

Official Transcript of Proceedings
NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards
 Metallurgy and Reactor Fuels Subcommittee

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Tuesday, December 2, 2014

Work Order No.: NRC-1259

Pages 1-167

NEAL R. GROSS AND CO., INC.
Court Reporters and Transcribers
1323 Rhode Island Avenue, N.W.
Washington, D.C. 20005
(202) 234-4433

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
+ + + + +
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
(ACRS)
+ + + + +
METALLURGY AND REACTOR FUELS SUBCOMMITTEE
+ + + + +
TUESDAY
DECEMBER 2, 2014
+ + + + +
ROCKVILLE, MARYLAND
+ + + + +

The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 1:00 p.m., Peter C. Riccardella, Chairman, presiding.

COMMITTEE MEMBERS:

PETER RICCARDELLA, Subcommittee Chairman
RONALD G. BALLINGER, Member
DENNIS C. BLEY, Member
DANA A. POWERS, Member
JOY REMPE, Member
GORDON R. SKILLMAN, Member

1 ACRS CONSULTANT:

2 WILLIAM J. SHACK

3

4 DESIGNATED FEDERAL OFFICIAL:

5 CHRISTOPHER L. BROWN

6

7 ALSO PRESENT:

8 CHAKRAPANI BASAVARAJU, NRR

9 DAVE GERBER, Structural Integrity Associates

10 BOB HARDIES, NRR

11 ALLEN L. HISER, JR., RES

12 K.R. HSU, NRR

13 PAT PURTSCHER, NRR

14 DAVE RUDLAND, RES

15 GARY STEVENS, RES

16 ALEXANDER TSIRIGOTIS, NRO

17

18

19

20

21

22

23

24

25

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1	A-G-E-N-D-A	
2	Opening Remarks and Objectives	4
3	Staff Opening Remarks	6
4	Background	6
5	Reasons for Revising Reg. Guide 1.207	22
6	Summary of Revisions to Reg. Guide 1.207	23
7	Revisions to Fen Equations	33
8	Estimated Schedule for RG and	
9	NUREG Publication	89
10	Public Comments	98
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		

P R O C E E D I N G S

1:03 p.m.

CHAIRMAN RICCARDELLA: Meeting will now come to order. This is a meeting of the Metallurgy and Reactor Fuels Subcommittee. I'm Pete Riccardella. I'm chairing the meeting.

ACRS members in attendance are Dick Skillman, Dennis Bley and Joy Rempe. We also have our consultant, Bill Shack, Chris Brown of the ACRS staff is a designated federal official for this meeting and I am expecting Ron Ballinger and Dana Powers to come in shortly.

The purpose of this meeting is to receive a briefing on the regulatory guidance for evaluating the effects of light water reactor coolant environments on the fatigue analysis of metal components, proposed Reg. 1 to Reg. Guide 1.207.

We'll hear presentations from the representative of the Office of Nuclear Regulatory Research. The subcommittee will gather information, analyze relevant issues and facts and formulate a proposed position and action as appropriation for deliberation by the full committee.

This meeting is open to the public. The rules for participation in today's meeting were

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 announced as part of the meeting notice previously
2 published in the Federal Register on November 25th,
3 2014.

4 We received no written comments or
5 requests for time to make oral statements from members
6 of the public regarding today's meeting. A transcript
7 of the meeting is being kept and will be made available
8 as stated in the Federal Register notice.

9 Therefore, we request that participants in
10 the meeting use the microphones located throughout the
11 room.

12 When addressing the subcommittee
13 participants should first identify themselves and
14 speak with sufficient clarity and volume so that they
15 can be readily heard.

16 A bridge line has been set up and I
17 understand there are several people on the bridge line.
18 It will be in listen-in mode only but we will open it
19 up after the briefing for public comments.

20 I request that everybody silence their
21 cellphones and other devices so as to not interrupt the
22 meeting.

23 We will now proceed with the meeting and
24 I call upon Gary Stevens from Research to make
25 introductory remarks. David, unless you want to make

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 some introductory remarks.

2 Okay. It's all yours, Gary. We are
3 scheduled to have a break. I don't see a break
4 schedule. We're scheduled to adjourn at 3:30 so maybe
5 we don't need a break.

6 MR. STEVENS: All right. Thank you. I'm
7 Gary Stevens, Office of Research Division of
8 Engineering Component Integrity branch. Dave Rudland
9 is the chief. Brian Thomas is the division director.

10 So when this was first presented to me it
11 was advertised as you wanted to know what's changing
12 in the Reg. Guide and with that I have one slide. But
13 I assumed at - because there aren't that many changes
14 to the Reg. Guide.

15 But we have done extensive updating and
16 revision to the technical basis, assuming that you want
17 to see what happened to the technical basis.

18 And then the other part that was a little
19 uncertain to me is I don't know the level of proficiency
20 I'll have with this topic. So I put this together.
21 You need only a little background of the topic. So it's
22 pretty basic.

23 So if I'm too slow for you just speed me
24 along. So I'm here at your request and we're revising
25 the guidance for environmentally assisted fatigue,

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 EAF.

2 By the way, the last page of your
3 presentation I tried to do my diligence and provide you
4 a hit list of acronyms because we overuse those here.

5 CHAIRMAN RICCARDELLA: This is the one
6 place where I don't need that.

7 MR. STEVENS: The very last page of your
8 PowerPoint is a cheat sheet for acronyms here. The
9 guidance consists of the Reg. Guide and a supporting
10 technical basis NUREG.

11 In both cases, we're incrementing the
12 documents to Reg. 1. The Reg. Guide - all Reg. Guides
13 when they go out for public comment as drafts get a DG
14 number and this one's been assigned DG-1309.

15 It went out for public comment last Monday
16 the 24th. The NUREG is still a draft. It went out for
17 public comment last spring. I'll detail that for you
18 on the forthcoming slides.

19 It was out for a 45-day review period. So
20 this is kind of the outline. I have a lot of background
21 where I'm going to try to get everybody on the same
22 playing field with the terminology and what this
23 methodology does and then I'm going to explain to you
24 why we revised the Reg. Guide, what we revised in it
25 and in particular these environmental multiplier

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 equations we have were the major change and I'll go
2 through those and then give you an estimated schedule
3 moving forward with this work.

4 Okay. So here's another acronym - CUF -
5 cumulative usage factor. What is cumulative usage
6 factor? A cumulative usage factor is really ASME's way
7 of estimating fatigue damage, calculating it, and it's
8 with this equation that you see here, a summation, and
9 what it is is if you look at the curve down here, which
10 is a typical fatigue curve in the lower right, otherwise
11 called an SN curve for being stress or strain versus
12 cycles.

13 That's a material dependent property curve
14 and it defines at any given stress level the number of
15 cycles that you would theoretically could tolerate
16 before you would initiate fatigue failure of a test
17 vessel.

18 So very simply, if we were at a stress level
19 here of - this is in KSI - 100 KSI, we could tolerate
20 just over a thousand cycles, which in theory would mean
21 if we applied the thousand cycles we would then initiate
22 a fatigue failure and a specimen.

23 What the summation does is it simply does
24 that ratio for all applied loads, given that most of
25 our components don't have one load applied to them -

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 they have many applied loads.

2 And what it says is that that ratio of the
3 applied cycles to the allowed cycles from this curve
4 must be less than 1.0. N is a function of the
5 alternating stress and here is the allowed number of
6 cycles, and as I mentioned these curves are material
7 - they are material properly. They are like yield
8 strength or ultimate. They belong to each material.

9 I'll probably throughout this talk refer
10 to the fatigue curves as SN curves and they are defined
11 in ASME Code Section 3, Mandatory Appendix I.

12 They have several different curves in there,
13 primarily two. There's one for ferritic materials and
14 one for austenitics.

15 These curves are design curves. They're
16 usually in log-log form and what they are they're best
17 fits of laboratory test data of test performed in air
18 with design factors applied to make them a design curve.

19 And I'll go through what those design
20 factors are intended to cover and what they aren't
21 intended to cover. So what you see there is one of the
22 design curves out of Section 3.

23 If I had my glasses I'd be able to tell you
24 what material that is. It looks like it's austenitic
25 materials.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: Austenitic - you
2 know, should you maybe mention the pseudo nature of the
3 stress? I mean, obviously, this goes to a million psi.

4 MR. STEVENS: Right. So the - as Pete
5 pointed out, you'll see the stress on the vertical
6 access can go quite high, which is well above the
7 material yield strength.

8 These curves are based on elastic stress
9 analysis. There's factors applied for stresses over
10 yield and it's - the stresses we're talking about here
11 are highly localized surface stresses not to be
12 confused that we're taking a through section stress
13 well above yield.

14 So what is EAF? Again, environmentally
15 assisted fatigue. As you heard me mention on the prior
16 slide, these curves were developed from laboratory
17 tests of small-scale polished specimens in air -
18 laboratory air.

19 That air test data were used to develop
20 these fatigue curves and they're based on best fit
21 log-log curves for each different material type.
22 Those curves are adjusted to account for mean stress
23 effects, primarily at the high cycle end.

24 Then they have factors applied on them to
25 develop design curves, which are intended to be

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 conservative lower-bound fatigue design curves for
2 each material.

3 The factors that ASME originally used for
4 these were two on strain or 20 or cycles, whichever was
5 more severe. We'll go into what the current factors
6 in our work as well as in the code. But this is how
7 the code initially established those curves.

8 And how EAF came about is more recent and
9 actually and I guess it's not so recent anymore but in
10 the 80s and 90s laboratory testing of specimens now in
11 water actually plotted out to be below the design curve
12 and what's on this figure here maybe this is the best
13 fit of the data in error and then when that curve gets
14 adjusted for environmental effects - I'm sorry, gets
15 adjusted to be a design curve with factors of two and
16 20, this would be the design curve, and what some of
17 the laboratory tests in water showed is the points were
18 coming below the design curve and what the conclusion
19 that came out of that was is in some cases for some
20 environments the design curves could potentially be
21 nonconservative.

22 What are the - why is there a guidance on
23 EAF? So, basically, we all - we always tie back to 10
24 CFR 50 and Appendix A in particular with the two general
25 design criteria about structure systems and components

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 designed, fabricated, erected and tested to quality
2 standards and the reactor pressure coolant boundary
3 being tested, erected and fabricated and all that to
4 the highest practical standards.

5 In addition, 50.55a(c) endorses ASME code
6 for use in design of safety-related systems and
7 components class one and that's where these fatigue
8 curves are included in Section 30 for class one
9 components.

10 The fatigue curves, and this is
11 specifically noted in Section 3 of the code, they do
12 not address the impact of the reactor coolant system
13 environment.

14 They were based on air with design factors
15 that apply to account for other things like surface
16 finish size effects, temperature of the laboratory,
17 environment, et cetera, but not for water.

18 CHAIRMAN RICCARDELLA: The code - I think
19 the code states that addressing environment is the
20 responsibility of -

21 MR. STEVENS: That's right. I'm flashing
22 it real quick. I thought I - yes, I have that NB-3121.
23 So these curves that are in Section 3, now, they've been
24 modified recently but they were originally developed
25 in the late 60s and early 70s and, like I say, air

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 environment at ambient temperatures margin of two on
2 strain and then 20 on cycle of life.

3 In NB-3121 in Section 3 of the code for
4 class one components identifies that the data used to
5 develop the fatigue design curves did not include tests
6 in environments that might accelerate fatigue failure.

7 I happen to be one of those that reads that
8 very clearly that the effects of the LWR environments
9 are not included. There are others in the code
10 committees that don't agree with me. But that's the
11 way I read it.

12 Now, in the 1980s the NRC initiated a
13 fatigue action plan and these were in response to a lot
14 of - there was some plant life extension which we now
15 call license renewal studies that occurred in the early
16 80s and there was various findings that came out of
17 those studies that - on a variety of topics, one of which
18 was fatigue and so there's fatigue action plan
19 undertaken.

20 Research in Japan as well as Argonne
21 National Laboratory identified these potentially
22 significant effects of the water environment and that's
23 back to that curve I showed you where some of the points
24 were plotting below the design curve.

25 The fatigue action plan was closed down in

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 1995 and by the way on all these slides I footnoted you
2 the appropriate references for these NRC actions that
3 I'm citing if you want to look at those.

4 They closed out the fatigue action plan and
5 they resolved the generic safety issue which had to do
6 with the adequacy of fatigue life of metal components
7 and included in that is that the risk to core damage
8 from fatigue failures for 40 years was very small and,
9 however, there was a potential for increased leaks
10 beyond 40 years into license renewal.

11 So they said that needed to be looked at.
12 So what you'll see throughout this presentation is EAF
13 is not considered for the current operating 40-year
14 term for the fleet but it is addressed for operation
15 beyond 40 years and all of our guidance has been set
16 up with that in mind. It was not back fit to the 40.

17 Where this all culminated is in 1999 the
18 various generic safety issues that captured all these
19 were closed out, the final one being the GSI 190,
20 fatigue evaluation of metal components for 60-year
21 plant life and that led to our guidance for license
22 renewal for EAF effects which we say meet the provisions
23 of 5421 aging management programs for license renewal.

24 Now, in December of 1999 the NRC wrote a
25 letter to the ASME Board of Nuclear Codes and Standards

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 requesting the ASME to revise the code to include EAF
2 effects and so embarked a long, long history of task
3 groups and committees and what not that continue to this
4 day.

5 There are two code cases that tried to
6 adopt some environmental effects but in the code itself
7 there are no rules for these effects yet.

8 ASME, in response to that letter,
9 initiated a steering committee with PVRC to look at this
10 and ultimately that committee published a WRC bulletin,
11 487, where they were recommended - they recommended
12 revising the code in fatigue design curves and pretty
13 much at that time it was consistent with Argonne's work
14 but there was an argument over how much conservatism
15 there was embedded in the existing code curves and
16 whether you could account for that.

17 So bottom line is ASME code has really
18 struggled on this issue now for more than 20 years.
19 There still are no rules in Section 3 that are
20 acceptable to the staff, although these two code cases
21 I've listed here have been published.

22 We have not endorsed those yet and so based
23 on the closeout of fatigue action plan the NRC developed
24 our own guidance for this issue, and there was a couple
25 of reports that were published in the 1999 time frame

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 that were applied to license renewal applicants and
2 eventually this Reg. Guide 1.207 was published in 2007
3 for new reactors.

4 All right. Here are the two reports that
5 were published in 1998 and 1999 respectively that many
6 of the earlier license renewal applicants used to
7 evaluate EAF effects. Dr. Shack here is one of the
8 co-authors on one of those.

9 One is for, basically, ferritic materials
10 and the other was for austenitics. The GALL report for
11 license renewal basically adopted the use of those
12 NUREGs for license renewal applicants and that's
13 contained in Chapter X.M1 of the GALL report and that
14 goes back to the original GALL report in 2001 that that
15 guidance was in there.

16 Effectively, these NUREGs they do remain
17 in the current revision two of GALL and the - that was
18 in 2010 when the GALL report was last issued and that
19 version of the GALL report also allows use of the Reg.
20 Guide which, again, is intended for new reactors but
21 it does allow its use for operating reactors.

22 So the guidance for new reactors, again,
23 is in this Reg. Guide 1.207, Rev. 0 issued in March 2007.
24 That's the Reg. Guide we're revising here - proposing
25 to revise, and the technical basis for that NUREG is

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 this NUREG CRC 6909, which is the technical basis we're
2 revising and I'll be talking to you about today.

3 Again, these were issued in the 2007 time
4 frame. Near as I can tell, they adopted the - all of
5 the environmental fatigue data through about the 2003
6 or 2004 time frame that was available.

7 The guidance for operating reactors - the
8 40-year fleet there is no requirement to address EAF
9 so there is no guidance for that and the license renewal
10 applicants follow the guidance in NUREG 1801 Rev. 2 and
11 here's kind of how it reads.

12 It says that for carbon steel they have a
13 choice of using the 1999 NUREG or the 6909 that was
14 associated with Reg. Guide 1.207. Same for stainless
15 steel and for nickel alloy. They were directed to use
16 the methods in 6909.

17 In all three cases, the licensee, since
18 this is only guidance, can use an NRC-approved
19 alternative of their own choice should they so choose.

20 The early - the 1999 and 1998 NUREGs did
21 not address methods for nickel alloys. That is why for
22 the nickel alloys the GALL report does not allow the
23 use of the earlier NUREGs.

24 So what is Reg. Guide 1.207 and 6909?
25 Well, it defines this fatigue multiplier F_{en} . I'll

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 refer to that as Fen and it's just a multiplier and
2 you'll see how that multiplier fits back into the CUF
3 calculation I showed you back on slide two.

4 MEMBER SKILLMAN: Gary, what does the EN
5 stand for?

6 MR. STEVENS: Environmental.

7 MEMBER SKILLMAN: Oh. Gotcha.

8 MR. STEVENS: This is EAF guidance, again,
9 for new reactors and what you'll be hearing here is when
10 we revise it we're trying to consolidate everything
11 into a Rev. 1 that applies to everybody.

12 As I mentioned, the GALL report allows
13 license renewal applicants also to use the this Reg.
14 Guide which is for new reactors and, really, these two
15 documents are the best vehicle we at the NRC have to
16 update and consolidate our guidance.

17 So if we're going to update and put
18 everything in one place revision of these is the place
19 to do it.

20 MEMBER BLEY: Is there anything likely to
21 be needed if we go beyond six years with a subsequent?

22 MR. STEVENS: Yes. The intent - you know,
23 there's internal activities underway working on the
24 GALL for subsequent license renewal, which is basically
25 operation beyond 60 years and that document, which will

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 be a GALL specifically aimed at SLR is - I think the
2 schedule shows it's going out for public comment next
3 year and the intent is that document will refer to the
4 Revision 1 of these two documents.

5 Okay. So what is this Fen? That's a
6 factor - environmental factor and now you can see down
7 below the CUF calculation on slide two of these factors
8 tied in.

9 On the first slide, you know, each - we had
10 each of these views were just the ratio of the cycles
11 - the point loads to allowable and you can kind of see
12 now the attractiveness of Fen.

13 What we've done is for each of those
14 summation factors we can come up with a multiplier to
15 just insert into that calculation. So this method is
16 a really nice way and easy way to adopt these factors
17 into the current structure for CUF calculations.

18 In the beginning, NRC looked at two
19 approaches. One was to revise the fatigue curves
20 themselves and the other was to use this factor
21 approach, and we used this factor approach because the
22 primary reason was that there are conditions in power
23 plants where fatigue effects don't apply.

24 This factor allows you to turn on and off
25 environmental effects easy, whereas if you revised the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 fatigue curve these effects would always be there. So
2 you'd either have to have multiple fatigue curves -

3 MEMBER BLEY: Multiple fatigue curves,
4 right.

5 MR. STEVENS: So this was considered at
6 the time to be the easier way to adopt these methods
7 and that's what was adopted and what it is defined as
8 is the ratio of the fatigue life - fatigue life is the
9 number of allowed cycles for a material - the ratio of
10 the fatigue life in air to water.

11 So it kind of makes sense that if this CUF
12 calculation I showed you on slide two was based on air
13 then if you have a factor that's based on the ratio of
14 air to water that's where the multiplier comes from.

15 So it is the allowable number of cycles in
16 air room temperature to those in water at the surface
17 temperature.

18 All right. Now, this is an example of what
19 those factors look like and it's a relatively simple
20 equation that you could plug into a spread sheet.
21 These are the - this is an equation for stainless steel
22 out of the Rev. 0 of 6909. So I don't want you to think
23 this is what the equation looks like today. I'm going
24 to show you that in a few slides.

25 And what these - what these equations are

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 it's an exponential term that in this case had a
2 constant and then it has three variables which
3 basically have temperature, oxygen content of the fluid
4 and strain rate.

5 MEMBER SKILLMAN: And that was a product,
6 fatigue?

7 MR. STEVENS: Those are - yes, those are
8 product of fatigue terms, yes. Now, the one thing
9 that's not intuitive here, and you'll see this
10 throughout, is, you know, a lot of folks look at the
11 minus sign and say wow, these terms actually subtract
12 off.

13 But what happens if you look at this last
14 term here on strain rate, it's a logarithm and it's a
15 logarithm of a ratio that's less than one so it ends
16 up being a negative number.

17 So even though that's a minus sign the
18 product is negative so it's actually a plus. So what
19 you have here, and it kind of makes sense, you know,
20 the effects are based on how you load the - how you load
21 the component in terms of strain rate and then the
22 conditions of the environment - temperature and oxygen.

23 This is stainless. Ferritic materials
24 for carbon and alloy steel are similar but they have
25 the introduction of a sulfur term. The sulfur is the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 sulfur content of the metal.

2 And I'm going to go into - this I just
3 wanted to show you so now you kind of know what an Fen
4 is and how it's calculated and I'll go into new
5 expressions, how they're developed and these
6 parameters how they're determined.

7 Okay. So the real question is for the
8 brief is why are you revising Reg. Guide 1.207. I have
9 one slide for that. There's actually three reasons.

10 We're trying to consolidate all the EAF
11 guidance in one place so that we don't have a set for
12 new reactors, another set for license renewal
13 applicants and they're different. So we're trying to
14 consolidate. We are trying to update the guidance
15 based on stakeholder feedback as well as our own.

16 There have been some issues - some
17 practical issues with applying the EAF rules in the past
18 and I'll show you what those are and so we're revising
19 it to try and take care of those issues, and then we
20 are updating the guidance based on more recent research
21 data available since that 2003-04 time frame when the
22 Reg. Guide was first written.

23 So shortly after I arrived here at the
24 agency in 2010, the Office of New Reactors and Nuclear
25 Reactor Regulation both prepared a user need for

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 research to work on this and update the guidance and
2 that's been a three-year research effort and follow-on
3 activities to get these documents published.

4 It's noteworthy that also as a part of this
5 we did embark on an MOU - memorandum of understanding
6 - with EPRI to tie their research efforts in with ours
7 and EPRI co-funded the research on this project to the
8 tune of about 45 percent.

9 That was very helpful to get the research
10 done that we wanted to do. Okay. So that's why we
11 embarked on it. We had a request from the program
12 offices and here's all we did to the Reg. Guide.

13 The title of the Reg. Guide used to have
14 new reactors in it so we removed it. It's applicable
15 to everybody.

16 The guidance was clarified to apply to all
17 metal components exposed to the LWR environment - I'm
18 reading this carefully because the words are carefully
19 chosen - that have a CUF calculation required by the
20 plant's current licensing basis and what that says is
21 we are not mandating or we are not providing guidance
22 to licensees that they have to create CUF calculations
23 to address the environment.

24 If they have them and they're part of their
25 current licensing basis then these effects need to be

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 addressed for operation beyond 60 years and for new
2 reactors.

3 CHAIRMAN RICCARDELLA: For operation
4 beyond 60 years.

5 MR. STEVENS: Sorry. Forty.

6 CHAIRMAN RICCARDELLA: Forty.

7 MR. STEVENS: Beyond 40.

8 CHAIRMAN RICCARDELLA: It seems though
9 that there's a significant change here because the GALL
10 report and the prior work said pressure boundary,
11 right? And this doesn't say pressure boundary. This
12 says example reactor internals or -

13 MR. STEVENS: Yeah. It actually -
14 although it may cite an example of internals it doesn't
15 use that terminology and it says components exposed to
16 the environment that had a CUF calculation as part of
17 their licensing basis. You are correct. That's a
18 change.

19 CHAIRMAN RICCARDELLA: So I understand
20 that for subsequent license renewal. But now how does
21 this affect plants that have already done an initial
22 license renewal by the old rules?

23 MR. STEVENS: Doesn't affect them in the
24 sense that we're not - we're not back having them
25 change anything like that.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: So it's similar to
2 the last one.

3 MR. STEVENS: Right.

4 CHAIRMAN RICCARDELLA: So we don't have to
5 do it for a 40-year -

6 MR. STEVENS: Right.

7 CHAIRMAN RICCARDELLA: - projected to do
8 it for 40 or 60. Now we're saying that you don't have
9 to do this new stuff if you're already licensed. What
10 about a plant that's coming up now for 40 to 60, if there
11 are still a few?

12 MR. STEVENS: They would be subject -
13 well, they're following GALL Rev. 2. All current - the
14 current fleet is going to continue to follow GALL Rev.
15 2 so they would need to meet those requirements, which
16 is Rev. 0 of this Reg. Guide or the old NUREGs.

17 CHAIRMAN RICCARDELLA: Okay.

18 MR. STEVENS: Now, obviously, with -
19 before the Reg. Guide addressed new reactors and now
20 we're bringing in the operating fleet for license
21 renewal so the background had to be expanded quite a
22 bit to bring in the relevant content for the operating
23 reactors and license renewal and that's really the most
24 significant change to the Reg. Guide if you were to do
25 a side by side comparison. There's a lot of background

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 that we brought in.

2 But the guidance itself really didn't - the
3 guidance section of the Reg. Guide didn't change that
4 much. The Fen equations were revised based on a
5 research on all the stakeholder feedback.

6 The Fen equations actually are not
7 contained in the Reg. Guide. They're in the NUREG
8 document. So when you look at the Reg. Guide the
9 guidance says use the equations in the NUREG. It still
10 says that. It's really not much of a change. But the
11 equations have changed in the NUREG and the NUREG has
12 more than doubled in size.

13 CONSULTANT SHACK: Just coming back to
14 Pete's question, I mean, why does this renewal treat
15 the aging management programs as sort of living
16 documents? We've certainly seen plants go back and
17 address buried piping as the considerations for buried
18 piping have changed with submerged cables. Why
19 wouldn't this be like any other aging management
20 program?

21 MR. STEVENS: I'm looking at Mr. Hiser.
22 So I would say that - all right, go ahead.

23 MR. HISER: This is Alan Hiser at license
24 renewal. Actually, these - the calculations of CUF,
25 CUF EN are time limited aging analyses so they're not

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 ANPs.

2 So once they've been demonstrated to be,
3 you know, the prior analysis is still - well, actually,
4 and see, these are even more bizarre. The
5 environmental effects are not time limited aging
6 because they're not in the COV for the first operating
7 period.

8 But plants treat them like a TLAA. So they
9 evaluate them - evaluate the environmental effects like
10 it's a TLAA. So, for example, they say that the
11 calculations are still valid or they update them and
12 show they're less than one or they do aging management
13 which sometimes they end up having to do for pressurized
14 or surge lines and things like that that have a high
15 usage and a fairly high Fen as well. So it's a little
16 bit different from EG management programs in that
17 perspective because they are time limited aging
18 analyses.

19 And I guess the one other thing I'd comment
20 on the internals for PWR plants that use MRP-227-A for
21 aging management there is a provision at staff SC that
22 if plants have CUF values for internals that they need
23 to incorporate environmental effects for those
24 internals. For DWR plants that doesn't apply but for
25 PWR they should be including environmental effects for

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 internals.

2 CHAIRMAN RICCARDELLA: They've already
3 been doing it in accordance with Rev. 0. Is that what
4 you're saying?

5 MR. HISER: No, they haven't been but if
6 there's NRP 227 didn't exist at that point so that what
7 they would do is use GALL Rev. 2 guidance on how to do
8 environmental effects. Then they would use the MRP 227
9 provision that they had to do environmental effects for
10 internals and that would be included in their license
11 renewal application.

12 CHAIRMAN RICCARDELLA: Then what's the
13 logic for having a different set of rules for BWRs
14 versus PWRs? What difference does it make?

15 MR. HISER: We have not updated GALL to
16 incorporate internals at this point in time. There are
17 many inconsistencies. You know, as Dr. Shack
18 mentioned, you know, if you update the Reg. Guide should
19 that go back and apply to all plants. That's not the
20 licensing - that's not the way we regulate plants. If
21 we felt that it was necessary then we would go to the
22 measures of doing a back fit. But we haven't made that
23 determination at this point.

24 CONSULTANT SHACK: But, again, most of
25 those license renewals, since you didn't have MRP 227

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 said that we would base our aging management program
2 for the internals on the updated guidance when it became
3 available.

4 So that MRP 227 then would apply to
5 virtually all of the plants - all the PWRs, at any rate,
6 because they neither directly cited it or they said they
7 would follow it when it became available.

8 MR. HISER: Yeah, I think that's correct.
9 In the industry, MRP 227-A, the implementation of it
10 is through an industry initiative and so all PWRs should
11 be implementing that so they should be, if they have
12 CUF calculations for internals, which is a critical
13 piece, they may not have been a part of the original
14 design in many cases if a plan came in for a power
15 upgrade or some other modification then we in some cases
16 wanted them to consider fatigue effects through a CUF
17 calculation for internals, in that case they would -
18 they should update the calculation for environmental
19 effects. But if there are - there's no need to generate
20 new CUF values.

21 CHAIRMAN RICCARDELLA: But if they've
22 been doing it in accordance with Rev. 0, my
23 understanding is that Rev. 1 actually of these
24 documents actually makes the adjustments a little less
25 onerous.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. STEVENS: It depends. Yes, in
2 general. There is a case where that might not be true
3 and if the Rev. 0 guidance was interpreted by some
4 applicants to allow the use of average temperature and
5 if an applicant used average temperature that could be
6 nonconservative most of the applicants that we saw that
7 we've seen used maximum temperature. So your comment
8 is correct.

9 CHAIRMAN RICCARDELLA: And what is the new
10 guidance required?

11 MR. STEVENS: The new guidance says you
12 need to - you can use average temperature but you need
13 to evaluate the appropriateness of doing that for - and
14 justify it.

15 CHAIRMAN RICCARDELLA: Okay.

16 MR. STEVENS: My expectation is a lot of
17 the applicants may just end up using maximum
18 temperature to get around that. But we don't - we don't
19 mandate that.

20 The other thing I was going to say, at least
21 with regard to the BWRs, I mean, whenever this
22 conversation has come up about internals with them it's
23 generally recognized that their aging management
24 programs are inspection based and that those
25 inspections are driven more by SEC, which is much more

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 limiting than fatigue would be. And so generally the
2 inspections address fatigue concerns.

3 CHAIRMAN RICCARDELLA: Yeah. And so is
4 temperature. I mean, shouldn't you be addressing the
5 temperature at the time that the peak stress occurs?

6 MR. STEVENS: Yes.

7 CHAIRMAN RICCARDELLA: Which, I mean, if
8 -

9 MR. STEVENS: Well -

10 CHAIRMAN RICCARDELLA: - this peak stress
11 in the cycle or, you know -

12 MR. STEVENS: Yeah, it's - it depends on
13 what method, how you're calculating your Fen. It could
14 be an integrated average of the temperature between
15 adjacent peaks.

16 But, generally speaking, you would
17 evaluate in the load pair you're looking at at the two
18 temperatures of the peak stresses and take the higher
19 of the two. In some cases, the applicants based on what
20 - how Rev. 0 was worded maybe is the average
21 temperature, which would be less conservative than the
22 maximum temperature because the temperature term is
23 lower for the lower temperature.

24 So what you just said would be correct if
25 they were taking the temperatures of where the peak

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 stress occurred and they were using the maximum of the
2 two -

3 CHAIRMAN RICCARDELLA: Of the two.

4 MR. STEVENS: - in a loaded pair, that
5 would be correct.

6 CHAIRMAN RICCARDELLA: But I keep
7 thinking of, like, you know, like a thermal shock type
8 stress where you hit it with cold water, when the time
9 the peak stress develops it's - the surface is fairly
10 cool.

11 MR. STEVENS: Yeah.

12 CHAIRMAN RICCARDELLA: But then you're
13 saying you'd also have to look at where you started?

14 MR. STEVENS: Well, the temperature
15 that's in here is the metal temperature.

16 CHAIRMAN RICCARDELLA: Yeah, but the
17 metal temperature at what time during the transient?

18 MR. STEVENS: When those peak stresses
19 occur.

20 CHAIRMAN RICCARDELLA: Okay. But if you
21 have another - if that's just one part of the load pair
22 and then you've got a compressive part of the load pair,
23 say, where the temperature is higher you'd have to use
24 that.

25 MR. STEVENS: Right.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: Okay.

2 MR. STEVENS: Or if you wanted to use
3 something else like an average and you could justify
4 it then we're all open for it.

5 Okay. So what did we change in - you know,
6 the real crux of what we did it was all background and
7 title.

8 We changed these Fen equations and we
9 expanded the technical basis to clarify, to explain,
10 to - you know, to provide more details, et cetera, and
11 that's why the NUREG more than doubled its size.

12 So what did we do to these equations?
13 Initially, when Argonne and RES embarked on this our
14 intent was to collect all publically available fatigue
15 data published since the time of Reg. Guide 1.207.

16 That was published in 2007 but, as I
17 mentioned, the fatigue data captured was through the
18 2003 or 2004 time frame.

19 So in 2010 we thought there was six or seven
20 years of fatigue data out there we can capture and, like
21 with Reg. Guide 1.207, there were some informal
22 exchanges.

23 But most of the data that was provided was
24 taken out of the publically available literature. So
25 our intent was to do that again and update and whatever

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 was out there we would incorporate that into this work.

2 At the start of this research this wasn't
3 really a part of this program and on the side Office
4 of Research embarked on negotiations with JNES, which
5 is the research organization in Japan for the regulator
6 and they're now known as JNRA, to formally obtain all
7 of their research data.

8 They were the largest researcher - not the
9 largest, the researcher with the largest amount of data
10 available in the world. And so we embarked upon trying
11 to get that information with them and our pursuit of
12 that was under the Cooperative Materials Research
13 Agreement that NRC has with them.

14 And basically what this led to is the
15 Japanese recompiled and published their information
16 and gave it to us in October of 2011. I've noted the
17 report here.

18 Now, I can't say enough good things about
19 the Japanese and providing us the information they did,
20 as you'll see, and what it - how it expanded our
21 database.

22 You have to look at the date and understand
23 that they had a lot bigger issues ongoing in their
24 country at the time and yet they still took the time
25 to embark on this exchange with us and were very

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 gracious about that so -

2 CHAIRMAN RICCARDELLA: The date was 2007?

3 MR. STEVENS: No, 2011 is when we got their
4 report.

5 CHAIRMAN RICCARDELLA: After March?

6 MR. STEVENS: October is when they
7 provided us their report. So I can't say enough good
8 things and have a lot of respect for that organization,
9 that culture and that country and what they've done for
10 us.

11 And here's a summary of the air fatigue
12 data. On the next slide I'll show you the water data,
13 and what I've done is I've showed you the - I've given
14 you reference to the specific figures in Rev. 0 of 6909
15 and in the draft of Rev. 1 and what they did.

16 The expansion of the data in air was, you
17 know, as much as 74 percent in terms of the number of
18 data points.

19 Dr. Chopra at Argonne and I were actually
20 astonished when we did get our hands on the data. We
21 expected an increase but never of this magnitude. The
22 20 percent or 10 percent was what we expected.

23 So when we got - and as you'll see in the
24 water data in some cases a doubling of the amount of
25 data available we truly were astonished.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 It also allowed us to - I don't want to say
2 correct but much of the data that was taken out of
3 publications - publicly available publications in the
4 past were digitized off log-log plots, which was - you
5 can get within 10 percent but with the transmittal of
6 this data we were able to refine the database
7 significantly as well.

8 CHAIRMAN RICCARDELLA: In tabular form?

9 MR. STEVENS: Yes.

10 MEMBER REMPE: So just out of curiosity
11 you had an existing agreement. You didn't have to
12 provide funding - they just - you said hey, we'd like
13 it as part of our existing agreement without having -
14 they didn't ask for anything in return?

15 MR. STEVENS: Correct.

16 MEMBER REMPE: That's interesting.

17 MR. STEVENS: They didn't ask for anything
18 in return but it means an awful lot to them that we're
19 using their data and citing it as such in our guidance.

20 But you're right, this is - this represents
21 more than \$100 million worth of testing on their behalf
22 that they literally handed over to us. Now, that the
23 -

24 CHAIRMAN RICCARDELLA: They used the ASME
25 codes too so to the extent that this gets recognized

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 an ASME code that -

2 MR. STEVENS: Yeah, and you'll see as we
3 go through this, I mean, there was a benefit to them
4 in the sense that our research was done independent of
5 theirs and effectively going through two different
6 methods of whatever you want to call it - processing
7 - we've now come to agreement in terms of - general
8 agreement and what our predictions are versus theirs.

9 And I think in their - in their efforts to
10 get the SNE code to adopt work and all that they've done
11 many presentations and for us to be in alignment is -
12 it adds to their credibility and their ability to get
13 ASME convinced of their work.

14 In terms of the water data, it's a drastic
15 increase - 64 percent up to as much as 150 percent. I
16 couldn't quantify nickel-chrome alloys because I don't
17 really - I probably have it somewhere but I wasn't able
18 to look at the data that Argonne had available at the
19 time the Reg. Guide was written but it was a substantial
20 increase still.

21 MEMBER SKILLMAN: Gary, is there a reason
22 why they did so much research?

23 MR. STEVENS: To quantify these effects.
24 I mean, they believed that these effects are real and
25 so they were doing so much research to quantify and come

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 up with a methodology that would accommodate it.

2 They continue to do some amount of research
3 to now, I'll say, hone the methodology. There's areas
4 that haven't been addressed in the research in terms
5 of particular effects and parameters and their testing
6 is aimed at looking at some of those, and I'll talk about
7 some of those a little bit.

8 So what I have here are - I'm going to show
9 you the air curves for each of the materials. So on
10 the left is the curve and the data that we published
11 in Rev. 0 of 6909 and on the right are the curves we
12 published in Rev. 1, and really here's the short
13 one-liner version of this.

14 What you see here is more data on the right
15 and I just showed you why there's more data on the right,
16 and when you do a best fit through the data you basically
17 get the same answer.

18 Some folks, when I put that result out,
19 were disappointed - wow, we got all that data and
20 nothing happened. I said, well, that's actually a
21 pretty good message because my message to the industry
22 is it's time to quit testing small specimens.

23 We saturated the result now. We've proven
24 that when we doubled the data our answers didn't change
25 that much. So let's move on to more important things

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 like maybe testing real components.

2 CHAIRMAN RICCARDELLA: But also what's
3 significant, though there was a significant change from
4 the original code best fit to this best fit.

5 MR. STEVENS: That's right.

6 CHAIRMAN RICCARDELLA: And it shows that
7 the code best fit was very conservative.

8 MR. STEVENS: The - yeah, and we're going
9 to talk about this as we go on and remember the code
10 factors were two and twenty and in Rev. 0 we adopted
11 factors of two and twelve and the work we've done now
12 were factors of two and ten.

13 So we've improved upon what's in the code.
14 So what you see here is - you know, take away from this.
15 On the right, a lot more data points. The same best
16 fit curve goes through it.

17 As I note at the bottom, it's the same best
18 fit curve on both sides. We didn't change it. And
19 what really happened is if you do the statistics of the
20 curve on the left and you get the curve fits for it and
21 you do the same thing with the one on the right, they
22 do change but it leads to less than a 10 percent
23 difference in fatigue life, and a 10 percent difference
24 in fatigue life is truly in the noise.

25 So we did not change the coefficients for

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the curves because effectively for the purposes of what
2 we have here they did not change.

3 CHAIRMAN RICCARDELLA: Is the data on the
4 left included in the data on the right?

5 MR. STEVENS: Yes. Well -
6 (Simultaneous speaking.)

7 CHAIRMAN RICCARDELLA: -- cycles.

8 MR. STEVENS: Well, I don't really know -
9 yeah, no. It's supposed to be but these are the curves
10 I took out of the report. So I have - I have difficulty
11 resurrecting exactly which points were used in the Rev.
12 0 work.

13 So but the point is I do have all the data
14 from Rev. 0 and Rev. 1 and when we do the statistics
15 on them there is no meaningful difference between the
16 two, and this is true for all the materials in air.

17 It's the same for low alloy steel and -

18 CHAIRMAN RICCARDELLA: Wait. Go back to
19 the previous one. I mean, there's data on the left hand
20 -

21 MR. STEVENS: That's not on the right.
22 Correct.

23 CHAIRMAN RICCARDELLA: No. Go back to
24 the carbon - the carbon steel. There's significant
25 data above - at least three data points above ten to

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the sixth and on the right there's nothing above ten
2 to the sixth, and it seems to me that those data points
3 should have to be significant in driving the tail of
4 that curve.

5 MR. STEVENS: Yeah. So just consider it
6 - that all that data was considered is just not
7 reflected on these plots.

8 CHAIRMAN RICCARDELLA: Just not showing
9 the plots. Okay.

10 MR. STEVENS: And, unfortunately, it was
11 very difficult for me to go back and get a one to one
12 plot between these two pieces of work. This is low
13 alloy steel.

14 Okay. So all I'm trying to show here is
15 give you some more detail on the curve fits. These
16 curve fits are fit to the - using the Langer fit, as
17 shown at the bottom, where there's three constants -
18 A, B and C - and then you have the variables.

19 N is the fatigue life and the epsilon sub
20 A is the strain amplitude. And basically what I'm
21 showing you here is the difference in the constant A
22 between the Rev. 0 analysis and the Rev. 1 analysis and
23 for now just focus on the statistics.

24 The median value here before we got 6.583
25 and in the new data when we doubled the data we got

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 6.592. So when I say that the curve fits didn't change,
2 you know, it had - it had an impact in the third decimal
3 point in the coefficients of the fit. It was not
4 significant enough for us to change.

5 So in Rev. 1 we documented this but we
6 maintained the curve fits that were developed in Rev.
7 0. Same curve for low alloy steel. So before we had
8 a median of 6.449. Now it's 6.513. Again, very small.
9 We maintained the curve fit.

10 CHAIRMAN RICCARDELLA: These aren't log
11 plots so that -

12 MR. STEVENS: No.

13 CHAIRMAN RICCARDELLA: - does that imply
14 that it's a normal as opposed to log normal?

15 MR. STEVENS: Correct. So we also
16 developed design curves consistent with that Section
17 3 does, yes.

18 CHAIRMAN RICCARDELLA: Okay. But it's
19 log of N so -

20 MR. STEVENS: Right.

21 CHAIRMAN RICCARDELLA: - so it is log
22 normal.

23 MR. STEVENS: And log of epsilon. So we
24 came up with design curves consistent with what Section
25 3 does. Remember that originally the ASME's curves

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 were based on factors of two and twenty.

2 So what we did is, and this is another
3 interesting point that we've been questioned on, but
4 we maintained a factor of two on strain amplitude and
5 then we determined through Monte Carlo simulations what
6 the factor - what should be the appropriate factor on
7 life.

8 Now, the factor of twenty that's built into
9 the code as you see here is meant to address material
10 availability and scatter about a factor of two, size
11 effects factor of two and a half, surface finish a
12 factor of four, and when you multiply those four numbers
13 together you get the factor of twenty that Section 3
14 adopted originally, and these come out of the Section
15 3 basis criterion document.

16 For our work, based on research and
17 available data we looked at, what you see is the range
18 of values we saw for each of these various parameters
19 and what we did is we assumed log normal distributions
20 for those and did these Monte Carlo simulations to
21 determine what the factor on life would be to bound 95
22 percent of the data with 95 percent confidence.

23 And when we did that we come up with a
24 factor of 10.2. So what that says is for carbon steel
25 factors of two and ten are supported by the statistics

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 for building the design curve.

2 Before I comment on what we're using that's
3 different than Rev. 0, in Rev. 0 we determined that
4 factor to be twelve - two and twelve.

5 So here our research is supporting factors
6 of two and ten and I'm going to run through the other
7 materials and then I'll describe to you what we
8 recommended.

9 CHAIRMAN RICCARDELLA: How did you do a
10 Monte Carlo - maybe Bill can help me with this - to
11 address size effect? Arguably, you'd have to have
12 tests on different sizes - on larger sizes. I can see
13 you could account for the scatter - the material
14 variability.

15 MR. STEVENS: Right.

16 CONSULTANT SHACK: It's just that when we
17 looked at things for the size effect we really couldn't
18 find a big effect when you actually look at the data
19 where people made the things. So we - you know, we just
20 sampled from those ranges we found for the effects in
21 the literature and decided that they - you know, they
22 wouldn't apply - you know, you didn't get the worst case
23 every time. So we sampled and -

24 CHAIRMAN RICCARDELLA: You did use data
25 from the literature from -

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CONSULTANT SHACK: Yeah. So, you know,
2 we looked for data on surface finish effects in the
3 literature, you know, and that -

4 CHAIRMAN RICCARDELLA: And what is the
5 loading history?

6 MR. STEVENS: Loading history has to do
7 with, you know, the specimens are tested under uniform
8 R ratio minus one loading versus in power plants, you
9 know, you could go for days or weeks or months without
10 a load and then you have a load. So just the sequence
11 effects.

12 CHAIRMAN RICCARDELLA: Okay.

13 MR. STEVENS: Okay. So we get ten -
14 roughly, ten for carbon steel and now, when we drafted
15 the NUREG 6909 Rev. 1 and we put it out for public
16 comment we maintained factors of two and twelve to be
17 consistent with Rev. 0 and to be consistent with past
18 work because we didn't want to, I'll just say, perturb
19 the system.

20 However, we said and we showed the data
21 that supported the factor of ten and ten in the Federal
22 Register notice we requested specific feedback from the
23 public on that and we said we put in twelve. The
24 research supports ten.

25 We kept twelve because it's consistent

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 with what we did in the past. We don't want to change
2 but give us your feedback. So that's the way we are
3 now and we haven't - as we work through the comments
4 on both the NUREG and the Reg. Guide we'll make a
5 decision as to which one we finally adopt or recommend.

6 But, clearly, even if we stayed with a
7 factor of twelve a factor of ten is supported
8 technically. So it's something you want to -

9 MEMBER POWERS: Geometric mean of ten and
10 twenty, almost exactly.

11 MR. STEVENS: So right now that's the way
12 the revised NUREG reads.

13 CONSULTANT SHACK: But, I mean, you should
14 point out that when they did 792 they kept the twenty.

15 MR. STEVENS: That's right. The code
16 still uses - they did adopt a factor of twelve for
17 austenitics in 2009 but they have not changed from the
18 factor of twenty on ferritic materials.

19 So, you know, I'll point out that whether
20 we use ten or twelve - ten or twelve or whatever we
21 recommend for ferritics our curves are inconsistent
22 with the code right now. It's been our recommendation
23 to ASME to change the ferritic curve.

24 CHAIRMAN RICCARDELLA: But also out in the
25 high - out in the high cycle range it's controlled by

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the factor of two -

2 MR. STEVENS: That's right.

3 CHAIRMAN RICCARDELLA: - on stress and yet
4 you're still way above the original code curve. I'm
5 looking at the solid curve versus -

6 MR. STEVENS: That's right.

7 CHAIRMAN RICCARDELLA: - the lowest of the
8 curves.

9 MR. STEVENS: You know, keep in mind that
10 - so we're conservative, we are - however you want to
11 say - we're less conservative in the code for two
12 reasons.

13 Well, in this particular case it's really
14 one. They maintain the factor of twenty versus our
15 twelve.

16 CHAIRMAN RICCARDELLA: Not at the high
17 cycle end. At the high cycle end the factor of twenty
18 doesn't come into play. It's that your mean curve is
19 higher and therefore a factor of two below the mean
20 curve is higher.

21 MR. STEVENS: That's correct.

22 CHAIRMAN RICCARDELLA: Right?

23 MR. STEVENS: In that end, that's right.

24 CHAIRMAN RICCARDELLA: And, now, is the
25 Fen intended to apply to your design curve or the code

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 curve?

2 MR. STEVENS: Well, either.

3 CHAIRMAN RICCARDELLA: But it's -

4 MR. STEVENS: I mean, we - logistically
5 our curve. But if they want to use their curve and be
6 conservative then more power to them.

7 CHAIRMAN RICCARDELLA: Okay. So -

8 MR. STEVENS: And in fact our guidance
9 says that. For ferritic we say use our curve and
10 alternatively you can use the code curve and that would
11 prevent them from having to change their fatigue
12 calculation.

13 And low alloy steel - now, here the
14 difference is we have the twelve and twenty but, you
15 know, we have a separate curve defined for low alloy
16 steel compared to carbon steel and the code combines
17 the two.

18 CHAIRMAN RICCARDELLA: Yeah.

19 MR. STEVENS: And when you combine the two
20 it's really controlled by carbon steel and that makes
21 that curve conservative for low alloy steel
22 applications.

23 So another comment we would have to the
24 code to remove conservatism is to separate those two
25 curves into carbon and low alloy steel. They have not

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 done that.

2 Here, when we did the Monte Carlo
3 simulation for low alloy steel we got that factor of
4 nine. So, again, we're about in the factor of ten
5 range. Two and nine would be supported versus two and
6 twelve.

7 Austenitics the same kind of results and
8 here I show the factor went from 6891 to 6913 - again,
9 a very small change. And here what you see is that we
10 matched the code curve.

11 It was actually to a curve that's shown
12 there just for reference is the old ASME code curve
13 prior to the 2009 edition.

14 The current code matches the Argonne
15 design curve for austenitics. Factors of two and
16 twelve. In our Monte Carlo simulation for austenitics
17 we got a factor of 9.6. So, again, we're down around
18 the ten range.

19 And then nickel, chrome, iron, steel here
20 there was - there is a different relationship for nickel
21 chrome iron alloys for Fen. They make use of the
22 austenitic fatigue curve for the CUF calculations.

23 Now, one area of improvement we see here
24 and we saw this with the data we looked at for nickel
25 chrome iron steels is that, you know, there is a

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 difference.

2 In grouping all the austenitics into one
3 curve there is conservatism in doing that for some of
4 those materials. Based on the research and the amount
5 of data we had, you know, the - we used the austenitics
6 stainless steel design curve.

7 That's consistent with what's in the code.
8 An area of further improvement, in my opinion, would
9 be to separate the austenitic materials into different
10 curves and that's been our recommendation to the
11 industry to look into.

12 Okay. So the changes to the Fen
13 equations, what I tried to do here is I tried to put
14 the old equations on the left, old equations being
15 what's in 6909 Rev. 0 and the new equations on the right,
16 Rev. 1, I tried to color code the variables so you can
17 tie them into the definitions below. So you remember
18 the Fen example I gave you back on slide ten or whatever
19 it was was for austenitics.

20 So here's for the carbon steel material and
21 as you can see it has a similar form but there's another
22 term here, the sulfur term based on the sulfur content
23 of the material, and one of the biggest comments we got
24 from the stakeholders was the constant in these
25 expressions - the point - in this case the .632 and the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 expression on the left.

2 And what happens there is if you zero out
3 - if you say - you're in a situation where you have no
4 environmental effects that is the second term with the
5 S, the T, the O and the R zero out. Your Fen is still
6 non - you get a value greater than one.

7 CHAIRMAN RICCARDELLA: The .632 is about
8 two, isn't it?

9 MR. STEVENS: Right. Even if .632 comes
10 out for this case to be about two. So what that means
11 is even when you don't have environmental conditions
12 present you would hit it with a factor of two, which,
13 you know, kind of doesn't make technical sense.

14 CHAIRMAN RICCARDELLA: Over and above the
15 existing factor of twelve or twenty or whatever it is.

16 MR. STEVENS: Right. This would say - if
17 you didn't have environmental - if environmental
18 conditions didn't apply for the component you're
19 looking at you'd still have to double the CUF, just by
20 using these rules and that, you know, technically just
21 was a little bit inconsistent.

22 And what that was a function of really was
23 the constraints that were used to fit the environmental
24 data. So when we redid the fits in Rev. 1 we basically
25 put a constraint in it and had to go down to one - one

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 environmental condition.

2 Now, it's hard to see out here but here you
3 have a leading constant in the new term .003 but, see,
4 it's multiplied by - so if environmental effects go away
5 -

6 CHAIRMAN RICCARDELLA: Yeah. Yeah.

7 MR. STEVENS: - you basically go to a Fen
8 of one.

9 CHAIRMAN RICCARDELLA: E to the zero is
10 one.

11 MR. STEVENS: This was the significant
12 feedback that we received from stakeholders as well as
13 ourselves. But so this was the most significant change
14 and, again, it just amounted to when you do the fit of
15 the data to put an extra constraint on it to force it
16 through an Fen of one.

17 So the new equation has the same kind of
18 form, the same variables but it just comes up with a
19 different value when environmental conditions don't
20 apply. And for low alloy steel, the previous equation
21 - the lead coefficient which I kind of outlined in
22 yellow instead of being .632 was 702, otherwise it was
23 the same.

24 We use the same Fen for both carbon and low
25 alloy steel. There's no difference there. They have

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 different fatigue curves but the environmental
2 multiplier is identical.

3 Okay. These plots - you know, you can
4 never put these on one plot and get everything because
5 of all the terms. So, you know, anytime you want to
6 know what's the Fen you have to do it as a function of
7 something.

8 So on the left is a plot of Fen as a function
9 of strain rate, given a sulfur content of temperature
10 and there's several curves for a family of dissolved
11 oxygen content.

12 The solid lines represent the Rev. 1
13 expressions and the dotted lines represent the Rev. 0
14 expressions and basically what you see, and this is
15 consistent with your comment, Pete, the new expressions
16 come with better - all other things pretty equal they
17 give you a lower Fen.

18 CHAIRMAN RICCARDELLA: Yeah.

19 MR. STEVENS: And what you see at the lower
20 end where they come down and bottom out is the old
21 expressions - the dotted line came out about two and
22 now they're coming out to be one. And then on the right
23 is the same plot except now instead of strain rate being
24 the variable you have temperature for a fixed strain
25 rate.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: But their - for low
2 strain rates they're -

3 MR. STEVENS: Low strain rates are the -

4 CHAIRMAN RICCARDELLA: High temperatures
5 - I mean, you're talking factors of twenty.

6 MR. STEVENS: They're large.

7 CHAIRMAN RICCARDELLA: That's huge.

8 MR. STEVENS: They can be large.

9 CHAIRMAN RICCARDELLA: I didn't realize
10 that.

11 MR. STEVENS: And where that's coming from
12 is, you know, back in the expression you're down here
13 into this, the low strain rates. This term becomes a
14 large - this is small. The logarithm is a large
15 negative number which causes the Fen to go up.

16 CHAIRMAN RICCARDELLA: Well, what are the
17 strain rates for typical transient? Where do you fall
18 on that in that range?

19 MR. STEVENS: So for this ten to the minus
20 - boy, I'm drawing a blank on, like, a start up event.
21 But that's on the order of, like, ten to the minus five,
22 ten to the minus four percent a second.

23 But the issue is though where you can get
24 the high Fen you don't get much stress. The transient
25 is so slow and, you know -

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: Like 100 degrees
2 per hour?

3 MR. STEVENS: Right.

4 CHAIRMAN RICCARDELLA: Heat up would be -

5 MR. STEVENS: You might get a very large
6 multiplier but your component may not have this - you
7 know, you may be below the endurance limit and you're
8 not getting any fatigue contributions. So if you get
9 a factor of twenty times, basically, zero it's zero.

10 The transients that drive the fatigue are
11 very high strain rate transients and those typically
12 have much lower Fen multipliers.

13 But that's what's caused a bit of the issue
14 because your intuition of in the past stepped - changed
15 transients always caused the highest fatigue. That's
16 true, but they caused the lowest Fen multipliers.

17 CHAIRMAN RICCARDELLA: Okay.

18 MR. STEVENS: And in - let's see, these
19 are, again, some - I guess I showed you this one, and
20 then okay. So now what we did is we took all the data
21 and we plotted our estimated fatigue life with our
22 expressions versus those using Japan's expressions.

23 If they were perfectly equal you would get
24 on a 45-degree line and you see here within the scatter
25 of the data they match. So back to the question of why

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 would they gives us the data.

2 This plot right here shows two independent
3 research organizations who did take a different
4 approach to how they fit the data basic and come up with
5 equations that look similar but are different are
6 basically getting the same answer, and this is - this
7 is a very important - a very powerful plot for them.
8 We do still see some deviations and in this case - so
9 for some of the lower cycle and, you know, we don't know
10 what's causing all of those other than in the backup
11 slides I've showed you we do have a different approach
12 to how we fit the data.

13 We minimize - basically when we do the best
14 fit we minimize each point with its distance -
15 perpendicular distance to the best fit curve and the
16 Japanese minimize only on life.

17 MEMBER BLEY: Just my eye arguing with the
18 curves I see because up at the high cycle the points
19 are above the lines and at the low cycle they're below
20 the lines. So you kind of expect your fit would have
21 twisted some to account for that.

22 MR. STEVENS: Yeah, and we - it's hard to
23 chase down some of these differences with that. I
24 mean, we did that - to us, this plot within the scatter
25 of the data looked really good. The Japanese looked

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 really good. But specifics get down to - you know, we
2 kind of deviate from the get-go on how we did our fits.

3 CHAIRMAN RICCARDELLA: Is the fit - the
4 dashed line -

5 MR. STEVENS: It's not a fit but it's -

6 CHAIRMAN RICCARDELLA: - it's not a fit.

7 MEMBER BLEY: That's where it is. That's
8 just the 45-degree line. So the fits -

9 MR. STEVENS: Oh, I'm sorry. I
10 misunderstood your -

11 MEMBER BLEY: - the fit's not really shown
12 on here.

13 MR. STEVENS: The 45-degree - the dotted
14 line is the 45-degree where their prediction would
15 exactly equal our prediction.

16 MEMBER BLEY: Okay.

17 CONSULTANT SHACK: So they have two
18 different formulas for predicting but they have the -
19 I mean, it's pretty close, especially in the middle.

20 CHAIRMAN RICCARDELLA: No, but if you -
21 but if you had a fit it would be some line that would
22 be different than or slightly different than that.

23 MR. STEVENS: Right. So you see, yeah,
24 the - our prediction versus theirs does have a little
25 bit of a slant to it like what you observed.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: So.

2 MR. STEVENS: And it really comes down to
3 how we started the fitting process in the beginning,
4 at least near as I can conclude from this work. They
5 fit it differently than we do.

6 CHAIRMAN RICCARDELLA: So we're more
7 conservative for low cycle fatigue and less
8 conservative for high cycle or vice versa? I'm having
9 trouble figuring that out.

10 MR. STEVENS: So for lower cycles - okay,
11 let's look at the plot for low alloy steel one on there.

12 CHAIRMAN RICCARDELLA: Low cycles - they
13 would predict the shorter lives than us.

14 MR. STEVENS: They predict a shorter life
15 than us.

16 CHAIRMAN RICCARDELLA: And for high
17 cycles -

18 MR. STEVENS: Be opposite.

19 CHAIRMAN RICCARDELLA: - they'd be longer
20 - longer ones.

21 MR. STEVENS: And given -

22 MEMBER POWERS: Your basic approach to
23 fitting is pretty sound.

24 MR. STEVENS: Yeah. I mean, given that
25 the quantity of data, the fact that there's a scatter

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 of two, the fitting process used in all that, I mean,
2 but given enough time and resources we would chase this
3 down and get it to be perfect and we just - at this -

4 CHAIRMAN RICCARDELLA: But you know
5 things always look good on log-log. I mean, if the low
6 cycle ends some of those data points are off by a factor
7 of five.

8 MR. STEVENS: Yeah, and there are some
9 that - and I think some of these -

10 MEMBER POWERS: Well, they're not off. I
11 mean, it's really that he's basically fitting two
12 things for the variable and he's taking a -

13 MR. STEVENS: Yeah.

14 MEMBER POWERS: - an approach in which he
15 has minimized the variance in both directions.

16 MR. STEVENS: And my recollection is some
17 of the deviations were occurring under, like, BWR water
18 conditions - normal water chemistry conditions.

19 CHAIRMAN RICCARDELLA: Oh, I see.

20 MR. STEVENS: And given that there was
21 another reason we kind of abandoned chasing this too
22 much is because there aren't really that many plants
23 following that anymore.

24 So what was the merit of chasing
25 differences in conditions that plants don't really

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 operate in. So -

2 MEMBER POWERS: Before I chased anything
3 I would say let's look and see how the prediction does
4 against the data, not against somebody else's
5 correlation.

6 MR. STEVENS: Right.

7 MEMBER POWERS: I mean, that's what's
8 misleading about this is people say well, you're off.
9 Well, no, no - you're not off. You're - you have to
10 look at the data -

11 MR. STEVENS: Right. It's them versus us
12 kind of prediction.

13 MEMBER POWERS: And I think the approach
14 you've taken in your fitting is very defensible - very
15 defensible.

16 MR. STEVENS: They were happy with this.
17 I think we're generally happy with it. There are some
18 areas that, you know, again, if we had more time and
19 resources we would pursue further as good researchers.
20 But -

21 CHAIRMAN RICCARDELLA: But fatigue is
22 that kind of a animal too. I mean, you take ten
23 identical specimens and put them on a fatigue - on a
24 fatigue - on an identical fatigue test and you'll get
25 one of them that'll fail a factor of ten shorter cycles

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 than another, and then the longest one. That's the
2 nature of the phenomenon of -

3 MEMBER POWERS: Because the metallurgists
4 can't make good materials.

5 MR. STEVENS: Metallurgy is a black art.

6 MEMBER POWERS: It still is. They say the
7 wrong incantations, you know.

8 (Laughter.)

9 MR. STEVENS: Okay. So then in - here we
10 have the austenitics stainless steel. We basically
11 got rid of the constant out front. However, the
12 transformed variables definitions changed a bit.

13 The other thing you'll note is before in
14 Rev. 0 we allowed this to go above 325 degrees C. The
15 data doesn't support that because the data we used was
16 325 degrees C and below. So we did limit it to that
17 and in the NUREG we noted that and we said that we don't
18 really know of any applications with the current fleet
19 where a higher temperature is needed than that. I
20 mean, and if somebody were to use it we need to - I don't
21 know that we would argue against a use of this beyond
22 that temperature but we're probably going to ask some
23 questions about that and its applicability.

24 We didn't want to put validity on these
25 equations that wasn't true is what it amounted to. So,

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 again, we got rid of the constant terms. Before I think
2 the exponent of .734 came out to be about two and a half
3 when no environmental conditions applied and that's
4 disappeared.

5 And, again, similarly, here's the plot of
6 the prior Fens and RFens and I think what we have here
7 the solid lines are the new expression. I don't know
8 if I called this out. We also have the Japanese
9 expressions on here. The Japanese expressions are the
10 chain dashed line whereas the dotted line are the Rev.
11 0 of the NUREG.

12 So you can see that we do have some
13 differences still with the Japanese in terms of, like,
14 cutoffs and things like that. And, again, at the lower
15 end we now go down to one as opposed to before it was
16 two or two and a half.

17 So we have a lot more data. Didn't really
18 change things much but we changed a constraint to get
19 the equations to bottom out at one and that's really
20 what happened. That's the differences we made.

21 Here, the Japan expressions versus ours
22 for stainless steel - again, pretty good agreement.
23 You see a little bit more deviation from that 45-degree
24 line.

25 Again, we could have pursued more but

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 everybody looked at this and thought this was pretty
2 good, especially compared to what some of these
3 comparisons were like before.

4 MEMBER POWERS: I think it would be really
5 interesting to see comparison against the database for
6 some of these areas where there are differences,
7 recognizing you had this problem and it's a
8 multidimensional space.

9 MR. STEVENS: Right.

10 MEMBER POWERS: It's kind of hard to plot
11 -

12 MR. STEVENS: Right.

13 MEMBER POWERS: - on a two-dimensional
14 plot.

15 MR. STEVENS: Right.

16 MEMBER POWERS: But you can - you can plot
17 predicted versus observed on a two-dimensional plot.

18 MR. STEVENS: Right.

19 MEMBER POWERS: And that one would be very
20 interesting at the tails because just to see if - I mean,
21 if you're within the scatter bounds on things you can
22 fit until your eyes fall out. You're just fooling
23 yourself.

24 MR. STEVENS: Right. Yeah, it does get
25 kind of wacky to try and chase some of this down and

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

-

MEMBER POWERS: I mean, people do this all the time. They end up fitting noise.

MR. STEVENS: Right.

MEMBER POWERS: And it was if you have a very nicely defensible approach to this thing I think you'd be congratulated for using that kind of approach because it's appropriate.

MR. STEVENS: Well, thanks.

MEMBER POWERS: And for two different approaches giving you this kind of agreement the real surprising thing is it's all on one plot.

MR. STEVENS: Right.

CHAIRMAN RICCARDELLA: Let me understand the previous point better. So the dashed curve is the old -

MR. STEVENS: Rev. 0.

CHAIRMAN RICCARDELLA: - Rev. 0 and the solid curve is the new -

MR. STEVENS: Rev. 1.

CHAIRMAN RICCARDELLA: - Rev. 1 and there's really not that much of a difference in those, at least the two blue curves.

MR. STEVENS: No. Mainly at the bottom end.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: Yeah. And but the
2 - and then the chain link curves are Japanese?

3 MR. STEVENS: Japanese. That's right.

4 CHAIRMAN RICCARDELLA: So therein you see
5 the big difference in the -

6 MR. STEVENS: So there you can see, for
7 example, in the BWR normal water chemistry -

8 CHAIRMAN RICCARDELLA: Yeah.

9 MR. STEVENS: - going way up, yeah.

10 CHAIRMAN RICCARDELLA: Huge difference in
11 that low strain area.

12 MR. STEVENS: And that's why I was saying,
13 like, in that one curve - well, this is austenitic but
14 I think a lot of the places on that comparison plot where
15 we deviated were there and, you know, we just didn't
16 delve into pursuing that condition.

17 CHAIRMAN RICCARDELLA: But one of the - I
18 mean, it's just at that low end we're a lot more - at
19 that low strain rate end they're a lot more conservative
20 then.

21 MR. STEVENS: Right. They're also making
22 changes. They continue to tweak on their model a bit
23 and I know that difference in particular kind of
24 bothered them.

25 CHAIRMAN RICCARDELLA: So do I understand

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 - forgetting about the Japanese, from the dashed curve
2 versus the solid curves that we're now distinguishing
3 between dissolved oxygen while the old - while the Rev.
4 1 only had one curve for all the oxygen levels.

5 MR. STEVENS: Correct.

6 CHAIRMAN RICCARDELLA: Okay. And that
7 difference is - that difference is huge.

8 MR. STEVENS: Right.

9 CHAIRMAN RICCARDELLA: And is the - is the
10 load dissolved oxygen typical of, I assume, PWRs and
11 the new BWR water chemistry?

12 MR. STEVENS: Mm-hmm.

13 CHAIRMAN RICCARDELLA: Oh, okay. Good.

14 MR. STEVENS: Yeah, in fact that's - for
15 that lower range on that is 40 PPB and that's - you know,
16 what I'm used to seeing is more like 10 PPB and below.

17 So it's close but it's - yeah, definitely
18 covers their normal dissolved oxygen levels at the
19 lower end and you see it's - you know, in terms of that
20 variable it's about a factor of three from the bottom
21 end to the top, almost.

22 CHAIRMAN RICCARDELLA: Yeah.

23 MR. STEVENS: Okay. So nickel chrome
24 iron alloys, we have an expression which is, as you see,
25 the same as - well, it has the same equation as

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 austenitic material.

2 I'll flash back to that real quick. But
3 the definitions below for the transformed parameters
4 are a little bit different. So even though it has the
5 same equation you get a different value.

6 Fen was not specified in Rev. 0. It was
7 noted in there that alloy 600 and 690, you know, in their
8 welds that the updated model at the time for austenitic
9 was either consistent or conservative for use with
10 those alloys.

11 Now, some licensees we noted used an Fen
12 of 1.49, a constant Fen of 1.49 for nickel chrome iron
13 alloys and this was based on an FRE report where they
14 recommended a nonmandatory appendix for inclusion into
15 Section - I don't remember if it was Section 3 or 11
16 of the code, and in there they came up with 1.49 and
17 they got that by ratioing a couple of curve fits that
18 Argonne had published for air and water.

19 And anyway, we don't subscribe to that
20 value and anybody that's used it we would expect them
21 to correct that.

22 CHAIRMAN RICCARDELLA: Significant
23 differences though if you look at the curves. You
24 know, for carbon steel you were seeing factors as high
25 as in the twenties - twenty to, you know, between twenty

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 and twenty-five. In stainless steel you see factors
2 on the order of ten.

3 MR. STEVENS: Right.

4 CHAIRMAN RICCARDELLA: And for the
5 inconel stuff you get, like, three. Huge difference.

6 MR. STEVENS: And that was consistent with
7 the old - I mean, if you were - so even with Rev. 0 if
8 you had ferritic material and you were BWR under normal
9 water chemistry for a slow transient you would be
10 calculating very high Fens. Whereas the old
11 expressions for austenitics have been peaked at about
12 eight.

13 CONSULTANT SHACK: But, yeah. Someplace
14 where fatigue is demanding that alloy 600 and crew were
15 pretty good.

16 CHAIRMAN RICCARDELLA: Which is
17 interesting contrast to stress curves and cracking.
18 Can a metallurgist give us some insights into that?

19 MEMBER POWERS: Into what now?

20 CHAIRMAN RICCARDELLA: It seems like the
21 -

22 MEMBER POWERS: Presume that they
23 understand source corrosion cracking that's a big
24 mistake.

25 CHAIRMAN RICCARDELLA: The alloy 600,

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 which has been very sensitive to stress corrosion
2 cracking in these environments shows a much less effect
3 of environment on fatigue. I would think the two would
4 somehow be related. But that's my mechanical
5 engineering mind.

6 CONSULTANT SHACK: Well, look at the
7 austenitics thing with steels where the PWR is worse
8 than the BWR.

9 MR. STEVENS: But yet it's just the
10 opposite on Ferritic.

11 CONSULTANT SHACK: The first time Omesh
12 and I said that out loud -

13 CHAIRMAN RICCARDELLA: But that's - but
14 you got sensitization, you know.

15 CONSULTANT SHACK: No, no. There's no
16 sensitization here. This is for unsensitized things.

17 CHAIRMAN RICCARDELLA: I understand. So
18 in the BWR environment unsensitized stainless steel
19 doesn't crack. It's the sensitized stuff that cracks,
20 right?

21 CONSULTANT SHACK: Still, anything in the
22 PWR - the PWR people didn't believe it at first.

23 MR. STEVENS: It'd be interesting to hear
24 -

25 MEMBER POWERS: Why don't you just say

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 that gee, Westinghouse is crappier than GE? Then we'd
2 get a controversy going.

3 MEMBER BALLINGER: See, I'm more used to
4 seeing cracked growth data plotted as opposed to SN data
5 because we're - what we're seeing here is a combination
6 of things that you have very high stresses and strains
7 that were - that are focusing on - they're focusing the
8 initiation. It's what's happening when the cracks are
9 actually growing where you see a big difference.

10 CHAIRMAN RICCARDELLA: That was going to
11 be one of my questions at the end is how does this stuff
12 all correlate with what we see in fatigue crack growth
13 behavior in the environments. Has anybody taken a look
14 at that?

15 MEMBER BALLINGER: Because what I was - we
16 were talking earlier we're doing some test right now
17 for the Navy people and at high sulfur - that is sulfur
18 at the high end of the band in the spec for stainless
19 steel -

20 CHAIRMAN RICCARDELLA: Are you sure you
21 can say this on the record?

22 MEMBER BALLINGER: Yeah. You shut down
23 cracked growth rate. Goes right down to the air line.
24 For large - for - a trapezoidal loading pattern for long
25 hold - long rise times, 500 seconds and higher, in

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 fatigue crack growth with sulfur at the high end at the
2 band the crack growth rate is down - right down on the
3 air line. If you drop the sulfur down to the low levels
4 which normally you would buy you get an acceleration
5 factor.

6 MEMBER POWERS: Your precipitating on the
7 crack there.

8 MEMBER BALLINGER: Yeah. What you're
9 doing is you're cropping up the crack dip and what
10 you're doing is you're lowering the decay at the crack
11 and so it's basically shutting it down. So you see big
12 effects and it's opposite on low alloy steel.

13 MR. STEVENS: Mm-hmm. Yeah, I think - you
14 can correct me, Bill, if I characterize this wrong -
15 you know, Omesh would say that the observations of
16 environmental effects are consistent between
17 initiation and growth.

18 But I don't know that the magnitude of the
19 effect from, like, these Fens versus growth rates is
20 entirely consistent.

21 CHAIRMAN RICCARDELLA: Like, what about
22 the trends like the carbon steel versus stainless steel
23 versus inconel? You would think that if one is
24 significantly worse than the other for crack growth you
25 would think it would be something --

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER BALLINGER: Well, but crack growth
2 rate in nickel-based alloy, especially 625 or 690
3 they're extremely slow - extremely slow, much slower
4 than 600 even and 600 is pretty slow.

5 CHAIRMAN RICCARDELLA: Yeah. Okay.
6 Environmental.

7 MEMBER BALLINGER: Yeah, we're right -
8 also right now we're setting up to do a test at pure
9 D2O. So we're going to do a crack growth test in
10 stainless steels and pure D2O and then go find the
11 hydrogen - deuterium. It's all over the place.

12 CHAIRMAN RICCARDELLA: Is an acceptable
13 alternative for all this to do some sort of a flaw
14 tolerance analysis for you to say I'll give up the
15 initiation and I'll just look at how the cracks grow,
16 assume I have a small crack. I mean, this is - this
17 is initiation of what, I think I saw three millimeter
18 cracks as the assumption?

19 MEMBER BALLINGER: Yeah. This is an
20 assumption that you have - that you can get initiation.

21 MR. STEVENS: Our definition of CUF 1 is
22 that it equates to a 3 millimeter crack in the
23 component.

24 CHAIRMAN RICCARDELLA: And in evaluating
25 the fatigue lives, right? The 25 percent load drop or

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 whatever it was?

2 MR. STEVENS: Right.

3 CHAIRMAN RICCARDELLA: Evaluating the
4 data. So, I mean, isn't it an acceptable alternative
5 to say well, I've got a 3 millimeter crack at day one
6 and I'll grow that - and I'll grow that crack.

7 Is that counted - is 3 millimeters
8 mechanically large enough to apply fracture mechanics?
9 I think it is.

10 MEMBER BALLINGER: Oh, yeah.

11 CHAIRMAN RICCARDELLA: Yeah. So -

12 MR. STEVENS: So my only comment on that
13 would be I think your starting crack is going to be
14 consistent with what you can detect by NDE, which is
15 probably quite a bit bigger.

16 But flaw tolerances we've approved at
17 least one instance of that in license renewal space as
18 an alternative to doing these calcs.

19 CHAIRMAN RICCARDELLA: Why does it have to
20 be bigger than what you assume for the initiating crack
21 in your - in these studies?

22 MR. STEVENS: Well, most folks are
23 applying Section 11 to Appendix L which requires as an
24 initial flaw size it be compatible with what you can
25 detect by NDE and so we - but to your point, there's

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 some work going on in the code and Steve Goslin is doing
2 it where he's - the other conservatism here is, you
3 know, we have small specimens and they're tested
4 basically under membrane loading and most of our - most
5 of the components in the real world aren't under
6 membrane loading.

7 We have a gradient loading and there's an
8 effect of that as well, and he's doing some work to
9 address that difference and he's starting with 3
10 millimeter cracks trying to equate CUF equal one values
11 and then into growth and all that.

12 I think it's a promising approach. He's
13 got a ways to go. So this is what he Fens look like
14 for nickel chrome iron alloys.

15 CHAIRMAN RICCARDELLA: Somebody's
16 running a fatigue test upstairs.

17 MR. STEVENS: Sounds like it.

18 MEMBER POWERS: But they're hoping it
19 fails up there.

20 MR. STEVENS: I didn't have the same plots
21 for the nickel chrome iron alloys where I predicted,
22 you know, I could show our prediction versus the
23 Japanese predictions.

24 Here what you see is the prediction versus
25 the experimentally observed values and basically what

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 you get here is you reproduce within the scatter of the
2 data which is what you'd expect if you did the curve
3 fitting right.

4 So these - you know, basically within about
5 a factor of two is the scatter on the data.

6 MEMBER POWERS: You know, if you had a real
7 problem on high cycle you're way conservative.

8 MR. STEVENS: Yeah. Some of that here may
9 be - well, no, I won't say that. Some of that may be
10 the fact that we're using the austenitic curve still
11 for the nickel alloys.

12 MEMBER POWERS: But where are the tests
13 that the experimental life tests that you're applying
14 this to?

15 MR. STEVENS: It's the laboratory tests.

16 MEMBER POWERS: But I read in the NUREG
17 something about laboratory tests on big pipe samples
18 and things like that. Is that what this is or is this
19 the actual small samples?

20 MR. STEVENS: No. This would be the test
21 specimen. It is basically -

22 MEMBER POWERS: Okay.

23 MR. STEVENS: - predicting the test you
24 use to come up with the predictions which, by some
25 standard, wouldn't be a, you know, an independent

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 assessment.

2 MEMBER POWERS: Yeah. So it's just - the
3 scatter you see is the scatter in the data.

4 MR. STEVENS: And I have a slide. I'll
5 talk a little bit. We tried to do some of the things
6 you're talking about in NUREG on big pipes and all that
7 and, you know, there were some - there were some good
8 parts of that and some more not so good parts -

9 MEMBER POWERS: Okay.

10 MR. STEVENS: - where we get into and know
11 where what we start getting into is the difference
12 between these small specimens and real components.
13 So here we are, a good lead-in - validation calculation.

14 MEMBER POWERS: Okay.

15 MR. STEVENS: So I had this idea in this
16 NUREG of, you know, so we got all this. We ought to
17 be able to - so if we have tests where we essentially
18 got failure in a specimen we could calculate CUF for
19 the specimens and then test how well this methodology
20 works on those.

21 So if we got failure then theoretically if
22 they're in an environment the CUFen should have been
23 1.0 for those tests. So we came up with a series of
24 six tests and what we wanted to do, and I highlighted
25 these in the blue font, we wanted to come up with

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 different types of testing to test the - or try to
2 validate the Fen and what you see is the last two are
3 more like real components.

4 We had the U-bend test that EPRI did over
5 in Germany and we also did the step pipe test that Bettis
6 did, which was these are both starting to get into where
7 they are real components whereas the first four tests
8 were just testing of specimens but under different
9 types of conditions.

10 The first one is changing the strain rate
11 and the second one was changing strain rate and
12 temperature and spectrum loading and complex loading.
13 So whereas, you know, these - so these tests start to
14 exercise, you know, the methodology - predictive
15 methodology kind of off from just doing straight fully
16 reversed uniform loading.

17 And so what we did in these is we took the
18 tests. We got the load. We calculated the stress in
19 the specimen. We calculated CUF. We calculated a Fen
20 with a predictive methodology for those test conditions
21 and we then calculated a CUFen and basically said did
22 we get 1.0 because the specimen failed.

23 And, you know, in theory we should get 1.0
24 plus or minus a factor of two, which is a scatter of
25 the data, and the short of it is we did through at least

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the first five.

2 We did not do so well on number six, and
3 I'll go into that a little bit more. But the idea here
4 was trying to get some kind of a validation of real
5 world type of calcs against this methodology and we were
6 very limited, especially with real component tests
7 because there's not many of those out there.

8 We looked at - and another place where you
9 get into is how you calculate Fen and primarily how you
10 calculate the strain rate in these expressions can be
11 different and so we looked at three different - we
12 assessed three different ways of calculating the strain
13 rate where, you know, in one case we had the peak and
14 the valley and we just drew a straight line and
15 calculated the average strain rate, which is item two
16 here.

17 In another case, we broke it up into -
18 instead of one ramp into as many as four ramps and that
19 would be the multi linear strain-based approach three.
20 And the other one is we did a very detailed integration
21 which the NUREG calls the modified rate approach as the
22 first one.

23 And we calculated Fen using all three
24 methods and we calculated CUFen and basically all our
25 validation calculations, certainly for the small-scale

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 specimens, agreed within a factor of about two. So I
2 guess, you know, we - again, we kind of - we reproduced
3 the data we used to create the expressions. You would
4 kind of expect that.

5 Now, in - when we got to the component test
6 -

7 CHAIRMAN RICCARDELLA: But wait, wait,
8 wait. The data you used to create the expressions
9 didn't have all these changing strain rates, changing
10 strain rate and temperatures -

11 MR. STEVENS: That's right.

12 CHAIRMAN RICCARDELLA: - spectrum
13 loading, things like that. So you did more than - you
14 did more than just analyze the data you used to create
15 - you analyzed data that was tested under different
16 loading conditions.

17 MR. STEVENS: That's right.

18 CONSULTANT SHACK: You didn't go from
19 small specimen to component, though.

20 CHAIRMAN RICCARDELLA: Not in the first
21 pool. In the last two you did.

22 MR. STEVENS: Well, in the last two.

23 CHAIRMAN RICCARDELLA: Yeah.

24 MR. STEVENS: In the last two. So and
25 that's where then we got mixed results. Basically, on

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the U-bend tests out of the seven tests they ran we got
2 five of them within the factor of two and the other were
3 not.

4 We conservatively predicted life, meaning
5 that we predicted failure prior to when the actual
6 component failed. And then for the step pipe test
7 results, the results were even more mixed and I say that
8 because, you know, we tried to get details behind that
9 test and there were some other papers written to
10 document analysis that was done on that step pipe, and
11 we made use of those and in going through the fine
12 element analyses associated with those, you know, I
13 found problems with that and we tried to sort that out
14 with the authors and just couldn't get there.

15 We tried to do our own independent analysis
16 and we couldn't get agreement with what they had. So
17 it became difficult because these - some of the results
18 they had we just didn't think the analysis supporting
19 them was consistent.

20 Bottom line is that we weren't very good
21 at - we were way overly conservative in those - most
22 of those tests at predicting.

23 CHAIRMAN RICCARDELLA: That's okay.
24 That's -

25 MR. STEVENS: And this leads to the last

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 one.

2 CHAIRMAN RICCARDELLA: Well, at least we
3 were on the - way overly conservative and not on the
4 opposite - not on the other side.

5 MR. STEVENS: We recognize that the use of
6 small-scale polished specimens fatigue test data for
7 real components may be conservative and in some cases
8 overly conservative, and I'll just - I'll just say that,
9 you know, all of our work was done on specimens to align
10 with the code curves and come up with this environmental
11 factor.

12 We think there's been enough testing and
13 data available for those specimens. Our input to the
14 industry is you're right - you should go pursue
15 component testing, and we're fully amenable to review
16 of that data and open to adjustments for accommodating
17 the real components.

18 CHAIRMAN RICCARDELLA: But this sounds
19 like this is just the opposite of that size correction
20 factor, if you go back to the very beginning.

21 CONSULTANT SHACK: Well, no -

22 CHAIRMAN RICCARDELLA: This says that -

23 CONSULTANT SHACK: Yeah, but the one thing
24 that we didn't correct in all those design factors is
25 this nonmembrane loading, which I think is a large part

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

-

MR. STEVENS: That's right.

CONSULTANT SHACK: - of the - of the -

MR. STEVENS: You're right. We got into sequence but the gradient, and we're getting - we're getting some work now - the gradient load or, you know, a three-wall variation in stress versus a membrane stress I think -

CHAIRMAN RICCARDELLA: Even on the initiation of a three millimeter crack? I mean, that - I'm surprised it's that important up to three millimeters. I could see on the cracked growth beyond that certainly it is but up -

MR. STEVENS: Not so much there but, you know, I think this - the crack growth beyond there, yeah, it is significant.

CHAIRMAN RICCARDELLA: Oh, for sure. But when you - when you evaluated these real components I'm assuming the tests were - failure was based on crack initiation, not on actual failure of the component.

MR. STEVENS: That's right. That's right.

CHAIRMAN RICCARDELLA: So -

MR. STEVENS: Step pipe it was, you know, cracks and, you know, the problem is is they didn't

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 always measure, you know, the number of cycles at a
2 three millimeter crack depth.

3 They might have stopped the test and looked
4 and it was a tenth of an inch deep or two-tenths or
5 whatever it might have been.

6 CHAIRMAN RICCARDELLA: Yeah. And then
7 they -

8 MR. STEVENS: And there was no, you know
9 -

10 CHAIRMAN RICCARDELLA: - and then they did
11 test them all the way to failure or -

12 MR. STEVENS: No.

13 CHAIRMAN RICCARDELLA: No?

14 MR. STEVENS: Not in that case.

15 CHAIRMAN RICCARDELLA: Okay.

16 MR. STEVENS: And in some of the component
17 tests the majority of them, you know, it's a 25 percent
18 load drop. They weren't tested to failure either.
19 Some of them were, other ones weren't.

20 CHAIRMAN RICCARDELLA: Was that - was that
21 Bettis work that -

22 MR. STEVENS: Yes.

23 CHAIRMAN RICCARDELLA: Dave Jones?

24 MR. STEVENS: Yes. I think here -

25 CHAIRMAN RICCARDELLA: The last one, item

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 six.

2 MR. STEVENS: Yeah.

3 CONSULTANT SHACK: So this is thermal
4 fatigue, though, I mean, so you could have a nongrade
5 - I mean, a gradient term is going to be important here.

6 MR. STEVENS: Right. That's the thing
7 about the Bettis test is there you do have the gradient.
8 That test has the gradient effect in it.

9 CONSULTANT SHACK: I mean, you may have a
10 gradient in the U-bend test but it's a gradient that's
11 a whole lot gentler -

12 MR. STEVENS: Plus, it's a real thin wall,
13 too. The Bettis test was the thick-walled pipe of
14 varying thicknesses and it does - and you may have
15 thermal shocks in it representing safety injection
16 transients.

17 So you definitely got gradient loading
18 there and, you know, none of our work - none of the
19 fatigue curve work is based on gradient loading. The
20 work that Steve Goslin has done to date, you know, with
21 his kind of calculation shows that if you take account
22 for gradient loading you get another factor of two or
23 three on CUF, and some of our results differed, you
24 know, when we were conservative by a factor of three.

25 CHAIRMAN RICCARDELLA: Even to crack

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 initiation?

2 MEMBER BALLINGER: Well, I mean, the
3 kicker - the killer on this is the Japanese have been
4 doing some - looking at pipes and residual stresses near
5 welds just eat the prediction alive because the
6 residual stress pattern in the heat affected zone in
7 the weld is so different than what they're doing in
8 these tests.

9 CHAIRMAN RICCARDELLA: But that's our
10 ratios.

11 MEMBER BALLINGER: Huh?

12 CHAIRMAN RICCARDELLA: But that's our
13 ratio. I mean, it's not cyclic. It's - I mean, the
14 stress -

15 MR. STEVENS: I guess - yeah, the mean
16 stress adjustment at the upper end depending on how many
17 - how much load you're applying.

18 CHAIRMAN RICCARDELLA: Yeah. But, you
19 know, the mean stress effect is important at real high
20 cycle fatigue but when you get down to low cycle fatigue
21 you wash that out for a few cycles. That's -

22 MR. STEVENS: So if I were to - if I were
23 to summarize, you know, where the action could be at
24 in the fatigue weld is, you know, okay, in some cases
25 we doubled our data - specimen data and it didn't change

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 anything.

2 Okay. So if I were doing testing I
3 wouldn't waste a whole lot of more money testing
4 specimens other than to maybe pursue some of the
5 adjustment factors like surface finish and Omesh and
6 I think hold time appropriately applied makes a big
7 difference.

8 A lot of the hold time calculations were
9 done at the highest strain level and we're thinking a
10 more - a better one would be to put a hold time in at
11 zero strain level in the middle of the cycle.

12 And so - and that could be - those kind of
13 effects could be measured through specimens. But
14 generally speaking, in terms of the strain
15 environmental effect, enough's enough - test
16 components. And then separation of the materials
17 we're getting enough data now.

18 For example, you could dissect the
19 austenitic curve into the various types of materials.
20 That would be a benefit. On the ferritic side of
21 things, doing the same thing in terms of ultimate
22 strength we see an effect of that.

23 That would be worthwhile to pursue. Those
24 are the areas we see as the recommendations for moving
25 forward here.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 And then the last one would be - at least,
2 I believe that Section 3 after 40 years could look at
3 the way they calculate CUF and maybe consider updating
4 that because we also have - you know, another thing we
5 haven't talked about - we talked about the gradient
6 loading versus the membrane but another thing here is
7 the specimens are basically uniaxial and our components
8 have triaxial stress dates. Somebody could look at
9 that and how CUF is calculated. There could be
10 something there.

11 So between the curves and that methodology
12 that's not our jurisdiction. That's for the code to
13 take on. We've encouraged them for four years now to
14 look at that.

15 The last thing I did to the appendix and
16 this probably added the most number of pages, I added
17 Appendix C sample problem. This was not meant to be
18 exhaustive or anything.

19 It was meant to give out an example to the
20 industry, a typical one based on finding element
21 analysis of how this approach would be applied. Meant
22 to give - just kind of give general direction and on
23 how these things were to be applied and eliminate the
24 low-hanging fruit in terms of questions and all that
25 and to provide enough detail in there that any of the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 users could reproduce the calculation on their own.

2 So all of the gory detailed stresses and
3 everything are provided in that appendix so that
4 someone could reproduce that calculation on their own
5 from scratch and dissect it any which way they want.

6 The sample problem actually came from the
7 industry. EPRI had a couple of round robin sample
8 problem solutions they funded and we took one of those
9 problems and basically solved it ourselves and put it
10 in Appendix C. So that's one example application of
11 the Fen but not meant to be exhaustive.

12 It's common but it still is relative -

13 CHAIRMAN RICCARDELLA: What type of a
14 component was it?

15 MR. STEVENS: It's basically a stepped
16 pipe -a very simple stepped pipe -bimetallic pipe with
17 transients and thermal fatigue, yeah.

18 So it was relatively simple. It wasn't a
19 surge line.

20 CHAIRMAN RICCARDELLA: Did the Fen have a
21 huge effect in this?

22 MR. STEVENS: It had about a factor of -
23 I can't remember what the final factor was. I don't
24 have it here with me. Yes, it was on - it was well above
25 1.0. It was designed to be that way.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: Okay.

2 MR. STEVENS: I think the usage without
3 Fen was up around .75. It was designed that with Fen
4 it would go over 1.0. So we took their problem that
5 they designed and we basically solved it.

6 We're trying to promote consistency and
7 all that so when applicants use it they kind of get the
8 idea of how to do it.

9 Feedback that I've received from a lot of
10 the stakeholders on that sample problem through code
11 meetings and whatever has been very positive.

12 They said that was a great aid to them, and
13 I even got - I got one set of comments that came in one
14 month after the close of comments on the NUREG where
15 a guy solved it and said, I basically got your same
16 answer - you know, I took the problem, I solved it
17 without looking and I got the same answer - this is
18 great. So I think it was a very useful thing for us
19 to do.

20 So what's our schedule? As I mentioned,
21 the Reg. Guide went out for public comment last Monday,
22 a 60-day review. The public comment period closes on
23 January 23rd. The NUREG - the NUREG went out for public
24 comment 45 days last spring. I had more than 200
25 individual public comments received on that which was

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 a surprise.

2 The reason it was a surprise is because two
3 years prior to that Dr. Chropra and I did a very detailed
4 presentation at code on here's everything that's going
5 to be in this NUREG when it comes out, and we received
6 over a hundred comments on and we treated that as a
7 public meeting and put it on the docket and said you
8 have 90 days to comment and encouraged everybody around
9 the world to comment.

10 We received over a hundred comments on that
11 presentation, which we responded to, and addressed in
12 the NUREG before we released it for public comment. So
13 we thought we had vetted the comments and we got 200
14 more so you never know.

15 The comments that are on this slide and,
16 you know, these - we got ten sets of comments from,
17 basically, the worldwide leaders that are invested in
18 this research so they're very good comments.

19 Still working through that. I really -
20 you know, once those comments are documented and
21 addressed the size of that document is probably going
22 to rival the size of the NUREG itself.

23 It's going to take me a while to get those.
24 Right now, I'm hoping to have those addressed by the
25 end of next summer.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: The 200 comments
2 came from these ten - MR. STEVENS: Right.
3 There's one set of public comments I didn't include on
4 here that came in about a month and a half after the
5 public comment period closed and that was mainly, like
6 I said, the guy solved the sample problem.

7 I didn't include those here. I don't
8 think there's anything in there that would lead to any
9 changes in the NUREGs so I didn't list them here.

10 CHAIRMAN RICCARDELLA: In any of these?
11 I mean -

12 MR. STEVENS: No, no. Just in that one.

13 CHAIRMAN RICCARDELLA: So you think there
14 are things in these that would lead to changes in the
15 methodology or -

16 MR. STEVENS: Not the methodology. You
17 know, there will be changes - there were some typos
18 identified in all that and that's one of the things we
19 looked at. I think there's probably going to be some
20 change in some of the discussion of the document.

21 I don't see any changes in methodology. A
22 lot of the comments that I saw were looking at well,
23 you guys didn't do this or, you know, you didn't
24 separate, like, for example - an example that would be
25 on the ferritic curve you didn't separate out by

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 ultimate strength.

2 That has an effect. And my response is
3 going to be you're right but we chose not to and we're
4 not going to and if you wanted to do that feel free.
5 You know, that kind of response.

6 MEMBER POWERS: That's the screw you,
7 strong letter to follow up.

8 MR. STEVENS: We got comments on you know
9 what you didn't do. We know there's a lot we didn't
10 do. We got to say when at some point and if we were
11 invested in this topic as a high priority moving forward
12 and funding more research for sure we'd pursue those.

13 But what I have found in worldwide
14 application of this, everybody in the world is using
15 it and can successfully - can show successful results
16 for 60 years.

17 Nobody has ever yet given me an example of
18 a case where they couldn't pencil whip it if they chose
19 to. In the case - in some cases what we've seen, like,
20 in one licensee they chose - rather than pencil whip
21 it they chose to do flaw tolerance and they did that.

22 CHAIRMAN RICCARDELLA: This argues for
23 why we didn't back fit it.

24 MR. STEVENS: And even two weeks ago at
25 code the Koreans came and said, we just did our AP 1400

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 or whatever reactor it was and they said and here's the
2 results we got for 60 years, and nobody could read the
3 chart.

4 So when he was finished I said, can you back
5 up to that slide and magnify it and all his usage factors
6 with environmental effects were less than one. The
7 Japanese, in all the discussions I've had with them,
8 apply this regularly for 60 years and in all cases they
9 are able to show acceptable results.

10 So for 60 years this methodology is
11 sufficient. Now, beyond that for 80 years I suspect
12 there will be challenges. But that's what we've seen.

13 I - you know, in the all the meetings I've
14 gone to in the code I've - for the vendors that have
15 complained about the methodology I said bring me an
16 example of where you're having hardship and no one's
17 ever been able to produce that.

18 CHAIRMAN RICCARDELLA: So they just have
19 to do more sophisticated analyses, I assume?

20 MR. STEVENS: That's what it comes down
21 to. They have to do more detailed analysis but in all
22 cases with - they're not doing anything different but
23 doing more refined calculations. They're not going to
24 plastic analysis or anything like that.

25 CHAIRMAN RICCARDELLA: I mean, we have had

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 a number of notable fatigue failures in plants and
2 they're summarized very nicely in the NUREG. But I
3 guess by and large those occurred because we didn't
4 define - not because of the - not because we didn't know
5 but we just - there were loads that we didn't know about
6 or we didn't find, right? Thermal stratification,
7 lightning, all those -

8 MR. STEVENS: I still don't know of any
9 failures caused by environmental effects as opposed to
10 - maybe a better way to say it is there could have been
11 environmental effects at work there but like what you
12 said the failures we've seen have been caused by loads
13 not considered by the design or vibration.

14 CHAIRMAN RICCARDELLA: Yeah.

15 MR. STEVENS: So we expect the comment
16 period to close in late January on the Reg. Guide
17 addressing comments into next summer.

18 I expect to probably come before you all
19 in the fall with the final drafts of the documents and
20 the public comments addressed and all that and I'm
21 hoping to issue both by the end of next year, and that
22 schedule supports the needs of subsequent license
23 renewal so they can reference the documents in their
24 new GALL report when it gets published.

25 That's all I have.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN RICCARDELLA: I've got a
2 question, Gary. Has anybody done a trial calc to push
3 beyond 60 to 80? Pick a couple of what you consider
4 to be the most sensitive components and just try it and
5 see what the CUF would look like?

6 MR. STEVENS: Actually, a couple. In my
7 prior life I actually did one because the licensee asked
8 for - happened to be one of the licensees who was sort
9 of thinking out like that and so they asked for
10 calculations to be done at 60 and 80 years. And they
11 didn't ask for the 80-year calculations to be shown to
12 be acceptable.

13 They just wanted to see what they were. So
14 I'm aware of a few calculations like that and, you know,
15 some of those - it's what you'd expect. If you take the
16 60 years numbers and scale them up some of them work
17 and others don't and so I've seen those types of
18 assessments.

19 I don't think the - to my knowledge I
20 haven't seen any here at the NRC that have been formally
21 submitted.

22 So I - you know, I expect that 25 percent
23 of the components are going to require further analysis
24 of some sort or to switch over to flaw tolerance.

25 I'll just note that the one application we

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 saw of flaw tolerance was applied to the surge line and
2 there the licensee elected not to pursue acceptable CUF
3 calculations and they went to flaw tolerance and that
4 analysis supported a ten-year inspection interval,
5 which is what Section 11 would require you to do.

6 MEMBER SKILLMAN: I would expect in a lot
7 of cases that there is a significant amount of margin
8 because the early functional specifications require
9 including in the CUF a large number of fatigue cycles
10 and plants are not operated that way.

11 They're basically not quite base loaded by
12 pretty close. So you've got a lot of margin in the -
13 in the cycles that are not used to allow those
14 components to stretch out quite a bit in the future.

15 MR. STEVENS: Right. So generally
16 speaking the PWRs have shown the number of cycles that
17 were postulated for 40 years remain valid for 60 years.
18 I imagine there will be some subset of those that might
19 be able to show the same for 80.

20 MEMBER BALLINGER: I mean, a lot of these
21 - a lot of these plants nowadays and new plants are doing
22 stress improvements on the build and so they're
23 compressive on the surface to start with from the stress
24 load cracking point of view. But it's got to help on
25 the fatigue side.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. STEVENS: Well, it's interesting - and
2 Section 3 is also pursuing a flaw tolerance approach
3 and basically what they're advocating is they really
4 want to depart from the CUF calculation and go straight
5 to an inspection-based method.

6 You know, where we - the devil's in the
7 details on that and we're not quite sure how that fits
8 within the structure of Section 3 and all that and
9 everything. But anyway, that is being pursued. They
10 got a code case. In fact, there's a conference call
11 tomorrow.

12 CHAIRMAN RICCARDELLA: That's a big
13 change.

14 MR. STEVENS: It is.

15 CHAIRMAN RICCARDELLA: When we put flaw
16 analysis into Section 11 only Section 3 has what cracks
17 - you can't analyze cracks - cracks are unacceptable.
18 Of course, the inspections they did - the inspections
19 they did didn't find the - didn't find cracks but they
20 were there. But if you find them they're unacceptable.

21 MR. STEVENS: And those - you know, those
22 approaches are based on the premise that you - that you
23 do an inspection and you don't find anything. I mean,
24 that -

25 CHAIRMAN RICCARDELLA: And the bottom

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 line is don't look for the cracks?

2 CONSULTANT SHACK: I mean, some - you
3 know, cask stainless is always going to be a problem
4 from that point of view.

5 CHAIRMAN RICCARDELLA: Yeah.

6 CONSULTANT SHACK: It's going to be very
7 difficult to convince anybody with the inspection.

8 MR. STEVENS: Dave and I are laughing
9 about cask because aside from fatigue there's a whole
10 another issue on that going on right now. And yes, at
11 the - at the heart of it is inspection.

12 CHAIRMAN RICCARDELLA: Okay. Well,
13 thank you again.

14 MR. GERBER: Oh, I'm going to - hi, I'm
15 Dave Gerber, Structural Integrity Associates. We did
16 - we've taken a quick look.

17 First - the first plant we've been taking
18 a look at for SLR and so PWR and we have been discovering
19 on a first cut basis that not only was 40 equal to 60
20 but 40 is equal to 80 also, as far as numbers of cycles
21 that they'd look at.

22 It's not all the cycles there are but it's
23 the ones in their FSARs. So that will be, I think, an
24 approach that will work for PWRs for most transients.

25 CHAIRMAN RICCARDELLA: Thank you. Okay.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 So let's first go around the table and start with Joy.
2 Is there any further comments?

3 CONSULTANT SHACK: Excellent
4 presentation, brilliant work.

5 MR. STEVENS: I figured if I - I figured
6 if I didn't show today you could have just done the
7 presentation.

8 CHAIRMAN RICCARDELLA: Ron?

9 MEMBER BALLINGER: Same thing.
10 Brilliant work.

11 CHAIRMAN RICCARDELLA: Good.

12 MEMBER SKILLMAN: Excellent
13 presentation. I apologize for my cold but I've been
14 completely tuned in. I'm fighting through it. But
15 excellent. Thank you.

16 MR. STEVENS: Thank you.

17 CHAIRMAN RICCARDELLA: Dana?

18 MEMBER POWERS: Well, I would say
19 excellent presentation and brilliant work but that
20 would be agreeing with Shack and I'm constitutionally
21 ill disposed to doing that.

22 But it really is quite good on your,
23 certainly, calculations but come away a little confused
24 about the ranges that you've used in your Monte Carlo
25 sampling.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Not too concerned about distribution but
2 the ranges are the ones that I - I did not come away
3 with a warm and fuzzy feeling for their - in the course
4 of making modifications to your documentation if you
5 can make that a little clearer that would have helped
6 me a lot on that.

7 MR. STEVENS: Okay.

8 MEMBER POWERS: I don=t have a problem with
9 your methodology, and like I say, your methods are
10 excellent. I really like what you've done there.

11 MR. STEVENS: Okay. Thank you.

12 CHAIRMAN RICCARDELLA: Dennis?

13 MEMBER BLEY: Nothing additional from me.

14 CHAIRMAN RICCARDELLA: Okay. I have a
15 few but I think most of them have been answered. Are
16 you going to seek a code case? Is it your desire to
17 get a code case on this?

18 MR. STEVENS: So - okay, regarding code
19 cases, as I mentioned on slide - I know that was pretty
20 early -there's two code cases -

21 CHAIRMAN RICCARDELLA: And there are some
22 code cases that -

23 MR. STEVENS: There's two code cases out
24 and a few more being developed, okay, and one of them
25 is a flaw tolerance code case for Section 3 and I'll

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 just not talk about that right now.

2 So the other three code cases there's seven
3 - N-761 which is environmental fatigue curves. I'm
4 going to point you to the right slide here. Right here
5 - slide number ten.

6 N-761 is environmental fatigue curves and,
7 you know, we didn't approve that because this was a
8 curve put together by the subgroup on the fatigue
9 strength for Section 3 where Bill O'Donnell was the
10 chair.

11 CHAIRMAN RICCARDELLA: Yeah.

12 MR. STEVENS: And, you know, we asked how
13 they developed the curves and, frankly, they haven't
14 provided a technical basis that allows us to understand
15 that, and I'm now under discussions with folks at Bettis
16 to try and get that.

17 Section 3 has been basically ordered to try
18 and get us to get a code case that's amenable to us
19 because they believe - Section 3 members believe the
20 Fen is too complicated.

21 They just want to use curves so far and the
22 curves as we see them are not consistent with our work
23 and we need to understand that and we're trying to work
24 through that process. So that code case is issued.

25 We have not endorsed it and we won't and

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 we're trying to work through with that committee now
2 to come up with something that's acceptable.

3 The other code case you see here is N-792.
4 N-792 is an Fen code case. Effectively, it adopts Rev.
5 0 of the NUREG with the exception of it does not have
6 a strain threshold below where the environmental
7 effects don't apply.

8 So as I've stated, the ASME, for the first
9 time in the history of the industry, the code is more
10 conservative than the regulator.

11 We didn't approve that code case because
12 at the time we had an agreement we had started on this
13 research and we said do you think it's better if you
14 hold off on the code case and then make it match our
15 work and then issue it.

16 CHAIRMAN RICCARDELLA: Make it match Rev.
17 1?

18 MR. STEVENS: Yeah. Fundamentally,
19 we're okay with that code case. The fact that it
20 doesn't have a strain amplitude threshold is
21 conservative. So we would vote for it. But what we're
22 going to say is they need to revise it now to match this
23 and they have plans to do that.

24 The third code case is a strain rate code
25 case that the Japanese are putting together and it has

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 intricate detail on how to calculate strain rate, and
2 I haven't really evaluated that but, frankly, it
3 carries the science way beyond anything that's - that
4 can be - I mean, that can be proven.

5 You know, they're getting into so much
6 detail and they have nothing to benchmark what is
7 recommended. So I don't necessarily have any
8 complaints with it and we haven't evaluated it in detail
9 but the issue I'll have is in the end, you know, they're
10 trying to evaluate triaxial stress dates and all these
11 other things and I don't have anything to benchmark
12 it up against.

13 So whether they're right or, you know, they
14 have ten guys on the committee and they've all
15 recommended a way, whose way is right and there's no
16 way to know.

17 So I recommended to them that they need to
18 tie in with EPRI's longer term efforts and come up with
19 a test where they can benchmark it. So we don't have,
20 and I don't remember the number on that code case
21 offhand - I know we don't have a problem with that
22 approach. It's just that it'll be difficult for them
23 to technically justify it.

24 And so those are the three things and my
25 understanding there's a working group now devoted to

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 environmental fatigue effects in the code, which I try
2 and attend quarterly.

3 What they want to do is get these three code
4 cases done and out and approved and then they want to
5 put them into a nonmandatory appendix in Section 3.

6 CHAIRMAN RICCARDELLA: 761 and 792,
7 they're not issued - they're just being worked on?

8 MR. STEVENS: They're both issued. It's
9 just that we haven't endorsed them in the Reg. Guide.

10 CHAIRMAN RICCARDELLA: But they're
11 working on a rev to 792? MR. STEVENS:

12 They're working on a rev to 792. Well, actually - I
13 believe right now 792-1 is issued. The next thing they
14 would do is issue a dash two that would incorporate Rev.
15 1 and they're waiting to do that until we issue Rev.
16 1.

17 CHAIRMAN RICCARDELLA: All right.

18 MR. STEVENS: The code case for flaw
19 tolerance I don't know if it's been assigned a number
20 yet. It's not been approved. That one's got a long
21 ways to go, in my opinion, because, you know,
22 fundamentally they made a match in Section 11 Appendix
23 L.

24 CHAIRMAN RICCARDELLA: Yeah.

25 MR. STEVENS: And they just said, you

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 know, go to the Section 11 and NDE qualification and
2 acceptance standards tied into all that. Section 3
3 hasn't figured out how to do that part of it yet. So
4 the flaw tolerance analysis part is okay.

5 But what they're postulating for initial
6 flaw size and where it comes from and how it ties into
7 the NDE world and all that, they haven't figured that
8 out yet.

9 So in my opinion, that's probably going to
10 be harder than the technical flaw tolerance part of the
11 code case and they just haven't done that. So it's
12 probably got a ways to go. The strain rate code case
13 I think I just saw a presentation two weeks ago that's
14 up to draft rev 18 or something ridiculous. It's still
15 going through the working group.

16 I expect it'll probably be issued in, like,
17 a year - something like that, and then I think their
18 fatigue action plan that they have for Section 3 says
19 once we get all these done we want to get the regulator
20 to endorse them.

21 Then we're going to put them in a
22 nonmandatory appendix in Section 3 in which case then
23 they're - the other issue with these code cases is
24 there's nothing that would point you to use them.
25 There would have to be - if they put it in a nonmandatory

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 appendix now they'd have to put some invoking words into
2 Section 3 as to what would ever get you that appendix,
3 and I think where it's NB-3121 or whatever the section
4 was I cited here you just add a sentence there and say
5 one way to address these effects is in the appendix and
6 then they have it covered. But that's quite a ways off.

7 CHAIRMAN RICCARDELLA: Okay. Thank you.
8 So do we have any comments from anybody else in the room?
9 Okay. Could we get the - it's open. Okay. So we do
10 have, I understand, some people on the bridge line.

11 I wonder if we have any comments from
12 people on the bridge line. Would somebody out there
13 just say hello so I can confirm that it's open?

14 PHONE PARTICIPANT: Hello. No comment.

15 CHAIRMAN RICCARDELLA: Thank you. Okay.
16 So I guess with that the topic is closed. I think we're
17 going to - this is kind of a preliminary review in
18 parallel with it going on for public comment.

19 I think we'll be addressing the issue when
20 we get any comments back and I don't know if we'll take
21 any full committee action on it.

22 But we will certainly hear from you again
23 once you have the comments back. Okay. Thank you.

24 MR. STEVENS: Thank you.

25 CHAIRMAN RICCARDELLA: Meeting is

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 adjourned.

2 (Whereupon, the above-entitled meeting
3 concluded at 3:13 p.m.)
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

**Advisory Committee on Reactor Safeguards
Metallurgy and Reactor Fuels
Subcommittee Meeting**

**Technical Brief on
Regulatory Guidance for Evaluating the Effects
of Light Water Reactor Coolant Environments
in Fatigue Analyses of Metal Components
(Proposed Revision 1 to Regulatory Guide 1.207)**

Gary L. Stevens, Sr. Materials Engineer

*Office of Nuclear Regulatory Research
Component Integrity Branch*

**Tuesday, December 2, 2014
NRC Headquarters
Rockville, MD**

Objective

- **At ACRS's request, the staff is providing this brief**
- **NRC is revising the guidance for environmentally assisted fatigue (EAF)**
 - **Regulatory Guide (RG)**
 - **Draft Regulatory Guide DG-1309, "Guidelines for Evaluating the Effects of Light Water Reactor Coolant Environments in Fatigue Analyses of Metal Components"**
 - **Supporting technical basis NUREG**
 - **Draft NUREG/CR-6909, Revision 1 (ANL-12/60), "Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials"**
- **Both draft documents were released for public comment**
 - **The draft RG was published for 60-day public comment on 11/24/2014**
 - **The draft NUREG was published for public comment during the time period of 4/17/2014 – 6/2/2014**

Outline

- **Background**
 - What is cumulative usage factor (CUF)?
 - What is EAF?
 - Why is there NRC guidance on EAF?
 - What is the NRC guidance on EAF?
 - What is Reg. Guide 1.207 and NUREG/CR-6909?
 - What is F_{en} ?
- **Reasons for Revising Reg. Guide 1.207**
- **Summary of Revisions to Reg. Guide 1.207**
- **Revisions to F_{en} Equations**
 - Review of updated fatigue data
 - Review of air fatigue curves
 - Review of changes to F_{en} expressions
- **Estimated Schedule for RG and NUREG Publication**

BACKGROUND

What is cumulative usage factor (CUF)?

What is EAF?

Why is there NRC guidance on EAF?

What is the NRC guidance on EAF?

What is Reg. Guide 1.207 and NUREG/CR-6909?

What is F_{en} ?

What is cumulative usage factor (CUF)?

- For nuclear plant design, cumulative fatigue damage due to applied cyclic loading is estimated using cumulative usage factor (CUF):

$$\text{CUF} = \sum_i^Z \frac{n}{N} = U_1 + U_2 + U_3 + \dots + U_Z < 1.0$$

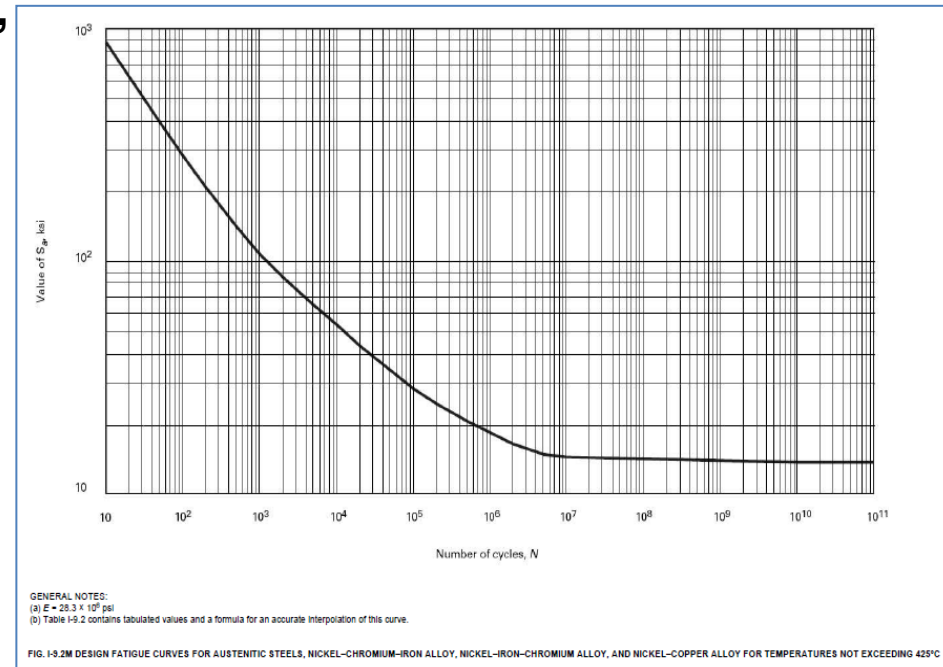
where: n is the applied number of cycles for load i

N is the allowable number of cycles for the stress associated with load i

Z is the number of applied loads

- N is a function of the alternating stress, S_a , applied to a component, and is material dependent (i.e., it is a material property)
- S-N curves (“fatigue curves”) are given in ASME Code, Section III, Mandatory Appendix I for different materials
- Design fatigue curves are based on best fits of air test data with design factors applied

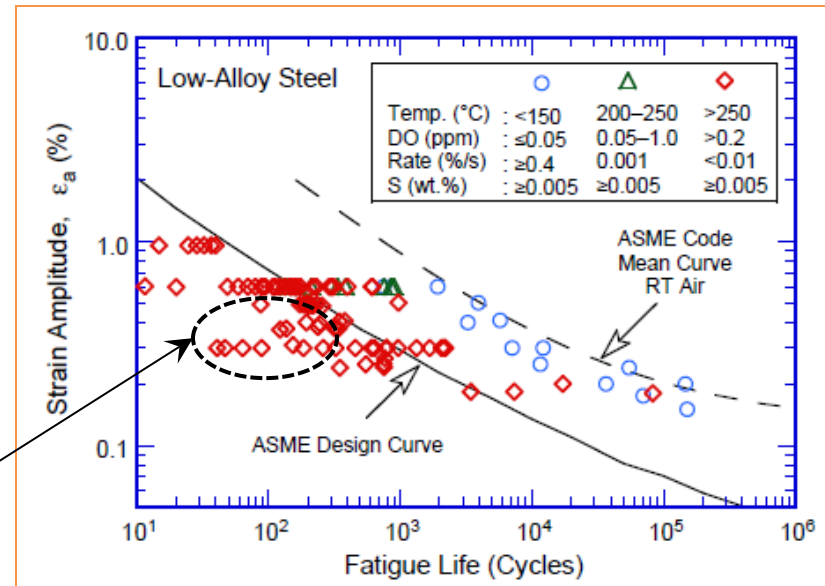
S-N curves are usually defined in log-log form



What is EAF?

- The fatigue curves in Section III of the ASME Code were developed from laboratory test data from small-scale, polished specimens tested in **AIR**
- The **AIR** test data were used to develop design fatigue curves suitable for design:
 - Develop best fit log-log curves for the **AIR** data for each material type
 - Adjust the best fit curves to account for worst-case mean stress effects using the Modified Goodman relationship
 - Apply factors* of 2 on strain amplitude (ϵ_a) or 20 on cycles (N), whichever is more conservative, to develop **AIR** design curves for each material
- More recent laboratory testing of specimens tested in **WATER** indicated that the **AIR** design curves may not adequately define fatigue life for materials exposed to **WATER** environments:

Note how some of the points for tests in **WATER** fall below the **AIR** design curve.



* Factors to account for data scatter, size effects (i.e., small laboratory specimens vs. large power plant components), surface finish, atmosphere, etc.

Why is there NRC guidance on EAF? (1/4)

Related Regulatory Requirements

- **Title 10 of the Code of Federal Regulations (10 CFR) Part 50, “Domestic Licensing of Production and Utilization Facilities, Appendix A, “General Design Criteria for Nuclear Power Plants”**
 - **General Design Criterion 1**
Safety related SSCs must be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety function performed
 - **General Design Criterion 30**
Components included in the reactor pressure boundary must be designed, fabricated, erected, and tested to the highest practical quality standards
 - **10 CFR 50.55a (c), endorses ASME Code for design of safety-related systems and components (Class 1)**
 - **ASME Code, Section III includes fatigue design curves**
 - **Fatigue design curves do not address the impact of the reactor coolant system environment**

Why is there NRC guidance on EAF? (2/4)

- **ASME Section III fatigue design curves developed in the late 1960s and early 1970s**
 - Air environments at ambient temperatures
 - Margin of 2 on strain and a margin of 20 on cyclic life
 - ASME Section III, NB-3121 identifies that the data used to develop the fatigue design curves did not include tests in environments that might accelerate fatigue failure
- **In the 1980s, the NRC initiated the Fatigue Action Plan (FAP) in response to findings primarily from early Plant Life Extension Studies**
- **Research in Japan (Higuchi and Iida, 1991) and those at ANL (NUREG/CR-4667, 1990) identified potentially significant effects of light water reactor (LWR) coolant environment on fatigue lives of steels**

Why is there NRC guidance on EAF? (3/4)

- **In 1995, closeout of the FAP* and resolution of Generic Safety Issue (GSI) 166, “Adequacy of Fatigue Life of Metal Components,” established that**:**
 - Risk to core damage from fatigue failure of RCS very small; no action required for current plant design life of 40 years
 - NRC staff concluded that fatigue issues should be evaluated for extended period of operation for license renewal (under GSI 190)
- **In 1999, resolution of GSI 190, “Fatigue Evaluation of Metal Components for 60-Year Plant Life” *****
 - 10 CFR 54.21, Aging Management Programs for license renewal should address component fatigue including addressing the effects of the LWR coolant environment

* SECY-95-245, “Completion of the Fatigue Action Plan,” September 25, 1995, ADAMS Accession No. ML031480210.

** NUREG/CR-6674 (PNNL-13227), “Fatigue Analysis of Components for 60-Year Plant Life,” June 2000.

*** Thadani, Ashok C., Director of the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, memorandum to William D. Travers, Executive Director for Operations, U.S. Nuclear Regulatory Commission, “Closeout of Generic Safety Issue 190, ‘Fatigue Evaluation of Metal Components for 60 Year Plant Life,’” August 26, 1999, ADAMS Accession No. ML003673136

Why is there NRC guidance on EAF? (4/4)

- **On December 1, 1999, by letter to the Chairman of the ASME Board on Nuclear Codes and Standards (BNCS), the NRC requested that ASME revise the Code to include environmental effects in the fatigue design of components**
- **ASME initiated the Pressure Vessel Research Council (PVRC) Steering Committee on Cyclic Life and Environmental Effects**
- **PVRC recommended revising the Code design fatigue curves (Welding Research Council (WRC) Bulletin 487)**
- **ASME Code has struggled with this issue for more than 20 years; still no acceptable rules to address EAF in Section III**
 - **Two Section III Code Cases have been published (N-761 and N-792), but these have not been endorsed by NRC**
- **Based on NRC's FAP efforts, guidance was developed for operating plants* to address EAF (1999) and new reactors to address EAF (2007)**

* License renewal applicants only (i.e., only applicable for operation beyond the 40-year design life of operating plants).

What is the NRC guidance on EAF? (1/3)

- **In the late 1990s, NRC published the results of their research efforts related to the impact of LWR coolant environments on the fatigue lives of steels:**
 - **Chopra, O. K., and W. J. Shack, “Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels,” NUREG/CR-6583, ANL-97/18, 1998.**
 - **Chopra, O. K., “Effects of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steels,” NUREG/CR-5704, ANL-98/31, 1999.**
- **Based on the direction of the FAP closeout, these NUREGs were adopted for use in guidance for license renewal applicants in the initial release of NUREG-1801, “Generic Aging Lessons Learned (GALL) Report” (2001)**
 - **Chapter X.M1, “Metal Fatigue of Reactor Coolant Pressure Boundary”**
- **These NUREGs remain in the current license renewal guidance documented in NUREG-1801, Rev. 2 (2010)**

What is the NRC guidance on EAF? (2/3)

GUIDANCE FOR NEW REACTORS

- **EAF guidance for new reactor design was issued in 2007:**
 - **RG 1.207, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light Water Reactor Environment for New Reactors” March 2007.**
- **The technical basis document for RG 1.207 is NUREG/CR-6909:**
 - **NUREG/CR–6909, ANL–06/08, Chopra, O. K., and W. J. Shack, “Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials – Final Report,” February 2007.**

What is the NRC guidance on EAF? (3/3)

GUIDANCE FOR OPERATING REACTORS

- Currently, operating reactors that are not in the license renewal period have no guidance or requirements for considering EAF
- Recent license renewal applicants follow the guidance of NUREG-1801, Rev. 2:
 - For carbon steel: May use either NUREG/CR-6583 OR NUREG/CR-6909 OR an NRC-approved alternative
 - For stainless steel: May use either NUREG/CR-5704 OR NUREG/CR-6909 OR an NRC-approved alternative
 - For Ni-Cr-Fe alloys: May use NUREG/CR-6909 OR an NRC-approved alternative.

What is Reg. Guide 1.207 and NUREG/CR-6909?

- **Defines fatigue multiplier, F_{en} , methodology**
- **EAF guidance for new reactors**
- **May also be used by license renewal applicants**
- **These documents provide the best vehicle for the NRC to consolidate and update EAF guidance**

What is F_{en} ? (1/2)

- Initially, the NRC reviewed two methods for incorporating EAF effects; the **second method** was adopted:
 - 1. Develop new environmental fatigue curves
 - 2. Use of an environmental correction factor, F_{en}
- F_{en} is defined as the ratio of fatigue life in air at room temperature to the fatigue life in water **at the service temperature**:

$$F_{en} = N_{air} / N_{water}$$

- F_{en} is multiplicative to the calculated CUF in air:

$$CUF_{en} = U_1 F_{en,1} + U_2 F_{en,2} \dots U_Z F_{en,Z}$$

What is F_{en} ? (2/2)

- How is F_{en} computed?
- For example, from Revision 0 of NUREG/CR-6909 for **stainless steel materials**:

$$F_{en} = \exp [0.734 - T' O' R']$$

where:

T' = transformed temperature:

T' = 0 for temperature, $T \leq 150^\circ\text{C}$

T' = (T - 150)/175 for $150 < T < 325^\circ\text{C}$

T' = 1 for $T \geq 325^\circ\text{C}$

O' = transformed oxygen:

O' = 0.281 for all fluid dissolved oxygen levels

R' = transformed strain rate:

R' = 0 for strain rate, $R \geq 0.4\%/s$

R' = $\ln(R/0.4)$ for $0.001 \leq R < 0.4\%/s$

R' = $\ln(0.001)$ for $R < 0.001\%/s$

REASONS FOR REVISING REG. GUIDE 1.207

Reasons for Revising Reg. Guide 1.207

- **There are three reasons the NRC is revising the EAF guidance in RG 1.207:**
 1. **To consolidate all EAF guidance**
 2. **To update the guidance based on stakeholder feedback**
 3. **To update the guidance based on all available research data**
- **In 2010, the Office of New Reactors (NRO) and the Office of Nuclear Reactor Regulation (NRR) prepared a joint User Need Request (UNR)**
 - **Requested the Office of Nuclear Regulatory Research (RES) to perform research activities to update EAF guidance and revise RG 1.207 and NUREG/CR-6909**
 - **NRC also implemented an addendum to the NRC/EPRI Memorandum of Understanding (MOU) that authorized EPRI participation and co-funding of the NRC's EAF research activities**

SUMMARY OF REVISIONS TO REG. GUIDE 1.207

Summary of Revisions to Reg. Guide 1.207

- **The following revisions were made to RG 1.207:**
 - 1. The title was revised to remove “New Reactors” (i.e., the RG was made applicable to all LWRs)**
 - 2. The guidance was clarified to apply to all metal components exposed to LWR environments that have a CUF calculation required by a plant’s current licensing basis (CLB)**
 - 3. The background section was revised to incorporate the relevant content for operating reactors, license renewal, etc.**
 - 4. The F_{en} equations were revised based on stakeholder feedback and the updated research documented in NUREG/CR-6909, Rev. 1**

REVISIONS TO F_{EN} EQUATIONS

Review of updated fatigue data

Review of air fatigue curves

Review of changes to F_{en} expressions

Validation calculations

Sample problem

Review of Updated Fatigue Data (1/3)

- **Initially, RES planned to gather and incorporate all publically available fatigue data published since the initial release of RG 1.207 (2007)**
- **At the start of NRC research efforts, negotiations were undertaken with the Japan Nuclear Energy Safety Organization (JNES), now the Japan Nuclear Regulatory Authority (JNRA), to formally obtain all EAF data from Japanese research programs**
 - **Pursued under the NRC/JNES Cooperative Materials Research Agreement**
 - **Led to formal release of Japanese EAF data to NRC in October 2011***

* RES gratefully acknowledges the release of the Japanese EAF research data, as documented in Report No. JNES-SS-1005, "Environmental Fatigue Evaluation Method for Nuclear Power Plants," Nuclear Energy System Safety Division, Japan Nuclear Energy Safety Organization, March 2011, ADAMS Accession No. ML113010189.

Review of Updated Fatigue Data (2/3)

Summary of air fatigue data in Rev. 0/Rev. 1 of NUREG/CR-6909:

Material	Data Available for Rev. 0	Data Available for Rev. 1	Increase*
Carbon Steels	153 points (8 heats) [Figure 7(a) of Rev. 0]	254 points (19 heats) [Figure 32(b) of Rev. 1]	66 %
Low-Alloy Steels	358 points (19 heats) [Figure 7(b) of Rev. 0]	430 points (22 heats) [Figure 32(d) of Rev. 1]	20 %
Austenitic Stainless Steels	357 points (38 heats) [Figure 35 of Rev. 0]	622 points (40 heats) [Figure 45(b) of Rev. 1]	74 %
Ni-Cr-Fe Alloys	Not quantified [Figures 56 & 57 of Rev. 0]	559 points (45 heats) [Section 3.3 of Rev. 1]	N/A

* The majority of the increase in data is attributed to the additional data reported in Report No. JNES-SS-1005.

Review of Updated Fatigue Data (3/3)

Summary of water fatigue data in Rev. 0/Rev. 1 of NUREG/CR-6909:

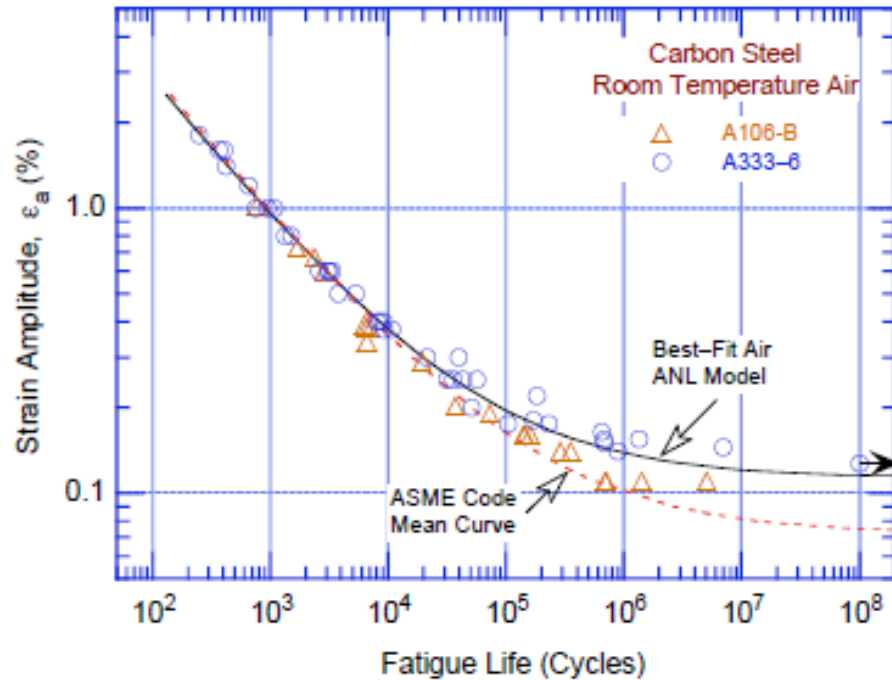
Material	Data Available for Rev. 0	Data Available for Rev. 1	Increase*
Carbon Steels	318 points (12 heats) [Figure 27 of Rev. 0]	638 points (21 heats) [Figure 79 of Rev. 1]	100 %
Low-Alloy Steels	327 points (13 heats) [Figure 27 of Rev. 0]	536 points (20 heats) [Figure 79 of Rev. 1]	64 %
Austenitic Stainless Steels	276 points (14 heats) [Figure 52 of Rev. 0]	683 points (32 heats) [Figure 110 of Rev. 1]	147 %
Ni-Cr-Fe Alloys	Not quantified [Figures 58 & 59 of Rev. 0]	162 points (13 heats) [Section 4.3 of Rev. 1]	N/A

* The majority of the increase in data is attributed to the additional data reported in Report No. JNES-SS-1005.

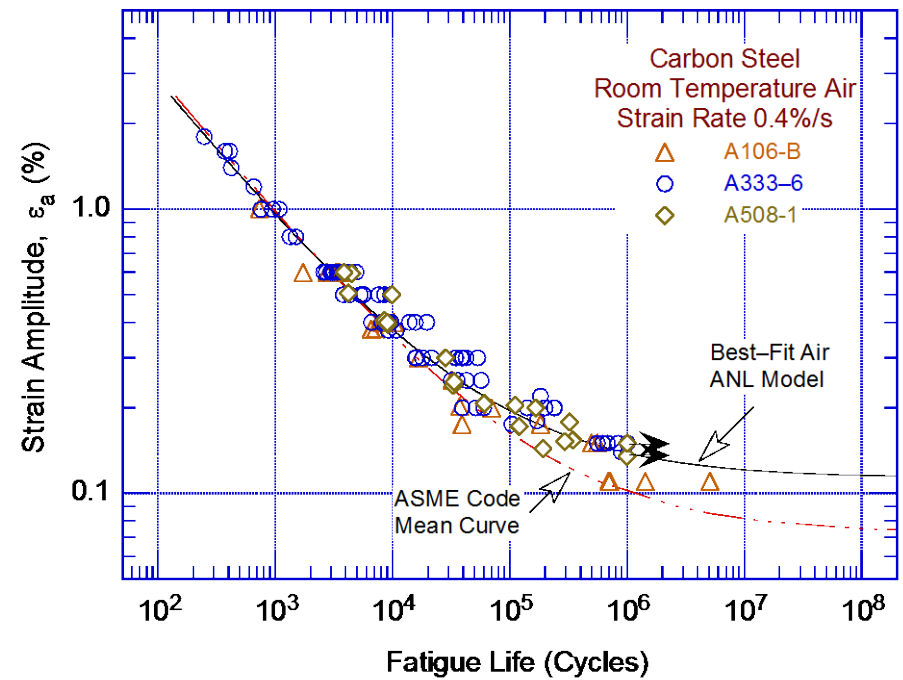
Review of Air Fatigue Curves (1/12)

Best Fit AIR Curves for Carbon Steel

From NUREG/CR-6909, Rev. 0:



From NUREG/CR-6909, Rev. 1:

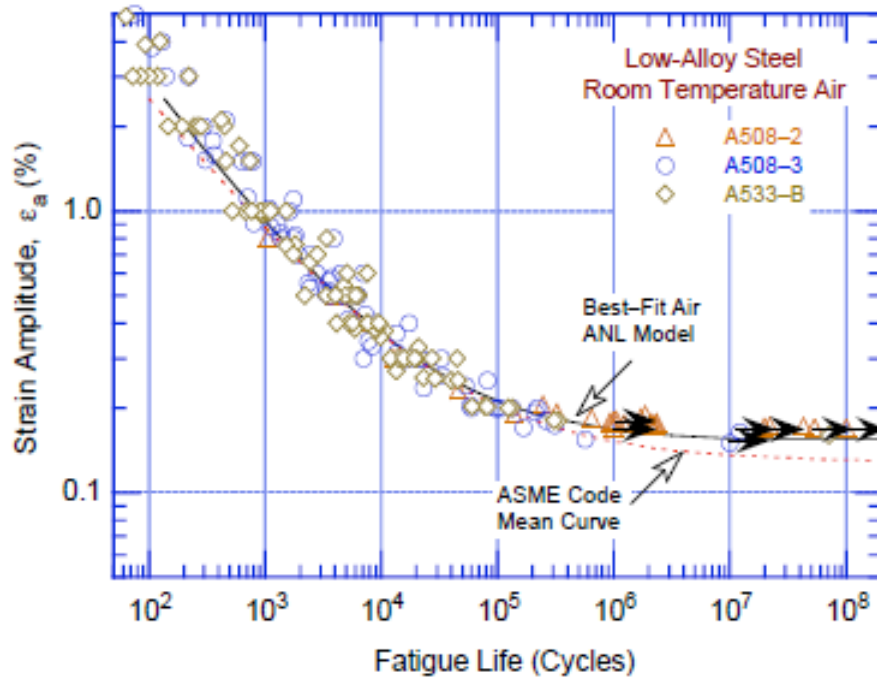


NOTE: The ANL best-fit air curves are identical in both of the above figures.

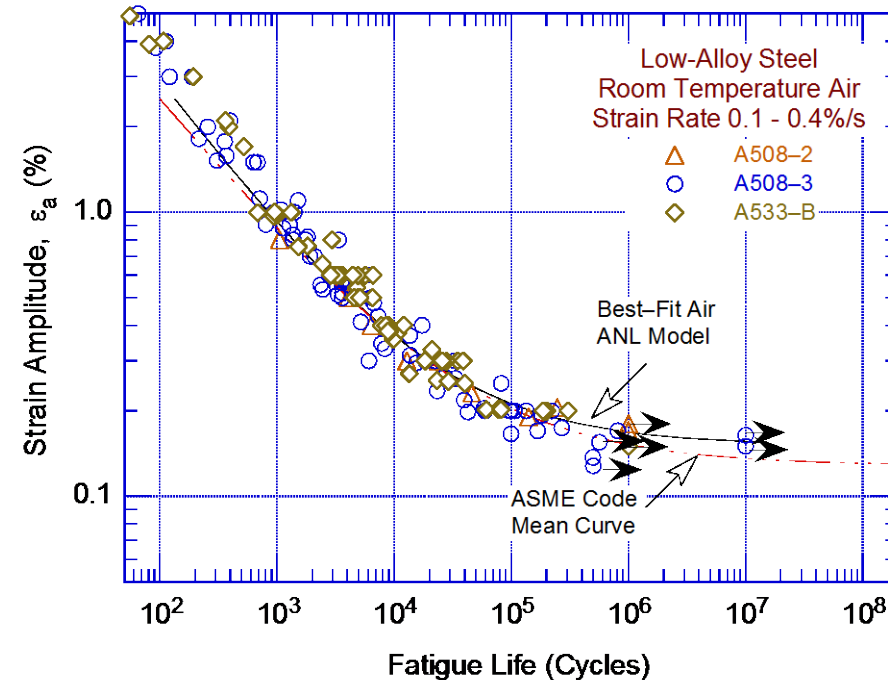
Review of Air Fatigue Curves (2/12)

Best Fit AIR Curves for Low Alloy Steel

From NUREG/CR-6909, Rev. 0:



From NUREG/CR-6909, Rev. 1:

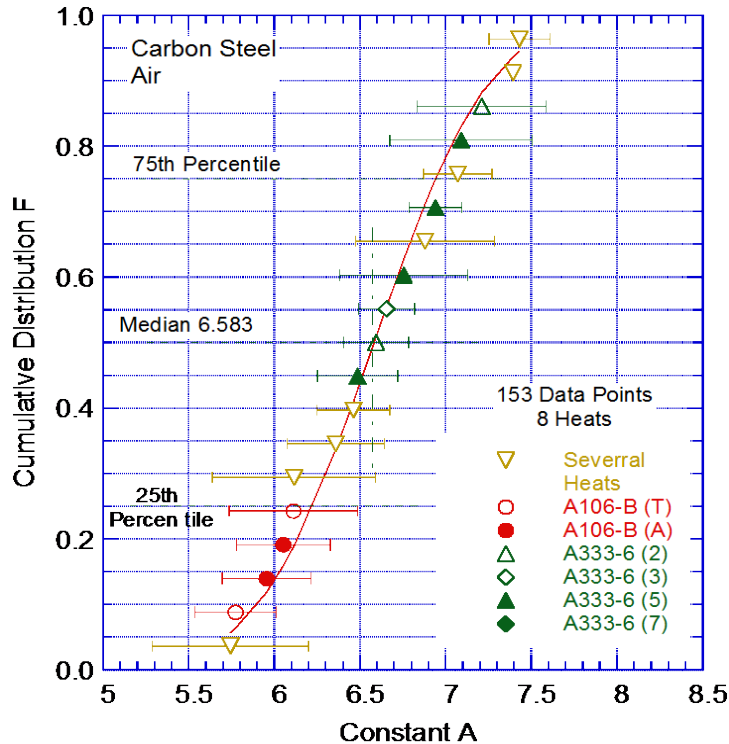


NOTE: The ANL best-fit air curves are identical in both of the above figures.

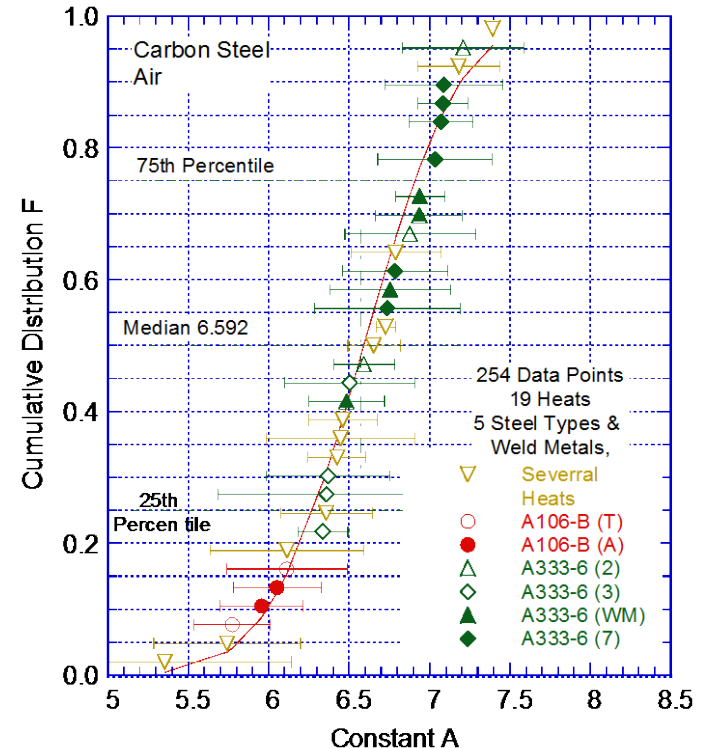
Review of Air Fatigue Curves (3/12)

Distribution of Constant A for AIR Curves for Carbon Steel

From NUREG/CR-6909, Rev. 0



From NUREG/CR-6909, Rev. 1



Curve fits are made using a Langer fit of the form:

$$\ln(N) = A - B \ln(\epsilon_a - C)$$

where: **A, B, C** are constants

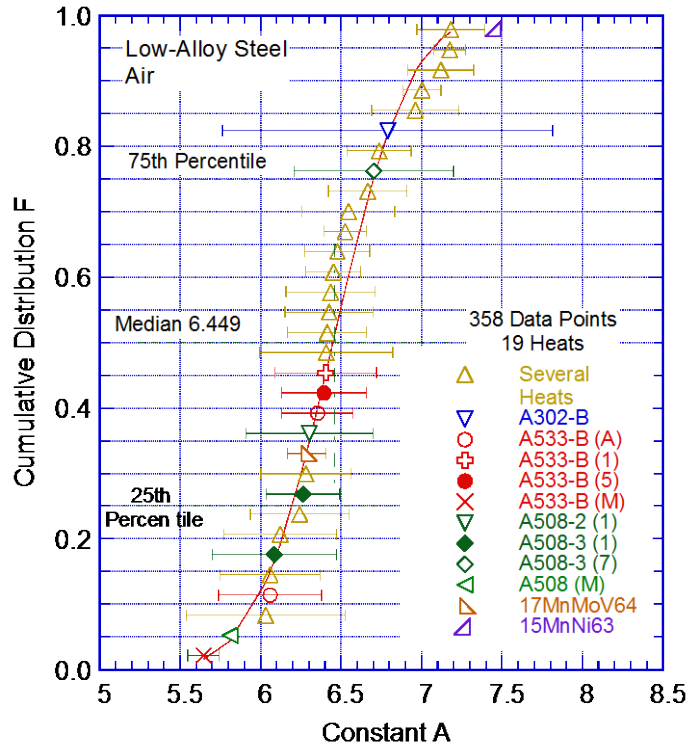
ϵ_a is the strain amplitude

N is the fatigue life (cycles)

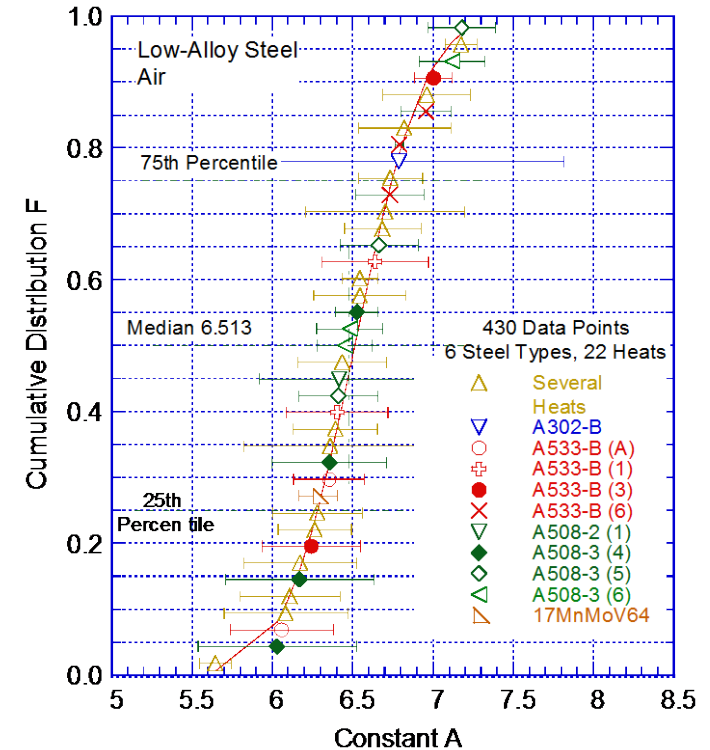
Review of Air Fatigue Curves (4/12)

Distribution of Constant A for AIR Curves for Low Alloy Steel

From NUREG/CR-6909, Rev. 0



From NUREG/CR-6909, Rev. 1



Curve fits are made using a Langer fit of the form:

$$\ln(N) = A - B \ln(\epsilon_a - C)$$

where: **A, B, C** are constants

ϵ_a is the strain amplitude

N is the fatigue life (cycles)

Review of Air Fatigue Curves (5/12)

Design **AIR** Curve for **Carbon Steel**

- Consistent with the ASME Code Section III Design Curve, adjustment factors must be applied to best-fit air curves to accommodate various material, loading, and environmental parameters
- ASME's factor of 2 on strain amplitude was maintained
- To determine the most appropriate value for the adjustment factor on fatigue life, 25,000 Monte Carlo simulations were performed using the following factors:

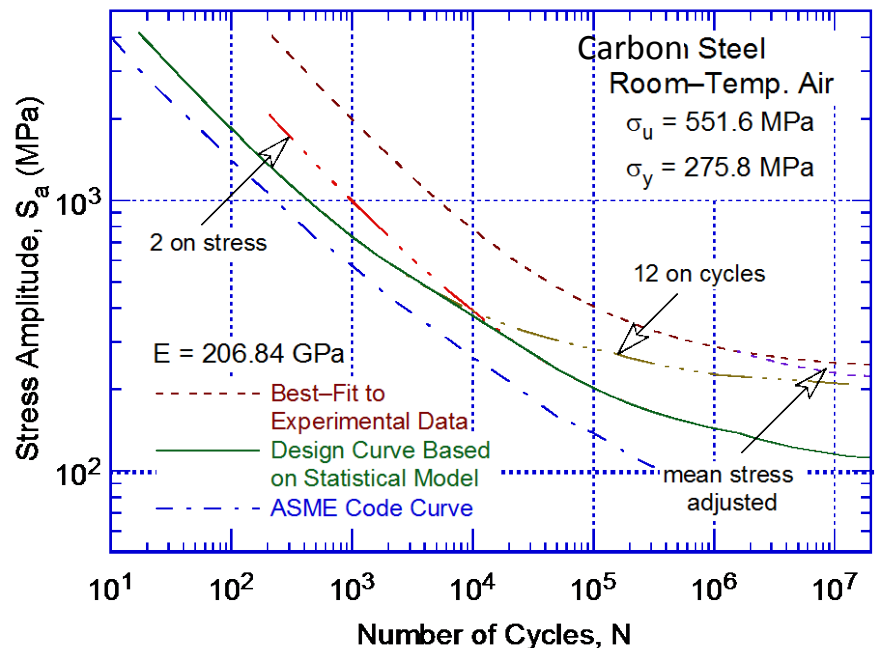
Parameter	Section III Criterion Document	Present Report
Material Variability and Data Scatter		
(minimum to mean)	2.0	2.1–2.8
Size Effect	2.5	1.0–1.4
Surface Finish, etc.	4.0	1.5–3.5
Loading History	–	1.0–2.0
Total Adjustment	20	4.7–27.4

- Lognormal distributions were used, and the 5th and 95th percentile values were assumed as the minimum and maximum values for each factor
- The 95th percentile value for the adjustment factor was calculated as 10.2

Review of Air Fatigue Curves (6/12)

Design AIR Curve for Carbon Steel

- Although a factor of ~ 10 was supported by the Monte Carlo evaluation, adjustment factors of 2 and 12 were used to provide consistency with Rev. 0 work
- Therefore, there is no change in the carbon steel design air curve between NUREG/CR-6909, Rev. 0 and NUREG/CR-6909, Rev. 1
- NRC requested feedback on maintaining a factor of 12 vs. changing to a factor of 10 when the draft of NUREG/CR-6909, Rev. 1 was released for public comment last spring

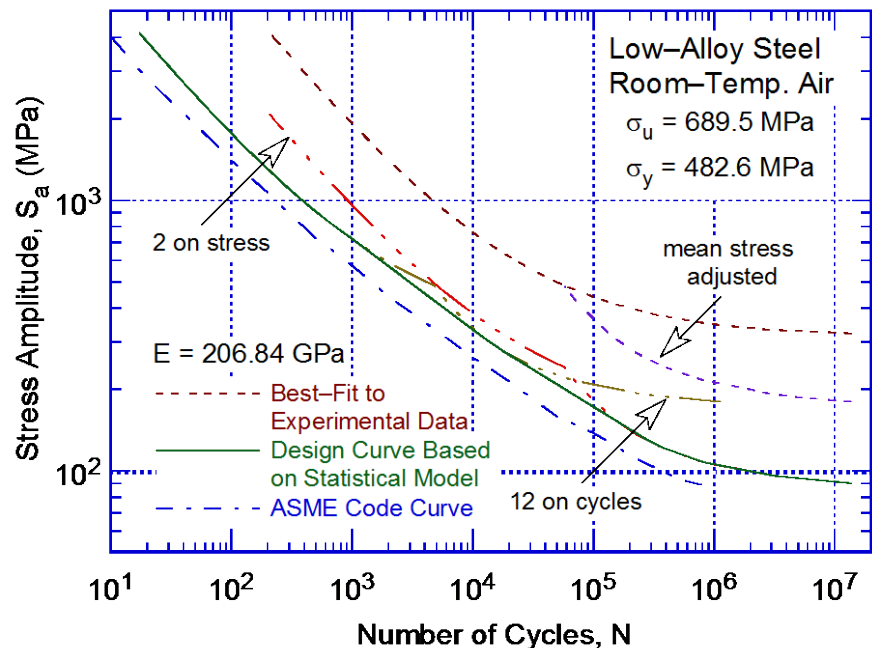


NOTE: Existing ASME Code Section III design air curve is conservative compared to NUREG/CR-6909, Rev. 1 (because of factor of 20 vs. 12)

Review of Air Fatigue Curves (7/12)

Design **AIR** Curve for **Low Alloy Steel**

- A factor of 9.0 was obtained from the Monte Carlo simulations; again, adjustment factors of 2 and 12 were used to provide consistency with Rev. 0 work
- Therefore, there is no change in the low alloy steel design air curve between NUREG/CR-6909, Rev. 0 and NUREG/CR-6909, Rev. 1
- NRC requested feedback on maintaining a factor of 12 vs. changing to a factor of 10 when the draft of NUREG/CR-6909, Rev. 1 was released for public comment last spring



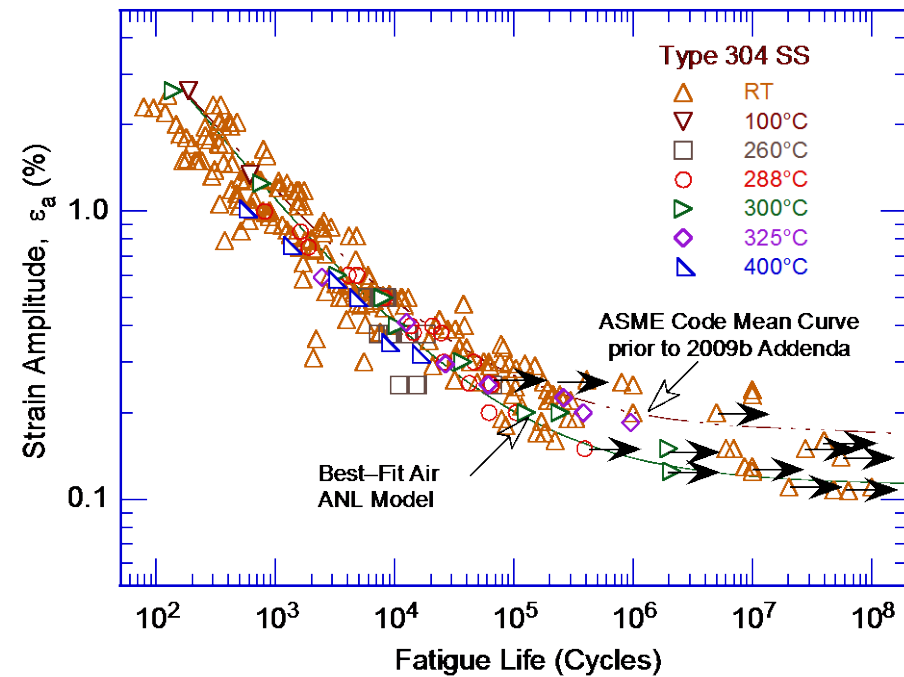
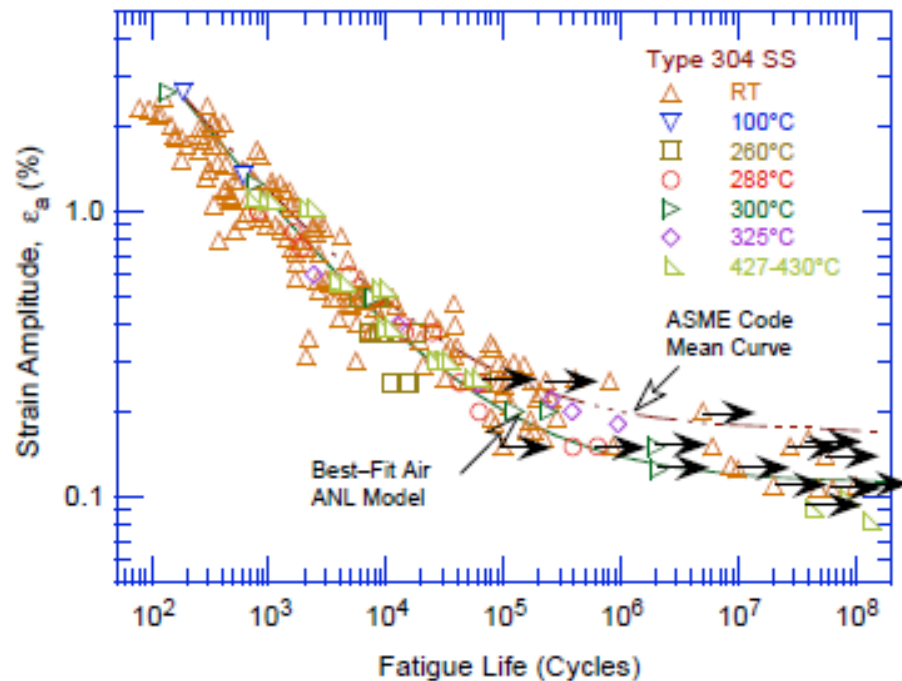
NOTE: The existing ASME Code Section III design air curve is conservative compared to NUREG/CR-6909, Rev. 1 (because of factor of 20 vs. 12 and the combining of the carbon steel and low alloy steel curves into one curve in Section III)

Review of Air Fatigue Curves (8/12)

Best Fit AIR Curves for Austenitic Stainless Steel

From NUREG/CR-6909, Rev. 0:

From NUREG/CR-6909, Rev. 1:

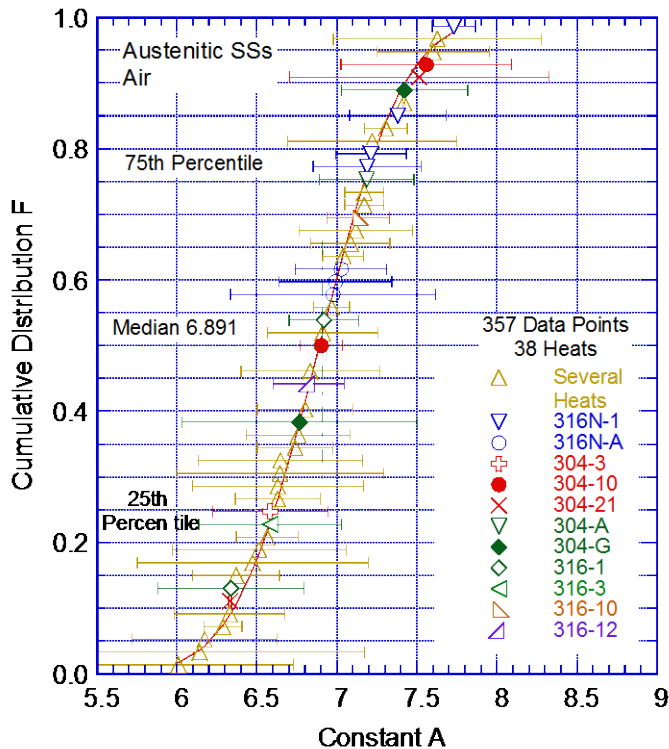


NOTE: Only Type 304 materials are shown; the ANL best-fit air curves are identical in both of the above figures.

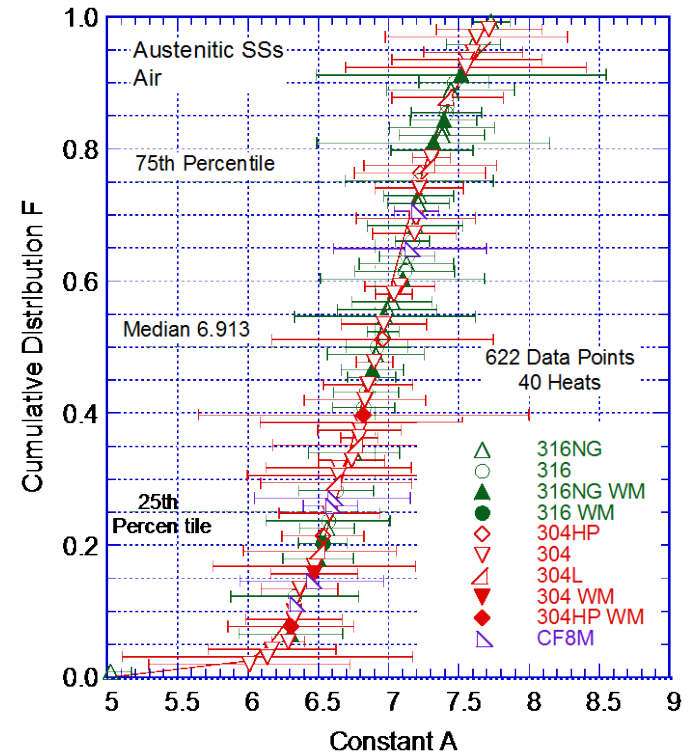
Review of Air Fatigue Curves (9/12)

Distribution of Constant A for AIR Curves for Austenitic Stainless Steel

From NUREG/CR-6909, Rev. 0



From NUREG/CR-6909, Rev. 1



Curve fits are made using a Langer fit of the form:

$$\ln(N) = A - B \ln(\epsilon_a - C)$$

where: **A, B, C** are constants

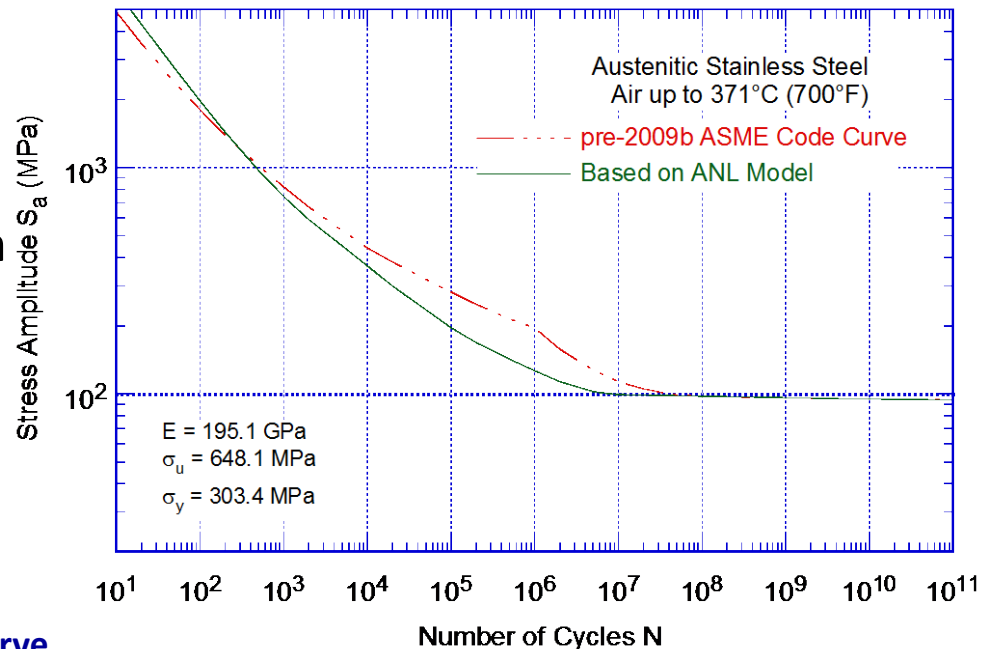
ϵ_a is the strain amplitude

N is the fatigue life (cycles)

Review of Air Fatigue Curves (10/12)

Design **AIR** Curve for **Austenitic Stainless Steel**

- A factor of 9.6 was obtained from the Monte Carlo simulations; again, adjustment factors of 2 and 12 were used to provide consistency with Rev. 0 work
- Therefore, there is no change in the austenitic stainless steel design air curve between NUREG/CR-6909, Rev. 0 and NUREG/CR-6909, Rev. 1
- NRC requested feedback on maintaining a factor of 12 vs. changing to a factor of 10 when the draft of NUREG/CR-6909, Rev. 1 was released for public comment last spring

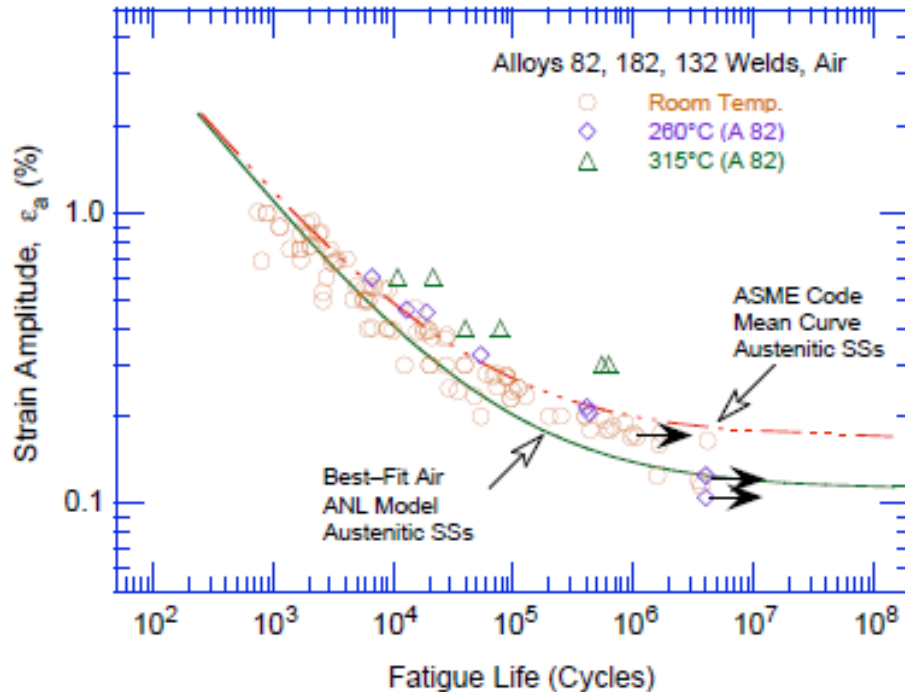


NOTE: The existing ASME Code Section III design air curve is identical to the ANL design air curve shown.

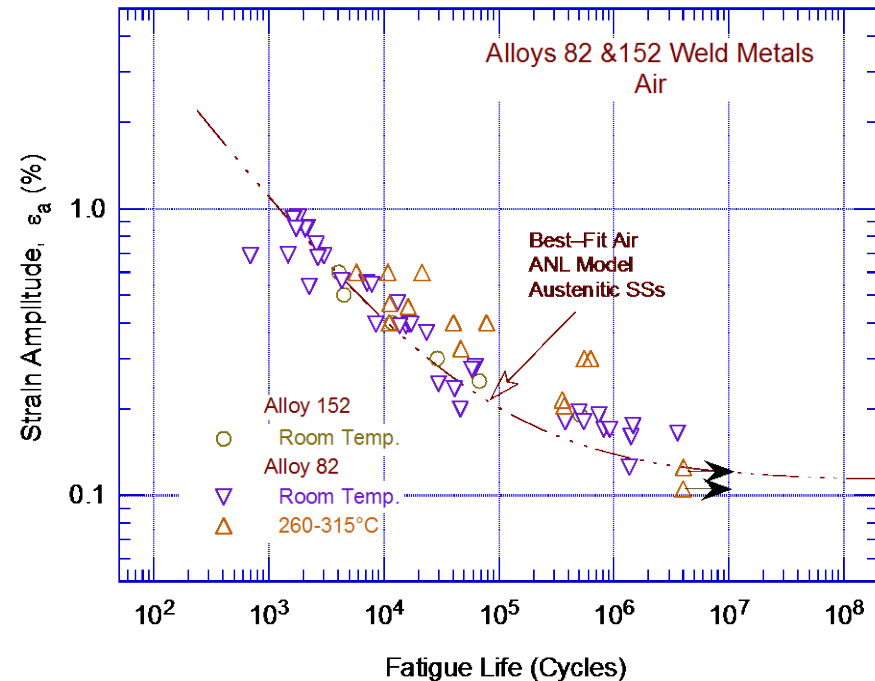
Review of Air Fatigue Curves (11/12)

Best Fit AIR Curves for Ni-Cr-Fe Steel

From NUREG/CR-6909, Rev. 0:



From NUREG/CR-6909, Rev. 1:



NOTE: Only Ni-Cr-Fe weld metals are shown; the ANL best-fit air curves are identical in both of the above figures.

Review of Air Fatigue Curves (12/12)

Design **AIR** Curve for **Ni-Cr-Fe Steel**

- Estimates of the cumulative distribution of Constant A in the fatigue ϵ -N curve for the various heats of Ni-Cr-Fe steels and their associated weld metals yielded a median value of 7.129
- This value is slightly greater than the value of Constant A derived for austenitic SSs (6.891)
- In other words, the fatigue lives of these Ni-Cr-Fe steels are approximately 25% greater than those for austenitic stainless steels
- Based on these findings, the design air curve for austenitic stainless steel is used for Ni-Cr-Fe steel

NOTE: The existing ASME Code Section III design air curve for stainless steel is also used for Ni-Cr-Fe steel.

Review of Changes to F_{en} Equations (1/10)

F_{en} equations for Carbon Steel

From NUREG/CR-6909, Rev. 0

$$F_{en} = \exp[0.632 - 0.101 S^* T^* O^* R^*]$$

where:

Transformed sulfur, S^* :

$$S^* = 0.001 \quad (S \leq 0.001 \text{ wt.}\%)$$

$$S^* = S \quad (S \leq 0.015 \text{ wt.}\%)$$

$$S^* = 0.015 \quad (S > 0.015 \text{ wt.}\%)$$

Transformed temperature, T^* :

$$T^* = 0 \quad (T < 150^\circ\text{C})$$

$$T^* = (T - 150) \quad (150 < T \leq 350^\circ\text{C})$$

Transformed dissolved oxygen, O^* :

$$O^* = 0 \quad (\text{DO} \leq 0.04 \text{ ppm})$$

$$O^* = \ln(\text{DO}/0.04) \quad (0.04 < \text{DO} \leq 0.5 \text{ ppm})$$

$$O^* = \ln(12.5) \quad (\text{DO} > 0.5 \text{ ppm})$$

Transformed strain rate, R^* :

$$R^* = 0 \quad (R > 1\%/s)$$

$$R^* = \ln(R) \quad (0.001 \leq R \leq 1\%/s)$$

$$R^* = \ln(0.001) \quad (R < 0.001\%/s)$$

From NUREG/CR-6909, Rev. 1

$$F_{en} = \exp[(0.003 - 0.031R^*) S^* T^* O^*]$$

where:

Transformed sulfur, S^* :

$$S^* = 2.0 + 98 S \quad (S \leq 0.015 \text{ wt.}\%)$$

$$S^* = 3.47 \quad (S > 0.015 \text{ wt.}\%)$$

Transformed temperature, T^* :

$$T^* = 0.395 \quad (T < 150^\circ\text{C})$$

$$T^* = (T - 75)/190 \quad (150 < T \leq 325^\circ\text{C})$$

Transformed dissolved oxygen, O^* :

$$O^* = 1.49 \quad (\text{DO} < 0.04 \text{ ppm})$$

$$O^* = \ln(\text{DO}/0.009) \quad (0.04 \leq \text{DO} \leq 0.5 \text{ ppm})$$

$$O^* = 4.02 \quad (\text{DO} > 0.5 \text{ ppm})$$

Transformed strain rate, R^* :

$$R^* = 0 \quad (R > 2.2\%/s)$$

$$R^* = \ln(R/2.2) \quad (0.0004 \leq R \leq 2.2\%/s)$$

$$R^* = \ln(0.0004/2.2) \quad (R < 0.0004\%/s)$$

NOTE: For Rev. 0, $F_{en} > 1.0$ even when environmental effects do not apply.

Review of Changes to F_{en} Equations (2/10)

F_{en} equations for **Low Alloy Steel**

From NUREG/CR-6909, Rev. 0

$$F_{en} = \exp[0.702 - 0.101 S^* T^* O^* R^*]$$

where:

S^* , T^* , O^* , R^* are defined the same as for carbon steel

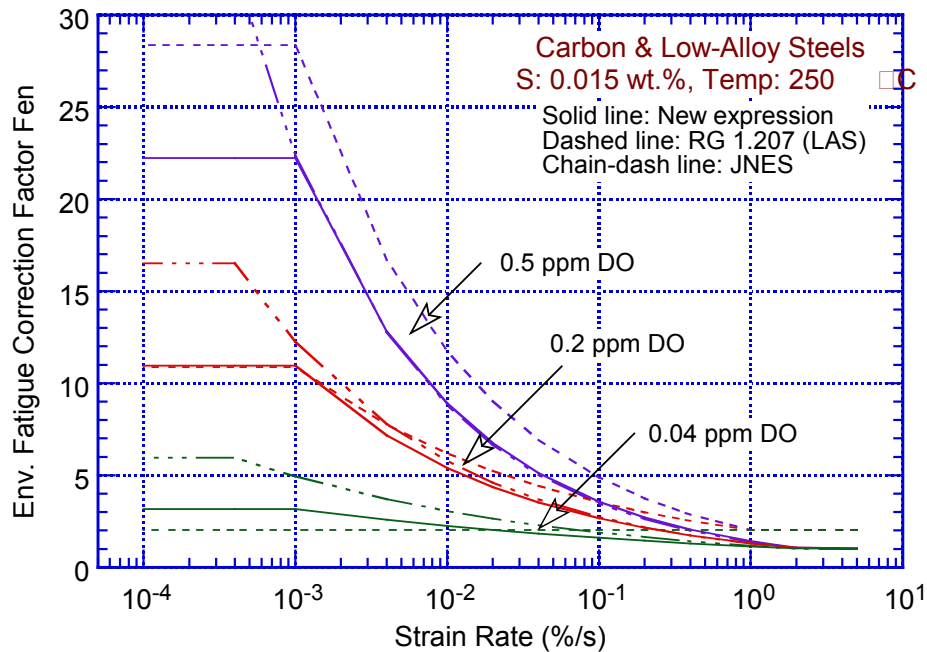
From NUREG/CR-6909, Rev. 1

F_{en} = same expression as for carbon steel

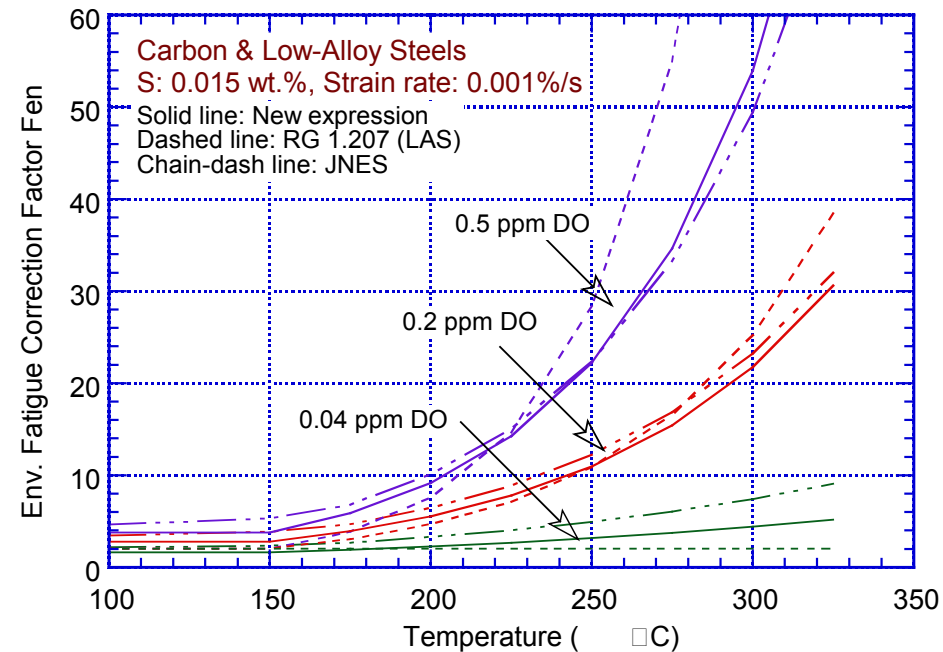
Review of Changes to F_{en} Equations (3/10)

F_{en} plots for Carbon and Low Alloy Steels

F_{en} vs. strain rate, R:



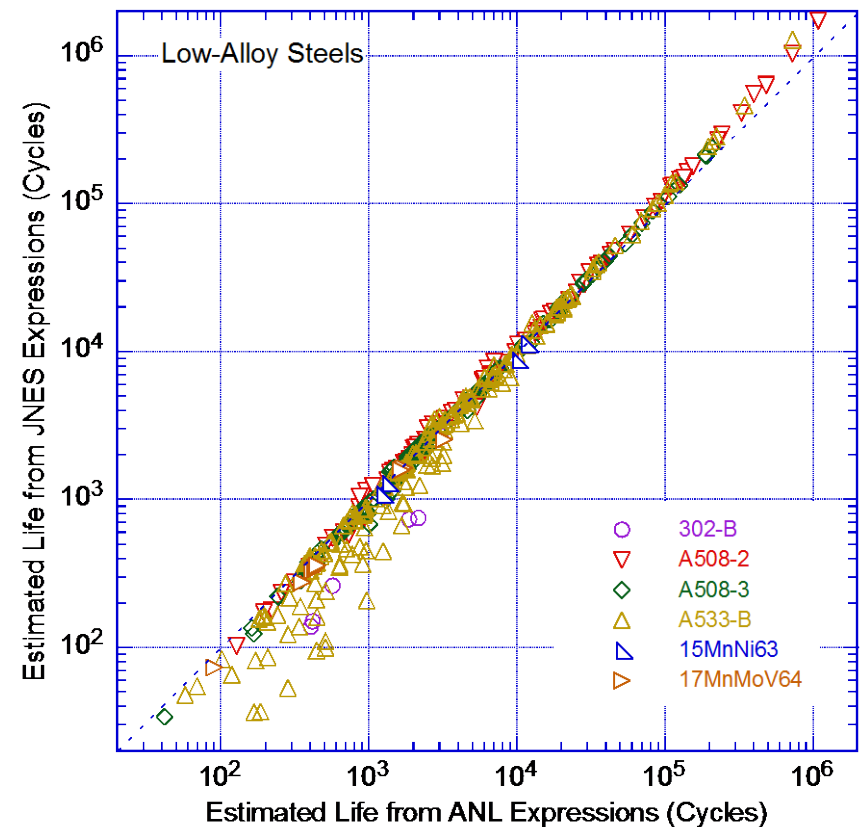
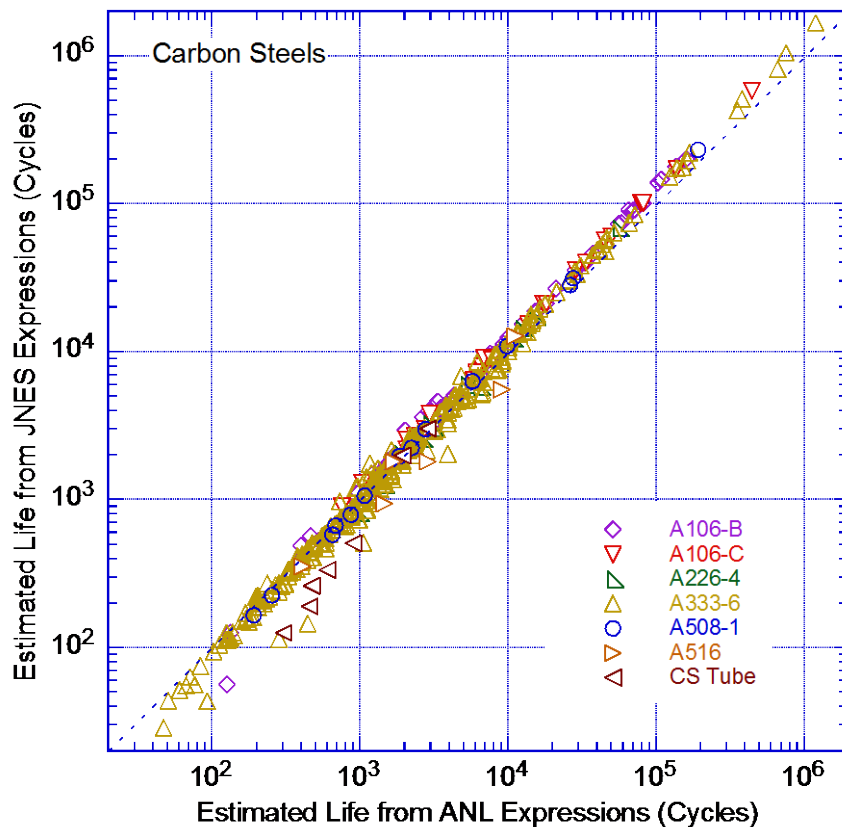
F_{en} vs. temperature, T:



Review of Changes to F_{en} Equations (4/10)

Life predictions for Carbon and Low Alloy Steels

The NRC and JNES predictions are in good agreement:



Review of Changes to F_{en} Equations (5/10)

F_{en} equations for Austenitic Stainless Steel

From NUREG/CR-6909, Rev. 0

$$F_{en} = \exp[0.734 - T^*O^*R^*]$$

where:

Transformed temperature, T^* :

$$\begin{aligned} T^* &= 0 && (T < 150^\circ\text{C}) \\ T^* &= (T - 150)/175 && (150 < T \leq 325^\circ\text{C}) \\ T^* &= 1 && (T > 325^\circ\text{C}) \end{aligned}$$

Transformed dissolved oxygen, O^* :

$$O^* = 0.281 \quad \text{all DO levels}$$

Transformed strain rate, R^* :

$$\begin{aligned} R^* &= 0 && (R > 0.4\%/s) \\ R^* &= \ln(R/0.4) && (0.001 \leq R \leq 0.4\%/s) \\ R^* &= \ln(0.001) && (R < 0.001\%/s) \end{aligned}$$

From NUREG/CR-6909, Rev. 1

$$F_{en} = \exp[-T^*O^*R^*]$$

where:

Transformed temperature, T^* :

$$\begin{aligned} T^* &= 0 && (T < 100^\circ\text{C}) \\ T^* &= (T - 100)/250 && (100 < T \leq 325^\circ\text{C}) \end{aligned}$$

Transformed dissolved oxygen, O^* :

$$\begin{aligned} O^* &= 1.49 && (\text{DO} < 0.04 \text{ ppm}) \\ O^* &= \ln(\text{DO}/0.009) && (0.04 \leq \text{DO} \leq 0.5 \text{ ppm}) \\ O^* &= 4.02 && (\text{DO} > 0.5 \text{ ppm}) \end{aligned}$$

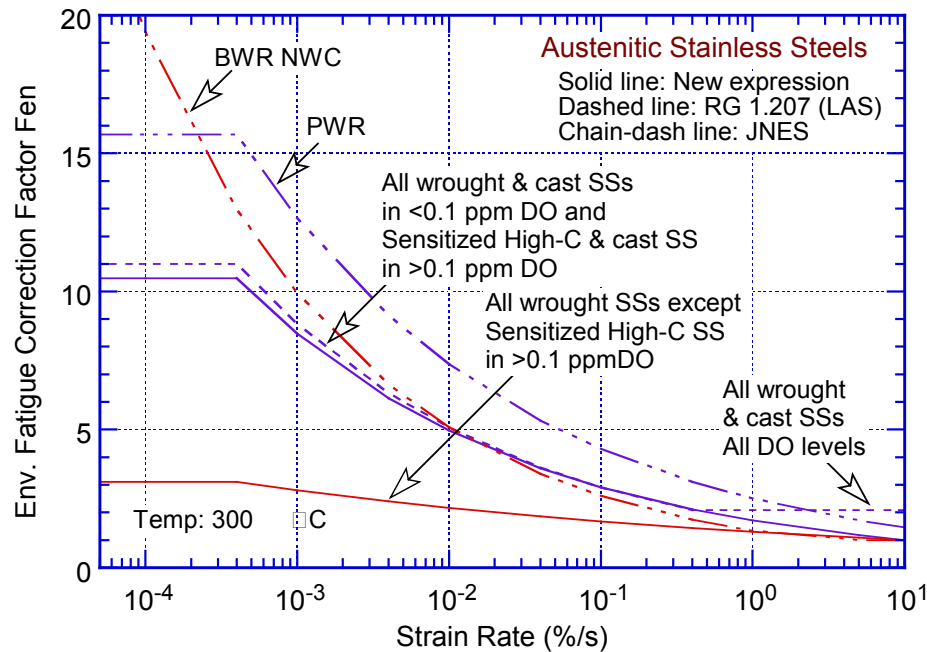
Transformed strain rate, R^* :

$$\begin{aligned} R^* &= 0 && (R > 10\%/s) \\ R^* &= \ln(R/10) && (0.0004 \leq R \leq 10\%/s) \\ R^* &= \ln(0.0004/10) && (R < 0.0004\%/s) \end{aligned}$$

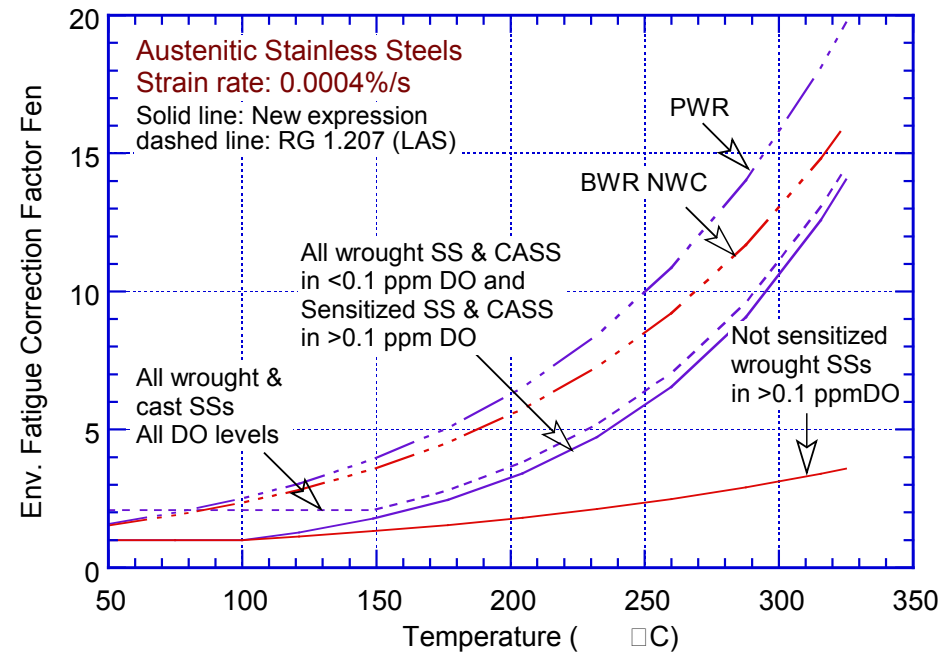
Review of Changes to F_{en} Equations (6/10)

F_{en} plots for Austenitic Stainless Steel

F_{en} vs. strain rate, R:



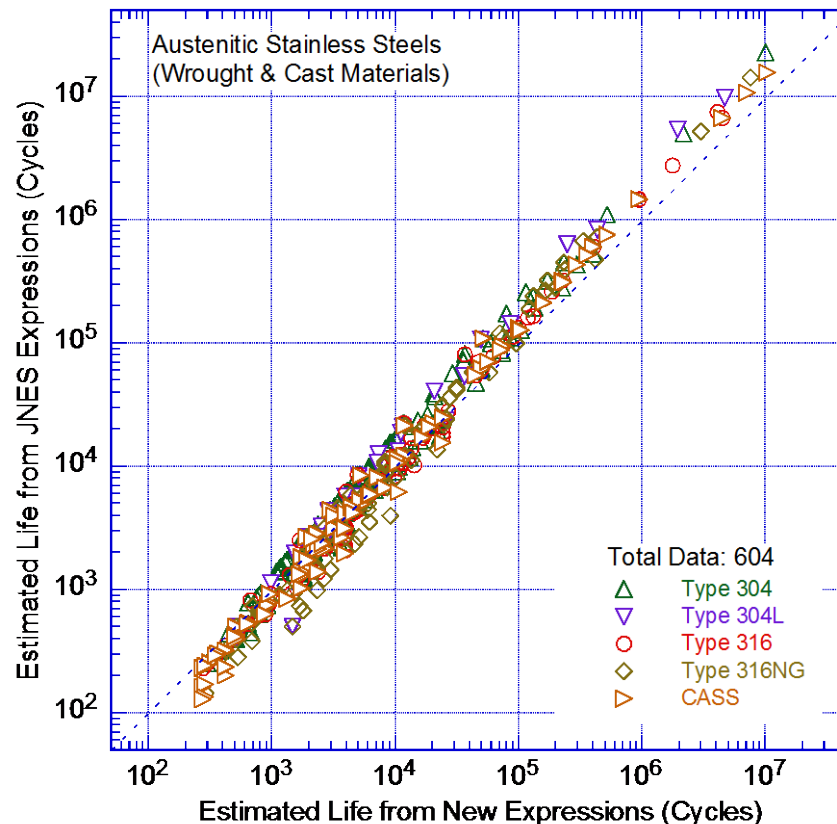
F_{en} vs. temperature, T:



Review of Changes to F_{en} Equations (7/10)

Life predictions for Austenitic Stainless Steel

The NRC and JNES predictions are in good agreement:



Review of Changes to F_{en} Equations (8/10)

F_{en} equations for Ni-Cr-Fe Steel

From NUREG/CR-6909, Rev. 0

F_{en} not specified

It was noted that for Alloys 600 and 690 and their welds, the updated ANL fatigue life model proposed for austenitic stainless steel was either consistent or conservative with respect to the fatigue ϵ - N data.

Some licensees used a constant F_{en} of 1.49 based on earlier recommendations made by EPRI*; this value is not supported by the available test data.

From NUREG/CR-6909, Rev. 1

$$F_{en} = \exp[-T^*O^*R^*]$$

where:

Transformed temperature, T^* :

$$T^* = 0 \quad (T < 50^\circ\text{C})$$

$$T^* = (T - 50)/250 \quad (50 < T \leq 325^\circ\text{C})$$

Transformed dissolved oxygen, O^* :

$$O^* = 0.06 \quad (\text{BWR NWC, DO} \geq 0.1 \text{ ppm})$$

$$O^* = 0.14 \quad (\text{BWR HWC/PWR, DO} < 0.1 \text{ ppm})$$

Transformed strain rate, R^* :

$$R^* = 0 \quad (R > 5.0\%/s)$$

$$R^* = \ln(R/5.0) \quad (0.0004 \leq R \leq 5.0\%/s)$$

$$R^* = \ln(0.0004/5.0) \quad (R < 0.0004\%/s)$$

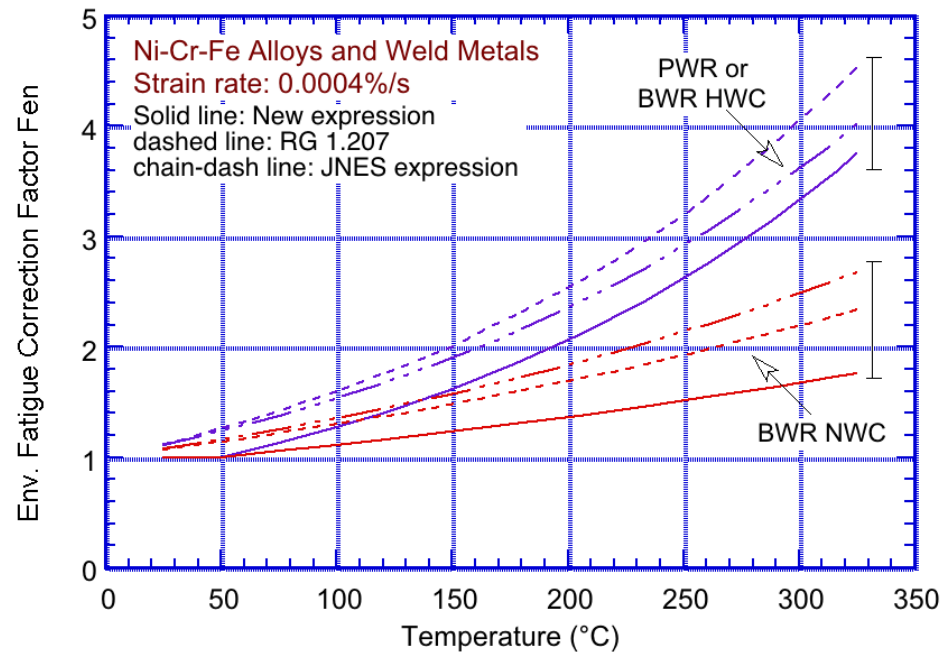
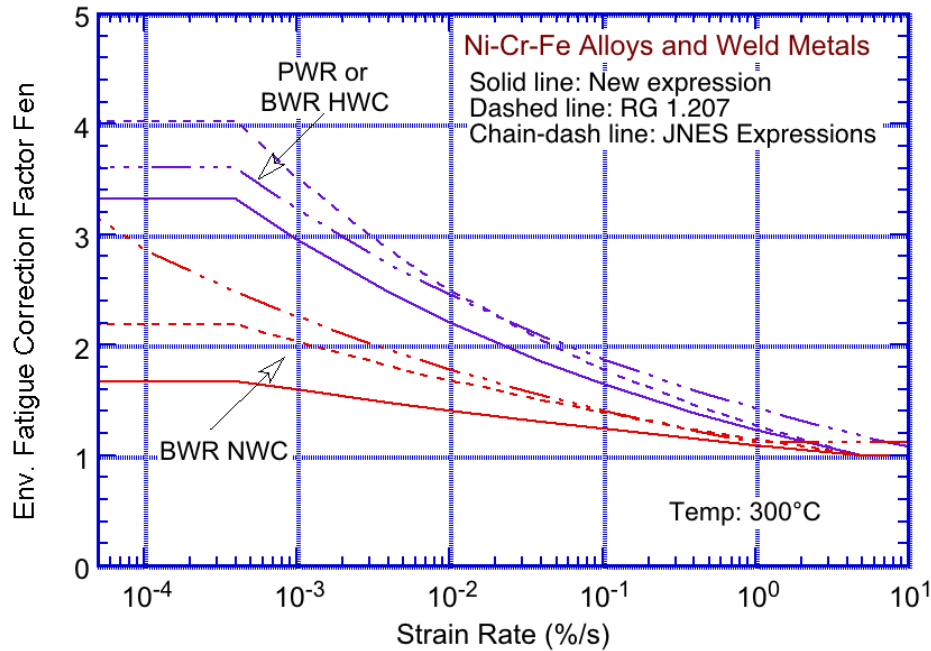
* EPRI TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," August 1996.

Review of Changes to F_{en} Equations (9/10)

F_{en} plots for Ni-Cr-Fe Steel

F_{en} vs. strain rate, R:

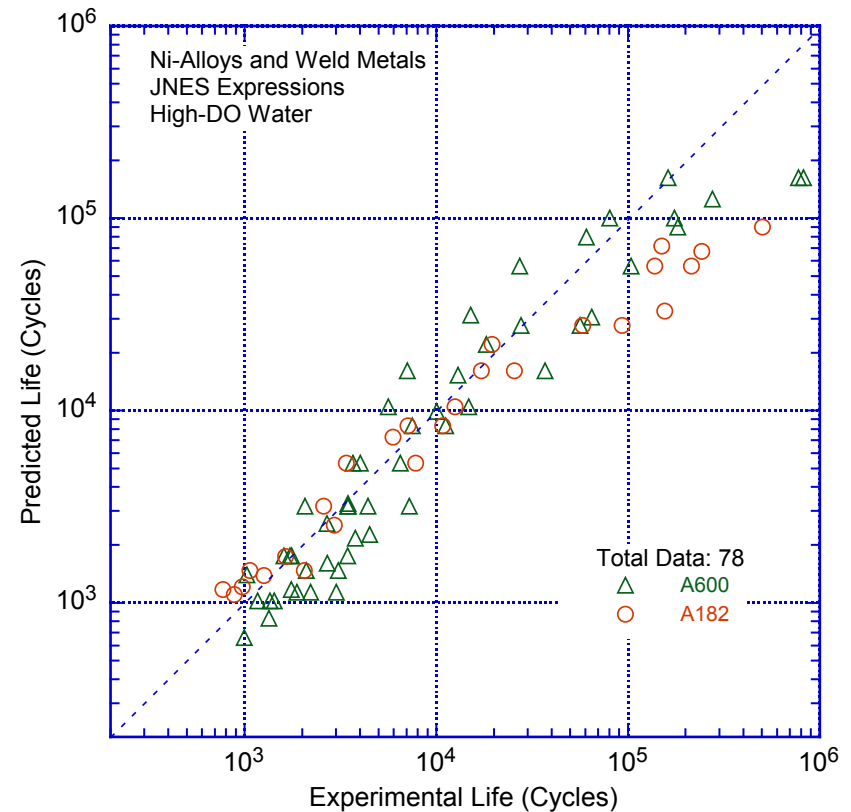
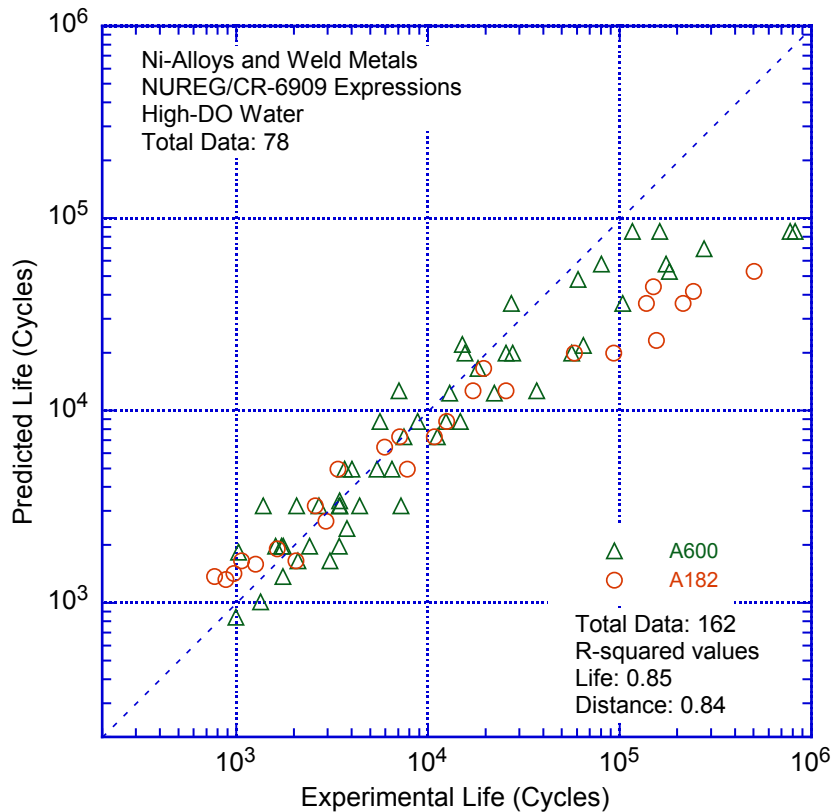
F_{en} vs. temperature, T:



Review of Changes to F_{en} Equations (10/10)

Life predictions for Ni-Cr-Fe Steel

The NRC and JNES predictions are in good agreement:



Validation Calculations (1/2)

- Several validation calculations were performed by estimating life using ASME Code methods (i.e., calculate CUF) and comparing the results to the experimental (i.e., measured) fatigue life
 - Since the experimental data sets selected were tested to failure (i.e., CUF = 1.0+), the goal of these evaluations was to benchmark the F_{en} methodology and make adjustments, if warranted
- The results of the following experimental data sets were compared with estimates of fatigue life based on the F_{en} methodology to validate the revised F_{en} expressions
 1. Tests with **changing strain rate** within a strain cycle (Higuchi, Iida, and Asada, ASTM STP 1298, 1997; Higuchi, Iida, and Sakaguchi, ASME PVP-419, 2001; Higuchi, Sakaguchi, and Nomura, ASME PVP2007-26101, 2007)
 2. Tests with **changing strain rate and temperature** within a strain cycle (Nomura, Higuchi, Asada, and Sakaguchi, ASME PVP-480, PVP2004-2679, 2004; Sakaguchi, Nomura, Suzuki, and Kanasaki, ASME PVP2006-ICPVT-11-93220, 2006)
 3. Tests with **spectrum loading** (random strain amplitudes, Solin, ASME PVP2006-ICPVT-93833, 2006)
 4. Tests with **complex loading** (actual PWR transient – cold and hot thermal shock, Le Duff, Lefrancois, and Vernot, ASME PVP2009-78129, 2009)
 5. EPRI **U-bend tests** in inert and PWR environment (Hickling, Kilian, Spain, and Carey, ASME PVP2006-ICPVT-11-93318, 2006)
 6. Thermal fatigue test of a **stepped pipe** (Jones, Holliday, Leax, and Gordon, ASME PVP-482, PVP2004-2748, 2004)

Validation Calculations (2/2)

- **Three F_{en} methods were used**
 1. **Modified rate (strain-integrated) method**
 2. **Simplified (average strain rate)**
 3. **Multi-linear strain-based method**
- **The validation calculations for specimens agreed within the data scatter (i.e., factor of 2)**
- **The validation calculations for components had mixed results**
 - **For the EPRI U-bend tests, 5 out of 7 tests fell within the data scatter; the remaining 2 tests were conservatively predicted**
 - **For the stepped pipe tests, results were mixed; however, NRC found issues with finite element analysis and did not pursue corrected analysis**
- **NRC recognizes that use of small-scale specimen fatigue test data to predict the fatigue lives of actual components may be conservative under certain conditions**

Sample Problem

- **Appendix C of NUREG/CR-6909, Rev. 1 contains a detailed sample problem**
 - Same as sample problem developed and solved by industry under EPRI guidance and funding
 - Finite element based
- **Intent was to demonstrate one example application of the F_{en} methodology**
 - A common but relatively simple problem
 - Promote consistency in the application of EAF methods
- **Not intended to be an exhaustive treatment for EAF evaluation**
- **Feedback from public stakeholders has been very positive**

ESTIMATED SCHEDULE FOR RG AND NUREG PUBLICATION

Estimated Schedule

- **RG 1.207, Rev. 1**
 - All internal reviews completed; comments addressed
 - Published for public comment on 11/24/2014 (79 FRN 69884)
 - Public comment period closes on 01/23/2015
- **NUREG/CR-6909, Rev. 1**
 - All internal review completed; comments addressed
 - Published for public comment 4/17/2014 – 6/2/2014
 - More than 200 individual public comments were received from 10 commenters (see next slide)
 - Responses are under development
- **Best-Estimate Publication Schedule**
 - Address all public comments on both documents – Summer 2015
 - Reviews (including ACRS) – Fall 2015
 - Publish final documents – December 2015

Public Comments on NUREG/CR-6909, Rev. 1

No.	ADAMS Accession No.	Commenter Affiliation	Commenter Name
1	ML14157A322	Consultant, Japan	Makoto Higuchi
2	ML14157A323	Consultant – CF Int. Engineering, France	Claude Faidy
3	ML14157A324	AMEC, United Kingdom	David Tice
4	ML14157A325	Westinghouse Electric Company, USA	James Gresham
5	ML14157A326	Mitsubishi Heavy Industries, Japan	Seiji Asada
6	ML14157A327	Rolls Royce PLC, United Kingdom	Keith Wright
7	ML14157A328	Electricite de France, France	Thomas Metais
8	ML14157A330	Hitachi, Japan	Akihiko Hirano
9	ML14157A331	AREVA, Inc., USA	Devin Kelley
10	ML14157A332	Kansai Electric Power Company, Republic of Korea	June-soo Park

Questions or Comments?

BACKUP SLIDES

Method for Best Fit of Experimental Data

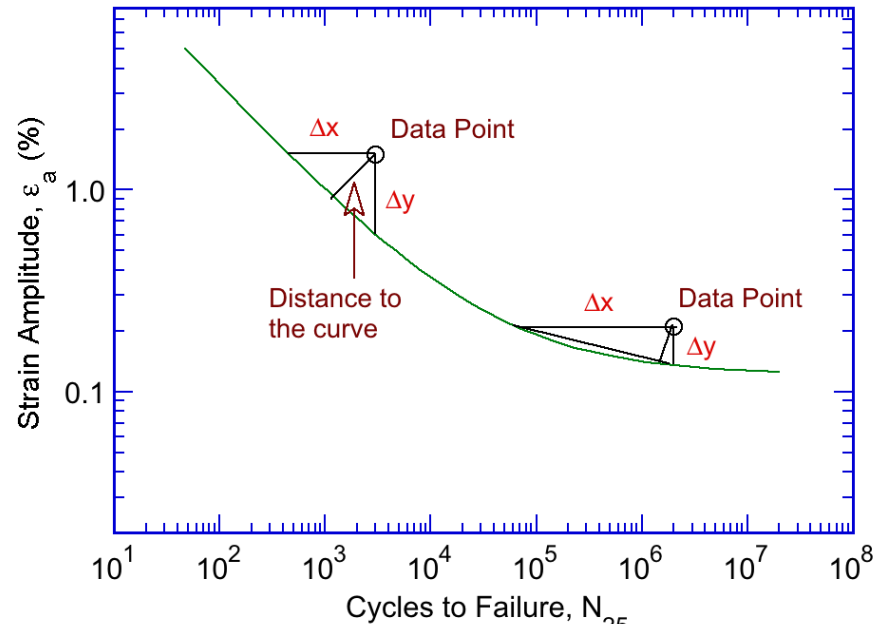
- Fatigue strain amplitude (ϵ_a) vs. life (N_{25}) data are expressed as:

$$\ln(N_{25}) = A - B \ln(\epsilon_a - C)$$

- Constants determined from a best-fit of the fatigue ϵ_a -N data

NUREG/CR-6335 (1995) gives rigorous statistical analysis to estimate probability of initiating a fatigue crack

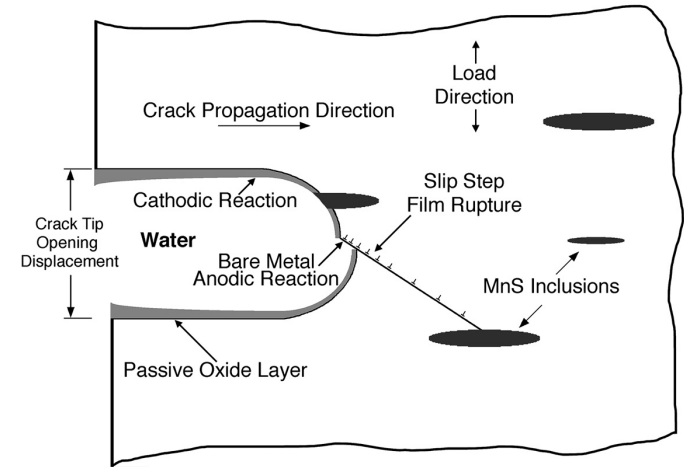
- Ideally, a best-fit of the experimental data should be determined for:
 - low-cycle fatigue by minimizing the error in life
 - high-cycle fatigue by minimizing the error in strain
- NRC used a best-fit of the experimental S-N data determined by minimizing the error in the distance between the data point and the curve
- However, both of these analyses may be biased depending on the heats of material used in obtaining the fatigue ϵ_a -N data



Possible Mechanisms for Fatigue Crack Initiation

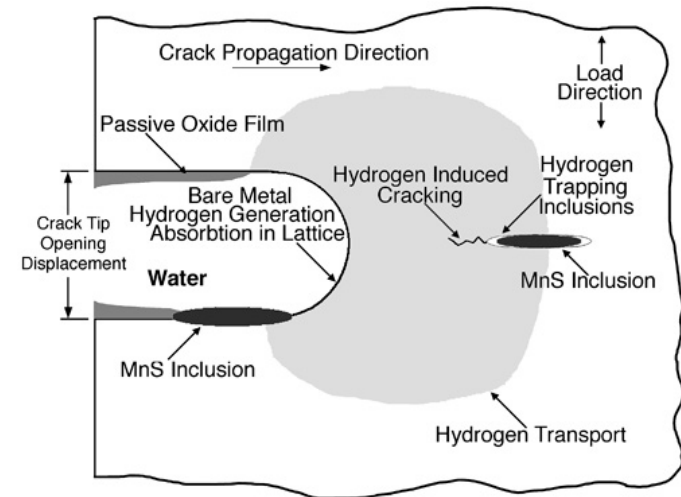
- *Film Rupture/Slip Dissolution:*

- Incremental strain ruptures the protective surface oxide film
- Crack extension occurs by dissolution/oxidation of the freshly exposed surface
- Critical concentration of sulfide / hydrosulfide ions is required at the crack tip



- *Hydrogen-Induced Cracking:*

- Hydrogen and vacancies produced by corrosion reaction enter the steel
- Hydrogen diffuses to strong trapping sites (manganese-sulfide inclusions) ahead of the crack tip, which act as initiation sites for local quasi-cleavage cracking as well as void formation
- Crack advances by linking of these microcracks with the main crack

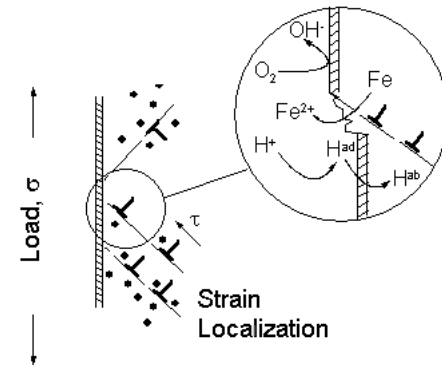


Fatigue Crack Initiation - Significant Results

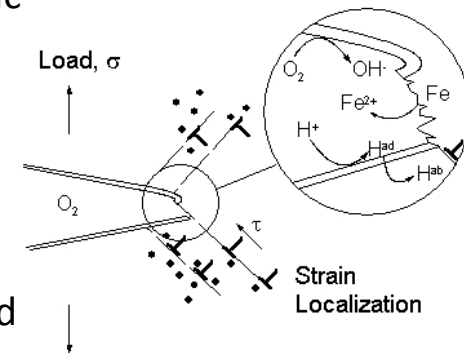
- Fatigue data show very strong strain-rate dependence of life in LWR environments
- For low-alloy steels, fatigue data suggest that cracking occurs by hydrogen-induced cracking at high strain rates and by film rupture/slip dissolution at slow strain rates
 - At high strain rates, surface cracks are inclined to the stress axis and grow in a tortuous manner; fracture surface exhibits the typical fan-like or quasi-cleavage cracking
 - At slow strain rates, surface cracks are absolutely straight, perpendicular to stress axis; fracture surface is flat with evidence of crack arrest
- Fatigue crack initiation and crack growth may be enhanced in LWR environments by a combination of the two mechanisms
 - Hydrogen produced by the oxidation reaction diffuses into the steel ahead of the crack tip, thereby changing the stacking fault energy, which results in more localized deformation
 - Strain localization leads to increased film rupture frequency, and crack extension occurs by dissolution/oxidation of the freshly exposed surface
- Dynamic strain aging may play an important role in the cyclic deformation process
 - Dynamic strain aging occurs in alloys containing solutes that segregate strongly to dislocations resulting in strong elastic interactions between the solute and dislocation stress-strain field
 - Depends on temperature and strain rate

Effect of Dynamic Strain Aging

- In high-temp water, the synergistic interactions between environmentally assisted corrosion and dynamic strain aging in a fatigue environment may be rationalized as follows:
 - Hydrogen and vacancies produced by the corrosion reaction at the crack tip enter the steel and hydrogen diffuses to strong trapping sites inside the crack tip maximum hydrostatic stress region (e.g., manganese-sulfide inclusion) ahead of the crack tip
 - According to hydrogen-induced cracking, these sites act as initiation sites for local quasi-cleavage cracking and void formation, and these microcracks link with the main crack
 - According to an alternative mechanism, at a given macroscopic strain, the microscopic strain in a steel that is susceptible to dynamic strain aging is higher because of strain localization to small areas, which leads to higher rates and larger steps of oxide film rupture. Therefore, the film rupture/slip dissolution process would enhance crack initiation or crack growth rates
 - Such processes occur under certain conditions of temperature, strain rate, and DO level, and may enhance environmentally assisted corrosion and increase fatigue crack initiation and crack growth rates



From Devrient et al. Env. Degradation Conf., 2007



Abbreviations and Symbols Used in this Presentation

Abbreviation	Definition
ANL	Argonne National Laboratory
ASME	American Society of Mechanical Engineers
BNCS	Board on Nuclear Codes and Standards
CFR	Code of Federal Regulations
CLB	Current Licensing Basis
CUF	Cumulative Usage Factor
DO	Dissolved Oxygen Content
EAF	Environmentally Assisted Fatigue
FAP	Fatigue Action Plan
GALL	Generic Aging Lessons Learned
GSI	Generic Safety Issue
JNES	Japan Nuclear Energy Safety Organization
JNRA	Japan Nuclear Regulatory Authority
LWR	Light Water Reactor
MOU	Memorandum of Understanding
NRO	Office of New Reactors
NRR	Office of Nuclear Reactor Regulation

Abbreviation	Definition
PNNL	Pacific Northwest Nuclear Laboratory
PVRC	Pressure Vessel Research Council
RES	Office of Nuclear Regulatory Research
RG	Regulatory Guide
WRC	Welding Research Council

Symbol	Definition
A, B, C	Constants for Langer Curve Fit
ϵ_a	Strain Amplitude (%)
F_{en}	Environmental Fatigue Multiplier
O O*	Fluid Dissolved Oxygen Content Transformed Oxygen Content
R R*	Strain Rate (%/s) Transformed Strain Rate
S S*	Metal Sulfur Content (wt. %) Transformed Sulfur Content
T T*	Temperature (°F or °C) Transformed Temperature