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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

December 6, 2006

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE ON MATERIALS, METALLURGY, AND

REACTOR FUELS

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WEDNESDAY,

December 6, 2006

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The meeting was convened in Room T-2B3 of Two White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 1:30 p.m., Dr. J. Sam Armijo, Chairman of the subcommittee, presiding.

MEMBERS PRESENT:

J. SAM ARMIJO, CHAIRMAN

MARIO V. BONACA, ACRS MEMBER

SAID ABDET KHALIK, ACRS MEMBER

SANJOY BANERJEE, ACRS MEMBER

THOMAS S. KRESS, ACRS MEMBER

JOHN D. SIEBER, ACRS MEMBER

GRAHAM WALLIS, ACRS MEMBER

CHARLES G. HAMMER, DESIGNATED FEDERAL OFFICIAL

CAXETANO SANTOS, ACRS STAFF

I N D E X

P-R-O-C-E-E-D-I-N-G-S

1:31 P.M.

CHAIRMAN ARMIJO: The meeting will now come to order. This is a meeting of the Materials, Metallurgy and Reactor Fuels Subcommittee. My name is Sam Armijo, Chairman of the Committee. ACRS Members in attendance are Dr. Mario Bonaca, Mr. Jack Sieber, Dr. Bill Shack is sitting as a member of the audience or staff at this point, Dr. Thomas Kress and Dr. Graham Wallis are also present.

Gary Hammer of the ACRS staff is the Designated Federal Official for this meeting.

The purpose of this meeting is to discuss Regulatory Guide 1.207, guidelines for evaluating fatigue analyses incorporating the life reduction of metal components due to the effects of light-water reactor environments for new reactors. We will hear presentations from the NRC's Office of Nuclear Regulatory Research and their contractor, Argonne National Laboratory.

We will also hear presentations from representatives of the American Society of Mechanical Engineers and AREVA.

The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate for deliberation by the Full Committee.

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the Federal Register. We have received no written comments from members of the public regarding today's meeting.

A transcript of the meeting is being kept and will be made available as stated in the Federal Register notice. Therefore, we request that participants in this meeting use the microphones located throughout the meeting when addressing the Subcommittee.

Participants should first identify themselves and speak with sufficient clarity and volume so that they may be readily heard.

We will now proceed with the meeting and I call on Mr. Hipolito Gonzales of the Office of Nuclear Regulatory Research to begin.

MR. GONZALEZ: Thank you. I am Hipolito Gonzalez. I'm the Project Manager for Regulatory Guide 1.207. I'm from the Corrosion and Metallurgy Branch and with me, Omesh Chopra. He's from Argonne National Lab. He's going to be presenting part of the regulatory basis, technical regulatory basis.

I would like to acknowledge William Cullen from the Office of Research and John Ferrer, NRR, for their helpful reviews and comments on this project.

Next slide.

The agenda today, we're going to be discussing Regulatory Guide 1.207. I'm going to give a quick historical perspective and then we're going to go over an overview the reg. guide. And then Omesh will present the technical basis which is the NUREG report CR, NUREG CR 6909, Revision 1.

I'm going to give a summary of the regulatory positions. And the last presentation is going to be the resolution of public comments.

The ASME Section 3, fatigue design curves were developed in the late 1960s and the early 1970s. The tests conducted were in laboratory environments at ambient temperatures. And the design curves included adjusted factors of 2 constraint and 20 on cyclic life to account for variations in materials, surface finish, data scatter and size.

Results from the studies in Japan and others in ANL, Argonne National Lab, as illustrated. Potential significant effects of the light-water reactor coolant environment on the fatigue life of the steel, steel components.

Next slide.

Since the late 1980s, the NRC staff has been involved in the discussion with ASME co-committees, the PVRC and Technical Community to address the issues related to the environmental effects on fatigue.

In 1991, the ASME Board of Nuclear Code and Standards requested the PVRC to examine worldwide fatigue strain versus like data and develop recommendations.

In 1995, it was resolution for GSI 166 which established that the risk to core damage from fatigue failure of the reactor coolant system was small. So no action was required for current plant design life of 40 years. Also, the NRC staff concluded that fatigue issues should be evaluated for extended period of operation for license renewal and this is under GSI-190.

In 1999, we had GSI-190 and the fatigue evaluation of metal components for 60-year life plant, plant life. Staff concluded that consistent with requirements of 10 CFR 54.21, that aging management programs for license renewal should address components of fatigue including the effects of the environment.

On December 1, 1999, by letter to the

Chairman of the ASME Board of Nuclear Code and Standards, the NRC requested ASME to revise the code to include the environmental effects on the fatigue design components.

Next slide.

ASME initiated the PVRC Steering Committee on cyclic life and environmental effects and the PVRC Committee recommended revising the code for design fatigue curves. This was to WRC Bulletin 487.

After more than 25 years of deliberation, there hasn't been any consensus regarding environmental effects on fatigue life on the light-water reactor environments.

The NRR requested research under user need requests to 504 to develop guidance for determining the acceptable fatigue life of ASME pressure boundary components with consideration of the light water reactor environment and this guidance will be used for supporting reviews of application that the Agency expects to receive for new reactors. The industry was immediately notified that the NRC staff initiated this work, the development of the reg. guide. In addition, this is one of the high priority reg. guides to be completed by March 2007.

In February and August this year, NRC

staff and ANL, we had presented at the ASME Code Meetings the technical basis draft, NUREG CR6909. On July 24, 2006, both the draft reg. guide and the NUREG technical basis report were published for public comments and the public comment period ended September 25.

In addition, on July 25, ANL presented a paper on the technical basis again.

CHAIRMAN ARMIJO: Just to clarify something, new reactors, does that include -- do these rules apply to already certified design, such as the ABWR and the AP1000? Are they grandfathered by virtue of their certification?

MR. FERRER: This is John Ferrer from NRR staff. They're grandfathered by virtue of their certification that's already been addressed in the reviews there, so we're not backfitting this reg. guide to those certified designs.

DR. SIEBER: For 40 years though.

CHAIRMAN ARMIJO: Well, actually, if you read the safety evaluation, the way it was written said that they were evaluated for 60 years.

DR. SIEBER: Okay.

CHAIRMAN ARMIJO: That's kind of an inconsistency in a way because they haven't been built in the United States and if they were being certified after this reg. guide is issued, that would be the rule -- that would control the design, wouldn't it?

MR. FERRER: I wish I -- I agree with you. Unfortunately, the way certified design works is once we certify it, we'd have to go through a backfit evaluation if we were going to apply this. And what happened in the backfit evaluation, if you go back a couple of slides on the GSI-166 and the GSI-190, we did a backfit evaluation and showed the risk was not high enough to justify a backfit, but the reason we implemented it on license renewal was the fact that the probability of leakage increased significantly within 40 and 60 years.

But again, the risk which is the probability of getting a pipe rupture that would lead to core damage was still low.

CHAIRMAN ARMIJO: Thank you.

MR. GONZALEZ: Now I am going to go to an overview of the reg. guide.

Next slide.

How the reg. guide 1.207 relates to the regulatory requirements. GDC criterion, general design criterion 1, quality standards and waivers. And the part says that safety-related systems, structures and components must be designed, fabricated, erected and tested to the quality standard commensurate with the importance of the safety function performed.

GDC-30 states, in part, that components included in a reactor pressure boundary must be designed, fabricated, erected and tested to the highest practical quality standards.

In 10 CFR 50.55A endorses the ASME boiler pressure vessel code for design of safety-related systems and components. These are Class 1 components.

ASME Code Section 3 includes the design fatigue, includes the fatigue design curves. But these fatigue design curves do not address the impact of the reactor coolant system environment.

The objective of this regulatory guide is to provide guidance for determining the acceptable fatigue life of ASME pressure boundary components with the consideration of the light water reactor environment for major structural materials that will be carbon steel, low-alloy steels, austenitic stainless steel and nickel-based alloys. For example, alloy-600, 690.

So in this guide, describes an approach that the NRC staff considers acceptable to support reviews about the applications that the Agency expects to receive for new reactors.

Implementation, this will only apply to new plants. And no backfitting is intended. And this is due to the conservatism in the current fleet of reactors because of the design practices for fatigue work conservatisms all plants were designed.

Next slide, please.

Now I'm going to -- how the technical basis was developed. Omesh is going to give the presentation on the technical basis report.

MR. CHOPRA: Thanks, Hipo.

DR. BONACA: I have a question regarding your last statement. No backfitting is intended, conservatism on coolant reactors. If the approach was conservative on coolant reactors, I mean could it be used also for new reactors?

MR. FERRER: Let me try to answer that. In reviewing GSI-166 which was backfit to current operating plants, we evaluated the as-existing fatigue analyses and there were a number of conservatisms in the specification of transients and the methodology and the analysis.

We don't know whether or not that same conservatism will be applied in the new reactors. In addition, there have been some changes in the ASME code criteria since those original analyses were done that removed some of the conservatisms in the analysis. So if somebody were to do code analysis to the current code criteria may not have the same level of conservatisms.

DR. BONACA: I understand. Thank you.

MR. CHOPRA: The issue we are discussing here today is effect of light water reactor coolant environments on the fatigue life of structural steels. Over the last 20 to 30 years, there's been sufficient data accumulated, both in the U.S. and worldwide, especially in Japan, which shows that coolant environments can have a significant effect on the fatigue life of these steels.

And this data is very consistent. It doesn't matter where it has been rated, all show similar trends without any exception. And also, the fatigue data is consistent with a much larger database on fatigue crack growth rates affect on environment of fatigue crack growth rates. There's no inconsistency. The mechanisms are very similar and both show similar trends, effects of radius parameters, material loading and environmental parameters have similar inference on fatigue crack initiation and fatigue crack growth.

And this fatigue data has been evaluated to clearly define which are the important parameters. They're well defined and also the range of these parameters for which environmental effects are significant, it's clearly defined.

So we know the conditions under which environment would have an effect on fatigue life. The question is do these conditions exist in the fleet? If they exist, we will have an effect on the environment and it should be considered. We know from subsection 31.32.21 that the current fatigue design curves do not include the effect of aggressive environment which can accelerate fatigue failures and has to be considered.

So the burden is on the designer to better define these transients, to know what conditions occurred during these transients and whether environment would be involved.

Next, before getting into the environmental effects, I just want to cover a few background information. We are talking about the effect of environment on fatigue life. Let's understand what do we mean by fatigue life? The current code design curves were based on data which was where the specimens were tested to failure. Quite often, these design curves are termed as failure codes, but I think the intent was to define fatigue life as to prevent fatigue crack initiation, because the data which has been obtained in the last 20 to 30 years in these results fatigue life is defined as the number of sitings for the peak load to decrease by 25 percent.

And for the type of specimen, size of specimens used in these tests, mostly quarter inch or three-eighth round cylindrical specimens, this would correspond to creating a three millimeter crack. So we can say the fatigue life is the number of cycles for a given strain condition to initiate a three millimeter crack and from several studies we know that surface crack, about 10 micron deep form quite early during fatigue cycling.

So we can say that fatigue life is nothing but it's associated with growth of these cracks from a 10 micron size to 3 millimeter size and typically this is the behavior of the growth of these cracks is in this shape where crack length is a fraction of fatigue life varies like this and it's divided into two stages, initiation stage and a propagation stage. Initiation stage is characterized by decrease in crack growth rates. It's very sensitive to micro structure.

It involves sheer crack growth which is 45 degrees to the stress axis, whereas propagation stage is not very sensitive to microstructure. It was tensile crack growth which is perpendicular to the stress axis and this is the stage where you see on the fracture surface well defined striations.

Various studies have shown that this transition from an initiation stage to a propagation stage occurs around -- depending on the material, 150 micron or 300 micron, that range.

So initiation stage is growth of crack up to 300 microns. Propagation stage is beyond that to 3000 or 3 millimeter size.

Next slide.

CHAIRMAN ARMIJO: Before you leave that curve, just for the benefit of people who don't understand these curves, what is the time difference between or the fatigue life difference from the three millimeter crack initiated crack to through-wall failure in the case of let's say a one-inch pipe, one-inch wall thickness?

MR. CHOPRA: We would use the crack growth rate data.

CHAIRMAN ARMIJO: Would that typically increase the number of cycles by a factor of 2 or a factor of 10?

MR. CHOPRA: It depends on the conditions, loading conditions and environment and so on. So we know what the crack growth rates are for various conditions. So we have to use that. But maybe I can answer another way. In a test specimen, the difference between 25 percent load drop and complete failure of a specimen is very small. It's less than one or two percent.

So whether we call it failure of a specimen or defining it 25 percent drop, would be very small difference. The idea of using 25 percent load drop was to be consistent so that we define life as some consistent -- all the labs do the same thing. So that was the idea.

Otherwise, for a real component, if we deal with three millimeter steel in a tube, it would depend on crack growth rates.

CHAIRMAN ARMIJO: Okay.

MR. CHOPRA: Now the same curve I've plotted a slightly different way where I plotted still our cracked growth rates was the crack depths, decreasing growth rates in the initiation stage and increasing growth rates.

Now of course, crack growth would depend on applied stress ranges. The higher the stress range, the higher the crack growth. The delta sigma one at very low stresses, the cracks which form during cyclic loading may not growth to large enough size that they can -- the propagation stage takes over.

DR. WALLIS: Crack velocity is really growth rate and microns per cycle, not per unit of time.

MR. CHOPRA: Right, but depending on the time period one could convert it to --

DR. WALLIS: I know, but velocity is a strange word.

MR. CHOPRA: Yes, maybe this should be crack growth rate.

DR. WALLIS: If there's no cycling, there's no crack growth.

MR. CHOPRA: Yes, yes. Beta sigma one, when the stresses are very low, cracks may grow to large enough size for the propagation to take over and this is known as the fatigue limit of the material. This is true for constant loading.

MR. BANERJEE: What's the mechanism that changes the velocity so much?

MR. CHOPRA: Initial sheer crack growth. It will extent maximum couple of degrees. So it's a sheer crack growth, 45 degrees, whereas, once you go deep enough, large enough size, you get into a different process where actually fracture mechanics methodology can be used to express that. It's a tensile crack growth.

MR. BANERJEE: It's a multi-grain sort of size and then it starts -- a different mechanism.

MR. CHOPRA: Typically, a couple of grains. Fatigue limit is applicable only under constant stress conditions. If we have random loading, as in the case of a real component, then we can have situations where we have higher stresses, few cycles of higher stresses, where cracks can grow beyond this depth that you can grow even at stresses which are much lower than fatigue limit.

So the history of cycling is also important for evaluating fatigue damage.

DR. WALLIS: Delta sigma is the magnitude of this?

MR. CHOPRA: Of the stress range, applied extracted stress range. And environment also.

DR. WALLIS: Does it matter if it's 10 silo or compressible?

MR. CHOPRA: On the tests which are used for obtaining fatigue data, the strain range ratio is

-1, completely reversed. So we go from tensile to compressive.

Even in environment, corrosion processes can cause the cracks to grow beyond this and then propagation can take over. So environment also could accelerate. So the question is which part -- which of these stages is affected by environment? Initiation or propagation, or both?

DR. WALLIS: Your scales are linear, are they?

MR. CHOPRA: This is a schematic.

DR. WALLIS: Schematic.

MR. CHOPRA: This portion is plotted here where I have actual numbers. And I just wanted to show you that we know from crack growth studies that crack growth rates are affected by environment and it's very well documented.

DR. WALLIS: These data look unreasonably well behaved for materials data.

(Laughter.)

MR. CHOPRA: If we plotted a few tests, we will see this happen.

CHAIRMAN ARMIJO: Agreement is log, log.

DR. WALLIS: Even so, I mean.

MR. CHOPRA: Anyway, effect of environment is also, has been studied in fatigue crack initiation.

DR. WALLIS: These are real data?

MR. CHOPRA: These are real data. But we have calculated the crack growth rates in the fatigue samples by benchmarking the fatigue crack front at different stages during fatigue life. And so we can see the three environments here: high oxygen -- high dissolved oxygen water; low dissolved oxygen; PWR water and air. And we see if you take 100 micron crack length and air -- it took about 3,000 cycles to reach that. In water, it took only 40 cycles, which gives me an average growth rate of 2.5 micron per cycle and this is this region here, average of this.

In this case, it's .0033 microns per cycle. So we see two orders of magnitude effect of environment which suggests that even the initiation stage may be affected even more than what crack growth rate is affected.

I just wanted to show you that both stages are affected by the environment, even the growth of very small cracks.

Now next, the design curves, what do the design curves --

DR. WALLIS: Presumably, this is not just one batch of data like this.

MR. CHOPRA: There's lots of data. I'm just giving --

DR. WALLIS: There's a whole lot of data.

MR. CHOPRA: I'm just giving you one set, yes. There's a lot of data.

DR. WALLIS: Because if there were uncertainty in these, these curves might switch positions.

MR. CHOPRA: sure, but I'm just presenting that data to show that environment has a large effect. It's the relative difference between air and water which I was trying to show, not absolute crack growth rates, just to show that it took only 40 cycles in high oxygen water compared to 3,000 which suggests that environment has a large effect on fatigue crack initiation.

Now the design curves, we have -- the data which we have obtained is on small specimens. They are absolutely smooth and they were tested in room temperature air. This is what was used to generate the design curves in the current code. And all of them were tested under strain control, fully reversed, strain ratio of -1.

Now this gives me the best behavior of a specimen when a crack would be initiated in a specimen. To apply those results to actual reactor component we need to adjust these results to account for parameters or variables which we know affect fatigue life, but are not included in this data. And these variables are mean stress, surface finish, size, loading history.

DR. WALLIS: Does the humidity of the air make a difference?

MR. CHOPRA: Actually, if you look at the basis document of the current code, they use a subfactor which included surface roughness and environment and by that environment they meant a lab, well-controlled lab environment.

DR. WALLIS: Does the humidity of the air make a difference?

MR. CHOPRA: In some cases it would, but again, that is not studied as a -- it's not addressed as an explicit parameter in defining fatigue life. All data which was used was room temperature air to generate the design curves.

DR. WALLIS: Room temperature means 20 degrees Centigrade or something?

MR. CHOPRA: Yes, 25, yes. To account for these other variables like mean stress, surface roughness and so on, what the current code --

DR. WALLIS: I'm sorry, when you -- maybe you just said it. When you say PWR water, you mean at room temperature or --

MR. CHOPRA: No, no. The design curves do not address environment at all.

DR. WALLIS: But your data that you showed us, the well-behaved data.

MR. CHOPRA: Those are higher temperatures.

DR. WALLIS: Those are higher temperatures.

MR. CHOPRA: They would be at reactive temperatures.

DR. WALLIS: Okay. Could be a temperature effect as well as an environment effect?

MR. CHOPRA: There is and I'll come to that actually. In water, temperature is a very important parameter. And to convert this data on specimens to a real component, what the current code does now is take the best --

DR. WALLIS: Is the PWR water that is borated at initial strength or something?

MR. CHOPRA: PWR is. It both has boron and lithium.

DR. WALLIS: There's some sort of average condition throughout the cycle?

MR. CHOPRA: Right, right. Typically, people test around 1,000 ppm boron and 2ppm lithium.

To adjust these curves to an actual reactor component, what the code does is we take the best of the specimen data and adjust it for mean stress correction and then apply these adjustment factors of two on stress. We decrease the specimen curve by a factor of two on stress and 20 on life, whichever is the lower gets the design curve. But as I mentioned, it does not include the effect of an aggressive environment. In this case, what we are talking about is light-water reactor environments.

Now to summarize some of the effects of environment on carbon and low-alloy steels, there are several parameters which are important. Steel type, all of the data shows irrespective of steel type, it doesn't matter which grade of carbon steel or low-alloy steel, effect of environment is about the same. There is a strain threshold below which environments do not -- environmental effects do not occur. And this threshold is very close to slightly above the fatigue life of the steel. Strain rate is an important parameter. There is a threshold, 1 percent per second above that. Environmental effects are more great and lower the strain rate, higher the effect. And it diffuses the saturation at around .001 percent per second.

Similarly, temperature is very important. Once again, there is a threshold; 150 degree C. Higher temperatures, there's greater effect. Below 150 --

DR. WALLIS: Strain rate's lowest point is .001 percent a second makes a difference?

MR. CHOPRA: Yes. I'll show you some of the results.

DR. WALLIS: Really? That's awfully slow, isn't it?

MR. CHOPRA: Some of the transients are.

DR. WALLIS: Abnormally slow.

MR. CHOPRA: Temperature also, there is only a moderate effect below 150. Typically, when I mean moderate effect, up to a factor of 2. Any water touched surface may have up to a factor of --

DR. WALLIS: Linear decrease doesn't tell me how fast it is. Linear decrease in life after 150 doesn't tell me how rapidly it decreases.

MR. CHOPRA: There are some slides, I'll show you how much of a different it is.

MR. SANTOS: Do you have an equation?

MR. CHOPRA: Yes.

DR. WALLIS: Which goes right through the data?

MR. CHOPRA: Absolutely.

DR. WALLIS: Is this an Argonne equation or a universal equation?

CHAIRMAN ARMIJO: You'll see.

DR. WALLIS: We'll see, okay.

MR. CHOPRA: Dissolved oxygen is also similar. There's a threshold. In this case, low oxygen environmental effects on carbon low-allow steels are less. There's a threshold .04 ppm. Higher dissolved oxygen has an environmental effect, saturates around .05 ppm.

DR. WALLIS: How much sulfur is there in the reactor?

CHAIRMAN ARMIJO: That's in the steel.

DR. WALLIS: In the steel, I'm sorry. I thought you were talking about the environment. Now you're talking about the steel?

MR. CHOPRA: These are --

DR. WALLIS: Dissolved oxygen in the steel.

MR. CHOPRA: These are loading parameters. Some are environmental parameters. Some are material parameters.

DR. WALLIS: Okay.

MR. CHOPRA: Sulfur also has a large effect on fatigue crack initiation.

DR. WALLIS: There's no other effects, copper and stuff like that? There's no other effects?

MR. CHOPRA: In the steel? No. At least the ones which we have looked at. Sulfur is the one because it deals with the mechanism. Actually, the reason why these are higher for carbon and low-allow steels which these are very well documented. It's the sulfite iron density of the cracking. If we reach a critical sulfite iron density crack enhancement occurs. So these are very well documented in the data. This is a mechanism. That's why sulfur is important.

Roughness effects, we know if we have a rough specimen surface it provides sites for initiation. Life goes down. And in carbon low-alloy steel, in air, there is an effect of surface roughness, but some limited data suggests that in water, rough and smooth specimens have about the same life. So roughness effects may not be there for carbon low-alloy steel.

Flow rate also, most of the data has been obtained on very low flow rates or semi-stagnant conditions. If we do these tests in higher flow rates, effect of the environment does go down. Means fatigue life would increase in high flow rates by a factor of about 2.

Similarly, the effects on austenitic stainless steels, same parameters, steel type, again different grades of austenitic stainless steel, similar effects and even cast austenitic stainless steel have similar effects on the environment.

Once again we see a strain threshold below which there is no effect and it's very close to the fatigue limit. The dependence of strain rate and temperature are very similar to what we see in carbon and low-alloy steels.

The next three, dissolved oxygen, surface roughness and flow rate, the effects are very different from carbon and low-alloy steels. In this case, for austenitic stainless steel, it's the low oxygen which gives you a larger effect. And irrespective of what steel type we use or what heat treatment, heat treatment that means sensitization. Sensitized stainless steel or solution in the stainless steel both show similar life in low oxygen.

DR. WALLIS: That extends down to zero

oxygen?

MR. CHOPRA: Pardon me?

DR. WALLIS: That extends down --

MR. CHOPRA: If we can achieve that, you know, but typically in a PWR, we have around -- it's a low -- less than 50 ppm.

Yes, low oxygen, irrespective of the steel type or heat treatment, there's a large effect on environment, but in high oxygen, non-water chemistry, PWR conditions, some steels show less effect and these are solution annealed high-carbon steels which are not sensitized. All low carbon grades such as 316 nuclear grade or 304 L may have less effect in high oxygen.

Surface roughness and this is both in air and water environments, there's a reduction in life. Even in water. In carbonate steel we did not see a reduction in life for rough samples. In this case, both in air and water there is an effect of roughness. And flow rate, there is no effect of flow rate on fatigue life for austenitic stainless steels in water.

The differences between these three suggests that the mechanism may be different for austenitic stainless steels compared to carbon and low-alloy steel. I mention the mechanism for carbon and low-allow steels, the sulfite iron density of the crack depth. In this case, it's not well known -- there's no agreement on what is the mechanism. One possible mechanism would be that as we expose stress surface, hydrogen is created which changes the definition of behavior and of the crack depth. But this is one possible mechanism.

The next slides are details of what I summarized. Unless there are specific questions, I'm going to skip these next eight slides which basically give the data which I summarized in the previous.

CHAIRMAN ARMIJO: I think it would be better if you just highlight these things, just to make the key points from these charts because I think they're important.

MR. CHOPRA: This is the strain rate effect. You were asking about the strain rate. I plotted fatigue life for low-alloy steel, carbon steel under certain conditions, strain amplitudes. In air, PWR water and BWR.

DR. WALLIS: Are you claiming there's a significant difference between air and PWR?

MR. CHOPRA: It's up to about a factor of 2 and this could be a factor of 15 or 20 lower

DR. WALLIS: We're not going to put in that much oxygen, are we?

MR. CHOPRA: BWR has 200 to 300 ppb oxygen and in this case, there are correlations which will tell you how much -- depending on the oxygen, what would be the effect.

This is the maximum effect because this is I think .7. Saturation is at .5. So this is the maximum effect under these conditions.

This is strain threshold which I mentioned, the threshold about which effect of environment is there. This gives you dissolved oxygen at .04, this is carbon steel, higher oxygen levels, things go down. And again, in PWR there's only a modern effect.

I mentioned that for stainless steel, the effect of dissolved oxygen is different. Here, this is now three or four stainless at two different strainless amplitude. There are two different tests at different conditions, .25 and .33 and high oxygen, no effect upstream rate and low oxygen, it goes down. Whereas, a 316 NG or low carbon grade shows some reduction in life in high oxygen, but not at the same extent as you see in low oxygen.

So these are just a few examples I'm showing. There's a lot of data in Japan and Europe which shows similar trends. This shows the effect of sensitization. Sensitization is defined as a number, EPI number. Degree of sensitization is increasing and same conditions. In air, low oxygen, high oxygen and we see in high oxygen it decreases with degree of sensitization.

Effect of -- this is temperature again at 150 and lower, depending on what are the strain rates and what are the dissolved oxygen conditions. If it's very low, no effect. These are low oxygen conditions, no effect. High oxygen, depending on the strain rate and dissolved oxygen levels to the extent of the effect in pieces.

DR. WALLIS: You're just talking about a hundred cycles there, failure.

MR. CHOPRA: No, a thousand. In some cases in the environment, it is.

DR. WALLIS: Right.

MR. CHOPRA: There is up to a factor of 20 reduction in life.

Surface roughness again, stainless steel, open circles, smooth specimens; closed circles are symbols are rough samples. A factor of 3 in air, factor about the same in water.

CHAIRMAN ARMIJO: I don't want to belabor this, but I looked at these data and the one that shows -- the curve on the left for the air data, the right triangles. They don't go through the best fed curve at all.

MR. CHOPRA: Actually, this is 316 NG. 316 NG has a steeper slope, but for convenience we are using a curve for all steels.

CHAIRMAN ARMIJO: So that's the best fit curve there is for all --

MR. CHOPRA: All stainless steels, all grades, including high or low-carbon grades.

DR. WALLIS: The purpose of the ASME curve is to be below all the data, is that the idea?

MR. CHOPRA: Once we take into account, you know I mentioned those adjustment factors of 20 on fatigue and 2 on stress. Once we take that into account, once we do that adjustment, then we want to make sure that we are above that.

But these are best fit curves. So they give you the average behavior for all --

DR. WALLIS: The ASME code has a factor of 2 in it or something? I don't see that.

MR. CHOPRA: I'll come to that. Give me a --

DR. WALLIS: Okay. But the factor of 2 is in this curve here?

MR. CHOPRA: No, these are --

CHAIRMAN ARMIJO: ASME codes.

MR. CHOPRA: The code curve has the factor of 2.

DR. WALLIS: No safety factor.

MR. CHOPRA: This is the best fit. These are showing that even --

DR. WALLIS: Oh, I see. So you've give up your margin of 2?

MR. CHOPRA: Right.

DR. WALLIS: Okay.

MR. CHOPRA: What we are saying is only the margin or adjustment factors are gone for the --

CHAIRMAN ARMIJO: That's it.

MR. CHOPRA: Environment has taken care of all that and still be within bound for a lot of other factors like surface roughness and so on.

DR. WALLIS: You're going to tell us what you're going to do about that?

MR. CHOPRA: Sure.

DR. WALLIS: Okay.

(Laughter.)

CHAIRMAN ARMIJO: Absolutely.

MR. CHOPRA: This gives you the effect of flow rate. I mentioned that for carbon and low-alloy steels, effect of environment is less.

Now a few slides for nickel alloy. There's much less data on nickel alloys. Here, I've plotted the data which is available --

DR. WALLIS: Much less data. So you're showing us more than you showed us for steel?

MR. CHOPRA: What we do is rather than coming with a new curve for nickel alloys, unless we have enough data, what I'm trying to show is that we can use the austenitic stainless steel to represent the nickel alloys and even the few data we have for alloy 690 suggests that we can use the austenitic stainless steel code to determine usage factors, fatigue usage factors for nickel alloys in air.

MR. BANERJEE: So temperature has almost no effect here.

MR. CHOPRA: For carbon and low-alloy steels there is some effect. Going from room temperature to 300 may reduce life by about 50 percent, but stainless up to 400. There's not much effect.

MR. BANERJEE: Including nickel alloys?

MR. CHOPRA: Nickel alloys, no. At 400, in fact, they show longer life. But again, the data is very limited. There's few data sets at 400 which actually show longer life for alloy 600. But again, at present, since all curves are based on room temperature data, we are not taking any temperature dependence for air. But for water effects, temperature is important and explicitly defined in the expressions to calculate fatigue life in water.

DR. WALLIS: That means it is through the median of the data in some way?

MR. CHOPRA: I'll show you how we got the best fit curves.

DR. WALLIS: It's supposed to be an average right through the middle of the data.

MR. CHOPRA: Right.

DR. WALLIS: It's not best fit to a 95 percentile or something like that? You'll get to that too, but what you're showing here is --

MR. CHOPRA: Average, right. These results show nickel alloy data for alloy 600 and some of the welds. In BWR, normal water chemistry, BWR environment and PWR environment and again, what we see is the effects are similar to what we get for austenitic stainless steels. There's larger effect in low oxygen than in high oxygen. PWR environment has larger effect than BWR, but the focal effect is much less than what you would see for austenitic stainless steel.

Typically, under certain conditions in austenitic stainless steel we see a reduction of a factor of 14 or 15. In this, the maximum is a factor of 3. So the effect is much less, but we can use this limited data to define the important parameters and how to estimate environmental effects.

Now we have all this data. How do we generate the expressions? All -- in air, all data, fatigue data I expressed by this modified Langer equation where fatigue life is expressed in terms of strain amplitude and these constants A, B, C --

DR. WALLIS: Is this an equation because you plotted the data on log paper, is that why it is?

MR. CHOPRA: This is the expression used and it presents the data best.

DR. WALLIS: It's because you plotted it on log paper. It looks good on log paper and it's linear.

MR. CHOPRA: Well, the trend is also -- it does represent the trend.

DR. WALLIS: Okay.

MR. CHOPRA: And C is the fatigue limit or related with the fatigue limit of the material. B is the slope of that curve. A is a constant which would vary with heat to heat. Depending on a more resistant material would give a higher A or lower means it's less resistant to fatigue damage.

We can do a best fit of the data and also use this A to represent heat to heat variability and come up with a median value, how median material would behave. Best fit gives me the average behavior, whereas a distribution would give me how various materials behave and I get a median curve and then come up with a number which would bound 95 percent of the materials. And that's what I'm going to show.

One more thing, another term, D can be added to impute in 1, which would include parameters like temperature, strain rate and so on.

DR. WALLIS: Does the ASME curve have a similar equation?

MR. CHOPRA: Yes. The Langer equation is very -- yes.

This shows for low-alloy steels in air and water various heats. Now each did define even if I have 10 data points, it's 1 point. Another may have 500 data points. But if it's the same material, it's just one point on this plot. This way, I can give you, we can determine the median value for the materials and if I select a fifth percentile number, in this case, 5.56, if I select the A or 5.56, that curve would bound 95 percent of the --

DR. WALLIS: It's the coefficient.

MR. CHOPRA: So this is how we obtain the design curve by defining what subfactors I need to adjust the best fit curve for average curve to come up with a design curve which would bound 95 percent of the materials.

I'll give the loca probability of track initiation.

MR. BANERJEE: There's B and C as well, right?

MR. CHOPRA: B and C, what I do is use it for normalizing to get A for each heat which is the average heat and I get a standard deviation. That's what I've plotted here. For the particular heat, I've given the average value and the standard deviation for the data set.

MR. BANERJEE: You lost me.

CHAIRMAN ARMIJO: B and C are relatively constant.

MR. CHOPRA: A is the one that changes.

MR. BANERJEE: So you fix B and C to some value?

MR. CHOPRA: Right, right. And we know even environment does not change. The strain threshold was close to fatigue limit so I don't have to change the fatigue limit. And there is no data which suggests that C changes, means that the fatigue limit changes for material.

DR. WALLIS: The range of that is not very big, but if N is E to the A, so it's a factor of about 10 on the whole range.

MR. CHOPRA: Right.

MR. BANERJEE: Do B and C govern the shape of the curve?

MR. CHOPRA: Yes. Right. The slope is B. C is where at 10^6 or 10^7.

DR. WALLIS: I see where it's flat.

CHAIRMAN ARMIJO: So all the environmental effects are just put into the A constant?

MR. CHOPRA: Right.

CHAIRMAN ARMIJO: Okay.

MR. CHOPRA: Now we come up with these expressions which can be used for predicting fatigue life under various conditions. Again, Langer equation A, constant A; slope B and C. And this is the environmental term B which would have these -- which would depend on these three parameters for carbon low-alloy steel, same for content, given by these expressions, temperature, dissolved oxygen and strain rate.

CHAIRMAN ARMIJO: Now the A is the five percent number?

MR. CHOPRA: No. These are still the average numbers.

CHAIRMAN ARMIJO: These are average numbers.

MR. CHOPRA: Next, I'll get to where we apply those adjustment factors to get the design growth.

DR. WALLIS: What does N mean here?

MR. CHOPRA: Cycles --

DR. WALLIS: Environment. N for environment, is that PWR?

MR. CHOPRA: No, this is in error what the expression is. This is in the light water reactor.

DR. WALLIS: Okay.

MR. CHOPRA: It doesn't matter whether it's BWR or PWR because these are the parameters which will change in various environments, reactor environments.

MR. BANERJEE: Is there no effective hydrogen on it at all?

MR. CHOPRA: In BWR environment, there's about 2 ppm dissolved hydrogen, but I think it's the hydrogen which is created by the austenitic reaction which is more important than what is -- it does control ECP, the electrical potential of the environment. So hydrogen would change the ECP, but below -250 electrical potential, effects are not that much different. But you know, in crack growth rates there is some effect, depending on -- well, in this case all -- we use only 2 PPM hydrogen.

MR. BANERJEE: These are all done in autoclaves or whatever?

MR. CHOPRA: And we do simulate these conditions. BWR, it's high oxygen, high purity, very high purity. And pressurized water reactor, again high purity. Then we had boron or boric acid to get boron, 1,000 PPM and 2 PPM lithium, by adding lithium hydroxide. And measure the pH. We measure the conductivity and maintain all these water chemistry parameters constant during the test.

CHAIRMAN ARMIJO: These are flowing a loop type --

MR. CHOPRA: Very small flow rates. I think if you look at the -- my plot, they would amount to 10^{-5} meter per second. Very low.

CHAIRMAN ARMIJO: They're not static autoclaves?

MR. CHOPRA: They're not static and they are continuously reconditioned. So if they are, it's once through. They're not repeated.

DR. WALLIS: How long are the tests done typically?

MR. CHOPRA: Depends on the conditions. At low strain amplitudes and low strain rates, it may take up to 5 to 8 months and those results are very limited. In the range which people have -- we have tested .25 to .4 strain amplifies, it can take anywhere from a few days to a month or two, depending on the environmental effects. In air, they're much longer. So one has to consider all of these. We can't just dedicate and that's why you see very low, less data under conditions which have very long durations.

Now I just want to mention that these expressions are average behavior after median material. Same thing for rod and gas stainless steel. Now as you mentioned that the slope of the 360 NG was different, what we have done is we have used a single expression to represent all grades of steel and this number, the fatigue limit we chose what studies in

Japan have established. And Jaske and O'Donnell in 1978 pointed this out that the current design curve for stainless steel was not consistent with the experimental data.

DR. WALLIS: I want to check this about oxygen. You say it's worse to have less oxygen?

MR. CHOPRA: Pardon me?

DR. WALLIS: N goes down when you have less oxygen?

MR. CHOPRA: In stainless steel, life goes down dissolved oxygen is low.

DR. WALLIS: But these it goes the other way?

MR. CHOPRA: No. The oxygen, there's a constant factor --

DR. WALLIS: In the one before, the carbon and low-alloy steels?

MR. CHOPRA: Yes. Now in carbon and low-alloy steel it's the high oxygen which is more damaging.

DR. WALLIS: Then it doesn't make -- okay, okay. That's right. Okay. Because I thought it was the other way around. That's a negative --

MR. CHOPRA: The strain rate term is a negative.

DR. WALLIS: That's right. I was crawling through that and then I was trying to go back to before.

MR. CHOPRA: Actually, this whole term is --

DR. WALLIS: I understand that. Just before, but the other with the stainless steel, the low oxygen is bad.

MR. CHOPRA: Right.

DR. WALLIS: Okay, that's what I'm trying to --

MR. CHOPRA: I just mentioned that we established a single curve and this we selected from what was proposed by these studies.

Now we have the specimen data. We know how to predict what will happen with specimens.

DR. WALLIS: What effect does this have on welds of dissimilar metals?

MR. CHOPRA: Welds have different --

DR. WALLIS: All together different?

MR. CHOPRA: Yes.

DR. WALLIS: Is there some basis for that?

MR. CHOPRA: It depends on the data.

DR. WALLIS: You're not addressing that?

MR. CHOPRA: No. This is the current code design curves for these grades or types of structural steel.

CHAIRMAN ARMIJO: For example, a welded stainless steel is like a cast stainless steel, a weld --

MR. CHOPRA: I think the behavior is very similar. But --

CHAIRMAN ARMIJO: If it's similar, there's a difference.

MR. CHOPRA: Because in some cases there may be difference. We are just looking at here the rod products.

CHAIRMAN ARMIJO: Stainless.

DR. WALLIS: Is there any effect of fluence on this?

MR. CHOPRA: Irradiation? I'm sorry, I didn't get that?

DR. WALLIS: Is there any effect of fluence?

MR. CHOPRA: We're not studying that. There is an effect, but that's not -- in the design curve --

DR. WALLIS: It's all synergistic.

MR. CHOPRA: No environment is considered and the designer has to account for other environments which are not considered in their design.

We have the data for specimens. Now to use it to come up with a design curve for components, I mention that they apply this adjustment factor of 20 on life and this factor is made up of effects of material availability, data scatter, size, surface finish, loading history.

In the current code, these are the subfactors which are defined in the basis document. Loading history was not considered, a total of 20 adjustment factors. In our study, based on the distribution I showed for individual materials, this subfactor can vary anywhere from a minimum of 2.1 to 2.8. These numbers are taken from studies in the literature. Size can have an effect, minimum 1.2, 1.4 and so on. So we see a minimum of 6, maximum of 27. When we take a large number, for example, 20, what we are basically saying is I have a very bad material which is very poor in fatigue resistance. I have rough surfaces and I have the worse loading history.

So we used a Monte Carlo simulation and using these as a log normal distribution to simulate what would be the best adjustment needed to define the behavior of components.

CHAIRMAN ARMIJO: So the present study,

you've agglomerated the date for carbon steels and austenitic stainless steels and all these factors are all pushed together.

MR. CHOPRA: Right.

CHAIRMAN ARMIJO: But you've separated them. Are they different?

MR. CHOPRA: No, these are not the effects of materialability is here and that depends on the material. But effects of surface finish of the component, size of the component or loading history means random loading, high stress cycle followed by low stress cycles. These -- in the current data, these effects are not included. So somehow I need to include these effects to come up with a design curve which would be applicable to a real actual reactor component.

Now the question is 20 was selected with some basis. Is this reasonable because quite often, this is what is being questioned. There may be conservatism in this which we need to eliminate. So we are trying to see what possible conservatism might be there in this margin or the adjustment factor of 20.

DR. BONACA: Twenty was arbitrarily taken as a bounding number, right?

Where did you get the 27?

MR. CHOPRA: I just took from the literature what people have observed, effect of surface -- surface finish is very well documented. Depending on the average surface finish, an autonomous value of surface finish, they have a harmless reduction in light. So I can use typical finish for grinding or milling operation and so on. It's well documented. We can come up with what would be a typical fabrication process, minimum and maximum. So that's how we came up with this number.

DR. WALLIS: What is the basis of the numbers? Is it trying to bound the data or bound the 95th percentile?

MR. CHOPRA: To come up with a design curve which will be applicable to components.

DR. WALLIS: What's the basis of this? Is there a rationale?

MR. CHOPRA: Right, 95 percent.

DR. WALLIS: Ninety-five, 99, 95?

MR. CHOPRA: Ninety-five?

DR. WALLIS: Why is 95 good enough?

MR. CHOPRA: Well --

DR. WALLIS: Why not 99?

MR. CHOPRA: We can do a statistical

analysis to see what are the probabilities.

CHAIRMAN ARMIJO: I think 95/5 basis is sort of a typical basis we've used in a lot of other studies on failure data. But the reason that 95/5 is okay is we've already done risk studies with fatigue cracks initiating and growing to failure and growing to leakage and the fact of a 95/5 probability of fatigue crack initiation still keeps you in acceptably low probability of getting a failure.

DR. WALLIS: Okay, so it's related to the overall --

CHAIRMAN ARMIJO: Overall margin, yes. If it were just a 95/5 to failure it would be an unacceptable criteria.

DR. WALLIS: If the consequence were much worse, you'd need to have a --

CHAIRMAN ARMIJO: Yes.

MR. BANERJEE: Can you expand a bit more by what you mean by this log normal distribution?

MR. CHOPRA: We assumed that the effects of all of these parameters have a log normal.

MR. BANERJEE: Of some mean?

MR. CHOPRA: Right. And I took these two ranges as the 5th and 95th percentile of that distribution.

MR. BANERJEE: So what happens if you chose a different distribution? Does it make any difference to the results?

MR. CHOPRA: We have tried three different, I think Bill tried and this gets the best --

MR. BANERJEE: Best in what sense?

MR. CHOPRA: Very consistent result. There's not much difference between normal and log normal was not much difference. And log normal -- you want to --

DR. SHACK: It's basically sort of an arbitrary engineering judgment question. Experience has indicated that when we have enough data, these things do seem to be distributed log normally.

We generally don't have enough data, actually, to determine the distribution. So we have sort of just made the engineering judgment that the log normal is close enough.

As John was explaining --

MR. BANERJEE: It doesn't affect the results.

DR. SHACK: It doesn't affect the results very much. What we're trying to do is to bound the data in some reasonable fashion because the consequence is not core damage when we're done. The fact that we're not highly precise on this is not something that concerns us, but we think we've built in sufficient conservatism to account for these variables in a sensible way without going overboard.

And the fact that these affects can be considered as independent is also something we don't have data on. We have to sort of work on an engineering judgment basis. So the Monte Carlo simulation that we do assumes the log normal distribution, assumes the independence.

MR. CHOPRA: I want to add one more, quite often, actually in the welding research that WRC Bulletin by industry, they are suggesting that in this margin of 20, we can use a factor of 3 to offset environment. This kind of analysis can suggest or show that 3 number is very high. We do not have that, at least what is the possible --

DR. KRESS: Is it a theoretical basis for assuming the log normal? There may be, you know. You can look at the physical phenomena and --

DR. SHACK: Well, the loading, probably --

DR. KRESS: Loading you would think would be log normal. I'm not sure about the effects of the other things.

DR. SHACK: The log normal turns out to be slightly more conservative than the normal and so those were my -- if I don't have enough data to define a distribution --

DR. KRESS: You might as well use --

DR. SHACK: I pick one or the other, sort of on some sort of engineering judgment. The differences are not very large between the two and we just pick the log normal.

DR. WALLIS: If you know the distribution, why do you need -- if you know the equation for the distribution, why do you have to do a Monte Carlo analysis?

DR. SHACK: Because I'm taking a bunch of random variables.

DR. KRESS: That's the way you find the mean, right?

MR. CHOPRA: There are four or five of these things.

DR. SHACK: There are four or five distributed variables.

DR. WALLIS: Easier to do it than to try to go through the mathematics of predicting.

DR. SHACK: Yes, it's easier. Yes, I could do it the other way, right.

DR. KRESS: Is the 95 value four times the mean?

DR. SHACK: No.

DR. KRESS: It has to be if it's log normal.

DR. WALLIS: Four times the mean on a constant A would be horrendous.

DR. KRESS: You've got to find the mean value.

DR. WALLIS: Mean value is about five.

CHAIRMAN ARMIJO: Let's move on.

MR. CHOPRA: Doing this simulation, we get these curves where this dash curve is now for the specimen, the distribution of A for the specimen and solid would be the distribution for the real component. And we see that the median value has shifted by about 5.3.

And 95 of 5th percentile is a factor of 12. So we can say that in this factor of 20, there is some conservatism and we can use adjustment factor of 12 on life instead of 20.

DR. WALLIS: Where did 20 come from?

MR. CHOPRA: It's in the design basis document of the current code.

DR. WALLIS: It's the judgment of a few

wise men?

CHAIRMAN ARMIJO: Many years ago.

MR. CHOPRA: Basically, that's what it was.

MR. BANERJEE: Not so bad.

MR. CHOPRA: The design has several -- yes.

I've covered -- there is some conservatism in the fatigue evaluations and often this conservatism is used to offset environmental effects and there are two sources of conservatism, in the procedures themselves, the way we define design stresses and design cycles or this adjustment factors of 2 and 20.

I showed there's not much margin, only 1.7 in this factor of 20, but the current code procedures --

DR. WALLIS: Is there enough to account for environmental effects?

MR. CHOPRA: No, environmental effects can be as high as a factor of 15.

DR. WALLIS: Yes.

MR. CHOPRA: Or carbon C would be even higher.

DR. WALLIS: These are all reactor data you've got, right?

MR. CHOPRA: Those are -- unless you define the operating transient conditions. In certain conditions those may be possible, but again, it's up to the designer to define what are the conditions during a transient, mean strain rates, temperatures and so forth.

MR. BANERJEE: But I'm wondering whether in your database you have anything which you've evaluated from N reactor data or reactor data. Do you have any information at all?

MR. CHOPRA: There are some components and so on and I list a few examples where there have been some studies. And I'll show you near the end of this.

DR. SHACK: The trouble with doing this with field data is it's hard to control variables like knowing that the strain range and because that has such a strong effect on it. Unless you know that accurate, it's hard to back out the result.

MR. CULLEN: Bill Cullen, Office of Research. I'd like to explore Dr. Banerjee's question a little more to find out what's behind it.

Are you concerned about irradiation effects which really do not come into play for pressure boundary? Or are you concerned about the actual aqueous environment and its characteristics?

I'm not sure -- what is the basis?

MR. BANERJEE: Well, the basis is more -- it would be nice to see some validation under field conditions. There are always sort of surprises between the lab and what happens in the field and even if this sort of validation is not all that thorough, a couple of data points would set your mind at rest that it's not some unexpected factor that comes in.

It's more like -- I have a concern always of going from the lab to a real field situation. It's not for any specific issue, not like radiation or combination of factors or boron plus temperature in fatigue cycles which are slow. All these things may or may not be there but just a general question, more a general question.

MR. CULLEN: I understand the general question. I'm a little concerned about your word about there always are surprises when you go from the laboratory to the actuality.

MR. CHOPRA: Maybe that's too strong.

MR. CULLEN: A little bit.

(Laughter.)

DR. WALLIS: Oftentimes, surprises may be small.

MR. CULLEN: Thank you.

MR. BANERJEE: I don't mean to say that this stuff should not be used or anything. Right.

MR. CHOPRA: I mentioned that in fatigue evaluations the procedures are quite conservative, but the code allows us to use improved approaches, for example, finite element analysis, fatigue monitoring to define the design stresses and cycles more accurately. So most of this conservatism can be removed with better methods for defining these design conditions.

So in that case, there is a need to address the effect of environment explicitly in these procedures.

Now the two approaches which we can use either come up with new set of design curves or use some kind of correction factor, F_{en}. Now since environmental effects depend on a whole lot of parameters, temperature, strain rate and so on, either we come up with several sets of design curves to cover the possible conditions which occur in the reactor or field conditions or if you use a bounding curve, it would be very conservative for most of the conditions.

Whereas this correction factor, F_{en} approach is relatively simple. You can -- it's very flexible. You can calculate the environmental effects for a specific condition. And this is what is being proposed in this reg. guide.

The correction factor is nothing, and this was proposed in 1991 by the Japanese. A correction factor is nothing but a ratio of fatigue life and air versus life and water. So we have these expressions I showed you in the previous slides and we can then calculate F_{en} for different steels, carbon steel, low-alloy steel, and below a strain threshold there's no environmental effects, so the correction factor would be one.

Other than that, we use these expressions, actual conditions, temperature, strain rates and so on to calculate the correction factor. To incorporate environmental effects, we take the usage, partial usage factors obtain for specific transients in air, U1, U2 and so on, multiplied by the corresponding correction factor and we get usage factor in the environment.

Now to calculate usage factors in air, we should use design curves which are consistent with or conservative with respect to the existing data. And as has been pointed out quite a few years back, the current code curve for stainless steel is not consistent with the current existing data and should not be used for obtaining usage. And I just want to show before I get to that, these are the expressions for nickel allows. Correction factor, again, as a function of these three variables. And usage and air would be obtained from the curve for austenitic stainless steels.

Now I mentioned that the current design curve for austenitic stainless steel is not consistent with the data. I plotted the fatigue data for 316, 304 stainless in air, different temperatures and this dashed curve is the curve, current code mean curve. This is the mean curve which was used to obtain the design curve.

DR. WALLIS: Where is your design curve?

MR. CHOPRA: Design curve would be what you adjust this curve for mean curve correction.

DR. WALLIS: Your recommended curve would actually bound the data, wouldn't it?

MR. CHOPRA: This is the best -- actually, this data, the curve is based on austenitic stainless steel.

DR. WALLIS: I thought you were recommending a bounding curve with this factor.

MR. CHOPRA: I'm just trying to show that the current --

DR. WALLIS: What's your design curve? You should show that, shouldn't you?

MR. CHOPRA: These are mean curves.

DR. SHACK: This is air data, mean curve. If we put a design curve on here, we could have a design curve in air and a design curve in --

DR. WALLIS: There's all this air data. Are you going to get to your -- it's so far down the road, I can't -- okay.

CHAIRMAN ARMIJO: I think he's just trying to show the difference between the two sets of means.

MR. CHOPRA: That the current means --

DR. WALLIS: You do show the effect of the F factors yet.

MR. CHOPRA: No. I'm just trying to show --

DR. WALLIS: We've just been talking about --

DR. SHACK: What he's trying to demonstrate here is that the F factor requires him to take the ratio in air. He's got to have the right air curve.

MR. CHOPRA: And the current mean curve for air, for austenitic stainless steel, is not consistent with the data.

Now I'd like to mention one thing, it's been suggested that this curve, the data may be different from the mean curve because of the way fatigue life has been defined or the way we conduct experiments. I can assure you that this difference in the mean curve and the data is not due to any artifact of test procedures or the way the fatigue life is defined in terms of failure or 25 percent load drop.

DR. WALLIS: What occurs to me is the ASME code mean curve was a mean curve to something.

MR. CHOPRA: Right.

DR. WALLIS: And it was presumably through other data.

MR. CHOPRA: This curve, the current code curve was based on very limited data. Now we have much more. So I'm just showing that the data which has been obtained since then is not consistent with what we have.

DR. WALLIS: You have a much broader data base.

MR. CHOPRA: Right.

DR. WALLIS: Okay, that's why yours is better?

(Laughter.)

MR. CHOPRA: We are saying we should

change the current code curve. The current code curve is not consistent with --

DR. WALLIS: It must have been based on something.

MR. CHOPRA: And that data is somewhere in here, up here. But since then we have much more data.

DR. WALLIS: Either that or steels have been getting weaker.

MR. CHOPRA: Actually, that is the reason. Mostly like because of the strength of the steel, probably these curves were obtained on steel which was stronger.

DR. WALLIS: Wait a minute --

MR. CHOPRA: Possible difference.

MR. CULLEN: Bill Cullen, Office of Research again. Omesh, if you could go back to that, I'd like to also point out that the curves on which the original ASME code were based I think the data only went out to a factor of about, fatigue life of 10^6 or something.

MR. CHOPRA: Not even 6.

MR. CULLEN: So you've got two orders of magnitude extrapolation there that we're doing now to illustrate. But the other thing again is those tests were all done at room temperature and you're showing data from a wide variety of temperatures up to and including operational.

MR. CHOPRA: Stainless does not --

MR. CULLEN: Doesn't show much difference, right. To me, that's kind of the point. It all hangs together on the lower curve.

MR. CHOPRA: This difference is genuine. We need to use a different curve. And we have now proposed a design curve for air for austenitic stainless steels, the solid line. The current dashed line is the current code of 10^6 and the high cycle extension in the code. And the solid line curve is based on the Argonne model plus adjustment factors of 12 on life and 2 on stress. It's not 20 and 2. It's 12 and 2.

DR. WALLIS: Now the kink that you have here at 10^6 doesn't appear in the previous curve you showed.

MR. CHOPRA: The design curve extends only up to 10^6.

DR. WALLIS: So you've just extrapolated it here in your figure?

MR. CHOPRA: Yes, because now there is a need to go all the way to 10^{11}.

DR. WALLIS: But you're saying mean curve, so where do you stop at 10^6?

CHAIRMAN ARMIJO: Two different things here, hold on.

MR. FERRER: This is John Ferrer. I think originally the stainless steel curve went out to 10^6. Later, they got more data at high cycles and the data was clearly showing that there was a drop off and so they -- this is an artifact of fairing the two curves together and the new correction we're doing really is straightening out what they should have straightened out to begin with.

DR. WALLIS: Well, it's a curve, it can't be straightened out.

(Laughter.)

MR. FERRER: Fur the earlier slide was the man curve through the data. Now we are talking about the code curve which would include these factors.

DR. WALLIS: Okay.

MR. GURDAL: There is still a curve A, B and C.

My name is Robert Gurdal. I'm AREVA, Lynchburg, Virginia. Those curves is because before just now there are three curves, there is A, B and C and they are not indicated there. I just wanted to be sure everybody knows.

The reason you have the lower one which is called a curve C --

MR. CHOPRA: But the region which we are talking about is this 10^6 to 10 --

MR. GURDAL: You go above 10^6, you have a curve A, curve B and curve C.

MR. CHOPRA: I have plotted that.

MR. GURDAL: The correct curve is curve A which is the top one.

DR. WALLIS: So it's C on this figure and it's A on the previous figure.

MR. GURDAL: Maybe, it could be.

DR. WALLIS: Maybe. It probably doesn't matter that much.

MR. GURDAL: And the C is for the heat affected zone compared to the A.

DR. WALLIS: This is the A in this one.

MR. GURDAL: That one could be the A, because it does not have the kink.

MR. CHOPRA: This is the mean curve.

MR. GURDAL: Oh, that's the mean curve. Sorry about that. But the design curve, if you go to the design, there is a curve continuing without any disconnection.

DR. WALLIS: Without any king, yes. Okay.

MR. GURDAL: And that's the A. This one is a C.

MR. CHOPRA: But the region we are talking about is this.

MR. GURDAL: Okay, but the question was about 10^6.

MR. CHOPRA: Which needs to be corrected.

DR. WALLIS: Okay, we've resolved that, I think. Thank you. That's very good.

CHAIRMAN ARMIJO: Which gets to the point, your design curve treats the weld heat affected zones or the base material, everything as the same as opposed to the code.

MR. CHOPRA: Yes, I think so.

MR. FERRER: I think so. In the code, I think the previous gentleman was talking about their -- in the high cycle regime, there are three separate curves proposed by ASME that extend past the 10^6 cycles.

In our proposal we've just bounded that with one curve.

MR. CHOPRA: We also have generated design curves for carbon and low-alloy steels based on the same approach using the Argonne models and adjustment factors of 12 and 2. This is for carbon steel and next is for low alloy.

Now current code curve for these is only 10^6 and now this is the current code curve and an extension has been proposed by a subgroup, fatigue strength. This was proposed a few years back and it's still not approved by the ASME code committees. We are -- we have another approach to define extension of this curve beyond 10^6 cycle. I just wanted to give a couple of slides to show that.

What the subgroup fatigue strength proposed was extension of the curve which is based on load control data and the data extends only up to 10^6 and they use maximum effect of mean stress and they propose extension which is expressed by applied stress amplitude given in terms of life with an exponent of -.05 which means 5 percent decrease in life, in stress every decade. And since the data only extends up to 5 times 10^6, extrapolation to 10^{11} may give conservative estimates.

Another way of extending this curve would be to use the approach with Manjoine had proposed a few years back where the high-cycle fatigue is represented by elastic strain with life blots and if we use existing data which we have extending up to 10^8 cycles for these various speeds, we get a slope of -

007. Manjoine proposed -.01 and we can use this expression where the exponent is smaller and which is consistent with the data and this would be for the mean curve.

Now we take this adjusted for mean stress correction using Goodman relation which is a conservative approach and actually if we do that this exponent would be .017. So it's slightly lower than what is being proposed by the subgroup fatigue strength, but we can use this expression and that's what we have used to define that extension to the curve.

DR. WALLIS: When you make these proposals, did you negotiate something with ASME or did you just say this is what we use --

MR. CHOPRA: This has been presented to them.

DR. WALLIS: There wasn't any give and take. It was just -- you deduced this from your data?

MR. CHOPRA: I attended the subgroup fatigue strength and all our work has been presented there.

DR. WALLIS: But the proposal is essentially yours. It isn't some compromise proposal. It's your proposal.

MR. CHOPRA: This was proposed by Manjoine a few years back, so this is nothing new.

DR. WALLIS: All these green curves are Argonne curves, proposed by Argonne?

MR. CHOPRA: No, the best fit curves are what we have defined.

DR. WALLIS: Right, so they're not something which has been negotiated and agreed on or anything like that?

CHAIRMAN ARMIJO: It's certainly been discussed.

DR. WALLIS: It's been discussed. IT's been presented. ASME hasn't come around and said yes, you guys are right.

DR. SHACK: One thing to think about for the carbon and low-alloy steels, there's really in air there's no disagreement over the mean curve. The shape may shift just a smidgen, but the only real difference between this design curve and the current is they use a factor of 12 instead of 20. Then you do have the discussion over how to extend it.

The environmental effect is a --

DR. WALLIS: It's the big one.

DR. SHACK: That's the big one.

CHAIRMAN ARMIJO: In the reg. guide, does this curve really extend out to 10^{11} or does it -- is it truncated at 10^{7}, since there seem to be a big difference.

MR. CHOPRA: The proposal is up to 10^{11}.

CHAIRMAN ARMIJO: Up to 10^{11}, but compared to the ASME code for this particular steel, your curve is nonconservative.

MR. CHOPRA: Well, this is --

CHAIRMAN ARMIJO: You predict a much longer life.

MR. CHOPRA: This is based on the data we have.

CHAIRMAN ARMIJO: Right, but nobody has data out to 10^{11}.

MR. CHOPRA: No.

CHAIRMAN ARMIJO: It's a less conservative --

DR. WALLIS: You have a C. You have a constant C or --

CHAIRMAN ARMIJO: Right.

DR. WALLIS: I'm surprised it isn't completely flat to a green curve.

MR. CHOPRA: Made up of two. I mentioned that extension is a different slope.

DR. WALLIS: Do they ever have 10^{11} cycles in a nuclear environment?

MR. FERRER: Vibration --

DR. WALLIS: Shaking things that shake.

MR. CHOPRA: So the method to apply the correction would be to use for carbon low-alloy steel you can use either the current code design curves or the curves I've mentioned to reduce some conservatism.

As you see, it's -- they're based on adjustment factors of 12, rather than 20.

For austenitic stainless steels and nickel alloys, we use a new design curve for austenitic stainless steels. And in the appendix to NUREG, there are certain examples given to determine some of the parameters.

For example, lab data shows quite often people don't know how to calculate, how to define the strain rates. Lab data shows average strain rate always is a conservative approach.

And similarly, if we have a well-defined linear transient temperature change, that can be represented by average temperature and it could be okay.

Now this one shows two more slides and I'll be done. There was a question that lab data does not represent the feed. There are certain reports where some operating reports where some operating experience and component test results have been published.

This is EPRI report, 1997, and gives a complete chapter, a couple of them, giving examples of corrosion fatigue effects on nuclear power plant components.

Similarly, studies in Germany, MPA and other places have shown the conditions which lead to what they call strain-induced corrosion cracking. This was demonstrated for BWR environments. And there are examples, even these examples are component test results. We support the lab data.

I want to just show the results of one particular test, component test, recent tests, again, sponsored by EPRI where they used tube u-bend tests tested in PWR water at 240. And I'm just plotting the results for a given strain amplitude what was the fatigue life they measured.

In earth environment, these are the triangles. So that serves as a baseline you would expect in air. Then they tested in PWR water in two conditions: a strain rate of .01 percent per second and diamonds are .005 percent per second. And this would give me for this strain amplitude a life in air of 12,500. This is about 36,000. This is 1700. And you can determine for a component test what is the environmental factor.

In this test, inert environment cracks were on the OD. And they were biaxial conditions. And the water, they were on the ID. And nearly uniaxial. So since there was a conversion, there's a question whether this number is accurate.

There's another way we can determine the baseline life. They have a very well-defined strain rate effect between these two. I applauded the component test results with the lab data, exactly the same slope and we know somewhere there's a threshold. That would be the life in air. So I've got a number 8,000; 12,000. I use an average of 10. Gives me a reduction of 5.8 for one strain rate; 2.8.

And the F_{en} we have presented, give you 5.5 and 3.6. Ii think these are very reasonable comparisons from a real component test.

MR. BANERJEE: So the test was done outside the reactor, right?

MR. CHOPRA: This is a component test, where they took an actual u-bend tube and strained it. So it's not a small specimen. They are testing a real component -- it demonstrates that lab data is applicable to actual component test conditions.

CHAIRMAN ARMIJO: Did you compare any of the other component tests that you referenced in the previous slide with your data to see how your data predicts?

MR. CHOPRA: Some of the earlier, no, we have not.

MR. BANERJEE: Do you have any idea of the -- is there anything which happened in a reactor where you have the strain history or something for a period of time?

MR. FERRER: I think the answer to that is it's very difficult to have the exact data on the strain history in an actual operating event. We've tried to estimate it and the best you can do is estimate it. I think Omesh presented some references. I think the EPRI one which attributed some of the cracking to environment, but you couldn't prove it absolutely because you just don't have the exact temperature measurements and the strain measurements at the location of your cracks.

MR. BANERJEE: But you can estimate them, right? Based on those estimates, what does it look like?

MR. FERRER: If you go back to the

reference EPRI report, you know, I think based on their estimates they attribute some of it to environmental, but I say those estimates are very crude. They're not nearly as controlled as the lab data and if you look at fatigue, the -- at the low cycle end, the small change in stress gives you a fairly large change in the number of cycles if you look at the shape of the curve.

And so it's not that easy. There are some estimates, but they're more judgmental than accurate calculations.

MR. BANERJEE: But the evidence or supports -- what you're saying --

MR. FERRER: Well, there's some evidence. What you'll hear from -- probably from ASME is the overall operating experience doesn't show that there's a big problem there.

MR. BANERJEE: Okay.

CHAIRMAN ARMIJO: Okay. That's it?

MR. CHOPRA: Yes.

CHAIRMAN ARMIJO: Any other questions from the Committee?

MR. GONZALEZ: I would like to go back to the reg. guide to present a summary of the three regulatory positions.

Regulation position 1, we are endorsing that we will calculate fatigue using air with ASME code analysis procedures plus use the ASME code air curves for new ANL modern air curves. This is for carbon and alloy steels only.

Then we will calculate the F_{en} using the appendix A of the NUREG for carbon and alloy steels and this will be applied to calculate the environmental uses factor.

But we're given the option of using the ASME curve or the new air curve from the ANL model. Or austenitic stainless steel, we will calculate the fatigue use factoring there with the ASME code analysis procedure, plus the new ANL model air stainless steel curve.

We'll use the -- also the F_{en} equation for stainless steel and then calculate the environmental usage factor.

For nickel chrome alloys, will be Alloy 600, 690. You will use again the ASME code analysis procedure plus the new ANL model air stainless steel curve. As the reason was it was explained before was because of the new data.

And if the F_{en} specifically for nickel alloys and calculate the usage factor -- the environmental fatigue usage factor.

In summary, Reg. Guide 1.207 will endorse the use of a new air curve for austenitic stainless steels and also will endorse the F_{en} methodology. It will give guidance on incorporating the environmental correction factor, the fatigue design analysis and this is described in Appendix A of the NUREG report and also the NUREG report will describe in detail the technical basis.

That's it. Any more questions?

CHAIRMAN ARMIJO: Okay, any questions? We're scheduled for a break about now, but we're a little bit ahead of schedule. I don't know if we can reconvene in 15 minutes or do we have to wait until 3:35?

We'll just take a 15-minute break. Be back at 3:25. Is that right? 3:25, thank you.

(Off the record.)

CHAIRMAN ARMIJO: Okay, we've got -- incredibly we're about five minutes ahead of schedule, so that's good.

So Mr. Gonzalez, would you like to continue?

MR. GONZALEZ: This is our second part, second presentation. It's in the resolution to public comments. The Draft Guide 1144 and the Draft NUREG CR-6909.

There were eight correspondents that submitted a total of 56 comments, both the draft Regulatory Guide and the draft NUREG and all comments were addressed individually.

The final reg. guide 1.207 and the final NUREG report reflects a resolution of these comments. There were six main issues identified.

The next slide is an example of the table that was provided to the ACRS where it's showing all the comments, how it was individually -- there was an individual response for each of them.

CHAIRMAN ARMIJO: Are these all the comments?

MR. GONZALEZ: These are the six main issues that we kind of --

CHAIRMAN ARMIJO: Right, but --

MR. GONZALEZ: Six main issues were identified, but not all of them. The numbers in the parentheses are the comments that apply to that particular issue, so comments 1, 714, 16, 45, 521.

CHAIRMAN ARMIJO: I just noticed, you received some comments, obviously from AREVA.

MR. GONZALEZ: Yes.

CHAIRMAN ARMIJO: You've received comments from GE.

MR. GONZALEZ: Yes.

CHAIRMAN ARMIJO: You did not receive any comments from Westinghouse?

MR. GONZALEZ: We received Westinghouse.

CHAIRMAN ARMIJO: I didn't see any there.

MR. GONZALEZ: No. We've got GE, NEI, ASME.

CHAIRMAN ARMIJO: Okay. All right, thank you.

MR. GONZALEZ: Then we identified the six issues and this is where I'm going to address each one of them.

The first one is the -- has to do with operating experience and the applicability of the specimen data. The comment was that the -- the first comment was there's no operating experience to support the need for this conservative design rules. And our response was that there was numerous samples on the fatigue cracking of nuclear power plant components. As an example, reported in the EPRI report reference here.

The other issue that has to -- is about the comments, questioning, the applicability of the specimen data being representative of the actual components and service. This being the applicability of the lab data, the component behavior has been demonstrated by mockup and component tests and references were provided in the previous, Omesh' presentation. In fact, it's the basis for that current ASME code fatigue curves.

The second comments have to do, the second set of comments have to do with the details on the approach. One of the comments said that the reference made to other guidance containing similar F_{en} approach, like the Japan F_{en} equations are also acceptable and endorsed.

Our response is that the papers listed in NUREG CR-16909 are for reference only and Section C of regulatory position of the regulatory guide contains the methodology endorsed by the staff.

The second issue on the details on the approach is that -- I'm quoting that "since draft Guide 1145 utilizes a similar F_{en} methodology to that evaluated in MRP-47 revision 1, the issues identified in MRP-47 are considered to be equally applicable to the draft guide methodology. Some, but not all, of the issues raised in the MRP-47 have been specifically addressed in the draft guide. Based on these, the MRP would like to see clarification on the remaining issues included in Draft Guide 1144 and the supporting document."

Our response was that the level of analytical detail discussed in the additional items in MRV-47 revision 1 are beyond the scope of this regulatory guide.

The third issue was the comments were asking to provide a guidance for nickel chromium alloys and this comment was incorporated. We saw that we have the EPRI methodology developed for the nickel based alloys and we have regulatory position 3 on that reg. guide that addresses this.

The fourth comment is on the burden due to the increasing location required to be analyzed. The practice will lead to more analyzed piping, reg. locations to more installed pipe width restraints and to the signs that will be more detrimental for normal operating conditions. The NRC staff will consider a justified modification with appropriate technical bases of the fatigue criteria for fossilation of pipe breaks implementation of the current criteria, saw a significant increase in the number of required pipe with restraints.

The fifth issue is the same commenter,

believes that the alternative methods for fatigue analysis in NUREG CR-6909 and draft Guide 1144 are too conservative and should not be used for the design of new reactors.

Our response was is that the staff position is based on a 95th percent confidence, that there is less than 5 percent probability of fatigue crack initiation. And implementation of this criteria results in a carbon and low-alloy steel air curves which are less conservative than the existing ASME Codes.

The last comment was from ASME that basically ASME will continue to develop a code case that will cover alternative ways of addressing the impact of light water reactor environment. And they're saying that the code case will be issued in early 2007. Once these code cases are issued, ASME will request NRC to endorse these codes in the revision Reg. Guide 1.84. And we agree with that. The NRC staff will consider endorsing available ASME code cases through its normal process for revising Reg. Guide 1.84.

Conclusion, the Reg. Guide 1.207 is ready for issuance and the final Reg. Guide and NUREG reports reflect a resolution of these comments and the final Reg. Guide and NUREG will be published by March 2007 and so we're seeking ACRS concurrence to publish a final effective guide.

Any questions?

DR. BONACA: Just a question regarding your last -- the sixth issue.

MR. GONZALEZ: Yes.

DR. BONACA: Talking about revising Regulatory Guide 1.84. Can you expand on that?

MR. GONZALEZ: Regulatory Guide 1.84 is a reg. guide that is updated each time for any new code cases. The NRC reviews and sets --

DR. BONACA: Okay.

MR. FERRER: Yes, this is John Ferrer. The intent of this statement is we'll look at what ASME puts out as a code case and if we think it's appropriate, we'll endorse in the update of 1.84 and maybe get rid of the reg. guide, but right now we can't wait for ASME to put something out because we have on-going reviews and we need a position established to do these reviews with.

MS. VALENTINE: This is Andrea Valentine from the Office of Research. This is normal procedure. There's a reg. guide that endorses Section 11 and O&M Code. So this is nothing different than what we normally do for code cases.

DR. BONACA: I want to make sure that revising that will not mean to modify what you are proposing in this NUREG.

MR. FERRER: Well, we could possibly, you know, ASME is going to come up with a position. We don't know whether it's going to be exactly the same as our position or it's going to be a different position. If they make a good enough argument that their position is better than our position, we may consider adopting the ASME position. But I mean that would be a tough case for ASME to make, once we get the reg. guide out.

(Laughter.)

MS. VALENTINE: And also to add to that, if you recall earlier from Hipo's slide, this has been deliberated for a number of years over 25, so this wasn't something we just did in a vacuum and decided to take this route because it was a short-term issue. It has been something that was discussed for many years.

DR. BONACA: Regarding issue five, I mean the contention here is that the NUREG will impose excessive conservatism and you disagree. You don't have the basis for that statement.

MR. FERRER: Well, let me explain the basis for that. There's a lot of -- a lot of comments we're arguing that we impose an overly conservative position in this reg. guide and what we're trying to point out here is the basis for our position which is a 95/5 with a shift in the current position of ASME and it's actually, if you apply it to air curves, it results in a curve that's less conservative than the ASME already has.

DR. BONACA: I guess I was trying to understand how the -- if they agree with your view.

MR. FERRER: You've got them up next.

(Laughter.)

CHAIRMAN ARMIJO: They're coming. They're coming.

DR. BONACA: Okay.

CHAIRMAN ARMIJO: Okay, if there are no other questions, the next speaker will be Mr. Ennis of ASME.

At least that's what's on the agenda.

(Pause.)

MR. BALKEY: My name is Ken Balkey and I'm Vice President of ASME's Nuclear Codes and Standards. And we appreciate the opportunity to meet with the Advisory Committee on Reactor Safeguards, Subcommittee, on Materials, Metallurgy and Reactor Fuels.

What we'd like to do is address our viewpoint and comments on the proposed reg. guide which is DG-1144 as issued for public comment.

Next slide.

What I'd like to do is -- this is a very broad issue that impacts particularly our ASME Section 3 of boiler and pressure vessel code. Joining at the table with me are Kevin Ennis who is the Director of ASME Nuclear Codes and Standards and is my counterpart as the ASME staff. I'm the Senior Volunteer for Nuclear Codes and Standards.

Joining me are Bryan Erler who is the Vice Chair of our Board on Strategic Initiatives and he's been a long-time member of ASME on the Boiler and Pressure Vessel Codes Subcommittee 3.

Dr. Chris Hoffman, who is a member of the ASME Boiler and Pressure Vessel Main Committee, Standards Committee is with us and he's also a member of the Code Subcommittee and also a member of many other subgroups and working groups in Section 3 as well as other parts of the code.

And then finally, Mr. Charles Bruny, who is a member of the ASME Subgroup on Design and he's past chair of the working group on vessels.

The reason we have this team assembled, first of all, I'd like to pass along the regrets of Mr. Richard Barnes who is the chairman of Subcommittee 3 and his schedule prevented him from being able to join us here today.

The folks who are here are true experts from Section 3 are Mr. Erler, Dr. Hoffman and Mr. Bruny. But in terms of background, my own background, well, I've done a significant amount of work in risk-informed, in-service inspection and other risk-informed initiatives prior to my role here with the Board on Nuclear Codes and Standards. I built plants back in the '70s and I actually applied the rules. We did the very first plant, B317 back in 1972 for the Trojan Plant. As we were transitioning from B311 to B317 and then to Section 3, I have my own personal insights about what's happening here with the proposed rules and what it means when you actually come and you're going to actually physically build a plant and the challenges you get into.

Mr. Erler was a senior executive with Sargent Lundy and also built reactors. Dr. Hoffman and Mr. Bruny are also long-term members involved with designing and building plants and components. And that's going to be one of the key elements you'll hear from us is that there's a lot of good work that was presented here this afternoon, but there's a practical aspect of translating this into use in actually designing and building a plant that really needs to be given serious consideration.

Next slide, please? I'm sorry, we already had that slide.

What I'd like to do is just take one minute, not to just -- I know you're familiar with the codes and standards, but I would like to touch upon our organization and how we do our work relevant to the proposal in front of you.

The other issues we did put a letter in in September, as you all well know, ASME, we wanted to have a chance to review this reg. guide and the proposal in detail and come up with a consensus technical position, but the reg. guide came out right before our Nevada meeting and we put our letter in asking for a 60-day extension in order that we could have such discussion at our meeting in Louisville, Kentucky about a month ago. But because of time schedule, we were not granted that request, but there are some comments that we have gathered from our colleagues within Subcommittee 3 related to this draft guide that we would like to go over.

And then we'd like to go over and give some background on efforts that we've done addressing the impact of fatigue. There's three approaches that have been looked at and we continue to look at and we'll have a technical discussion on each of those before we present a summary and some future actions.

Next slide.

On organization, just we have, of course we write codes and standards beyond just nuclear power plants. We have about 3,000 volunteers writing codes and standards for pressure devices, elevators, lifts, screw fasteners and a whole host of number of applications.

In our nuclear codes and standards, one unique feature is that Section 3 and Section 11 are two of the 12 sections of the boiler and pressure vessel code and so as we look design roles or materials or certification requirements, we just don't it within the nuclear. It's done, any technical requirements coming forward go in front of the Boiler and Pressure Vessel Standards Committee so that our practices can be reviewed by experts in similar areas from other industries who are addressing the same types of issues, whether it be fatigue or corrosion or other design factors that one would want to take into account.

And it does come in because one has to remember that the plants we are operating today were built on design requirements that were put in place in the 1960s and 1970s for the most part, and those rules evolved from the use of the B31 line power piping code as well as Section 1 and Section 8 for the vessels. So we -- our nuclear -- we've adopted those prior experience where there's been relevant experience for many, many years. That plays into what we'll be discussing here today.

I just wanted to mention that the Section 3 and 11 are part of this other organization that reviews it from broader than just a nuclear power industry.

The next slide is just a verbal description of some of the acronyms that make up the nine groups that report to the Board on Nuclear Codes and Standards. The next slide deals with the consensus process. There were comments made about hey, we've worked on this for 25 years. We haven't come to a consensus and I would really like to ask Kevin Ennis to go over some points relative to ASME, what it means when we achieve consensus or what it means when we don't achieve consensus. So Kevin, if you would be kind enough to do that.

MR. ENNIS: Thank you. All of our committees, all of our volunteers in nuclear codes and standards operate in an open and transparent process and that process is geared to achieving consensus on what appears in our codes and standards. Now these volunteers are made up of world experts. They're from all over the world. They come to our codes and standards meetings and if you know the hierarchy of our committees, the further down you drill into the committee structure, the higher the concentration of expertise, so that when you're really down into the people who do fatigue analysis, that's what they do and they come from all over.

We have much international participation and we always stress that we rely on industry to support this participation. We don't pay any of these volunteers. And I would also like to take a second to thank the NRC for their participation in ASME codes and standards.

But the achievement of consensus from the users' perspective, you only see the consensus results. But there is a whole process that the volunteers go through and the first thing that they have to achieve consensus on is the technical basis to respond to identified means.

DR. WALLIS: That my question here. Doesn't this work that we just heard about provide the broader technical basis than you had before?

MR. ENNIS: It provides some data that has been developed over time, but we also look at our past experience. We never forget our history. As Ken quite rightly noted, the original new plants are B311 plants. We still build coal-fired plants today to B311, the piping. And we have great success with them. As we identified needs for the nuclear industry, B317 was developed --

DR. WALLIS: Coal plants don't have pressurized water reactor environment.

MR. ENNIS: No, they don't, but there are other B31 documents that have dramatic impact on environmentally-caused failure mechanisms and we rely on those people too. One of the sections of the boiler code, Section 8, and its piping division, B313, they have lists of failure mechanisms that are dramatically long, much longer than what you see in a nuclear power plant.

We do rely on that expertise and experience. They operate at much higher temperatures and pressures and much more severe chemical environments. So we do have their expertise is also looking at this. And we rely on that heavily and they learn from us. We started out with the risk-informed before they did. So it's a mechanism whereby expertise that is -- grows up in different industries can exchange information and ideas and solutions to problems.

And when you read the statement, identify technical basis, implicit in that statement is that there is consensus on the need and I think you'll hear later today or later in our presentation, that really hasn't been achieved yet. And it's not only in nuclear, it's also in the design experts that come from outside nuclear that looked at our work that we talked to during boiler code week when all 12 subcommittees meet.

So there is a lot of discussion going on and still at least in the limited amount of discussion and exposure I have to the experts, because now I'm director, I don't, I don't perceive consensus has been achieved on the need. And that's one of the things that's taking so long. And, once that happens, then you can get a result and that's the consensus everybody sees outside of the committee structure.

And that consensus we always say must be technically accurate, must obviously assure adequate safety, but must be practical and workable.

And another one of the comments you'll hear from the other presenters from ASME goes along the idea of practical and workable. Are we really going to achieve good by making this change? And, is our achievement worth the cost?

DR. WALLIS: Well, presumably, a curve that's there now is practical and workable and if you replace it with another curve it's just as practical and workable as the previous one was.

MR. ENNIS: Not necessarily, and I'll leave up to the design experts to get into that detail. But at least they raised enough questions in my mind to say is it, is the new curve, practical and workable? But I'll leave it up to them to bring up.

DR. WALLIS: If the process is the same, of just taking the --

MR. ENNIS: No, it's, it would not be.

DR. WALLIS: -- if the process is the same, but you'll tell us --

MR. ENNIS: There's more to it than just the curve.

DR. WALLIS: -- you'll tell us. Okay.

MR. ENNIS: And what I do, any my role with my staff, is we provide the structure and the administrative support. Give the experts the opportunity to come to consensus and hopefully try to corral them into doing that. And with that, I'll pass it back on to Ken.

MR. ERLER: Well actually on to me.

MR. ENNIS: Yes. Mr. Erler is going to review the open comments, some technical comments we gathered. The reason we call them is open comments is that they were not in our paper, they have come from deliberations we've had and they're comments from the members. They're, it's not a, we haven't had a consensus to say these, there's a consensus, everybody agrees these are the comments on the Reg Guide --

DR. WALLIS: It doesn't look like a consensus at all, this slide here.

MR. ERLER: The process, really, it's a very unique process and I think that was why it was important that Kevin address the fact is that we have experts from around the world that are experts in all various industry and it really provides a strength in the code.

And the number one comment that we're dealing with is we've been working on it for 25 years.

The phenomena we have no disagreement with. It exists. The issues that we're dealing with are we've had no failures with regard to environmental fatigue impact. We looked back at our operation and the answer that was presented here today was, the EPRI research or there's a few of them. And they really were more related with corrosion or corrosion/stress corrosion and fatigue interaction. It was not a pure fatigue issue.

And many times, the fatigue issues -- not fatigue issues, other failure issues are dealing with vibrations or other related type phenomena and separating it out, we really look at the fundamental experience of today that the operating plans have been served well by the design basis we've had for a number of years. But we've looked very carefully. We've done research, we've assigned various task groups. We brought people in from around the world and we can't all agree amongst these experts that there's a need to change, that there's sufficient margin in the design, has proven itself to be very effective.

The other item really is how does it apply, you know? Some of the research that we have, there's obviously these specimens don't reflect environment that primarily piping or vessels are in, where the internal diameter of the components are the ones that are exposed to the environment, not the whole metal.

DR. WALLIS: Could you explain something to me? I sort of got the impression from what was presented, the Argonne work, that your curves are based on tests in air.

MR. ERLER: That's correct.

DR. WALLIS: How do you then account for the additional effects of putting it in water with various amounts of oxygen and so on in there?

MR. ERLER: The original criteria that goes back to 1960 --

DR. WALLIS: Twenty and --

MR. ERLER: It was the 20 and 2 factor that we put in.

DR. WALLIS: Is that good enough today?

MR. ERLER: That's correct. You've got to look at the methodology that was used for analysis. The methodology that was used for the margins that exist elsewhere in the code and the reluctance to really start taking out margin in the code or adding in for special analysis that was totally done in the lab.

So that's where we're looking at, trying to bring together an operating experience and the lab data that we have. We're not ignoring it as will be outlined in our approach that we have proposed. Twenty some years of working at it, we've had a lot of heated discussions from many, many experts that have brought forward some very, very valid points.

The issues that we're dealing with are just some of this data is not the same as was presented here. The methodology that was used for the dry test, with this 25 percent drop rate methodology is not the same as the crack growth. So there's some adjustment that has to be done and then analytical figuring of the F_{en} factor.

So there's a lot of analytical manipulation of data that may not apply to the actual components and we haven't seen the failure in the plants that we have --

CHAIRMAN ARMIJO: Now didn't the Argonne researchers do the manipulation and share that with you and did you find fault with the way they did it?

MR. ERLER: Yes, well, no. There's a lot of arguments with the way -- that's why you have the dispute in these meetings. There's some fundamental disagreements with how it's being done, how it's being adjusted and does it really represent what you have in today's environment?

DR. BONACA: Could you comment on bullet number two. I'm interested in understanding that better.

Environmental fatigue affects only inside surface --

MR. ERLER: We are dealing primarily -- our fatigue is really dealing with the inside surface of piping and so therefore you're not dealing with components that have been submerged in water or in oxygen or other environments that you have. And so when you apply it to the methodology that you have, piping analysis is a structural analysis. You don't look at internal and external. You have to apply it to the whole component.

And so here you have a bending component, bending, not bending on the piping, but bending within the wall thickness that we're applying a penalty on across the board. So that's part of the application problem that you have here. You've got realize some of the design, for a vessel, it's pretty simple. You have certain rules and certain -- that's in the code rules and we've expanded it to cover phenomena, but the fact of the matter is that when you start applying this analysis, as even stated here, that you need to go into a very detailed finite analysis, finding out exactly the stress concentrations, the cycles that you have to go with. And it doesn't really apply to the same methodology you really had in the code directive. So we have a way of translating that. That's what we've been working on is arguing how you translate that into applications into today's analysis.

MR. BRUNY: Could I add to that? Chuck Bruny. Current methods in today's piping analysis is done with some standard equations that are in the code and stress indices that are developed for various components in the piping system and for various loading conditions. Now this stress index is a way of getting the maximum stress somewhere in that component that is generated by that load or that condition. These are then are all added together. It may not be the stress at the ID surface and the stresses from one load condition may not occur at the same location as another. So the industry today works with a simplified approach which comes up with very conservative stress evaluations for most of the piping components.

The addition of the F_{en} approach and the impact is that many of these locations analyzed under this current methodology will prove to be unacceptable and therefore significant detail analysis will have to be undertaken in order to evaluate the stresses at specific locations on the inside surface of these components throughout the piping system in order to apply the F_{en} approach in a way that isn't so overly conservative that it has dramatic impact on the piping.

CHAIRMAN ARMIJO: Do you know how to do these analyses?

MR. BRUNY: Yes.

CHAIRMAN ARMIJO: So it's the amount of work and the amount of detail you have to do.

MR. BRUNY: It's a significant amount of additional work over and above current methodology to do that and the approach that was taken in life extension was a very limited number of locations were evaluated in the life extension analysis and application of F_{en} and some of those did use this extensive analysis, but on a very limited number of locations, not the entire piping system for a plant.

CHAIRMAN ARMIJO: When you did not particular analyses did you compare them what the standard code process would predict? I mean were they consistent? Was the standard code analysis conservative compared to the more sophisticated analysis?

MR. BRUNY: I haven't looked at the detailed analysis or detailed results. What I have heard is that the F_{en} approach, in general, would give higher fatigue usage factors than the code analysis. In other words, there were more locations, many more locations that would have a fatigue usage factor higher than the .1 value that is the current threshold for determining a potential pipe break location.

MR. ERLER: Let me expand on that a little bit, because that's a -- the F_{en} approach and you look back in '91 and a lot of this was done, was identified as an issue in pursuit, primarily focused on analysis for life evaluation where you go in and make sure, find out where you are in the plant and that's why in all of the license renewal, you find the plants are acceptable, so the answer to that is I say yes, because every place you've applied it in plants for license renewal or for existing plants that are currently certified have been acceptable.

So it's a lot more work, but it was very important in operating plants to be able to verify that for the added 20 years that you were putting on it. I think the difference we're focusing on here, Section 3, we're talking about design, up front design where you don't know necessarily. You're designing something you don't want to go into detail analysis evaluating research and pick out -- design is significantly different than evaluating the impact. And therefore, we need a design approach which is, has the margin in there that we know can be handled by the various conditions and environment and cycles that we have.

DR. WALLIS: Can we talk more about this F_{en}? As I understand it, there's a curve that you get from tests in air when you do tests in other environments such as PWR water, different temperatures, you get some other data. All F_{en} does is tells how much the curve moves when you move to a different environment. That seems to me an appropriate way of treating the data. Now you may be arguing about how practical it is, but I don't see how you can argue it's not an appropriate way of treating the evidence.

MR. ERLER: It may be. If you look at our last comment that we have here is that the implementation of the code design rules has a number of issues. Those issues were identified in the EPRI report MRP47.

DR. WALLIS: It's the application of these factors you complain about, not the way that -- it's not an inappropriate way of treating the data, are they?

MR. ERLER: It's the conservatism in it and the application of it in a design environment in designing a new component.

DR. WALLIS: The application is what you object to.

MR. ERLER: This write up was significant, going into a lot of detail on the difficulties of trying to apply it and it is appropriate. Where ASME is coming from and the debate that we have in all of our committees is for what benefit? If we haven't seen a problem --

DR. WALLIS: For public safety, you have a better --

MR. ERLER: Well, then let's go back to our item, bullet two here. One of the things that we're very much concerned with, those usage factors is the fact that we're going to end up with a lot more pipe restraints installed, a lot more in-service inspection required because of usage factor being up. And you're going to have a lot of other issues for, again, very little benefit.

It kind of reminds a lot of our people

that are around the table of where we were in the '70s and '60s where we were putting in more pipe restraints because of increase in seismic analysis response specter, decrease in damping values that were allowed, and then 10 years later we spent another bunch of money taking it all out, because what we're doing is we're constraining a system that would prefer to be, have some more flexibility to respond to the thermal and the dynamic response.

So it has a possible negative safety risk that we have and that's probably the more stronger opinions at the table when you're debating it. It's not the fact that we have to work more at it because most of the people there probably get paid more for doing that analysis. The fact is that it would be unconservative. The application of F_{en} for evaluation of existing plants and life prediction is a very good approach. It's applying it as a design approach that we object to, especially when you look at it and it hasn't had been proven that the existing design approach is a problem.

And we're going to get into more detail when Dr. Hoffman goes through the approaches that we have. Like I say, we haven't given up on the fact that we need to address this. It's how do we address it, what is the issue we need to address and what approach should we use?

CHAIRMAN ARMIJO: But if you wanted to freeze the approach with the codes that are in existence today, the ASME curves, would you also freeze all the analytical procedures to the state-of-the-art at the time that they were imposed and not allow any more sophisticated analysis? Because otherwise you're eroding margin.

MR. ERLER: That's right. There's a lot of debate on that and you can't -- you can't freeze either, really. What we try to have is some kind of standard, codes and standards stability to deal with and some kind of oversight with regard to the analytical capabilities that you have. But not for every Class 1 piping system do you want to have to do it, or every valve that you have to do it.

DR. WALLIS: No debate that in the environment and in the PWR the metal is more prone to fatigue than in air? There's no debate about that, is there?

MR. ERLER: I think the statement is we agree that that phenomena exist. Does the current standard cover --

DR. WALLIS: The current standard doesn't take account of that, does it?

MR. ERLER: Not explicitly, but it does state in the criteria document that the 20, that will account for environmental effects.

DR. WALLIS: It's good enough to take account of it.

MR. ERLER: That's what currently in our criteria document.

DR. WALLIS: Twenty is good enough. You don't need to adjust it any other way. That's your position?

MR. ERLER: Let me say this. We really should go through the rest of our position. Because we're not digging our heels in on this here. We just want to get to the right solution.

DR. WALLIS: I thought you were.

MR. ERLER: No, no, no, no.

DR. WALLIS: You are flexible on this?

MR. ERLER: It's a very complicated area to deal with and finding the right solution, that doesn't bring the bad stuff with the good solution.

DR. WALLIS: There is hope for compromise after 25 years?

MR. ERLER: I believe there is. So we've dealt with, I think -- does the implementation approach result in unnecessary code, regulatory burden? This is the analysis and then we're talking about then the implementation side. So I guess that really covers most of the open issues.

DR. WALLIS: Have you evaluated that? The burden and the benefit? Is that being evaluated or are you just raising a question?

MR. ERLER: We're tying it together with the bullet above it, that the fact of the matter is it does take more analysis in order to bring within allowables just like potential new allowables like Chuck Bruny stated.

DR. SIEBER: That you quantified that additional effort?

MR. BALKEY: Let me try a different tack here because it came up in the discussions here. When we did the risk-informed in-service inspection, more than 90-some reactors have implemented here in the United States as well as six or seven other countries, in a way that was -- that assessment was almost a check on the plants that were operating. How does the risk from the operation of these pressure boundary components, how does it compare to the risk for other contributors to overall plant safety?

When we did the risk-informed ISI where

you're combining the probability of failure at various locations and at that point you already have a fixed design. It was done to whether it was B311, B317 or Section 3, and you're doing this assessment. One method uses policy fracture mechanics, another one went through an entire operational history, and what you find out that the risk, first of all, the risk from pressure bond through failures using this code is a small contributor. It is not a large contributor.

DR. WALLIS: Small has been used before today. How small is it?

MR. BALKEY: We're talking definitely less than 10^{-6}.

DR. WALLIS: On CDF?

MR. BALKEY: On CDF. Now let me come back to it. Even if -- I don't want to argue how low is low enough, but when you look at where the predominant contributors were to the risk from the piping, it's not from fatigue. It's from the things where you may have the possibility of back leakage through a check valve. It may be in thermal stratification that you may be predicting. It may be that hey, we have an environment --

DR. WALLIS: That's thermal fatigue or is this a stressor solution we're talking about?

MR. BALKEY: You could have a -- if a check valve started leaking, you'd end up with thermal striping and you'd end up with a very --

DR. WALLIS: It's a fatigue problem?

MR. BALKEY: Pardon me?

DR. WALLIS: A fatigue problem.

MR. BALKEY: Yes, but the issue is not the calculation of fatigue, the issue is the loading environment itself, once you get into a loading environment that's causing that challenge.

And the point I'm trying to make is that even when you -- I went through the regulatory assessment. The statement was made that when this -- the impact of environmental fatigue, even for life extension, the NRC did risk analysis calculations to show that it's acceptable to safety. So the question you have to ask like I said, we're not trying to say you don't address these factors. The question is do you do it here in design or do you address it through your in-service programs. And that will come bearing out.

So therefore, the NRC and the industry have worked very hard to focus our resources where it matters. And one question you have to put on the table is are we asking the industry to do a significant amount of work on an area where the risk may be low.

DR. WALLIS: The question I would ask is how big does this F have to be before you are forced to make a change?

MR. BALKEY: What we're saying is the operating experience today is not bearing that out.

DR. WALLIS: You say the influence is so small that it's not important. How big would it have to be? Would it have to be twice as big or something before you say you have to do something?

MR. BALKEY: Well, I'll respond when we look at Section 11. Section 3 is talking about design. If I go over to Section 11, as soon as we have experience and our Section 11 group is dealing with all the different cracking mechanisms that are coming and we have reached consensus on a number of code cases in order to change the inspection and the repair and replacement of that equipment. But it comes back to what Kevin Ennis said, that the challenge and the question we have is is the information that's available, does it warrant going back to do all this work and is it going to add additional burden?

DR. WALLIS: The problem I have with your presentation so far is you really haven't demolished the view of ANL and the NRC. You've talked about a lot of things, but you haven't convinced me that in any way they're at fault.

MR. BALKEY: I think that the position that we're saying is the fact that in design part, we have found that the design of the plants you end up with fatigue being adequately covered by the process originally set up.

DR. WALLIS: Are you going to show that somehow?

MR. BALKEY: The way to keep that going forward is to keep an eye on it through the monitoring program that you have in place, rather than trying to make, squeeze a more conservative design on existing component system.

CHAIRMAN ARMIJO: But if you do a better job in designing piping by using data, modern data and modern analytical procedures, somewhere along the line you ought to be able to say I don't need to do as much in-service inspection. I don't -- there will be a benefit coming out of it, even though there's an upfront cost. I agree there will be an additional cost, but it seems to me that if we know these environmental effects exist, and we measured the phenomena. We've got data. It seems strange that we wouldn't use it along with our more modern analytical procedures. You know, just everything improves.

MR. BALKEY: And we are committed to working with everybody to look for that solution.

CHAIRMAN ARMIJO: And a benefit of this, you might have a much better piping design by virtue of doing the more -- using the modern data and the modern analytical approaches and the payoff could be in less in-service inspection or more reliable piping system.

I just -- or both. I can't see why you're just looking at it as just a burden and we ought to stick with --

MR. BALKEY: Except that the F_{en} procedure or the revised fatigue curves may not be the solution.

CHAIRMAN ARMIJO: There may be other solutions.

MR. BALKEY: It's a better solution than we've -- and that's what we want to work for.

CHAIRMAN ARMIJO: I think we should move over now to --

MR. BALKEY: Dr. Hoffman is going to go through a little more technical information on what ASME has done.

DR. HOFFMAN: This you've already seen and heard previously. There has been activity within the ASME Code Committees and initially with the PVRC Steering Committee on Environment for a long time. The only thing that I would like to highlight from this slide is that there are a couple of items, the introduction of Appendix and Code Case N643. There were specific actions that the Code Committees did come to agreement on and published new rules to address environmental effects in both of those items.

The N643 code cases is of note because it allows you to decide, based on the environmental conditions and the transience occurring in a component whether or not the environmental effects need to be considered. It kind of turns them on or off, depending on the local conditions.

Next slide.

Just earlier this year, the Section 3 has a task group on trying to decide what to do about environmental effects. They just completed their efforts earlier this year and these were the recommendations that they forwarded to subgroup design of Section 3 to decide whether any changes needed to be made to the design rules or to adopt new fatigue curves that incorporated environmental effects or to use an F_{en} type approach. These are the various items that we've heard about earlier today, either changing the curves or the F_{en} effect.

So subgroup design is still looking at these.

DR. WALLIS: It seems that option 2 here would involve some change in the fatigue curves that ASME recommends.

DR. HOFFMAN: Right, there have been --

DR. WALLIS: Factor 20 would become 30 or something or whatever.

MR. BALKEY: Or the fatigue curves --

DR. WALLIS: Right.

MR. BALKEY: There have been proposals to introduce new curves that have the factors built in.

MR. BANERJEE: What do you mean by without the extra conservatism in the guide?

MR. ERLER: That particularly was addressing the -- there's a number of factors that are included in the guide in terms of applying F_{en}. If you look at some of the early research that you had and now the subsequent research that would indicate the factor should be 1.5 as opposed to 2.

DR. WALLIS: Is the conservatism in this 95th percentile or moving the curve over further than it needs to be?

MR. ERLER: Well, you know, obviously, they've moved some of the curves, the stainless steel down and they've moved some of the carbon steel up and -- but the margin that they're aiming for has been consistent and the margin is, we think, is too conservative when you consider you're improving your knowledge that you have and you're improving what you're considering in your analysis, so that some of that margin should be reduced.

So part of the debate, if you're going to apply it, what should that margin be?

DR. WALLIS: Isn't the margin based on some statistical evaluation based on this log normal thing and Monte Carlo analysis?

MR. ERLER: That's correct. That's what their analysis was based on.

DR. WALLIS: Is something wrong with that? Is that extra conservative to do it --

MR. ERLER: By the time you apply it, you end up with sometimes an increased amount of fatigue usage factor or decrease that causes considerable problems. Some of it goes beyond what would be reasonable in terms of --

DR. WALLIS: The problem being that you

have to restrain the pipes more?

MR. ERLER: You really get down to details and the usage factor is really connected with a lot of -- the transients that you have and the number of cycles. You end up changing details in order to make --

DR. WALLIS: How is it you know how much these things vibrate in the first place?

MR. ERLER: That's the advantage of looking at it in an operating environment because when you know the number of transients, you have monitoring, you have data.

When you apply Section 3, you're looking at future.

MR. BANERJEE: Where are most of these restraints? I mean the issue that you're bringing up that you have to restrain these pipes more than they are currently being restrained. And that is introducing some problem.

MR. ERLER: There are two issues. One is the issue of if the usage factors go up, you have to postulate breaks more frequently. If you postulate breaks, then you've got to put in pipe restraints and protection against those breaks. You can't get at the pipe as well for inspection and monitoring very well.

MR. BANERJEE: Could you just give us an example of where this would have the most impact?

MR. ERLER: On pipes, on class 1 pipes.

DR. WALLIS: Main steam line or something like that?

MR. BANERJEE: Steam line?

MR. ERLER: The surge line has a lot of them on, you know. Feedwater line.

MR. FERRER: This is John Ferrer. Could I add a point on this issue you were just talking about? One of our responses to the public comments was that that concern that you could increase the number of postulated rupture locations was legitimate and that if in implementing this new criteria it turns out it causes a lot of extra pipe rupture locations to be postulated, we will reconsider the criteria based on fatigue so that doesn't happen.

MR. SIEBER: Then what do you accomplish when you do that?

MR. FERRER: There was back in the '80s when they were trying to get rid of the problem with the excessive number of pipe whip restraints, one of the issues that was implemented was leak before break.

MR. SIEBER: That's right. That was a sensible one.

MR. FERRER: There was another proposal at the time to increase the fatigue usage factor from .1 which is the usage you postulate a rupture at to .4. However, at the time this particular change was postulated, we were aware of the concern with environmental fatigue and that the ASME fatigue curves may not be conservative. So we did not accept that change.

Now if we're taking care of that problem with the ASME fatigue curves, then a change in the pipe rupture criteria may be appropriate at this time.

DR. WALLIS: Is the idea to reduce the burden?

MR. FERRER: Well, what we've said in our responses is if the industry comes in and shows us that this is going to cause an excessive number of rupture postulations to occur, we will reconsider the criteria to try to levelize it so it doesn't increase or decrease the burden.

MR. SIEBER: Well, you have to balance the increases or decreases in the burden with increases or decreases in the risk and so it takes more to say oh, I don't think we should do that.

DR. WALLIS: He's saying if you know more, you might be less conservative.

MR. SIEBER: That's right.

DR. WALLIS: Usage factors, but actually, it would make it easier for industry to reduce the burden.

MR. SIEBER: That's right, and that would be acceptable. On the other hand, just to reconsider what somebody is complaining --

DR. WALLIS: But the claim of the ASME seems to be by implementing these F factors you actually increase the burden.

MR. SIEBER: Yes.

MR. BANERJEE: And is there a case for thinking that it would reduce the burden?

MR. FERRER: Well, if you increase it when you implement the environmental fatigue curves and we've done that in license renewal, a lot of the cases, the change in fatigue usage wasn't that great. So if we were to increase the usage factor for postulating breaks from .1 which is the current position to .4 which was the proposed position in the '80s, this would be about a factor of 4 change in the usage. So you might indeed reduce the burden in some cases.

DR. HOFFMAN: Just to complete, you've already heard a lot on the three options here about whether there's a need to make a change.

DR. WALLIS: These members of Subcommittee 3, are these taken from the nuclear industry?

DR. HOFFMAN: Yes. We've also heard recently from the French. They've done a lot of updating of their codes and standards recently in the last few years and they've decided not to include this as a design consideration in their code. Similarly, the Japanese have introduced this as an operating plant evaluation methodology.

MR. BANERJEE: Have they heard the view that NRC just put forward?

DR. HOFFMAN: The French?

MR. ERLER: Both.

MR. BANERJEE: And they agree with what was said or they disagree with what was said?

DR. HOFFMAN: I'm not sure exactly which --

DR. WALLIS: Did they see the Argonne data though?

DR. HOFFMAN: They've seen the data, yes. They participated in the --

MR. BANERJEE: The last argument was actually not increase the burden, but may reduce the burden because you've got better knowledge now, you're going through a more sort of a fundamentally sound procedure than you were before, so it may actually reduce the burden, correct?

DR. HOFFMAN: Potentially.

MR. BANERJEE: Now did they actually hear that view and did they disagree with it or did they agree with it?

DR. HOFFMAN: I don't think -- they probably have not heard that view. I think most people's perception in these meetings is initially that the burden is going to be increased. And until you've got through that process --

DR. WALLIS: If the burden was reduced, would that make this more acceptable then?

DR. HOFFMAN: The problem is you have to go through the process to find out if that burden is going to be reduced or not.

MR. ERLER: The Japanese, they participate significantly on all the code committees, on the Board, as well as on Section 3 and Section 11. And so they're very much involved in all of the data that's being talked about here.

The same is true, not as much in terms of active involvement, but the French are always at the meetings and following what we're doing. They do share their decisions on it.

DR. WALLIS: Maybe we should move on to the next slide and see what the other options are.

DR. HOFFMAN: As I said, the adoption of new curves, that's been considered. There have been a couple of proposals brought forward. The problems with this have been identified. They tend to be overly conservative. We're applying a factor across the board for everything and again, the concern that the additional restraints that might be needed resulting from higher usage factors.

CHAIRMAN ARMIJO: Is that really the only solution you have, that you'd have to put pipe whip restraints? Couldn't you change the dimensions of the pipe beam or wall thicknesses or just sharpen your pencil and do more detailed analysis? It seems like there's only one outcome and that's a whole bunch of pipe whip that nobody wants.

DR. HOFFMAN: The comment we received from Don Landers who chaired the Subcommittee 3 task group was that applying this F_{en} factor or having new curves isn't going to change the routing of the pipe. It's just going to mean you have to do additional analysis. And I'd ask if Mr. Bruny would have any further comment on that?

CHAIRMAN ARMIJO: It's additional, more sophisticated analyses that will cost more money.

MR. BRUNY: Yes, and I am not privy to all the details, but John mentioned that in the life extension analysis there in several cases there was not a significant increase in the fatigue usage factor, but I challenge whether that was on the same, using the same analytical basis as the original calculations or whether it required to go through the much more extensive analysis in order to achieve that similar result.

MR. FERRER: I don't mind answering that question. I thank you for asking it.

I think one of the comments I made earlier was that the original design of these plants were done to codes that were back in '69, '71, '74. In the intervening years, in piping, there was a significant change to the criteria related to fatigue that makes it less conservative and that was a change to the parameters that were included in the primary plus secondary stress calculation. And the significance of that is if you exceed a certain value, you apply a strain concentration for the peak stress when you do the fatigue analysis and these strain concentrations are the things that really drive the fatigue usage at most locations.

What was done in later codes was to pull out what they call a delta T1 or a through-wall temperature transient stress from that equation 10 and that significantly reduced the number of locations you had to apply to strain concentration location. We took advantage of that when we were looking at license renewal, so that did have an impact. Using the more recent version of the code is not as conservative as the old version that a lot of the analyses were done to.

DR. HOFFMAN: The last item on the F_{en} I think most of these points have already been addressed to one extent or another.

DR. WALLIS: Why would they make the plants less safe now? I wasn't sure about that.

DR. HOFFMAN: That's the additional supports and restraints.

DR. WALLIS: They put it in order to make the plants more safe, why would they result in making them less safe? I don't understand that. If they were put there to stop the vibration and the strain of the motion and so on.

MR. ERLER: It is the issue of being -- if you look at the plants that we ended up with putting in a lot of supports, constraining the pipe, you have more of a chance of having other stress concentrations due to binding up of the expansion and --

DR. WALLIS: Is it a badly designed restraint system?

MR. ERLER: Like I says, it sends us back to where we were in the '70s and saying we're really better off getting a more appropriate criteria where we allow expansion, allow supports to be appropriate.

DR. WALLIS: That's not a question of F factors, that's a question of when you use this -- any kind of fatigue method, you're using the right kind of solution to --

MR. ERLER: Except if you have a greater conservatism, you end up cranking it up more. The other is the issue of access of pipe whip restraints, getting at pipes for in-service inspection is a significant problem, the more restraints you have.

DR. WALLIS: Despite the fact you think this is a lousy piece of work or something that you are going to try to adopt it anyway, is that -- am I just putting it in those terms to try to -- by taking that position to get you to respond.

What do you mean by the first bullet here? You're going to try to do something similar to what they did?

MR. ERLER: That's right. Work with everybody that's working on it, do what we've been doing and try to work our way through some of the fundamental issues that have to be addressed and making sure -- you've got to remember that the F_{en} factor is from one specific curve to another issue, depending on the environment that you're in.

DR. WALLIS: right.

MR. ERLER: And that's a different factor depending on which curve you're starting from and what the environment -- how to apply it is what we'd be working at to making sure that it would be a design practical approach.

DR. WALLIS: So in principle, it's not a bad idea?

MR. ERLER: Make an adjustment for it has merit.

DR. WALLIS: Sounds --

MR. ERLER: Like I say, the phenomena, we're quite --

DR. WALLIS: By following this bullet, you might actually reach consensus with the staff.

MR. ERLER: You have to sit in the meetings --

DR. WALLIS: Why don't you do that?

MR. ERLER: And to hear the different points of view from around the world and different experts to understand the issues that are technically sound on the table. But there's a feeling you can work it out. It's just going to be a --

DR. WALLIS: The problem I have is it seems that there's an unwarranted reluctance to take this approach.

MR. ERLER: No, I don't think so. I think that it's finding the right F_{en} and how to apply it.

DR. WALLIS: Well, yes, but let's find the right F_{en} and then apply it if it's a reasonable approach.

MR. ERLER: That's correct.

DR. WALLIS: You wouldn't say that's unlikely. That's something that you could work with the staff to achieve?

MR. ERLER: Absolutely.

DR. WALLIS: How long would it take? It wouldn't take 25 years?

MR. ERLER: Or even 10 years or even 5 years.

DR. WALLIS: This is like the last time we went with ASME and the staff on these issues or issues like this. We simply said you guys ought to go away and work on one of these bullets and make it happen.

DR. BONACA: It would be interesting to hear from the staff now. Clearly, there is a search for a consensus and what really troubles me the most is that ASME is a nationwide organization, it's a worldwide organization and typically we strive for consensus. And so I hear two sides and I would like to see an effort to reach consensus. To reach consensus you have typically all parties try to step to the table and I really would like to know what you think about this.

MR. ERLER: I think at least at the lower group level because I did sit in on one of the groups on fatigue analysis that we were reasonably close to consensus and there were a couple of issues that were apart on the staff and the industry on a level of conservatism of these F_{en} factors.

With the current version, we changed the basis for defining these factors to this 95/5 which reduced some of the conservatism in the original staff position.

So we believe we've moved towards the F_{en} position that the industry was proposing at one time and we were hoping that to see a little bit of movement at ASME to recognize that one, we had moved our position slightly to be slightly less conservative and it shouldn't be that far away from what they were at least proposing at the lower code committee levels.

DR. WALLIS: So they are proposing an F_{en} approach?

MR. ERLER: They had an F_{en} approach that was proposed. It never got through the lower committee levels.

DR. WALLIS: On Slide A, they seemed to be saying the F_{en} approach itself is no good. The factors are not appropriate and inconsistent.

MR. ERLER: That's directed at the reg. guide itself and the specific factors.

DR. WALLIS: But you're saying that the F_{en} approach itself is no good?

MR. ERLER: No.

DR. WALLIS: I thought you were saying that the whole approach is no good.

CHAIRMAN ARMIJO: I guess I am more troubled by the fact that at this stage, there is still wording in your chart that say there's a lack of agreement on need to do anything. And I would -- that means that some people in your committees are just saying we don't have to do anything at all, period.

And somehow that's gotten past your hierarchy that says sorry, guys, there is a need to do something, so we're not going to put that bullet on there, but we're going to do something.

At least I'd be a little more comfortable with the ASME's position if they said hey, we recognize there's a need to do something. The old codes and methodology and the old data wasn't just perfect. We have modern ways of doing things and we're going to do it in a modern way and we'll work with NRC to work it out. That, to me, would be a more comfortable --

MR. ENNIS: That comes back to the focus of coming to consensus on the need. What is the need that you're trying to address? If the need is let's use more modern data or let's use more modern technique, to upgrade ourselves, that is satisfying one need.

If you're saying the need is there are fatigue failures of this type in plants and we have to change --

CHAIRMAN ARMIJO: I think this industry has failed many times to design things properly with respect to environment and we've cracked pipes and replaced pipes and cracked numerous components, spent billions of dollars and when that happens everybody agrees there's a need to do something.

This approach says hey look, we've gotten a lot smarter, we've got more data. We've got more experience. So we can anticipate these things, design it right, put the right criteria, maybe be more flexible on the usage factors that the NRC regulates because we know more. It seems to me that's fundamentally a sounder way of approaching it and rather than say well, let's wait and see if we get some unexpected fatigue failures. I just don't like that approach because that's what we've been doing for so many years.

MR. BALKEY: And for our last slide here, I guess we felt that -- you've heard through the presentations that well, it's not explicitly, but we do have factors that are considered in our design criteria and we've obviously wrestled with the need to change the current design requirements and if there is the need, then how that change gets implemented. So it's the aspect of in going back and --

DR. WALLIS: It seems to me the need is to respond to this new data which seems to be fairly broad and not comprehensive which shows that you can get fatigue failures earlier if you have these environments.

I think as I gather from this -- I mean your position is that your factor of 20 is good enough because these effects are not that big. Is that really your basic position, that if the effects turn out to be bigger, then it could be covered by your factor of 20, then there would be a more obvious need. Is that your position really, that the 20 covers this?

MR. ERLER: Basically, that is the position of the various codes and subgroups that the fact, everything has come to a vote. It's been extremely towards the side of not changing it. There's been new curves that have been proposed. There's been an EPRI approach that's been proposed and it ends up --

DR. WALLIS: The rationale has been that the factor of 20 covers this new --

MR. ERLER: There's a whole series of rationale. You've got to have --

DR. WALLIS: Some of it could be just we don't want to do anything.

MR. ERLER: No, no. I don't think that's the truth of any of the working group. We've had two task groups that have been assigned within Section 3 to work through it. The design group has been -- and it's going to be Richard Barnes wasn't able to make it here, but he wants to drive it up to Section 3 and make a decision with regard to get a vote at Section 3 and at such a vote you'll see the negative reasons. They have to be written reasons as to why -- as opposed to discussions.

We have months and months of discussions that last all day, arguing about the shape of these curves, the data, the statistics. The experts are quite amazed, you know, where they all come from, but the process is such that I think that it is really a series of concerns that have been identified of how to deal with it. The simple statement that we agree the phenomena is there.

To date, it looks like we haven't had any failures that we can identify specifically with environmental contributing to a shorter fatigue life for a particular component provides a lot of reassurance for people to -- at the same time, there has not been an agreement to stop doing anything on it.

I mean our last bullet down here is we're going to continue to get money and do research, work with the NRC, work with all of the organizations to get data, to find out where it's appropriate.

It's not unusual, the design of any -- of a building that you don't design for exact conditions that you have.

DR. WALLIS: Does license renewal make a difference? Now you're extending the life, so that experience up to date with fatigue may not cover the future.

DR. HOFFMAN: Can I? Well, this environmental fatigue effect is addressed for license renewal by a set of sample analyses. But, in fact, to my knowledge, no plant that's gone for license renewal has increased their number of transients by a factor of 50 percent.

DR. WALLIS: It is close to this usage factor limit? They don't get close to that?

DR. HOFFMAN: No. It's been addressed for license renewal and it's just another example of a lot of the extra margin that's built into the Section 3 design process.

The design transients that are identified are far grater than what are actually seen in operation. So there's lots of other sources of margin in the design.

MR. FERRER: May I comment on that because we have looked at at least two dozen plants on license renewal and actually we have a NUREG CR-6260 which we did some sample analyses. The staff had done by EG&G at Idaho. That's not quite correct. There are cases where the number of design transients was nonconservative and it occurred mostly on BWRs where they originally assumed 120 cycles of start-up and shut-down and now they're postulating something closer to 200 cycles.

And so there are cases where there were more design cycles, the original design was not necessarily conservative in terms of cycles. There are a number of cases that were evaluated where they did an evaluation and the fatigue usage came out greater than one. And there's an open issue for them to come back before the period of extended operations to propose to either do some more rigorous re-analysis or to do some kind of an aging management program at those locations. And that's an open issue in a number of license renewal reviews.

DR. WALLIS: Now if you use the F factor method as proposed, presumably those usage factors would become even bigger.

MR. FERRER: Well, that's what we did in license renewal.

DR. WALLIS: You did in license renewal.

You used the F factor.

MR. FERRER: Yes, but we used a slightly more conservative position than is now being proposed. We originally took the 2 and 20 adjustment factors to the environmental data to get the design curve. Now we use this 95/5 which is 12. So it's not quite as conservative.

CHAIRMAN ARMIJO: Did you have to relax the regulatory position on the -- what was allowed, the usage, the .1?

MR. FERRER: What we did in license renewal was we didn't apply the environmental on the calculation of the pipe postulation locations. We only applied it on the calculation of the fatigue usage for code compliance considerations.

The reason this hasn't been discussed previously, I think is the first time the staff really thought about it is based on the public comments to the reg. guide. When somebody mentioned that this may be a problem, causing additional pipe break postulations, we said we'll consider adjusting the criteria. But in license renewal, we've had no problems with that because we didn't specifically ask them to apply the environmental factors on a break location calculation.

DR. BONACA: Now these are Regulatory Guide. This is an approach. You still have the option of presenting alternatives.

MR. FERRER: You are correct.

DR. BONACA: That means there will be additional work and maybe there is some consensus.

MR. BALKEY: That's what we're trying to say in the last slide here. I mean it's -- we're not trying to say we don't want to do this. We do, but we're just wrestling wit how you do it and we're willing to even look at the draft reg. guide as a code case in order to get the input to the ASME constituents.

We're also looking at other alternatives and we have other alternatives in process. But it's a difficult challenge with getting all the stakeholders to agree, based on an extra day, how we can go forward in doing that, both from both design as well as in operational evaluation.

CHAIRMAN ARMIJO: Okay.

MR. BALKEY: Thank you.

DR. WALLIS: What do you expect the ACRS to do?

DR. SIEBER: There's always somebody.

(Laughter.)

DR. WALLIS: Are we supposed to come down on some side or the other or are we supposed to say knock your heads together and say go away and agree or what are we supposed to do with this?

MR. BALKEY: The thing that struck me, as I said, I did piping work in the 1970s for about 10 years and this issue became much more knowledgeable as the reg. guide came out over the summer.

And one thing, I get concerned when we met from B311 and it addressed the comment about we want to go to much better analytical methods. We went through B311 to 317. Everyone viewed 317 for better design rules. The plant that I worked on, the architect did all the piping layout based on 311. But when the commitment was one that hey, this plant would be licensed to the B317 code, then a confirmatory analysis was done.

And what happened when we moved and did this better work, we ended up adding in 230 snubbers at the last couple months before this plant needed to go on critical path. And I know when I went out to walk down the line with the architect, I mean we really had a lot of congestion. And you set yourself up for pipe growth that ended up, you know, snubbers would lock up and you end up with high stresses that you weren't counting on.

And as John Ferrer and my other colleagues said then, that was just one plant. That was experienced across a number of reactors back in the '70s. The code worked real hard with the NRC. We actually changed evaluation methods to pull all those restraints back out. But snubbers as well as whip restraints. That was an enormous amount of effort.

I think the question that I have from that experience from 30 years ago is right now I've not seen where somebody took a plant and did a trial application to see using these methods from a design standpoint. where do we end up here.

What we have to be careful is that we don't end up what we did 30 years ago where you do a lot of work and then you find out well, we're back here again. We're revising this criteria, that criteria and all it does is set up regulatory instability, both with the code as well as the regulations.

That would be -- that's the question in terms, because the plants that we hope are all coming forward, they're all looking for regulatory stability. They're trying to keep the design fixed and not get into what we did 30 some years ago.

So that would be the question I would have with -- and I know you've done this on other regulatory guides where instead of the issue is final, it's issued out as a trial application until you get real experience, then make the determination.

A trial application would be real helpful data to ASME.

DR. WALLIS: Would that fit in with your second bullet here? I'm not sure what the code case is.

MR. BALKEY: A code case allows -- whenever we have a new technology and you want to try it out, a code case allows for early use and gets some trial applications. A good example is --

DR. WALLIS: It doesn't make a lot of sense. Does the NRC agree with that sort of thing?

MR. SIEBER: They occasionally approve it.

MR. FERRER: Yes, as a matter of fact, one of the proposals in the ASME was exactly to do that and it was with the F_{en} approach, but it didn't go through the system.

We would have probably -- had they put one out, we would have probably endorsed it with some exceptions, minor exceptions. We would have been slight more conservative, but we would have endorsed it and I said that at many of the code meetings that I sat in when they were discussing that there was a difference between ASME and NRC that all they had to do was issue their proposal and we would adopt it with the exceptions that we thought were necessary.

MS. VALENTINE: And I would just like to add to that, this is really a timing issue. As we said many times before there has been discussion on this for many, many years.

The staff is very clear with the instruction from the Commission that we have several high priority reg. guides to issue by March 2007 to support new reactor applications. As we stated many times, this has been a consistent process, but this does not -- our reg. guide does not stop that consensus process.

This is a Regulatory Guide, not a regulation. So the staff has been very clear on what we expect to come out of this meeting which is agreement for issuance of an effective reg. guide.

CHAIRMAN ARMIJO: Okay, with that, I think we'll close on this one. We have one more presentation by -- thank you, gentlemen, for your presentation. I appreciate it.

(Pause.)

CHAIRMAN ARMIJO: Okay, let's start.

MR. COFFLIN: Mr. Chairman, Committee Members, first of all, I'd like to thank you for giving me the opportunity to make statement here today. I won't be presenting. I'll just be taking from some notes I have.

I kind of got inserted at the last minute and I appreciate that.

Thank you, Gary.

My name is David Cofflin, and I work for AREVA MP, Incorporated in Lynchburg, Virginia. I supervise a group of engineers who are responsible for loading, stress and fatigue analysis of the reactor coolant system for the USEPR which is AREVA's entry into the advanced light water reactor market. And as such, I have a practical viewpoint of what this reg. guide means to people say at the working level.

We have received DG-1144 some time ago and we issued it to all three regions of AREVA. That would be France and Germany and the U.S. And we reviewed in September on the 22nd. We sent a letter to the NRC which outlined out concerns and comments with the draft reg. guide.

I actually have copies of the letter here. There were some passed out earlier. Does everyone have one?

Others in the gallery, I have some here too.

My purpose here today is not to go through the letter point by point or in detail. I just want to summarize our major areas of concern with the draft reg. guide.

What AREVA would like out of this is that the advisory committee consider these concerns and questions when they're formulating their recommendation to the Commission regarding implementation of the draft reg. guide.

I'll move onto our concerns. AREVA is not aware of any operating experience that supports the need for the conservative fatigue design rules proposed in DG-1144. I guess my placement in the schedule was fortunate because ASME has handled most, if not all of these comments already.

DR. WALLIS: Are you saying that because nothing has happened we don't nearly need a rationale way to predict what might happen?

MR. COFFLIN: I would argue that the method that we're using now is sufficient for what we're doing.

DR. WALLIS: We don't need a rational

method of predicting what might happen?

MR. COFFLIN: That's a fair statement. But all I'm saying is I think the method that we have now is rational.

DR. WALLIS: But it seems to be the argument that because nothing has happened so far, we don't have to worry about it. We don't need to rationally predict what might happen?

CHAIRMAN ARMIJO: If absolutely nothing changed. And the methods and the data and the regulations of 1960 or whatever, then you might have an argument. But things are always changing and I don't know if we can count on that kind of stability in the analytical processes to be there to provide the conservatism that it provided by being just so simplistic.

And so I don't understand this idea that we have to have something fail before we do something.

MR. SIEBER: Let's not think that nothing has ever failed. There's been a lot of nickel-based alloys that have not performed well.

MR. COFFLIN: Through different mechanisms.

MR. BANERJEE: Every 7 or 10 years we find a surprise. Is that Bill Shack who said that?

(Laughter.)

MR. SIEBER: And that keeps a lot of us employed.

CHAIRMAN ARMIJO: Okay, go on.

MR. COFFLIN: AREVA believes that the proposed rules and we've been through this again, will lead to more postulated break locations which will lead to more whip restraints and jet shields.

This will lead, in turn, to reduction in overall plant safety due to the increased risk of our spring thermal expansion and more difficulty in obtaining accurate inspection results due to the addition of whip restraints and jet shields. Again, a point that the ASME has made.

It is not clear why the application of the proposed rules is not limited to those locations which are most sensitive to environmental fatigue effects similar to how environmental fatigue effects are treated in license renewals phase. License renewal is operating under a different set of rules.

AREVA does not believe that the NRC should establish very conservative design rules without peer consensus which we talked about.

The entire fatigue analysis methodology should be considered when developing rules to account for the effects of environment, rather than limiting considering to material effects only. And practiced the current ASME fatigue analysis and practice the current ASME fatigue analysis methodology already contains multiple conservatisms that are not easily removed from the fatigue analysis process.

Finally, in our September 22nd letter through the NRC, AREVA has highlighted several technical concerns with the proposed rules. These include concerns with the representative nature of the materials tested and the loading applied during the tests. The difficulty in translating results from laboratory specimen test results to field components and the lack of appropriate threshold values in some of the formulations.

And that is a very quick and brief summary of what's in the letter. You'll find much more detail in the letter. I'm a practical guy. I'm trying to look at it from the standpoint of what it means to me as a piping and component analyst, but particularly the technical component, the technical comments. There's a fair bit of detail and background in the letter that describes what they are. I just briefly hit them.

Thank you.

DR. WALLIS: You seem to agree that there is an environmental effect.

MR. COFFLIN: Yes, sir. There is.

DR. WALLIS: But it's not big enough to require any change in the procedures.

MR. COFFLIN: I believe to restate that is that it -- we believe that the methods that we're currently using would cover environmental fatigue effects.

MR. BANERJEE: Your letter here has quite a lot of detail technical points.

MR. COFFLIN: Yes, sir.

MR. BANERJEE: The NRC, presumably, has looked at this because the letter was sent on the 22nd of September. And did you respond to these points that they made?

MR. COFFLIN: I think one of the biggest points that they made and said previously that it may increase the number of pipe break postulations and we considered that a valid comments and would consider adding the criteria.

With regard to some of the detailed technical comments on the conservatisms and the analysis, we agreed with some of them, but some of them we disagree with and one of them we just mentioned earlier in the number of postulated transients is not always conservative as we found in our reevaluations. There's some that they under-estimated in the original design and it turned out to be more transients than they estimated.

One of the comments in the AREVA letter was technically incorrect. One of the arguments they made in the letter was that the ASME evaluation criteria is based on Tresca which is called the maximum stress criteria and that was overly conservative in the analysis.

Well, the Tresca criteria is an overly conservative failure criteria, but if you use a different criteria such as VonMises criteria, you would calculate a higher stress and therefore a higher strain to go into the ASME fatigue curves. So really that argument, that part of it is really not conservative, if you look at it in terms of VonMises criteria.

MR. GURDAL: But Omnesis is less. I hope it is so. I may not speak, but it is truth. In every book they list a rectangle, and an ellipse and it shows that you can go to a higher stress level to come to a rupture when you have Omnesis. So in other words, the Omnesis stress itself is less than Tresca.

Tresca is always more severe than Omnesis. All the same. All the same. Fifteen percent maximum. I'll send you that page.

MR. FERRER: I'll refer you to an MRP study where they were looking at those U-bend specimens that Dr. Chopra showed you and they evaluated them based on Tresca and showed that there was a clear effect of the environment. And they went back to a VonMises type criteria and showed that with higher calculated strains they were closer to the ASME fatigue curves. However, you don't use VonMises to do fatigue analysis.

MR. GURDAL: This is not a competition for Omnesis and Tresca. It's the one where it's called maximum total principle strain range. It's that one. It's not a comparison between Tresca and Omnesis.

MR. FERRER: I don't think we're going to get anywhere with this cross argument, but if you go into a textbook, they will show you a plot of VonMises versus Tresca. It's a standard plot under two dimensions.

MR. BANERJEE: To go back to the original question, they lay out a number of let's say technical comments. Now do we have a response to these -- okay. That's really the question I was asking.

And then these responses have been received by AREVA, presumably.

MR. GURDAL: No.

MR. BANERJEE: Have not. I see. I think that answers my question.

DR. SIEBER: Or by us.

MR. BANERJEE: Or by us, right.

DR. WALLIS: We have received them.

DR. SIEBER: We have?

MR. SANTOS: It's on the disk.

DR. SIEBER: Oh, okay. I'll look at this.

CHAIRMAN ARMIJO: But I think this thing about pipe whip restraints and snubbers and proliferation of those things as being the only outcome of applying this reg. guide is kind of hard to believe. It's either that or spend some more money and more sophisticated mechanical analysis and/or seek some relaxation of the criteria, all of which are available to you.

I don't think it's the end of the world and the only thing that will come out of this is a bonanza from the pipe whip restraint industry. It seems like that's the point that's getting overstated, at least my point.

DR. SIEBER: I guess I'm in a position to confirm that having to redo your analysis and have a ton of restraints costs millions of dollars, does occur.

CHAIRMAN ARMIJO: But I think this is a different situation now, Jack. They're saying that nobody wants it. The staff certainly doesn't want that to be the outcome, at least that's what I've heard.

DR. SIEBER: Well, you may be in better shape now than you were in 1980 when these things became a fact.

DR. WALLIS: I don't quite understand that. Because if the F factors are already within this ASME factor of 20 as they claim, I don't see why it's making that much difference.

DR. BONACA: Well, that is the point of ASME. I think the presentation we got from the staff made a case for addressing specifically environmental concerns and so now if, in fact, this causes many more restraints to be placed in location and an assumption to be made, does it mean that the ASME position, in act, does not address environmental concerns adequately. We're left with a question. It means that there is sufficient difference there to state that the ASME case currently does not address adequately the environmental concerns, it seems to me.

If you're telling me that there are going to be hundreds of additional constraints and locations for breaks, it means to me again that there is significant difference between what we have heard in a technical presentation where environmental concerns were specifically addressed in the ASME case which is really most about the basis. It simply provides some multipliers.

So I'm left with having to judge between something I understand. I saw a presentation. I saw some basis for it versus an assumption that says this number has not been causing problems in the past, so we just live by that.

I really have the feeling that I don't know, maybe it's not going to cause so many additional restraints.

DR. SIEBER: It seems to me that if the staff were to issue this reg. guide and ASME would develop their code case and staff would approve that with some delayed implementation, we would learn a lot of these answers.

DR. BONACA: Yes.

DR. SIEBER: Technically that's -- if we say don't issue the reg. guide, it will be 25 years --

that won't happen. On the other hand, industry arguments are good enough as to question whether this is too rigorous. I think this is a way to show whether it is rigorous or not, too rigorous or not.

DR. BONACA: You know, I agree with you, by the way, on the case. On the other hand, this is the first time I've seen specific calculations or tests addressing environmental concerns. We have discussed this through license renewals plenty of times and we had no information except we had GSI-190 and we were left with the question of what does it mean for license renewal 20 more years? This is the first time I've seen some of these.

Now the letter from AREVA questions some of the technical aspects of the tests, so that -- it's open here and I think there are answers for that. But in general, I think that we have seen some technical basis for what is being proposed.

DR. SIEBER: I think what the staff is now doing in license renewal space is probably as good as they can do with the regulatory authority that they have.

Yes sir?

MR. ERLER: I guess the one other issue that -- you've identified the issues that are critical. I'd add to that how to apply the F_{en}. That is a difficulty. It was identified in the MRP-47 and that has not been addressed. There's as many negatives on getting something through, of passing something that you don't know how to apply it to the person. So that's what's going to take us a little more time in our code case to be able to develop the application of it so that it makes sense, with the code equations and everything.

That's why we really would like to buy some time. I think it's good that you put some pressure on us to move by having something in front, but I would like rather than lock it in place, some time there to work through that.

DR. SIEBER: There is a way to do that, I think.

MR. FERRER: Again, we need something to implement our current reviews. If ASME develops something as has been stated here before, this is a regulatory guide, just gives a method acceptable to the staff and an alternative method could be found acceptable if we find you put out something that had an adequate basis to cover the concerns.

MR. BANERJEE: How many reviews are you facing in the near future?

MR. FERRER: Right now, two. We have ASBWR and EPR. That's why AREVA is here. The other one would be GE. And they're near term. We need the criteria now if we're going to implement something.

DR. WALLIS: We have no idea what is the actual impact of these criteria on say the ASBWR?

MR. FERRER: No, because at this point, this was an open issue in the review and we're waiting for the proposed response on how they're going to address it. Because at the time we raised it, they didn't -- the reg. guide wasn't on the street. In the interim, it has now been issued, so that they could come in an propose to use our reg. guide and then we could do an evaluation of its impact.

DR. KRESS: Won't it show up at the COL stage instead of --

DR. SIEBER: Yes, but that's certification. It will be grandfathered.

DR. BONACA: It will show up at the design stage.

MR. FERRER: This is not quite true because they are doing some sample analysis in the design certification stage for both plants, I believe, and so we will get a feel for the amount, whatever the amount they do in the design certification stages, what the impact is.

DR. SIEBER: Well, it certainly is easier to do before you've taken any mortar and steel and played with it. Pencil and paper is far cheaper.

MR. BANERJEE: Well, with EPR you still have time before that happens, right?

MR. FERRER: Yes, yes. Right now they have a topical in I think on the criteria which we're going to review. We haven't really gotten started with it yet. ESBWR, we're much further along. They're actually doing analyses of certain systems and we have the issue as an open issue with them, waiting to see how they're going to attempt to resolve it.

If we can't resolve it in the design certification review, then it will be an open issue and it will roll over to COL.

DR. BONACA: Now AREVA is in the process of building an EPR in Finland, correct?

MR. FERRER: That's correct.

DR. BONACA: So you should have some feedback there. I mean what kind of codes and standards are they using?

MR. COFFLIN: They are using RCCM which is the French code. It's roughly equivalent to the ASME. It does not have environmental fatigue rules in it.

DR. SIEBER: Then that's not going to help you.

MR. GURDAL: I am Robert Gurdal. For Finland, like David said, they are using RCCM which is the code from the French which was really based on the ASME to start with, but then it just further developed, so it's kind of a hybrid from the ASME. I don't know how to say. But now that code does not tell you to do environmental effect, but STUK, if you know them, S-T-U-K, that's like the corresponding NRC in Finland, can I say like that, I think.

DR. SIEBER: Right.

MR. GURDAL: And their code is called YVL. They are asking what the French, because it's really under France and Germany, are going to do for the environmental effects. So it's a question there, but it's kind of kept open to the French to see what they want to do. And what they have promised is to look at four locations very similar to the license renewal and those four locations are surge, surge nozzle and CDCS with a nozzle. What is it? Control and volume?

DR. BONACA: So AREVA has an ability to have a test then, it's an evaluation in and of itself.

MR. GURDAL: Yes.

DR. BONACA: This case, and really see

what the impact is.

MR. FERRER: It may be a timing thing. I prefer the music.

MR. GURDAL: They hope to do this analysis for the first three months of 2007, but then prior to that they are also doing tests, because what they don't really believe in is those triangular types of cycles. They say that the real cycles are more what I would call Delta T1, Delta T2 types. In other words, when the fluid is coming. So in that case, the environmental effects are in place. But the other big, big thing that they don't believe is that you don't have the surface effect and the environmental effects at the same time. Very important.

He has an incredible surface effect in his 12 which is what between 2 and 3.5. You take the square root of that, that's approximately 2.6 and the surface effect we see is something like 1.1, 1.2 that you can see in the EPRI tests done in Ireland.

So what they really think is that once you use the environmental effects, you should not have those factors of 2 and 20. If you have any factor a lot less of 2 and 12, and that's completely consistent with the Japanese who have a 1.5 down and nothing else. First, that's Dr. Nakamura if you want.

DR. WALLIS: That's in your letter, right?

MR. GURDAL: I don't remember. That was in September.

Part of it is. I could -- in the meantime, we learn a little more, but because of the deadline we have to rush. That's why it's September 22nd, which was a Friday for the 25th. We would have more information. And the French, I spoke with the French yesterday on the phone and he wants to be sure for Flamonville, that's the second EPR in the world, the third, hopefully, is in the United States. For Flamonville, it's already decided no environmental effects. And that's reported by EDF.

No, the environmental effects is an R&D phenomenon that you don't see in components. That's his one sentence. Maybe we shouldn't put that in the record.

So Flamonville -- the only interesting question about Flamonville is they are discussing whether the design would be according to ASME or RCCM. I don't know if that -- but for Finland, it's RCCM. Oh, but the fatigue curves in the RCCM are the same as ours, the fatigue curves.

CHAIRMAN ARMIJO: Okay, thank you very much.

MR. FERRER: Thank you. Thank you for your time.

CHAIRMAN ARMIJO: I think we've got -- we're done, unless the Committee wants to make any comments, speeches. There will be an abridged presentation to the Full Committee.

DR. WALLIS: Do you want to have a caucus of the Committee off the record, after this?

CHAIRMAN ARMIJO: Yes, I would. I think it would be a good idea of what to write.

Okay, with that, I'm going to close the meeting and thank everybody for their presentations and for the discussion. I think it was very well done. Off the record.

(Whereupon, at 5:18 p.m., the meeting was concluded.)

CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: Advisory Committee on Reactor Safeguards Subcommittee on Materials, Metallurgy and Reactor Fuels

Docket Number: n/a

Location: Rockville, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Eric Hendrixson
Official Reporter
Neal R. Gross & Co., Inc.

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*

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Presented to
Advisory Committee on Reactor Safeguards
Subcommittee on Materials, Metallurgy, and Reactor Fuels
Rockville, Maryland
December 6, 2006

Agenda

- Discuss RG 1.207
  - Historical Perspective
  - Overview of RG 1.207
  - Technical basis, NUREG/CR-6909 Rev. 1
  - Regulatory Positions
- Resolution of public comments on DG-1144 and draft NUREG/CR-6909

Environmental Effects on Fatigue Life: Historical Perspective

- ASME Section III fatigue design curves developed in the late 1960s and early 1970s
  - Air environments at ambient temperatures
  - Adjustment factors of 2 on strain and 20 on cyclic life

- Studies in Japan (Higuchi & Iida, 1991) and those at ANL (NUREG/CR-4667, 1990) - potentially significant effects of LWR coolant environment on fatigue life of steels

Environmental Effects on Fatigue Life: Historical Perspective (cont.)

- Since late 1980s, NRC staff have been involved in discussions with ASME Code committees, PVRC, and technical community to address issues related to environmental effects on fatigue

- 1991, ASME BNCS requested the PVRC to examine worldwide fatigue strain vs. life data and develop recommendations

- 1995, resolution of GSI-166 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)

Environmental Effects on Fatigue Life: Historical Perspective (cont.)

- In 1999, 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 the effects of coolant environment
- December 1, 1999, by letter to the Chairman of the ASME BNCS, the NRC requested ASME to revise the Code to include environmental effects in the fatigue design of components

Environmental Effects on Fatigue Life: Historical Perspective (cont.)

- ASME initiated the PVRC Steering Committee on Cyclic Life and Environmental Effects
- PVRC recommended revising the Code design fatigue curves (WRC bulletin 487)
- After more than 25 years of deliberation, no consensus has been reached

Environmental Effects on Fatigue Life: Historical Perspective (cont.)

- NRR User Need Request 2005-004 (January 7, 2005):
  - Develop guidance for determining the acceptable fatigue life of ASME pressure boundary components, with consideration of the LWR environment
  - For use in supporting reviews of applications that the agency expects to receive for new reactors.
  - Industry immediately notified

- High priority RG to be completed by March 2007

Environmental Effects on Fatigue Life: Historical Perspective (cont.)

- February and August 2006 - NRC staff and ANL presented at the ASME Code meetings the technical basis draft NUREG/CR-6909

- July 24, 2006 - DG-1144 and draft NUREG/CR-6909 published for public comments (60 day comment period)

- July 25, 2006 - ASME PVP Conference, ANL presented paper on technical basis

- Public comment period ended September 25, 2006

Overview of RG 1.207 – Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the LWR Environment for New Reactors

How RG 1.207 relates to the Regulatory Requirements

- General Design Criterion 1
  - Safety related SSC 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 BPV Code for design of safety-related systems and components (Class 1)
  - ASME BPV Code Section III, includes fatigue design curves
- Fatigue design curves do not address the impact of the reactor coolant system environment

Objective and Implementation

Objective

- To provide guidance for determining the acceptable fatigue life of ASME pressure boundary components, considering the LWR environment
  - Major structural materials: carbon steels, low-alloy steels, austenitic stainless steels, and Ni-Cr-Fe alloys (e.g., Alloy 600 and 690)
- Describes an approach that the NRC staff considers acceptable to support reviews of applications for new reactors

Implementation

- Applies to **New Plants**
- **No Backfitting is intended** (conservatism on current reactors)
- Regulatory guides are not substitutes for regulations, and compliance with regulatory guides is not required.

How the Technical Basis was Developed

Technical Basis Report: NUREG/CR-6909 Rev. 1 – Effect of LWR Coolant Environment on Fatigue Life of Reactor Materials

Omesh K. Chopra
Nuclear Engineering Division
Argonne National Laboratory

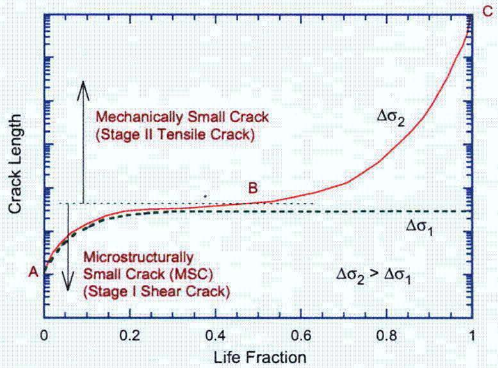
Argonne NATIONAL LABORATORY

Issue - Environmental Effects on Fatigue Life

- Fatigue data indicate significant effects of LWR environment
- Data are consistent with each other & with much larger database for fatigue crack growth (da/dN)
  - in LWR environments, effects of material, loading, and environmental parameters are similar for fatigue ε-N & CGR data
- ε-N data have been evaluated to
  - identify key parameters that influence fatigue life, &
  - define range for these parameters where environmental effects are significant, i.e., establish threshold & saturation values
- If these conditions exist during reactor operation, environmental effects will be significant & must be addressed
  - subsection NB-3121 recognizes that the data used to develop the fatigue design curves did not include tests in environments that might accelerate fatigue failure

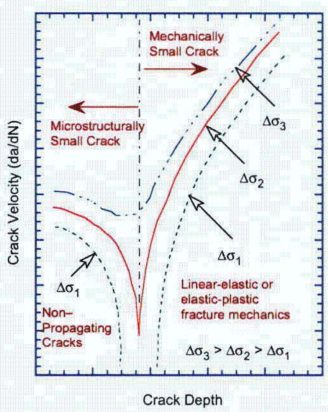
Fatigue Life

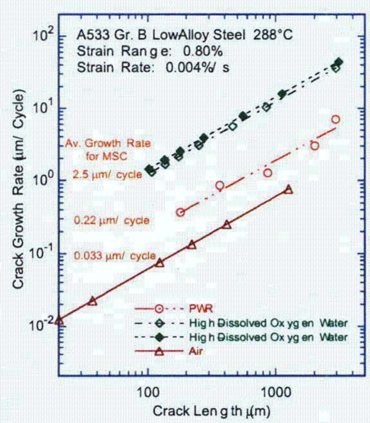
- Code fatigue design curves based on tests to failure of specimens; intent however is to avoid initiation of fatigue cracks
- Current test practice generally defines life of specimens as cycles to 25% load drop; typically this corresponds to a ≈3 mm crack



- Surface cracks ≈10 µm deep form early during fatigue loading
- Most of fatigue life associated with growth of cracks; 10 to 3000 µm
- Represented by two stages:
  Initiation: microstructurally small cracks, < 300 µm
  Propagation: mechanically small cracks 300-3000 µm (EPFM)

Fatigue Crack Initiation in Smooth Specimens





- Environment affects both stages: initiation & propagation
- Effects on fracture mechanics controlled-growth are widely recognized
- ε-N data indicate effects on growth of microstructurally small cracks may be even greater

ASME Code Fatigue Design Curves

- Code design curves based on data obtained on small, smooth specimens in RT air under constant loading conditions
  - obtained under strain controlled, fully-reversed loading (R = -1)
- To use small–specimen data for reactor components, best–fit curves must be adjusted to cover effects of variables that influence fatigue life but were not investigated in the data
  - such variables include mean stress, surface finish, size, & loading history. Data scatter & material variability must also be addressed
- To obtain Code design curves the best-fit curves were
  - first adjusted for effects of mean stress on fatigue life
  - then reduced by factor of 2 on stress or 20 on life to account for other variables, but not an aggressive environment

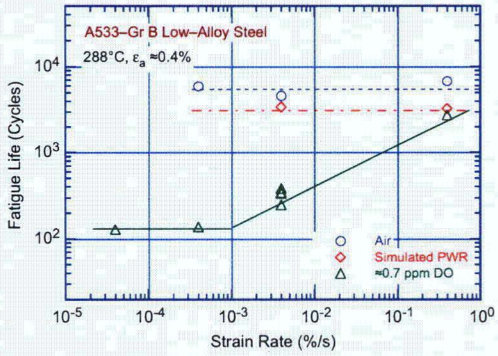
Environmental Effects on Carbon & Low-Alloy Steels

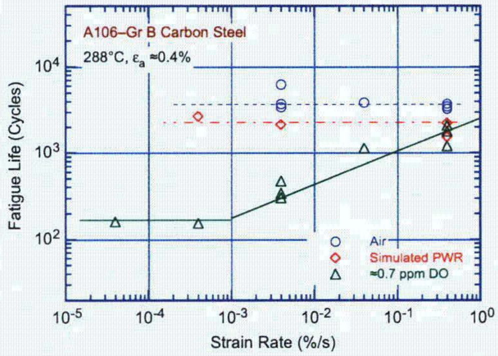
- The effects of critical parameters on fatigue life:
- – Steel type: effects identical for carbon & low-alloy steels
- – **Strain amp**: strain threshold near fatigue limit; no effect below threshold
- – Strain rate: logarithmic decrease in life below 1%/s, saturation at 0.001%/s; moderate effects above 1%/s
- – Temperature: linear decrease in life above 150°C; moderate effects below 150°C
- – Dissolved Oxygen: logarithmic decrease in life above 0.04 ppm, saturation at 0.5 ppm; moderate effects below 0.04 ppm
- – Sulfur: effects increase with increasing S level, saturation at 0.015 wt.%
- – Surface roughness: life of rough specimens is decreased in air; in high–DO water, surface roughness has little or no effect on fatigue life
- – Flow rate: in high–DO water, effects decrease with increasing flow rate

Environmental Effects on Austenitic Stainless Steels

- The effects of critical parameters on fatigue life:
  - Steel type: effects identical for wrought & cast austenitic stainless steels
  - **Strain amp**: threshold near fatigue limit; no effect below threshold
  - Strain rate: logarithmic decrease in life below 0.4%/s, saturation at 0.0004%/s; moderate effects above 0.4%/s
  - Temperature: linear decrease in life above 150°C; moderate effects below 150°C
  - Dissolved Oxygen: in high–DO, effect may be lower for some steels; in low–DO, effect significant for all steels & heat treat conditions;
  - Surface roughness: life of rough specimens decreased in air & low–DO water
  - Flow rate: no effect of flow rate on fatigue life in high-purity water

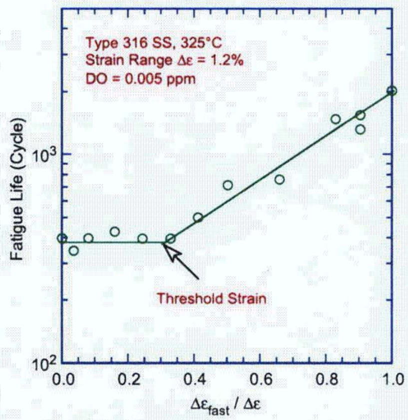
Effect of Strain Rate

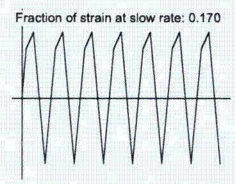




- Little or no effect of strain rate in air & PWR or HWC BWR
- In high-DO, life decreases with decreasing strain rate below 1%/s, effect saturates at ≈0.001%/s

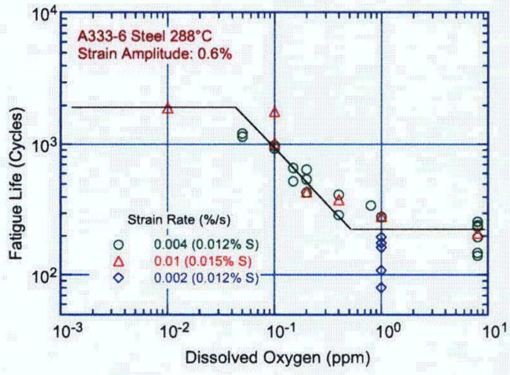
Strain Threshold - (Variable Strain Rate within a Cycle

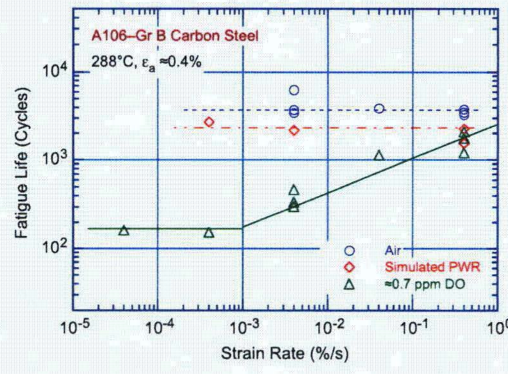




- Data indicate threshold strain amplitude slightly above fatigue limit
- Tests with variable strain rate indicate that relative damage due to slow strain rate occurs only after the strain exceeds a threshold value

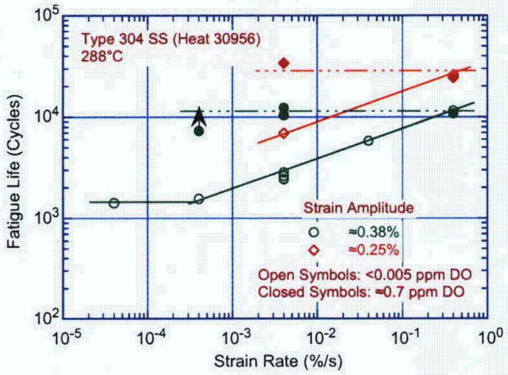
Effect of Dissolved Oxygen

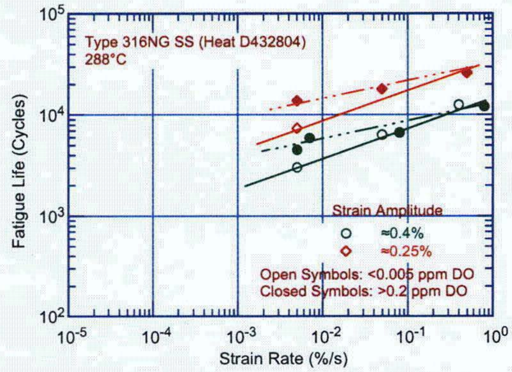




- Life decreases above 0.04 ppm; effect saturates at ≈0.5 ppm
- Moderate environmental effects in PWR or HWC BWR environment

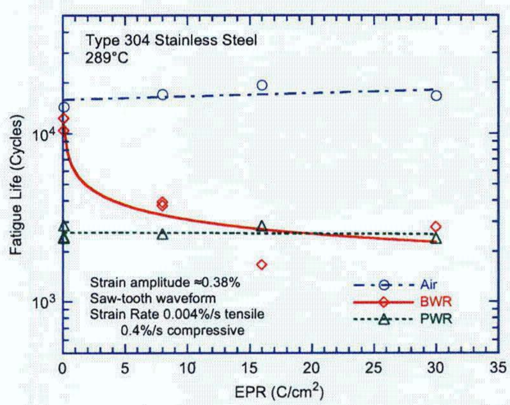
Effect of Dissolved Oxygen





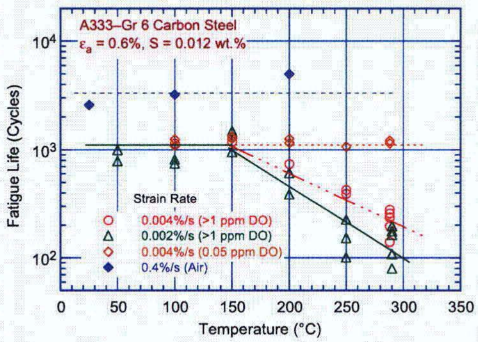
- Env. effects may be less in high-DO than low-DO water
  - for SA 304 SS, no effect of strain rate in high-DO water; for sensitized SS, strain rate effects same in high- & low-DO water
  - for low-C 316NG, smaller effect in high-DO than low-DO water

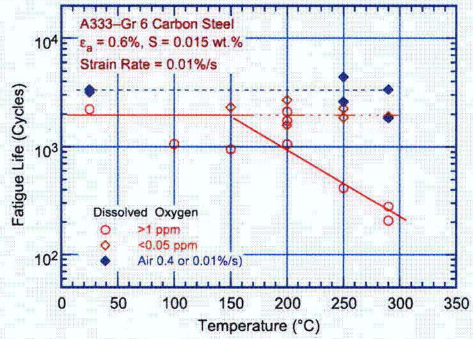
Effect of Material Heat Treatment



- In air & PWR water, heat treatment has little or no effect on life
- In high-DO water, fatigue life decreases with increasing degree of sensitization

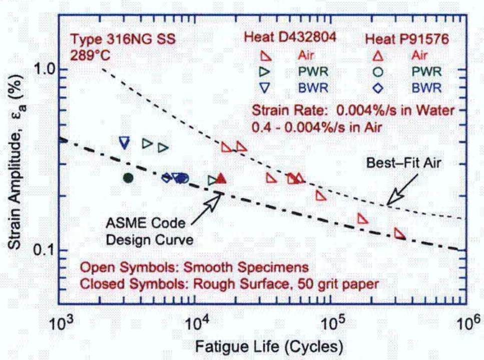
Effect of Temperature

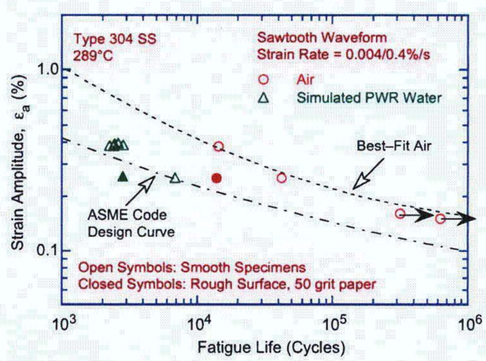




- Fatigue life in LWR environments is decreased above 150°C if the strain rate is below 1%/s and DO level is above 0.04 ppm
- Only moderate decrease in fatigue life at temperatures below 150°C or when DO levels in water is below 0.04 ppm

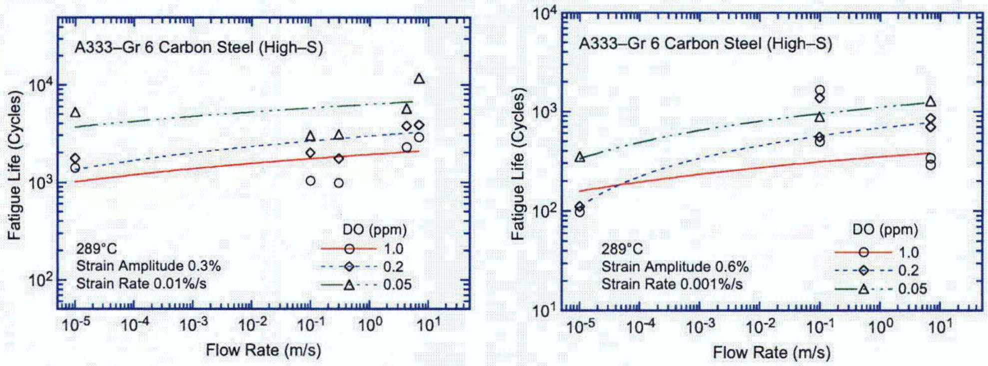
Effect of Surface Roughness





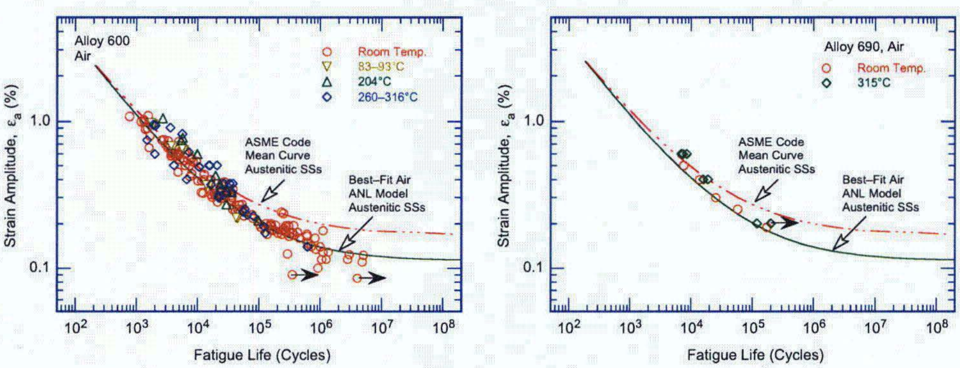
- For SSs, fatigue lives of rough specimens are lower than those of smooth specimens both in air and low-DO water
- For carbon & low-alloy steels, fatigue lives lower only in air, in high-DO water, lives of smooth & rough specimens are the same

Effect of Flow Rate



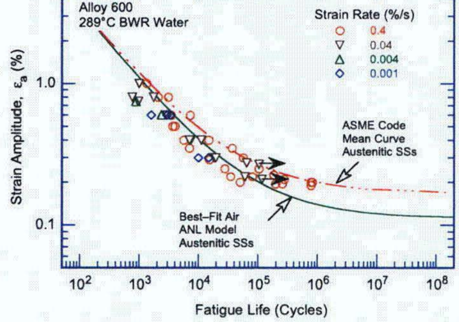
- In high-DO water, environmental effects decrease with increasing flow rate, lives are factor of 2 greater at ≈7 m/s than at 10^{-5} m/s
- Increasing flow rate has no effect on fatigue life of austenitic SSs

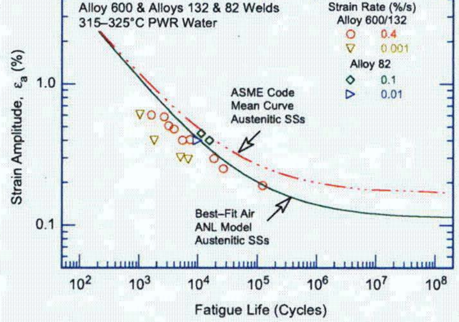
Fatigue Mean Curve for Ni-Cr-Fe Alloys in Air



- Fatigue ε-N data for Alloys 600 and 690 show very good agreement with the ANL model for austenitic SSs
- The data for Ni-alloy welds are also consistent with the ANL model in low-cycle regime and show the model is somewhat conservative in the high-cycle regime

Fatigue Life of Ni-Cr-Fe Alloys in LWR Environments





- Similar to austenitic SSs, environmental effects on fatigue life of Ni-Cr-Fe alloys are greater in low-DO than high-DO water
- Under similar loading & environmental conditions; however, effect is considerably less for Ni-Cr-Fe alloys than for SSs

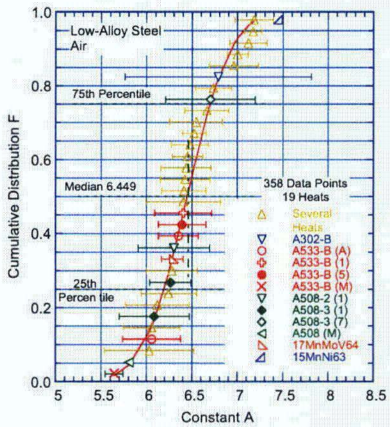
Fatigue Strain vs Life (ε-N) Curve

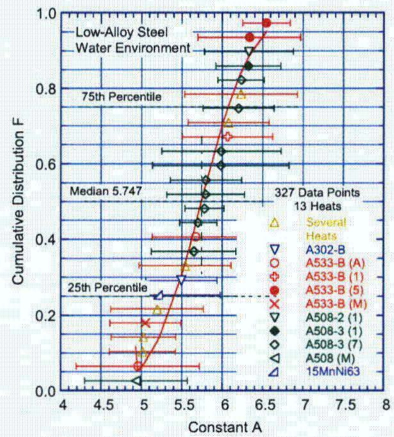
- Fatigue design curve obtained from best-fit curve of fatigue ε-N data expressed in terms of modified Langer equation;

$$\ln[N] = A - B \ln(\varepsilon_a - C)$$

- Constant A varies from heat to heat. Distribution of A assumed to represent variability in fatigue life due to material variability

Cumulative Distribution of Constant A





- The 5th percentile of these distributions give ε–N curve that is expected to bound fatigue lives of 95% of heats of material & test conditions of interest

Carbon and Low-Alloy Steels

Air $\ln[N] = 6.583 - 1.975 \ln(\varepsilon_a - 0.113)$ (CSs)

$\ln[N] = 6.449 - 1.808 \ln(\varepsilon_a - 0.151)$ (LASs)

Env $\ln[N] = 5.951 - 1.975 \ln(\varepsilon_a - 0.113) + 0.101\, S^*T^*O^*R^*$ (CSs)

$\ln[N] = 5.747 - 1.808 \ln(\varepsilon_a - 0.151) + 0.101\, S^*T^*O^*R^*$ (LASs)

where

$S^* = S$	($S \leq 0.015$ wt.%)
$S^* = 0.015$	($S > 0.015$ wt.%)
$T^* = 0$	($T < 150°C$)
$T^* = T - 150$	($T = 150$ to $320°C$)
$O^* = 0$	($DO < 0.04$ ppm)
$O^* = \ln(DO/0.04)$	(0.04 ppm $< DO \leq 0.5$ ppm)
$O^* = \ln(12.5)$	($DO > 0.5$ ppm
$R^* = 0$	($R > 1\%/s$)
$R^* = \ln(R)$	($0.001 \leq R \leq 1\%/s$)
$R^* = \ln(0.001)$	($R < 0.001\%/s$)

Wrought & Cast Austenitic SSs

Air $\ln[N] = 6.891 - 1.920 \ln(\varepsilon_a - 0.112)$

Env $\ln[N] = 6.157 - 1.920 \ln(\varepsilon_a - 0.112) + T^*O^*R^*$

where
$T^* = 0$	$(T < 150°C)$
$T^* = (T - 150)/175$	$(150 \le T < 325°C)$
$T^* = 1$	$(T \ge 325°C)$
$O^* = 0.281$	(all DO levels)
$R^* = 0$	$(R > 0.4\%/s)$
$R^* = \ln(R/0.4)$	$(0.0004 \le R \le 0.4\%/s)$
$R^* = \ln(0.0004/0.4)$	$(R < 0.0004\%/s)$

- A single correlation can be used for wrought & cast austenitic SSs; fatigue limit based on results by Tsutsumi et al. & Jaske & O'Donnell, slope B and constant A determined from best-fit of fatigue ε-N data, and obtained from cumulative distribution of A for various data sets

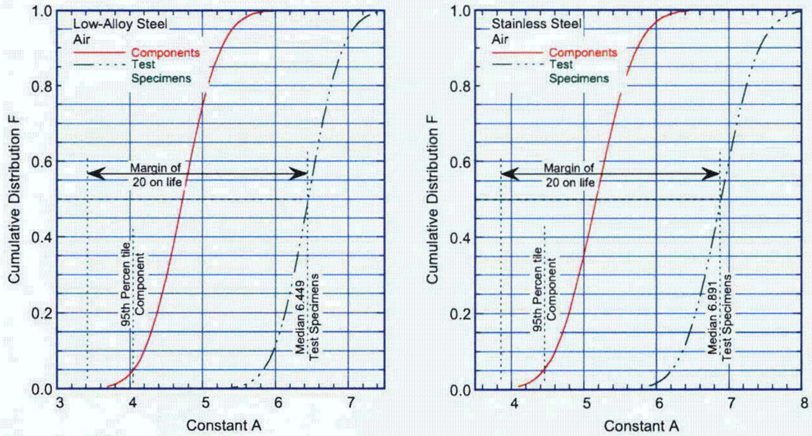
Fatigue Life of Components

- Available information reviewed to better define adjustment factor on life that must be applied to mean-data curve to account for effects of variables that influence life but were not explicitly addressed in the data

Parameter	ASME Code	Presented Study
Material Variability & Data Scatter	2.0	2.1 - 2.8
Size	2.5	1.2 - 1.4
Surface Finish	4.0	2.0 - 3.5
Loading History	–	1.2 - 2.0
Total Adjustment Factor	**20**	**6 - 27**

- Monte Carlo simulations performed to determine distribution of A for adjusted fatigue curve that represents behavior of actual component.
- Use material variability & data scatter results from present analysis
- Assume a lognormal distribution for effects of size, surface finish, & loading history, & min and max values of adjustment factor assumed to represent 5th and 95th percentile, respectively
- Assume effects can be considered as independent based on engineering judgment

Fatigue Design Adjustment Factors



- Monte Carlo analysis suggests adjustment applied to mean values of specimen fatigue life to bound component fatigue life of 95% of population is ≈12. Thus, current Code requirements of factor of 20 on life is conservative by about a factor of ≈1.7 for components

Effect of Environment on Code Fatigue Evaluations

- Conservatism in current Code fatigue evaluations will tend to offset effect of environment on fatigue life
- Conservatism in Code fatigue evaluations may arise from:
  - fatigue evaluation procedures (stress analysis rules & cycle counting)
  - adjustment factors of 2 & 20
- Analysis suggests conservatism associated with factor of 20 is modest; that associated with stress analysis rules can be much greater
- Code permits improved approaches to fatigue evaluations, e.g., finite-element analyses, fatigue monitoring, etc., that can significantly decrease the conservatism
  - suggests need to explicitly address environmental effects

Methods for Incorporating Environmental Effects

- Two approaches proposed for incorporating effects of LWR coolant environments into Code fatigue evaluations:
  - develop new fatigue design curves for LWR environments
  - use an environmental fatigue correction factor F_{en}
- Because fatigue life in LWR environments depends on several loading & environmental parameters, design curve approach would require developing multiple design curves to cover range of conditions or a conservative bounding curve
- The F_{en} approach is relatively simple and flexible enough to address effects without unnecessary conservatism

F_{en} Method for Incorporating Environmental Effects

- F_{en} is defined as ratio of fatigue life in air at RT to that in water under service conditions

  $\ln[F_{en}] = \ln(N_{RTair}) - \ln(N_{water})$

  $F_{en} = \exp(0.632 - 0.101\ S^*T^*O^*R^*)$ (Carbon Steels)

  $F_{en} = \exp(0.702 - 0.101\ S^*T^*O^*R^*)$ (Low-Alloy Steels)

  $F_{en} = \exp(0.734 - T^*O^*R^*)$ (Stainless Steels)

  $F_{en} = 1$ ($\varepsilon_a \leq 0.07\%$ CLAS & $\leq 0.10\%$ SSs)

- To incorporate environmental effects, fatigue usage based on air curve is multiplied by F_{en}

  $U_{en} = U_1 F_{en,1} + U_2 F_{en,2} \ldots U_n F_{en,n}$

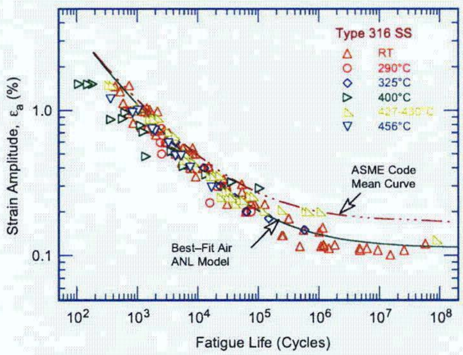
- Usage in air is determined from design curve that is consistent (or conservative) with respect to existing fatigue ε–N data. Current Code curve for SSs should not be used because it will yield nonconservative estimates of CUF

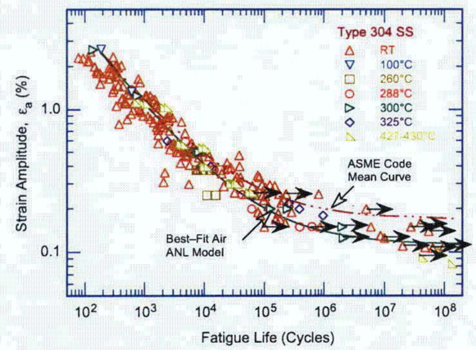
Environmental Correction Factor for Ni-Cr-Fe Alloys

$F_{en} = \exp(T^* O^* R^*)$		(Ni-Cr-Fe Alloys)
where	$T^* = T/325$	$(T < 325°C)$
	$T^* = 1$	$(T \geq 325°C)$
	$R^* = 0$	$(R > 5.0\%/s)$
	$R^* = \ln(R/5.0)$	$(0.0004 \leq R \leq 5.0\%/s)$
	$R^* = \ln(0.0004/5.0)$	$(R < 0.0004\%/s)$
	$O^* = 0.09$	(NWC BWR water)
	$O^* = 0.16$	(PWR or HWC BWR water)
$F_{en} = 1$		$(\varepsilon_a \leq 0.10\%)$

- Fatigue usage in air is determined from the new fatigue design curve for austenitic SSs developed from the ANL model

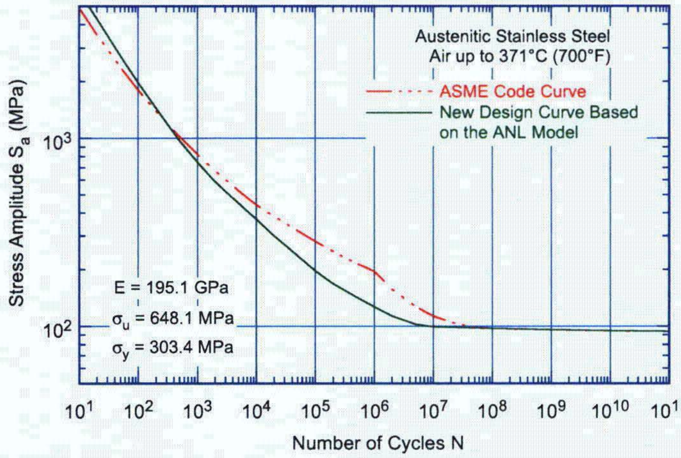
Other Proposed Changes in Code Mean Curve for Austenitic SSs





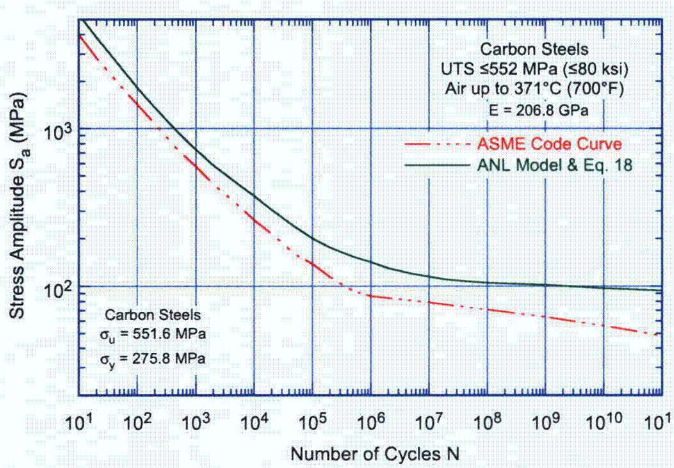
- Current Code mean curve is not consistent with existing fatigue data in air at strain amplitudes <0.3%, the Code mean curve predicts significantly longer fatigue lives than those observed experimentally

New Fatigue Design Curve for Austenitic Stainless Steels in Air



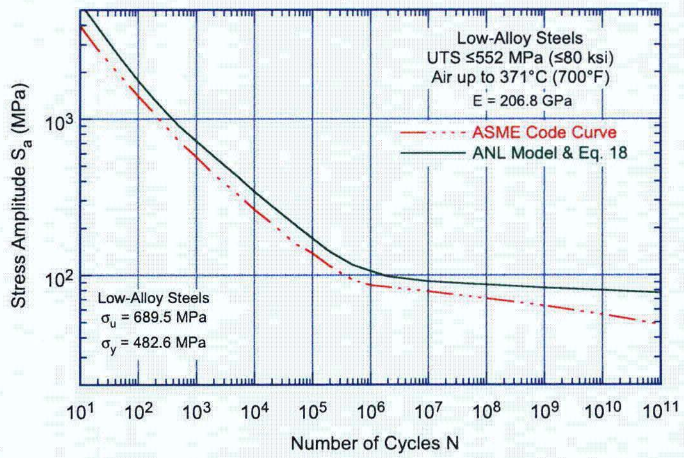
- Fatigue design curve based on the ANL correlation for austenitic SSs in air and a factor of 12 on life and 2 on stress

Fatigue Design Curve for Carbon Steels in Air



- Fatigue design curve based on the ANL correlation for carbon steels in air and a factor of 12 on life and 2 on stress

Fatigue Design Curve for Low-Alloy Steels in Air



- Fatigue design curve based on the ANL correlation for low-alloy steels in air and a factor of 12 on life and 2 on stress

Extension of Mean Curve from 10^6 to 10^{11} Cycles

- An extension of the Code fatigue design curve for carbon & low-alloy steels from 10^6 to 10^{11} cycles has been proposed by ASME Subgroup Fatigue Strength
  - extension takes into account the effect of maximum mean stress & is based on load-control data (R = 0) that extends up to 5 x 10^6 cycles
  - Stress amplitude (S_a) vs. life (N) relationship is expressed as

    $$S_a = E\varepsilon_a = C_1 N^{-0.05}$$

  - Extrapolation of this curve to 10^{11} cycles may yield conservative estimates

Extension of Mean Curve from 10^6 to 10^{11} Cycles

- In the high-cycle regime, plot of elastic-strain-vs.-life for the available fatigue data (that extend up to 10^8 cycles) yields a small slope (–0.007) instead of a fatigue limit; Manjoine & Johnson obtained an exponent of -0.01
- In high-cycle regime the mean curve for carbon & low-alloy steels can be expressed as

$$S_a = E\varepsilon_a = C_2\, N^{-0.01}$$

- To develop design curve, this curve is first adjusted for mean stress effects using the Goodman relationship, then adjusted curve is decreased by a factor of 12 on life and 2 on stress to obtain the design curve

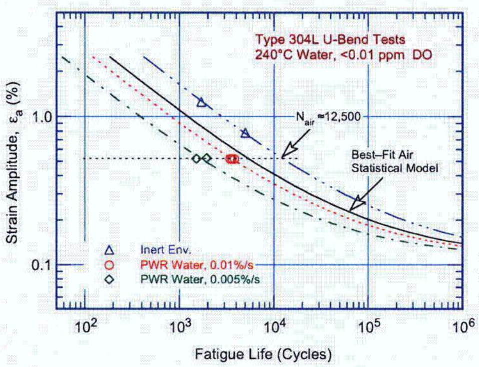
F_{en} Method (Contd.)

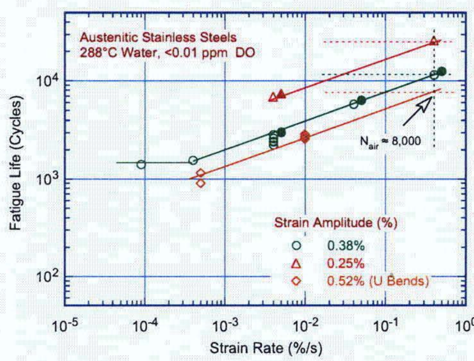
- For CSs & LASs, usage factors can be based on current Code design curves, or to reduce conservatism associated with the Code factor of 20 on life, usage factors could be based on design curves developed from ANL models
- For austenitic SSs & Ni-Cr-Fe alloys, usage factors determined from the new design curve developed from ANL model
- Guidance for key loading & environmental parameters
  - Using the average strain rate for a transient yields conservative estimate of F_{en}
  - When results of detailed transient analysis are available the average temperature may be used in calculation of F_{en}

Operating Experience & Component Tests

- Occurrences of corrosion fatigue damage and failures in nuclear power plants reviewed in EPRI TR-106696 (1997)
- Case histories & conditions that lead to SICC in LWR systems summarized in Nucl. Eng. Des. 91, 1986
  - Strain rates are 10^{-3}–10^{-5}%/s due to thermal stratification, under these conditions significant effect observed in lab tests
- Applicability of laboratory data to component behavior has been demonstrated by mock–up and component tests:
  - Katzenmeier et al., Nucl. Eng. Des. 119, 1990
  - Kussmaul, Blind, Jansky, Intl. J. Press. Ves. & Piping, 25, 1986
  - Lenz, Liebert, Wieling, 3rd IAEA Specialists Meeting, 1990
  - Stephan, Masson, Intl. Conf. on Fatigue, Napa, 2000
  - Kilian, Hickling, Nickell, Third Intl. Conf. on Fatigue, 2004

Type 304L SS U-Bend Tests in PWR Water at 240°C





- Measured environmental reduction factor F_{en} =10,000/1,728 =5.8 at 0.0005%/s & =10,000/3,624 = 2.8 at 0.01%/s. Predicted values are 5.5 and 3.6, respectively

Regulatory Positions

Regulatory Position 1: Carbon and Low-Alloy Steels

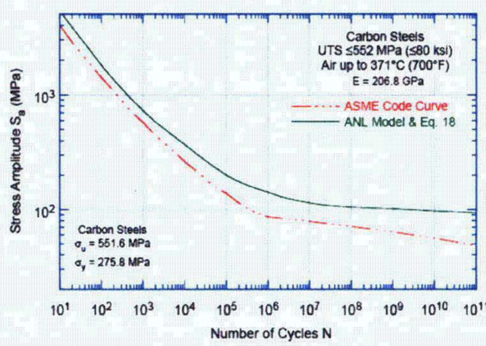
- ✓ Calculate fatigue usage in air with ASME Code Analysis procedures +
  - ✓ ASME Code air curves, **or**
  - ✓ New ANL model air curves
- ✓ Calculate the F_{en} using
  - ✓ Equation A.2 (CS),

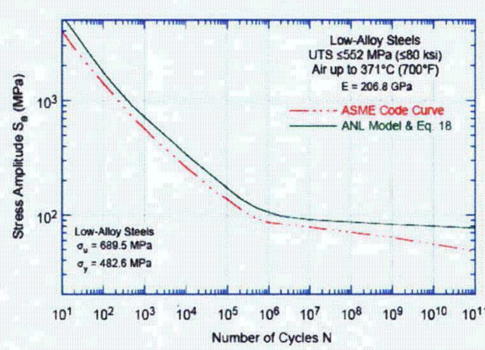
    $F_{en} = \exp(0.632 - 0.101\ S^*T^*O^*\dot{\varepsilon}^*)$
  - ✓ Equation A.3 (LAS)

    $F_{en} = \exp(0.702 - 0.101\ S^*T^*O^*\dot{\varepsilon}^*)$

  (Appendix A of NUREG/CR-6909)
- ✓ Calculate the environmental fatigue usage (U_{en})

  $U_{en} = U_1 F_{en,1} + U_2 F_{en,2} \dots U_n F_{en,n}$





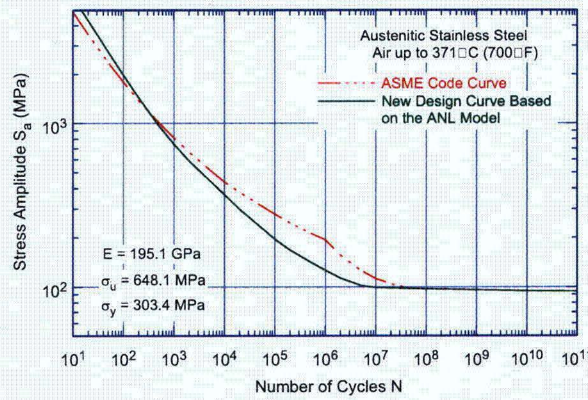
Regulatory Position 2: Austenitic Stainless Steels

- ✓ Calculate fatigue usage in air with ASME Code Analysis procedures +
  - ✓ **New ANL model air SS curve**
- ✓ Calculate the F_{en} using
  - ✓ Equation A.9

    $F_{en} = \exp(0.702 - 0.101\ S^*T^*O^*\dot{\varepsilon}^*)$

    (Appendix A of NUREG/CR-6909)
- ✓ Calculate the environmental fatigue usage (U_{en})

$U_{en} = U_1\ F_{en,1} + U_2\ F_{en,2}\ \ldots.\ U_n\ F_{en,n}$



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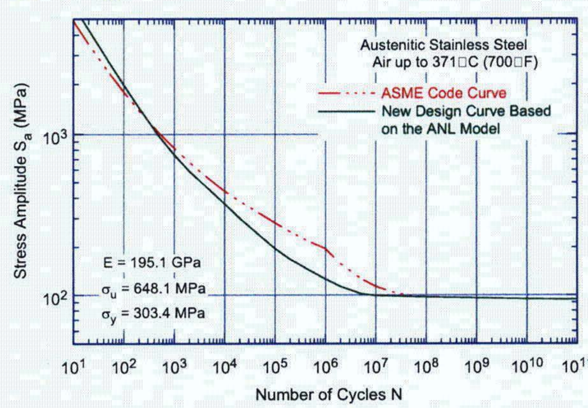
Regulatory Position 3: Ni-Cr-Fe Alloys (e.g., Alloy 600 and 690)

- ✓ Calculate fatigue usage in air with ASME Code Analysis procedures +
  - ✓ **New ANL model air SS curve**
- ✓ Calculate the F_{en} using
  - ✓ Equation A.14

    $F_{en} = \exp(\ T^*O^*\dot{\varepsilon}^*\ )$

    (Appendix A of NUREG/CR-6909)
- ✓ Calculate the environmental fatigue usage (U_{en})

$U_{en} = U_1\ F_{en,1} + U_2\ F_{en,2}\ \ldots.\ U_n\ F_{en,n}$



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Summary

- RG 1.207 endorses the use of new air curve for SSs
- RG 1.207 endorses the F_{en} methodology
- Guidance on incorporating environmental correction factor to fatigue design analyses
  - Appendix A of NUREG/CR-6909 Rev. 1
- NUREG/CR-6909 Rev. 1 describes in detail the technical basis

Resolution to Public Comments on DG-1144 and Draft NUREG/CR-6909

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Presented to
Advisory Committee on Reactor Safeguards
Subcommittee on Materials, Metallurgy, and Reactor Fuels
Rockville, Maryland
December 6, 2006

Resolution of Public Comments

- 8 correspondents submitted a total of 56 comments on DG-1144 and draft NUREG/CR-6909
  - –All comments addressed individually
- Final RG 1.207 and NUREG/CR-6909 Rev. 1 reflects the resolution of these comments
- 6 main issues identified

Resolution of Public Comments (cont.)

Staff Response to Public Comments on DG-1144 and Draft NUREG/CR-6909

#	Source*	Comment**	Response
1	I - 1a.	Each Comment appears individually in this column.	NRC staff response for each comment.

*

Source I.	Ronnie L. Gardner, AREVA NP, Inc.	ML062920056
Source II:	Takao NAKAMURA, The Kansai Electric Power Co., Inc.	ML062790143
Source III:	James H. Riley, Nuclear Energy Institute	ML062790136
Source IV:	C. L. Funderburk, Dominion Resources Services, Inc.	ML062790144
Source V:	Makoto EGUCHI, Ishikawajima-Harima Heavy Industries Co., Ltd.	ML062790138
Source VI:	Robert E. Brown, GE Energy Nuclear	ML062790141
Source VII:	Gerry C. Slagis, G.C. Slagis Associates, Consulting Engineering	ML062620349
Source VIII:	Kenneth R. Balkey, Nuclear Codes and Standards, American Society of Mechanical Engineers	ML062790139

**. Comments are quoted directly from the letter submitted by the commenter.

Resolution of Public Comments (cont.)

- Six issues (comment id #'s):
  1. Operating experience and applicability of specimen data (1, 7, 14, 16, 45)
  2. Details on approach (22, 24, 27, 37)
  3. Ni-Cr-Fe alloy fatigue curve (20, 25, 44)
  4. Burden due to increase in locations required to be analyzed (2, 43)
  5. Overly conservative position (4, 5, 15)
  6. ASME Code case (56)

1. Operating experience and applicability of specimen data (1, 7, 14, 16, 45)

Issue:

- *There is no operating experience that supports the need for these conservative design rules.*
- *Comments questioning the applicability of specimen data being representative of actual components in service.*

Staff Response:

- Numerous examples of fatigue cracking of nuclear power plant components reported - EPRI TR-106696.
- Applicability of laboratory data to component behavior has been demonstrated by mock–up and component tests (references provided in previous presentation). In fact, is the basis for the current ASME Code fatigue curves.

2. Details on approach (22, 24, 27, 37)

Issues:

- *References made to other guidance containing similar Fen approach (Japan) also acceptable/endorsed?*
- *"Since DG-1144 utilizes a similar Fen methodology to that evaluated in MRP-47, Rev.1, the issues identified in MRP-47, Rev.1 are considered to be equally applicable to the DG-1144 methodology. Some, but not all, of the issues raised in MRP-47, Rev.1 have been specifically addressed in DG-1144. Based on this, the MRP would like to see clarification on the remaining issues included in DG-1144 or the supporting document".*

Staff Response:

- The papers listed in NUREG/CR-6909 are for reference only. Section C, Regulatory Position, of the regulatory guide contains the methodology endorsed by the staff.
- The level of analytical detail discussed on additional items on MRP-47, Rev.1 are beyond the scope of this regulatory guide.

3. Ni-Cr-Fe alloy fatigue curve (20, 25, 44)

Issue:

Provide guidance for Ni-Cr-Fe alloys (e.g., Alloy 600 and 690).

Staff Response:

The staff incorporated F_{en} methodology for Ni-Cr-Fe alloy materials into RG 1.207 (RP 3) and NUREG/CR-6909 Rev. 1 (Section 6).

4. Burden due to increase in locations required to be analyzed (2, 43)

Issue:

Increase in the CUFs will lead to more analyzed piping break locations, to more installed pipe whip restraints, and to designs that will be more detrimental for normal (thermal expansion) operating conditions.

Staff Response:

Staff will consider a justified modification with the appropriate technical basis of the fatigue criteria for postulation of pipe breaks if implementation of the current criteria results in a significant increase in the number of required pipe whip restraints.

5. Overly conservative position (4, 5, 15)

Issue:

Commenter believes that the alternative methods for fatigue analysis provided in NUREG/CR-6909 and DG-1144 are too conservative and should not be used for the design of new reactors.

Staff Response:

The staff position is based on a 95% confidence that there is less than 5% probability of fatigue crack initiation. Implementation of this criteria resulted in a carbon steel and low-ally steel air curves which are less conservative than the existing ASME Code curve

6. ASME Code case (56)

Issue:

"ASME will continue to develop other Code Cases covering alternative ways of addressing [the impact of the LWR environment]... and the Code Case will be issued early in 2007. Once these Code Cases are issued, ASME requests the NRC to endorse these Code Cases in a revision of the Regulatory Guide 1.84".

Staff Response:

The NRC staff will consider endorsing available ASME Code Cases through its normal process for revising Regulatory Guide 1.84.

Conclusion

RG 1.207 is ready for issuance

- Final RG 1.207 and NUREG/CR-6909 Rev. 1 reflects the resolution of these comments
- Final RG 1.207 and NUREG/CR-6909 Rev.1 will be published by March 2007 (High priority RG)
- Seeking ACRS concurrence to publish final effective guide

ASME Nuclear Codes and Standards

Comments on Draft Regulatory Guide DG-1144 – "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"

Advisory Committee on Reactor Safeguards
Subcommittee on Materials, Metallurgy, and Reactor Fuels
December 6, 2006
Rockville, Maryland

ASME SETTING THE STANDARD

ASME Nuclear Codes and Standards Representatives

Ken Balkey, Vice President, ASME Nuclear Codes & Standards / Chair, ASME Board on Nuclear Codes and Standards (BNCS)

Kevin Ennis, ASME Director, Nuclear Codes & Standards

Bryan Erler, Vice Chair, BNCS Strategic Initiatives / Member, ASME Boiler & Pressure Vessel Code Subcommittee III

Dr. Chris Hoffmann, Member, ASME B&PV Standards Committee / Member, ASME B&PV Code Subcommittee III

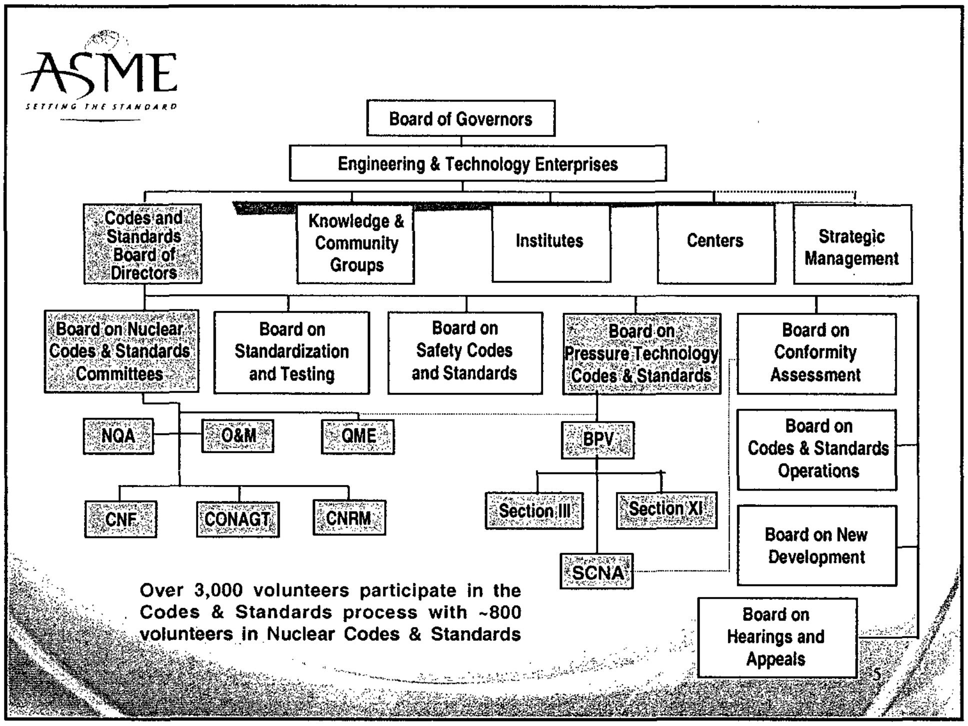
Charles Bruny, Member ASME Subgroup on Design (SC III) / Past-Chair, Working Group on Vessels (SG-D)(SC III)

ASME SETTING THE STANDARD

Topics

- ASME Nuclear Codes and Standards Overview
- Open Comments by ASME Subcommittee III Groups Related to Draft Regulatory Guide DG-1144
- Background on ASME Efforts to Address the Impact of Environmental Fatigue
- Technical Discussion on ASME Approaches
- Future Actions

4



ASME
SETTING THE STANDARD

Board on Nuclear Codes & Standards

Standards Committees

- Operation & Maintenance
- Qualification of Mechanical Equipment
- Nuclear Air & Gas Treatment
- Nuclear Quality Assurance
- Nuclear Risk Management
- Nuclear Cranes

Nuclear Subcommittees of BPV Code Committee

- III – Nuclear Power
- XI – Inservice Inspection
- Nuclear Accreditation

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Nuclear Codes and Standards Consensus Process

Participation and Achieving Consensus

- Committees made up of world experts
- Voluntary international participation
- ASME Codes and Standards relies on industry supporting participation
- Identify technical basis to respond to identified needs
- Resulting consensus must be technically accurate, assure adequate safety, and be practical and workable
- ASME provides the structure and administrative support

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Open Comments by ASME Subcommittee III Groups Related to Draft Regulatory Guide DG-1144

- Successful experience from today's operating reactors related to environmental fatigue raises a question as to if there is a need to change ASME B&PV Code Design Rules?
- Environmental fatigue effects only the inside surface of a component that is not consistent with test conditions of F_{en} approach and current design practices
- The test data cited were obtained using methodology that is inconsistent with the basis of the current ASME fatigue curves
  - The failure definition, specimen size, surface finish, loading application and temperatures were different; The original tests are based on through-wall cracking whereas the new tests are based on 25% load drop
  - Thus, accurate comparisons cannot be made; F_{en} factors are not appropriate
- Test data cited are not representative of nuclear plant operations

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ASME SETTING THE STANDARD

Open Comments by ASME Subcommittee III Groups Related to Draft Regulatory Guide DG-1144

- Design margin of DG-1144 is too conservative
- Increased conservatism in ASME B&PV Code Design Fatigue Rules could result in undesirable impacts
  - Conservative design will result in higher fatigue usage factors
  - Increase in postulated pipe break locations and restraints
  - Impacts plant operations and inservice inspection
- Does implementation of the proposed approach result in unnecessary Code and regulatory burden on users without a commensurate safety benefit?
- Implementation of proposed approach to piping Code design rules has a number of unresolved issues and questions (Per EPRI MRP-47)

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ASME SETTING THE STANDARD

Background on ASME Efforts to Address the Impact of Environmental Fatigue

1991	PVRC Steering Committee formed by ASME BNCS in response to NRC Branch Draft Technical Position on Environmental Effect on Fatigue
1993/1994	ASME members participate with NRC on fatigue issues (GSI-166 and SECY-94-191)
1995	WRC Bulletin 404 Environmentally Assisted Cracking Fatigue Crack Growth Curves; Bettis Studies
1996	ASME Section XI Appendix L added to address operating plant fatigue issues
1999	ASME Section XI Code Case N-643 FCG Rate Curves issued
2000	Section XI Task Group Appendix L formed to adopt PVRC recommendations
2003	Section III Task Group on Environmental Effects on Fatigue formed
2006	ASME Section III Task Group closed with recommendations for Section III Subgroup Design to evaluate if design rules should be changed

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Technical Discussion on Approaches that ASME has recently Explored

1. Make no changes to ASME Boiler & Pressure Vessel (B&PV) Code design rules; Treat impact of environmental fatigue as an operating plant life issue
2. Adopt fatigue curves that envelope test results in today's database; ASME Code Case under review
3. Utilize an environmental correction factor (F_{en}) similar to NRC proposal in Draft Regulatory Guide DG-1144 (without the extra conservatism in the guide)

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1. Make No Changes to ASME B&PV Code Design Rules

- Many members of Subcommittee III and the Subgroup on Design believe the current rules are acceptable to address environmental fatigue impact on current LWR nuclear plants
- The French have concluded that the RCC-M Code, which is based on ASME Section III, adequately covers environmental fatigue
- Japanese representatives on ASME Subcommittee III groups believe that their design rules, similar to ASME Section III, are adequate by treating environmental fatigue as an operating inservice item
  - Monitor operating conditions-load transients, loading rate, and numbers of events

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ASME SETTING THE STANDARD

2. Adopt Fatigue Curves that Envelope Test Results in Today's Database

- ASME Subcommittee III has put significant effort into developing a Code Case with new fatigue curves that envelope all data as best as possible
- This approach is the most conservative, but it does not reflect actual nuclear plant conditions
- Concern that added pipe supports and whip restraints resulting from this approach will make the plants less safe

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ASME SETTING THE STANDARD

3. Utilize an Environmental Correction Factor (F_{en})

- ASME is attempting to develop a Code Case implementing a similar F_{en} approach as DG-1144 correcting the concerns outlined in our comments above
- This effort has resulted in two concerns that continue to hold up a consensus agreement
  - Ability to develop implementation rules for piping that would not be excessively complicated
  - Lack of agreement on the need
- Concern that added pipe supports and whip restraints resulting from this approach will make the plants less safe

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ASME
SETTING THE STANDARD

Summary and Future Actions by ASME

- The impact of environment is one of the factors that is considered in ASME B&PV Code design criteria; ASME is wrestling with the need to change current design requirements and if there is a need, how the change would be implemented based on operating experience and considering safety and economic impacts
- ASME will consider adopting the proposed Regulatory Guide DG-1144 approach in the format of a Code Case to enable thorough review by ASME constituents
- ASME will continue to develop other Code Cases covering alternative ways of addressing the impact of environmental fatigue
- ASME plans will continue to foster cooperative efforts for research to better understand the impact of environmental fatigue

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AREVA

September 22, 2006
NRC:06:039

Rules and Directives Branch
Office of Administration
ATTN: Mr. Hipolito J. Gonzalez
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Comments on Draft Regulatory Guide DG-1144 and NUREG/CR-6909

Ref.: 1. Federal Register Notice (71FR47584), Draft Regulatory Guide: Issuance, Availability

Dear Mr. Gonzalez:

The NRC solicited comments on both Draft Regulatory Guide DG–1144, "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," and NUREG/CR–6909, "Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials," in the referenced Federal Register notice. The NRC requested comments by September 25, 2006.

AREVA NP appreciates the opportunity to provide comments on draft Regulatory Guide DG-1144 and NUREG/CR–6909. In general, AREVA has significant comments regarding the need for the proposed conservative methods as well as acceptability of some of the technical methods. These comments are outlined below.

1. General Comments from AREVA NP

a. Regulatory Analysis for DG -1144 notes that:

> *After about 20 years of research effort addressing the environmental degradation of fatigue crack nucleation, it has become apparent that exposure to light-water reactor environments has a detrimental effect on the fatigue life of metal components, which affects the major categories of structural materials (i.e., carbon steel, low -alloy steel, and austenitic stainless steel).*

AREVA agrees with laboratories fatigue tests results concerning demonstration of the role of pressurized water reactor (PWR) environment on the low cycle fatigue (LCF) behavior of reactor materials. However, AREVA is not aware of any operating experience that supports the need for these conservative design rules. The NRC should cite specific examples where operating events associated with a significant environmental effect have been at the root cause of fatigue failure. The NRC should also cite where in the fatigue analyses

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supporting the original design, it was necessary to account for environmental effect to demonstrate the need for this regulatory guidance.

b. The Regulatory Analysis states that the "costs associated with implementing this guidance are expected to be minimal." AREVA believes that an increase in the Cumulative Fatigue Usage Factors (as suggested in DG-1144) will lead to more analyzed piping break locations, to more installed pipe whip restraints, and to designs that will be more detrimental for normal (thermal expansion) operating conditions.

   In addition, there will be more restrictions on the Design Transients (in the Functional Specifications) and the analyses will have to be performed with added accuracy, such as performing elasto-plastic finite element analyses, to be able to reduce the conservatisms inherent to the current design and analysis methods. However, it is not usual to perform elasto-plastic finite element analyses at a design stage and this added complexity to new plant designs is unwarranted. Analysis costs will increase significantly owing to the involved nature of the F(en) calculation, particularly related to the determination of strain rate. This method will also require more detailed analyses of piping and components due to the severe nature of the F(en) penalty. For example, it can be anticipated that more locations in stainless steel piping will have to be evaluated using finite element approaches (NB-3200) instead of the traditional simplified rules in NB-3600.

c. The Regulatory Analysis has the following statements:

   This guidance will complement and be consistent with current established practices applied throughout the commercial nuclear power industry for license renewal evaluations.

   The practice reported in NUREG/CR-6260 applied to several plants and identified locations of interest for consideration of environmental effects using the fatigue design curves that incorporated environmental effects. Section 5.4 of NUREG/CR-6260 identified the following component locations to be most sensitive to environmental effects for PWRs.

   1. Reactor vessel shell and lower head
   2. Reactor vessel inlet and outlet nozzles
   3. Surge line
   4. Charging nozzle
   5. Safety injection nozzle
   6. Residual Heat Removal system Class 1 piping

   It is not understandable why the guidance for new plants, in spite of better materials, more modern nondestructive testing technologies, and improved manufacturing process, is not restricted to a limited number of locations. In lieu of evaluating the entire Class 1 systems for the environmental effects on fatigue, AREVA believes an approach that parallels the license renewal approach would provide more reasonable assurance that the environmental effects are bounded sufficiently.

d. The Regulatory Analysis for DG -1144 notes that:

> *The ASME Board of Nuclear Codes and Standards, Subcommittee on Environmental Fatigue, is still developing a Code Case and non-mandatory procedure to provide guidance regarding the application of an environmental correction factor for fatigue analyses. This task was assigned to the PVRC Steering Committee on Cyclic Life and Environmental Effects, which recommended revising the Code fatigue design curves (Welding Research Council Bulletin 487, " PVRC Position on Environment al Effects on Fatigue Life in LWR Applications"); however, despite years of deliberation, the ASME Subcommittee on Environmental Fatigue has not yet approved this proposal and has not reached a consensus regarding the approach or methodology that will be used for guidance.*

AREVA does not believe the NRC should establish very conservative design rules without peer consensus. The fact that consensus has not been reached in the industry highlights both that the research is not sufficiently finalized to be conclusive and that the correct method of treatment of environmental effects is not clearly established. For example, there is not enough evidence to support the combination of all detrimental effects. It is not appropriate to treat simultaneously all the detrimental effects of size, surface finish, loading history, data scatter, material variability, dissolved oxygen in the water, strain rate, and temperature to calculate the environmental fatigue penalty. AREVA believes that there are cases where, when one effect is taken at its worst (at saturation), the other effects do not further negatively affect the fatigue resistance of the component. Therefore, AREVA believes that for fatigue the "Cumulative Penalties" methodology is overly conservative.

e. The current ASME Code fatigue methodology is overly conservative. Examples of the conservatisms that are inherent to methodology include:

- use of conservative values for fatigue strength reduction factors,
- the piping stress indices,
- the piping stress methodology,
- use of Tresca criterion for the calculation of the stress intensity,
- use, in the design methodology, of minimum specified mechanical properties in place of representative materials properties,
- the fatigue plasticity penalty factor (K_e),
- design transients are more severe than the actual transients,
- grouping various transients into analysis sets in which each set is bounded by the most severe transient in the set, and
- there are fewer transients during the plant lifetime than specified in the Functional Specs.

It would be preferable to review the whole methodology rather than limiting efforts to the materials aspects.

f. There is no guidance in DG-1144 or CR-6909 regarding how to treat carbon steel and low alloy steel, which are "protected" from the primary coolant environment by stainless steel (or Alloy 690) cladding. AREVA believes it is reasonable to assume that there will not be any environmental effects on clad carbon steel and low alloy steel. For completeness, the guidance should address this subject.

2. Technical Comments from AREVA NP

a. The majority of the LCF tests were performed at high temperature on polished specimens in the NUREG/CR-6909. About ninety percent of the tests were done at high temperature (between 260°C and 325°C) in isothermal conditions with triangular strain signals leading to constant strain rates. These test conditions are not representative of realistic thermo-mechanical loadings applied on components during operation. Indeed, the triangular form of cycles with two slopes and a constant temperature chosen for the laboratory fatigue tests is very different from the actual cycles applied during operating transients, which contain successions of high strain rates and low strain rates with a variable temperature. Because the tests performed in the laboratory specimens are not representative of in-service reactor components, it is not clear that the F(en) factors derived from those tests apply to the components and operating conditions in a nuclear plant.

b. After a micro-structural crack has formed, the crack depth is approximately 0.3 mm and a surface finish effect is no longer required, since the fatigue process occurs at the crack tip. Surface finish effect were only established in air. It is supposed to affect the fatigue life by a factor of three. NUREG/CR-6909 recommends treating the environmental effect on a rough surface by multiplying F(en) factor by approximately 3 but this accumulation is not proven by sufficient data obtained on representative surface at various strain amplitudes in PWR environment.

c. Loading sequence effects should not be considered as an additional penalty for the factor of 12.0, as suggested in NUREG/CR-6909. During normal operation of the nuclear power plant, the cycles are reasonably well distributed for the entire life of the plant. Therefore, the Loading Sequence effect is not required. Furthermore, such a loading sequence is not supported by reviewed and accepted experimental results.

d. There should be a real threshold for both temperature and strain rate. In other words, below a certain temperature (150°C or 180°C), or above a certain strain rate (0.4 percent or 1 percent per second) penalty F(en) value should be 1.0. That has been shown clearly in the Figure 12 of the 2005 PVP Paper No. 71409 and in the Figure 10 of the 2005 PVP Paper No. 71410. These two technical papers are from William J. O'Donnell, William John O'Donnell, and Thomas P. O'Donnell.

e. The proposition of a new fatigue curve in air is based on insufficiently supported test results and some of which were obtained on unrepresentative materials. For instance, a paper cited in the NUREG/CR-6909 [reference 105] is used as data for this fatigue curve to analyze mean stress effect. Nevertheless, the material used in this reference has an inordinate high reduction of fatigue strength due to mean stress.

   In section 5.1.1 of NUREG/CR-6909, for example, it can be possible to obtain three different best-fit mean S - N curves for austenitic stainless steels types 304, 316 or 316 NG.

Other authors like Jaske and O'Donnell in 1977 or Tsutsumi in 2000 (see PVP 2000 – Vol. 410-2) have also proposed best fit mean S – N curve expressions for similar austenitic stainless steels (304, 316, 310, and 347), which are different from those proposed in NUREG/CR-6909.

Significant differences of about ± 20 percent are noticed on the fatigue life according to the best-fit S - N curve selected which shows that the S – N curve determination is a function of the chosen materials and associated fatigue test database. NUREG/CR-6909 does not sufficiently demonstrate that the tested materials and fatigue test data used for the definition of a reference best-fit mean S – N curve are representative of modern materials.

The fatigue $\varepsilon - N$ data are typically expressed by using one equation to cover the two domains (i.e., LCF and high cycle fatigue (HCF)). The proposed modification of the reference mean S – N curve comes from the consideration of recent fatigue test results corresponding to the HCF domain, whereas, for reactor components, design studies are mainly concerned with the LCF domain.

f. The conclusions in NUREG/CR-6909 regarding evaluations of the mean stress effect seem to be solely based on the paper published by Bettis Bechtel Inc. (see PVP 1999 - Vol. 386). This paper suggests - for an austenitic stainless steel type 304 - that the mean stress effect can reach 26 percent of the strain amplitude in the LCF domain and in the intermediate domain of fatigue life ($N < 10^6$ cycles).

   This evaluation of the mean stress effect seems too conservative and is probably mainly due to the selection of the tested materials by the Bettis Bechtel Inc. laboratory, which are not representative of modern materials. In fact, this result is essentially based on a fatigue test program performed on two stainless steel type 304 materials with very different tensile and fatigue properties.

   The new reference design fatigue curve in air is established in section 5.1.1 of NUREG/CR-6909 by using insufficiently supported data, since portions of the data were obtained on unrepresentative material. The hot yield strength of the tested materials can for example vary as much as 100 percent (152 to 338 MPa at 288°C). This strong scatter of mechanical properties is attributed to variations in cold working from the surface to the center of the forgings supplied for the study. In these conditions, depending on the cold working level, it is well known that the material can present significant variations of its fatigue life in the LCF domain and in the intermediate domain.

   Fatigue strength results were obtained by AREVA for $N = 10^7$ cycles on standard polished specimens in air at room temperature on a 304L austenitic stainless steel. These results (JIP 2006 – Paris, May 30-31, June 1, 2006) have shown that, in the case where progressive deformation and cold work associated to loading conditions are very limited, the maximum reduction of endurance limit is of about 10 percent, compared to 26 percent found in reference [105] cited in NUREG/CR-6909.

g. In NUREG/CR-6909 section 5.1.5, the surface finish conditions reproduced on LCF test specimens by using a 50-grit sandpaper to obtain circumferential striations - with an average surface roughness of 1.2 μm - is not sufficiently representative of those obtained on reactor components. In fact, the roughness parameter alone is not sufficient to ensure that surface finish is representative of those obtained during manufacturing of components. In addition, only two tests that were performed on rough specimens were reported in NUREG/CR-6909. This is not sufficient to determine a roughness surface effect.

Fatigue tests performed on turned and ground specimens by AREVA (S. Petitjean – Fatigue 2002) have shown that the radius at the bottom of machining striations is a second critical parameter to characterize the surface roughness, in addition to average value of roughness amplitude.

In conclusion, the reduction factor attributed to surface finish that comes from only one surface condition and a limited number of tests cannot be used for real components.

h. The majority of the LCF tests on polished specimens in NUREG/CR-6909 were performed at high temperature. Ninety percent of the tests were performed at high temperature (between 260°C and 325°C) and in isothermal conditions with triangular strain variations leading to constant strain rates.

   These test conditions are not fully representative of realistic thermo-mechanical loadings applied on components during operation. Indeed, the triangular form of cycles with two slopes and a constant temperature chosen for the laboratory fatigue tests is very different from the actual cycles applied during operating transients, which contain successions of high strain rates and low strain rates with a variable temperature. Because the tests performed in the laboratory specimens are not representative of in-service reactor components, it is not clear that the Fen factors derived from those tests apply to the components and operating conditions in a nuclear plant.

3. Conclusions and Recommendation from AREVA NP

AREVA recognizes the environmental effects demonstrated by laboratory fatigue tests on reactor materials. Nevertheless, AREVA believes that alternative methods for fatigue analysis provided in NUREG/CR-6909 and DG 1144 are too conservative and should not be used for the design of new reactors. The four main reasons for this recommendation are:

a. NUREG/CR-6909 only deals with materials aspects of environmental fatigue, and addresses it with a very conservative approach, while the whole methodology of fatigue is already treated at design stage with a conservatism that cannot be removed.

b. The concept of cumulative penalties, which leads to multiply by the environmental factor F(en), the reduction factor of 12, which already integrates surface finish, size effect, material variability, and loading sequence effect is too severe. In addition, AREVA believes that combining some of these effects is not justified.

c. There are too many uncertainties in the transposition of the specimen fatigue test results obtained in a PWR environment to component fatigue. For example, the results gathered in NUREG/CR-6909 are linked to laboratory tests for which the loading conditions are simple but not representative of the field operating conditions, where the loading parameters history (e.g., temperature gradient, pressure, strain rate, and dissolved oxygen) is much complex.

d. Past fatigue failures observed in nuclear power plants were due to failure of the designer/analyst to consider the actual loading conditions, such as thermal stratification, turbulent penetration, and thermal mixing. These past fatigue failures were not attributed to the fact that the designer/analyst used either a non-conservative methodology or non-conservative Design Fatigue Curves. In other words, there is no field experience on steel components, either in-air or in LWR environment, that points to the necessity to modify the current Design Fatigue Curves.

AREVA agrees that if, in the future, it becomes apparent that the environmental effects have an impact on component fatigue for the current fleet of nuclear power plants or for the new nuclear power plants, additional methods may need to be applied to the fatigue analyses.

In summary, AREVA NP is not aware of any operating experience that supports the need for these conservative design rules. Nor does AREVA believe that the NRC should establish very conservative design rules without industry peer consensus. The guidance for new plants should be restricted to a limited number of locations consistent with the approach taken for license renewal reviews. It would be preferable to review the whole methodology, including a new methodology for selecting the list of design transients relevant for environmental analysis, rather than limiting efforts to the materials aspects. Finally, if the NRC continues with the guidance in DG-1144 and NUREG/CR-6909 as written, considerable flexibility should be provided for the use of alternative methods to those provided.

AREVA NP looks forward to continued interactions with the NRC on this subject to ensure appropriate regulatory guidance is provided for new plant applications. Mr. Mark J. Burzynski is the point of contact for AREVA NP on this matter. He may be reached by telephone at 434.832.4695 or by e-mail at Mark.Burzynski@areva.com.

Sincerely,

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