Element	Method 1: Transient Severity	Method 2: Environmental Factors
Transient definition and fatigue analysis	Identify design transient severity	Collect data
Increase cycles for extended period	If necessary	If necessary
Perform environmental fatigue assessment	Compare design CUF with actual CUF including environmental effect	Perform F_{en} evaluation. Use actual transients with modern improved analytical methods
CUF	CUF < 1	CUF < 1
Manage fatigue in extended period	May require additional actions if calculated CUF > 1	May require additional actions if calculated CUF >1

TRANSIENT SEVERITY METHOD



TRANSIENT SEVERITY METHOD

Demonstration that Design Transients Bound Environmental Effects

- Given:

  $$CUF_{design} < 1$$

- Show:

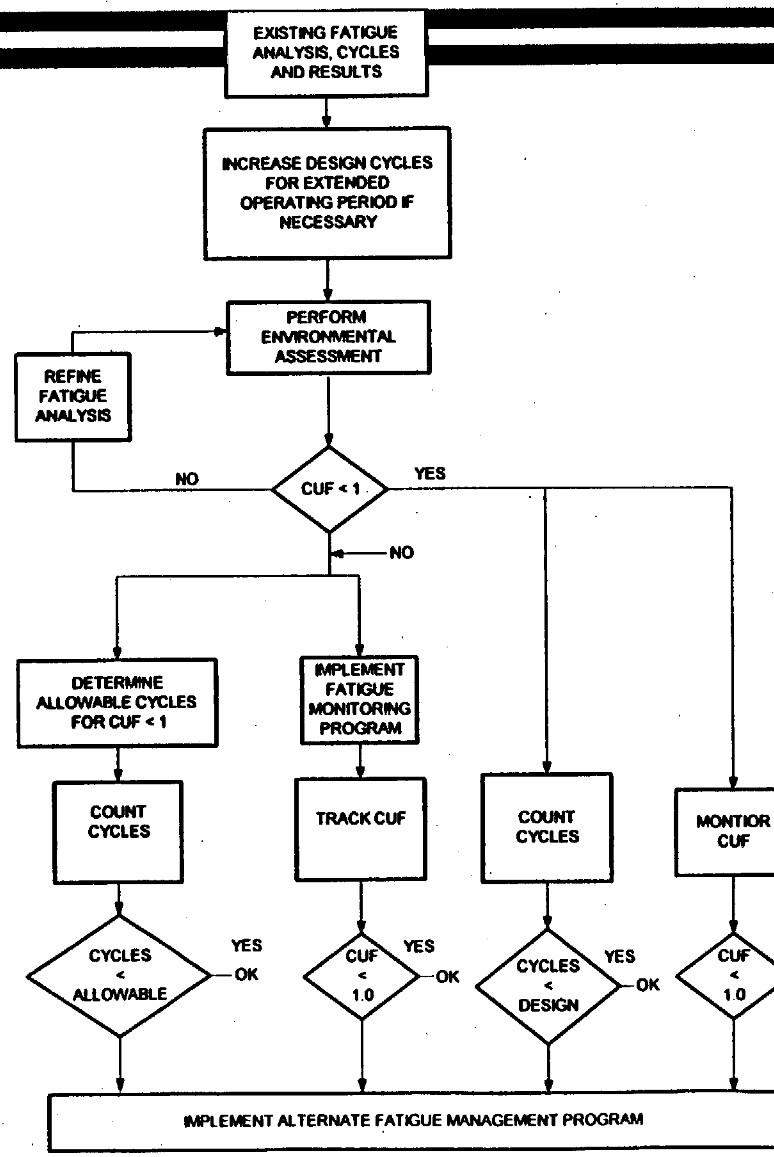
  $$CUF_{actual\ transients} \times \text{environmental factors} < 1$$

  or

  $$\Sigma\, u_i \times F_{en} < 1$$

- Approaches
  - Fatigue monitoring
  - Revised fatigue analysis using actual transients, applying F_{en} methodology (per PVRC recommendations)
  - Account for decreased number of cycles to end of life if justified

ENVIRONMENTAL FACTOR METHOD



ENVIRONMENTAL FACTOR METHOD

Performing Environmental Factor Assessment

- **Given:**

  $$CUF_{design} < 1$$

- **Show:**

  $$CUF_{actual\ transients} \times F_{en} \leq 1$$

  or

  $$\Sigma u_i \times F_{en} < 1$$

- **Approaches**
  - Determine F_{en} per PVRC recommendations
  - Use existing analysis *
  - Use refined analysis *
  - Use projected transients *

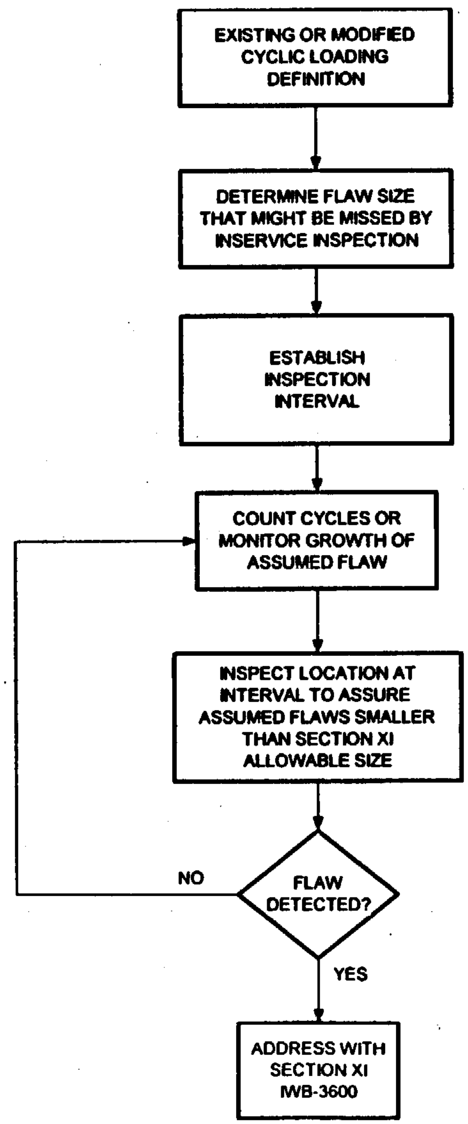
*like approach used in NUREG/CR-6260

FATIGUE MANAGEMENT IN EXTENDED OPERATING PERIOD

- **If Limits Exceeded in Extended Operating Period, Several Options Exist**
  - More re-evaluation (refined analysis)
  - Partial cycle counting (method 2 only)
  - Fatigue monitoring based on actual transients (method 2 only)
  - Flaw tolerance + inspection (ASME Appendix L)*
  - Modified plant operations
  - Repair/replacement

* Ongoing Code activities must be completed and accepted

FLAW TOLERANCE/INSPECTION METHOD



FATIGUE MANAGEMENT IN EXTENDED OPERATING PERIOD

- **If CUF Can Not Be Shown to be Less Than 1.0, Evaluation of Similar (Geometry, Loading, Material) Location(s) Should be Added to the Assessment**

GUIDANCE FOR B31.1 PLANTS

- **NUREG/CR-6260 Showed Little Difference Between Early-Vintage (B31.1) and Later Vintage Plants**

- **Approach Shown for ASME Section III, Class 1 Plants can be Applied**
  - ♦ **Transients may have to be established for tracking**
  - ♦ **Information in NUREG/CR-6260 or alternate fatigue evaluations can be used as fatigue basis**

CONCLUSIONS

- Guidance Provided to License Renewal Applicants on Selecting and Evaluating a Sample of Locations for Assessing Reactor Water Environmental Effects
    - Two approaches shown
- General Guidance Provided on What Can Be Done in Extended Operating Period
- An Agreed-Upon Approach Will Minimize Efforts of All Involved in Submittal/Review of License Renewal Applications

Robert E. Nickell
SIA Consultant

FATIGUE ENVIRONMENTAL EFFECTS DATA EVALUATION

NRC/MRP/NEI Meeting

November 28, 2000

Washington, DC

MRP Fatigue Issue Task Group

on

Reactor Water Environmental Effects

Dr. Robert E. Nickell, SIA Consultant

Robert E. Nickell
SIA Consultant

Fatigue Environmental Effects Data Evaluation

Purpose of Fatigue Environmental Effects Data Review

- **Existing laboratory fatigue data simulating the effects of reactor water environments should be collected (PVRC), analyzed, and evaluated for relevance to nuclear power plant component operating conditions and operating experience.**
- **Project jointly sponsored by EPRI and the U. S. Department of Energy under NEPO funding, with efforts just getting underway in the fourth quarter of 2000; Stan Rosinski, EPRI, is the Project Manager; Work to be carried out by Al Van Der Sluys, Sumio Yukawa, and Bob Nickell.**
- **Early results on selected topics (moderate environmental effects factors) included in Appendix C of guidelines document; complete results of data review to be published in mid-2001.**

Robert E. Nickell
SIA Consultant

Fatigue Environmental Effects Data Evaluation

<u>*Chopra and Shack,*</u> "Methods for Incorporating Effects of LWR Coolant Environment into ASME Code Fatigue Evaluations," in: Probabilistic and Environmental Aspects of Fracture and Fatigue, PVP-Volume 386, ASME International, New York, NY, August 1999.

"Because carbon and low-alloy steels and austenitic SSs develop a corrosion scale in LWR environments, the effect of surface finish may not be significant, i.e., the effects of surface roughness are included in environmentally assisted decrease in fatigue life in LWR coolant environments. In water, the subfactor on life to account for surface finish effects may be as low as 1.5 or may be eliminated completely; a factor of 1.5 on strain and 7 on cycles is adequate to account for the uncertainties that arise from material and loading variability. Therefore, the factor of 20 on life that is used in developing the design fatigue curves includes, as a safety margin, a factor of 3 or 4 on life that may be used to account for the effects of *[moderate]* environment on the fatigue life of these steels."

Fatigue Environmental Effects Data Evaluation

PVRC Z-Factor Recommendation

The equations used to fit the laboratory-simulated environmental fatigue data do not revert to the equations used to fit laboratory air data when moderate environmental thresholds are met. Instead, even for testing conditions such that simulated reactor water environmental effects are minimal, the equations contain an "environmental shift" much greater than 1. For example, the equation that fits reactor water environmental fatigue data for austenitic stainless steels predicts an asymptotic environmental shift of 2.55, even for temperatures below the environmental threshold.

Robert E. Nickell
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Fatigue Environmental Effects Data Evaluation

Interpretation of Recent Japanese Data

- **K. Tsutsumi, et al., "Fatigue Life Reduction in PWR Water Environment for Stainless Steels," in: PVP-Vol. 410-2, pp. 23-34, presented at ASME PVP 2000, Seattle, WA, July 24-27, 2000.**
- **Data scatter for test data in air is about a factor of 2 on cycles at the low-cycle end of the fatigue curve. Japanese researchers have suggested that data scatter in water environments is about a factor of 5. If so, no part of the ASME Code factor of 20 is available to account for moderate environmental effects. The rest of the factor of 20 is allocated to surface roughness, etc.**
- **Actual data scatter is much less, provided that apples and oranges are not mixed.**
- **The measure of data scatter is chosen here to be the ratio of the standard deviation to the mean value of a given population.**

Robert E. Nickell
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Fatigue Environmental Effects Data Evaluation

Interpretation of Recent Japanese Data

- Consider data on austenitic stainless steel specimens at strain amplitudes of 0.3 %, 0.29 %, and 0.305 % (43 data points) at temperature.
- Two populations -- relatively low strain rate (L) (22 data points) and relatively high strain rate (H) (21 data points).
- Mean H = 9,286 cycles; standard deviation = 2,614 cycles
- Mean L = 4,717 cycles; standard deviation = 2,490 cycles
- Ratio of mean values: about a factor of 2.
- Ratio of standard deviation to mean value: 0.28 for H; 0.49 for L.
- For total population: Mean value = 6,948 cycles; standard deviation = 3,387 cycles; ratio = 0.49.

Robert E. Nickell
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Fatigue Environmental Effects Data Evaluation

Interpretation of Recent Japanese Data

- Consider data on austenitic stainless steel specimens at strain amplitudes of 0.6 %, 0.58 %, 0.59 %, and 0.61 % (61 data points) at temperature.
- Two populations -- relatively low strain rate (L) (39 data points) and relatively high strain rate (H) (22 data points).
- Mean H = 1,655 cycles; standard deviation = 493 cycles
- Mean L = 538 cycles; standard deviation = 308 cycles
- Ratio of mean values: about a factor of 3.
- Ratio of standard deviation to mean value: 0.30 for H; 0.57 for L.
- For total population: Mean value = 941 cycles; standard deviation = 662 cycles; ratio = 0.70

Robert E. Nickell
SIA Consultant

Fatigue Environmental Effects Data Evaluation

Interpretation of PVRC Low-Alloy/Carbon Steel Data

- **Data on low-alloy (e.g., SA-533B) vessel steels, including weld and high oxygen (e.g., 8 ppm) data.**
- **Data populations limited to relatively high strain rate (e.g., 0.4 % per second) and operating temperature (e.g., 288°C).**
- **At 0.6 % strain amplitude, 25 data points -- 11 at high dissolved oxygen and 14 at low dissolved oxygen; six data points for CS fit into the high DO population.**
- **Low DO mean = 2,378 cycles; standard deviation = 1,055 cycles; ratio of standard deviation to mean = 0.44.**
- **High DO mean = 1,693 cycles; standard deviation = 419 cycles; ratio of standard deviation to mean = 0.25.**
- **Combined population mean = 2,076 cycles.**

Robert E. Nickell
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Fatigue Environmental Effects Data Evaluation

Interpretation of PVRC Low-Alloy/Carbon Steel Data

- At 0.5 % strain amplitude, 8 data points -- all data from Japan including high DO and weld data.
- 1 CS data point in the set.
- Data mean = 2,872 cycles; standard deviation = 850 cycles.
- Ratio of standard deviation to mean value = 0.30.
- At 0.3 % strain amplitude, 15 data points -- all from Japan including high DO and weld data.
- Three CS data points in the set.
- One clear outlier -- Kitigawa A 508-1 high DO (2,200 cycles).
- Data mean = 18,440 cycles; standard deviation = 9,001 cycles (outlier included)
- Ratio of standard deviation to mean value = 0.49.

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Fatigue Environmental Effects Data Evaluation

Interpretation of PVRC Low-Alloy/Carbon Steel Data

- **At 0.4 % strain amplitude, 16 data points -- all from Japan.**
- **1 CS data point in the set.**
- **Data mean = 6,089 cycles; standard deviation = 3,454 cycles.**
- **Ratio of standard deviation to mean value = 0.57.**
- **Standard deviation for the data set dominated by three potential outliers on the low side and one potential outlier on the high side (see Table 5).**
- **Outliers kept in the data set for this analysis.**
- **Weld data fits into this general population.**
- **High DO fatigue data fits into this general population.**

Robert E. Nickell
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Fatigue Environmental Effects Data Evaluation

Summary of Preliminary LAS/CS Data Assessment

- The measure of data scatter has been shown to be low when the data populations are divided into a set from relatively high strain rate testing and a set from relatively slow strain rate testing; the measure is 2 to 3 times larger for the relatively slow strain rate population than for the relatively high strain rate population.
- The ratio of mean values between the relatively high strain rate population and the relatively low strain rate population is between a factor of 2 and a factor of 3.
- The combination of these ratios matches the factor of ± 5 cited in the literature.
- Very high dissolved oxygen levels do not compromise the data scatter for low-alloy steels and carbon steels.
- As a rule, weld data fits into the general population for all classes of materials, but drives the standard deviations.

Robert E. Nickell
SIA Consultant

Fatigue Environmental Effects Data Evaluation

Conclusions

- **Measure of data scatter (i.e., ratio of standard deviation to mean value) very small for both austenitic stainless steels and carbon/LAS steels when the data populations are divided into a set from relatively high strain rate testing and a set from relatively slow strain rate testing.**
- **The findings from this analysis support the recommendations of PVRC that moderate environmental effects factors of 3 for carbon and low-alloy steel, and 1.5 for austenitic stainless steels, are conservative. Greater moderate environmental effects factors can be justified.**

Fatigue Environmental Effects Data Evaluation

Interpretation of Recent Japanese Data

- A. Hirano, et al., "Effects of Water Flow Rate on Fatigue Life of Carbon Steel in High Temperature Pure Water Environment," in: PVP-Vol. 410-2, pp. 13-18, presented at ASME PVP 2000, Seattle, WA, July 24-27, 2000.
- For strain rates above the PVRC threshold (0.1 %/sec), the effect of coolant flow rate on fatigue life at temperature is not significant. The reduction in fatigue life (from that in air) is approximately a factor of 2 to 4 at the higher strain rates, with the factor of 2 applicable to low dissolved oxygen and the factor of 4 applicable to high dissolved oxygen.
- For strain rates below the PVRC threshold, the effects of coolant flow rate is essentially equivalent to the effect of strain rate; i.e., the high flow rate - low strain rate reduction in fatigue life is essentially equivalent to the high strain rate reduction in fatigue life.

TABLE 1

Austenitic Stainless Steel (0.3 % Strain Amplitude)

Material	DO (ppb)	Temperature (C)	Strain Amplitude (%)	Tensile Strain Rate (%/sec)	Cycles to Failure
316	5	325	0.3	0.4	8799
316	5	300	0.285	0.4	6391
316	8000	325	0.29	0.4	8761
316 (Pre-strained)	5	325	0.3	0.4	8760
316 (Forging)	5	325	0.3	0.4	10754
316 (Sensitized)	5	325	0.3	0.4	7428
316 (Weld Metal)	5	325	0.31	0.4	4125*
316 (Weld Metal)	5	325	0.3	0.4	6184
316 (Weld Metal)	5	325	0.3	0.4	15142
304	5	325	0.29	0.4	8798
304	5	300	0.305	0.4	7020
304	5	360	0.28	0.4	10326
304	8000	325	0.29	0.4	10242
304	5	325	0.3	0.4	7928
304 (Sensitized)	5	325	0.3	0.4	9879
308 (Weld Metal)	5	325	0.29	0.4	7954
SCS14A	5	325	0.295	0.4	9242
SCS14A (Aged)	5	325	0.3	0.4	11795
CF8M (Aged)	5	325	0.3	0.4	13327
SCS14A	5	325	0.3	0.4	10154
SCS14A	5	325	0.3	0.4	12000

* Potential Outlier

TABLE 2

Austenitic Stainless Steel (0.6 % Strain Amplitude)

Material	DO (ppb)	Temperature (C)	Strain Amplitude (%)	Tensile Strain Rate (%/sec)	Cycles to Failure
316	5	325	0.59	0.4	2070
316	5	300	0.605	0.4	1916
316	8000	325	0.6	0.4	2027
316 (Pre-strained)	5	325	0.59	0.4	2238
316 (Forging)	5	325	0.6	0.4	1572
316 (Sensitized)	5	325	0.61	0.4	2009
316	5	325	0.58	0.4	2089
316 (Weld Metal)	5	325	0.61	0.4	666
316	5	325	0.6	0.4	2460
316 (Weld Metal)	5	325	0.61	0.4	1075
316 (Weld Metal)	5	325	0.6	0.4	1922
304	5	325	0.59	0.4	1344
304	5	300	0.585	0.4	1189
304	5	360	0.58	0.4	1172
304	8000	325	0.59	0.4	988
304	5	325	0.6	0.4	1411
304 (Sensitized)	5	325	0.6	0.4	1318
308 (Weld Metal)	5	325	0.6	0.4	2381
SCS14A (Aged)	5	325	0.6	0.4	1380
CF8M (Aged)	5	325	0.6	0.4	2136
SCS14A	5	325	0.59	0.4	1606
SCS14A	5	325	0.6	0.4	1461

TABLE 3
Carbon Steel/Low-Alloy Steel (0.6 % Strain Amplitude)

Material	DO	Temperature (C)	Strain Amplitude (%)	Cycles to Failure	Investigator
533B LAS	High	290	0.6	1600	Higuchi
533B LAS	High	290	0.6	1690	Higuchi
533B LAS	High	290	0.6	1640	Higuchi
508-3 LAS	Low	250	0.58	3040	Kasai
508-3 LAS	Low	290	0.605	2284	Kasai
508-3 LAS	Low	250	0.58	4210	Kasai
508-3 LAS	Low	290	0.59	2810	Kasai
508-3 LAS	High	290	0.585	2120	Kasai
508-3 LAS	High	290	0.575	2372	Kasai
533B LAS	Low	288	0.6	1728	Nakao
533B LAS	Low	288	0.6	1692	Nakao
533B LAS	Low	288	0.6	1276	Nakao
508-3 LAS	High	290	0.593	783	Endou
508-3 LAS	Low	250	0.584	1695	Endou
508-3 LAS	Low	290	0.587	1899	Endou
508-3 LAS	High	288	0.6	1660	Higuchi
508-3 LAS	High	288	0.6	1920	Higuchi
508-3 LAS	High	288	0.6	1250	Higuchi
508-3 LAS	Low	288	0.6	3540	Higuchi
508-3 LAS	Low	288	0.6	3625	Higuchi
508-3 LAS	Low	288	0.6	3435	Higuchi
533B LAS Weld	High	290	0.6	1810	Higuchi
533B LAS Weld	High	290	0.6	1774	Higuchi
533B LAS Weld	Low	288	0.6	960	Nakao
533B LAS Weld	Low	288	0.6	1091	Nakao

TABLE 4 Carbon Steel/Low-Alloy Steel (0.5 % Strain Amplitude)					
Material	**DO**	**Temperature (C)**	**Strain Amplitude (%)**	**Cycles to Failure**	**Investigator**
533B LAS	High	290	0.5	3348	Higuchi
533B LAS	High	290	0.5	3550	Higuchi
533B LAS	Low	288	0.5	1965	Nakao
508-3 LAS	Low	288	0.498	4022	Nagata
508-2 LAS	Low	288	0.5	2875	Nakao
533B LAS Weld	Low	288	0.5	1888	Nakao
533B LAS Weld	Low	288	0.5	1898	Nakao
333B-3 CS	Low	288	0.5	3426	Higuchi

TABLE 5

Carbon Steel/Low-Alloy Steel (0.4 % Strain Amplitude)

Material	DO	Temperature (C)	Strain Amplitude (%)	Cycles to Failure	Investigator
533B LAS	High	290	0.4	9400	Higuchi
533B LAS	High	290	0.4	6340	Higuchi
508-3 LAS	Low	250	0.395	8573	Kasai
533B LAS	Low	288	0.408	6353	Nagata
533B LAS	Low	288	0.4	8528	Nakao
533B LAS	Low	288	0.4	5700	Nakao
533B LAS	Low	288	0.4	6900	Nakao
533B LAS	Low	288	0.4	4030	Nakao
333B-3 CS	Low	288	0.4	15550*	Higuchi
508-3 LAS	High	290	0.404	1911*	Endou
508-3 LAS	High	288	0.4	5702	Higuchi
533B LAS Weld	High	290	0.4	5610	Higuchi
533B LAS Weld	High	290	0.4	5855	Higuchi
533B LAS Weld	Low	288	0.4	2670	Nakao
533B LAS Weld	Low	288	0.4	2708	Nakao
508-1 LAS	High	300	0.4	1600*	Kitigawa

* Potential Outliers

TABLE 6 Carbon Steel/Low-Alloy Steel (0.3 % Strain Amplitude)					
Material	**DO**	**Temperature (C)**	**Strain Amplitude (%)**	**Cycles to Failure**	**Investigator**
533B LAS	High	290	0.3	32080	Higuchi
533B LAS	High	290	0.3	28700	Higuchi
533B LAS	Low	288	0.3	14760	Nakao
508-3 LAS	High	288	0.3	8080	Higuchi
533B LAS Weld	High	290	0.3	18500	Higuchi
533B LAS Weld	High	290	0.3	14800	Higuchi
508-3 LAS	Low	288	0.285	26020	Nakao
533B LAS	Low	288	0.28	26730	Nakao
508-3 LAS	Low	288	0.298	29000	Nagata
533B LAS Weld	Low	288	0.3	13840	Nakao
533B LAS Weld	Low	288	0.3	18730	Nakao
333B-2 CS	High	290	0.3	8460	Higuchi
333B-2 CS	Low	288	0.3	10860	Higuchi
333B-2 CS	Low	288	0.3	23840	Higuchi
508-1 LAS	High	300	0.3	2200*	Kitigawa

* Potential Outlier

EPRI MRP Fatigue ITG on Reactor Water Environmental Effects

Report To

US Nuclear Regulatory Commission

CONCLUSIONS

Washington, DC
November 28, 2000

Conclusions

- Comprehensive program for considering the effects of a reactor water environment on fatigue that is supported by LR applicants
- Aggressive schedule for the completion and acceptance of the EPRI Guidelines Document
  - 12/08/00 - provide draft document
  - 3/15/01 - NRC agreement
- Industry and NRC must work very closely to derive maximum benefits from this generic approach.
  - Schedule future meetings between technical staffs