Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title:	Advisory Committee on Reactor Safeguards Future Plant Designs Subcommittee
Docket Number:	(n/a)
Location:	teleconference
Date:	Tuesday, July 20, 2021

Work Order No.: NRC-1595 Pages 1-109

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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FUTURE PLANT DESIGNS SUBCOMMITTEE

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TUESDAY

JULY 20, 2021

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The Subcommittee met via Videoconference, at 9:30 a.m. EDT, Peter Riccardella, Chair, presiding.

COMMITTEE MEMBERS:

PETER RICCARDELLA, Chair
RONALD G. BALLINGER, Member
VICKI M. BIER, Member
CHARLES H. BROWN, JR. Member
GREGORY H. HALNON, Member
WALTER L. KIRCHNER, Member
JOSE MARCH-LEUBA, Member
DAVID A. PETTI, Member
JOY L. REMPE, Member
MATTHEW W. SUNSERI, Member

ACRS CONSULTANT:

STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

KENT HOWARD

C-O-N-T-E-N-T-S

P R O C E E D I N G S

9:30 a.m.

CHAIR RICCARDELLA: This is a meeting of the Future Plant Designs Committee. The meeting will now come to order. I am Pete Riccardella, Chairman of this meeting. ACRS members in attendance are Ron Ballinger, Dave Petti, Joy Rempe, Walt Kirchner, Vicki Bier, Matt Sunseri, Greg Halnon, and Charles Brown. Is our consultant, Steve Schultz -- are you on the meeting?

(No response.)

CHAIR RICCARDELLA: Okay. Steve was expected to join. He might be on soon.

DR. SCHULTZ: I'm here, Pete.

CHAIR RICCARDELLA: Okay. And our consultant, Steve Schultz, is also in attendance. Kent Howard of the ACRS staff is the Designated Federal Official for this meeting.

The purpose of today's meeting is an information briefing from the NRC staff on potential endorsement of ASME Section III, Division 5, High Temperature Reactors. The subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate. However, at the subcommittee's direction, any matter will be considered for presentation at the full committee if necessary as the members see fit. The ACRS was established by statute and is governed by the Federal Advisory Committee Act, FACA.

The NRC implemented FACA in accordance with regulations found in Title 10 of the Code of Federal Regulations, Part 7. The committee can only speak to its published letter reports. We hold meetings to gather information and perform preparatory work that will support our deliberations at a full committee meeting, if necessary.

The rules for participating in all ACRS meetings, including today's, were announced previously in the Federal Register. The ACRS section of the U.S. NRC public website provides our charter, bylaws, agendas, letter reports, and full transcripts of all full and subcommittee meetings, including slides presented there. The meeting notice and agenda for this meeting were posted there.

Members of the public who desire to provide written or oral input to the subcommittee may do so and should contact a designated federal official five days prior to the meeting as practicable. Today's meeting is open to the public attendance. And there will be time set aside during the meeting for spontaneous comments from members of the public attending or listening to our meetings.

Due to the COVID pandemic, today's meeting is being held over Microsoft Teams for ACRS, NRC, and members of the public. There is also a telephone bridgeline allowing participation of the public over the phone. This public bridgeline is controlled by the ACRS staff and should not be muted by anyone other than the designated ACRS staff members.

A transcript of today's meeting is being kept. Therefore, we will request that meeting participants on the bridgeline identify themselves when they are asked to speak and to speak with sufficient clarity and volume so that they can readily be heard. At this time, I ask that attendees on the Teams and bridgeline mute their phones to minimize the disruption and to unmute your individual devices only when speaking.

We will now proceed with the meeting. I call on Louise Lund, Division Director of the Division of Engineering, Office of Nuclear Regulatory Research, to make introductory remarks. Louise, are you there?

MS. LUND: Yes, thank you. Thank you, Dr. Riccardella, and good morning to the ACRS members and all others here for this meeting. I hope everybody can hear me. Can I be heard?

CHAIR RICCARDELLA: You're fine, Louise.

MS. LUND: Great, wonderful. So I'm Louise Lund, Director of the Division of Engineering, Office of Nuclear Regulatory Research. I also serve as the Agency standards executive for the codes and standards program, coordinating the Agency participation on various standard development organization committees, and assuring Agency goals and activities relative to staff participation and development and use of consensus standards.

On behalf of the staff, we are very pleased to have the opportunity to present on the review and potential endorsement of the ASME Boiler and Pressure Vessel Code, Section III, Division 5, high temperature reactors. As you know, the NRC is executing its vision to become a modern risk informed regulatory by developing approaches to streamline and optimize reviews to enable the deployment of advanced reactor technologies. As part of the vision, the NRC developed implementation action plans for various strategic areas.

Consistent with its implementation action plans, NRC has been working proactively towards enhancing its non-LWR technical readiness and optimizing regulatory readiness. Today's presentation will be part of Strategy 4 which aims at facilitating development of industry codes and standards. To further that objective, the staff developed a prudent and balanced approach to ensure efficient completion of the endorsement project.

The approach involved building staff knowledge through training and collaborative activities, active participation in the ASME Section III working groups, engaging contractors to perform reviews and provide recommendations, and performing independent assessment of the code rules and procedures and contractor recommendations. Recognizing that the technical expertise on high temperature materials and components for advanced non-light water reactors was largely confined to a small group of people who were involved in the code development. But staff engaged these experts to seek clarification on staff's assessment and contractors' recommendations where applicable.

With such a comprehensive approach, the staff has pursued a holistic and balanced endorsement of the ASME Section III, Division 5 code. This review represents a major collaborative and successful undertaking by the staff across multiple divisions in both NRR and research. And we anticipate that the endorsement of the ASME high temperature provisions for use by a prospective non-LWR vendors will improve the efficiency and effectiveness at the NRC's review process.

Thank you again for the opportunity to present. And we look forward to our discussions this morning. Now Jeff Poehler of my staff will provide an overview of the ASME Code Section III, Division 5. Jeff?

MR. POEHLER: Good morning, everyone. Can you hear me well?

MS. LUND: Yes.

CHAIR RICCARDELLA: I hear you fine.

(Simultaneous speaking.)

MR. POEHLER: Yeah, I'll turn my camera off in a minute because I know you guys probably don't want to look at me too much but just so you know who I am. Yeah, so I'm going to be presenting an overview of Section III, Division 5, trying to give a high level overview and just give you a flavor of what it's about. I find that the Division 5 code is kind of hard to get your hands around.

There's a lot to it, even for people that are familiar with codes and standards. I've been immersed in it for about a year and a half, and I'm still -- frankly, still learning. So I am going to call on project team members if needed for questions, and also we have some experts from the national labs.

Sam Sham and Will Windes from Idaho National Laboratory are in the meeting. So I may throw some questions to them. But anyway, I would like to also thank the project team for all their help preparing these presentations.

And also this is the first presentation. The second presentation, we'll focus on the review process and potential exceptions and limitations to our review. So next slide, please. Okay. So I'm going to discuss the scope of Division 5.

So the scope of Division 5 governs construction of vessels, piping, pumps, valves, supports, core support structures, and nonmetallic core components for use in high temperature reactor systems and their supporting systems. And term, construction, here includes material, design, fabrication, installation, examination, testing, over-pressure protection, inspection, stamping, and certification, so basically the same areas covered by the low temperature construction code in Section III, Division 1. And high temperature reactors includes a wide variety of designs including gas-cooled reactors, liquid metal cooled reactors, and molten salt reactors.

Division is inclusive of all these technologies, meaning it's not specific to any of the particular reactor technologies. Let's go to the next slide, please. And this slide just kind of shows the spectrum of some of the advanced reactor designs that are being developed by the industry which span from fast reactors to gas reactors, heat pipe reactors.

You have molten salt reactors, and those can be either molten salt cooled and also molten salt fueled. And you have also -- you have fast and thermal reactors in this spectrum. So it's a lot of different types. Let's go to the next slide.

So Division 5 is a component code, and this is basically high level how it's organized. Class A is the highest safety class. The classes -- Class A is analogous to Class 1 in Division 1, and Class B is analogous to Class 2 in Division 1.

You also have Class SM for metallic core supports. And then you have Class SN for non-metallic core supports which at this point essential means graphite core support structures. And Division 5 recognizes different levels of importance associated with a function of each component as related to the safe operation of the advanced reactor plant.

So these code classes allow a choice of rules that provide a reasonable assurance of structural integrity and quality in line with the relative importance assigned to the individual components of the advanced reactor plant. Next slide, please. So this slide covers some of the things that Division 5 does not address, and those include corrosion, irradiation, mass transfer phenomena which would include things erosion and flow accelerated corrosion, radiation effects, other material instabilities which could be metallurgical phenomena.

It also doesn't cover continued functional performance of deformation sensitive structures such as valves and pumps. And what that means to me is it doesn't address whether the moving parts actually move. But let's go to the next slide. Just a little history now.

So there's a lot of history with the development of the high temperature rules which it's too much to go through in detail with the time we have. But the design rules do stretch all the way back to the 1960s with Code Case 1331. But really what I want to focus on the 1590 series code cases which were developed in the early '70s.

Those were reviewed by the NRC and endorsed in Regulatory Guide 1.87, Revision 1 which came out in June 1975. And that endorsed those code cases with conditions. And then later, the code case series, 1592 through 96, were converted into Code Case N-47, and that later formed the basis for Section III, Division 1, Subsection NH which cover high temperature components. NRC never reviewed N-47.

And then Division 5 was first published in 2011, and it combined Subsection NH and some other high-temperature code cases and also the rules for graphite core components which were completely new. They had never been in a code case before. Next slide, please.

So I call this slide the magic decoder ring for the organization of Division 5. I'm not going to go through it in detail. But I will point that for each subsection on metallic components, there are subparts for low temperature and elevated temperature service.

So Subpart A would be low temperature service. Subpart B would be elevated temperature service. And that holds for Class A metallic components, Class B metallic pressure boundary components, and also for core support -- metallic core support.

But the general requirements depart from that pattern with Subpart A being general requirements for metallic materials, Subpart B being general requirements for graphite and composite materials. And then when you get to graphite which is Subsection HH, you have Subpart -- or actually Subsection HH is not a metallic core component. So Subpart A of that would be graphite material. Subpart B is composite materials. Next slide.

So on this slide, I'm going to attempt to explain the temperature boundaries for low and high temperature reactor components under Section III, Division 5. This graph kind of explains the theory of when the high temperature rules are applied. So if you look at the table at bottom of the slide, it gives the temperatures.

And those are the temperature boundaries below which you can use the low temperature rules but above which you have to use the elevated temperature rules. Then the figure at the top here shows the different temperature regimes versus time. You see below a certain temperature, that's the temperatures corresponding to this table. The blue region here, you have no creep effects at all. So you can use the low temperature rules.

Above that line in the red and yellow regions, you do have creep going on in the yellow region which is at lower times and lower temperatures. You have creep going on but it doesn't affect cyclic life, whereas in the red region at longer times and higher temperatures creep does affect cyclic life. So you have a creep fatigue interaction.

MEMBER BALLINGER: This is Ron Ballinger. Where is 617 on this table?

MR. POEHLER: So 617 is addressed by a couple of code cases. So it's not actually in Division 5 itself. So I would have to look -- I could look up -- I would have to look up the maximum -- the temperature boundary for 617. But there is one. There is both a low temperature code case and a high temperature --

(Simultaneous speaking.)

CHAIR RICCARDELLA: Just for information, what does 617 mean?

MEMBER BALLINGER: It's --

MR. POEHLER: Go ahead, Ron.

MEMBER BALLINGER: No, go ahead. Go

ahead.

MR. POEHLER: Well, it's a nickel-based alloy that has very good high temperature strength, that has been qualified for use in high temperature reactors through a couple of code cases. Actually, there's one case for lower temperature use and then one for higher temperature use. And --

(Simultaneous speaking.)

MEMBER BALLINGER: It's not a -- it's a nickel, chrome, iron, cobalt alloy.

MR. POEHLER: Oh, okay.

MEMBER BALLINGER: And the code case for that -- the high temperature code case took -- oh, man. It took a very, very long time to get done.

CHAIR RICCARDELLA: And any idea what that cutoff temperature is, the Tmax is for that alloy?

MEMBER BALLINGER: It's got to be above 800 Fahrenheit for sure.

MR. POEHLER: We can get that for you. It's --

MEMBER BALLINGER: Will Windes -- Will would probably know. And so probably Will would know. But I don't see Richard Wright on this list either. He was the guy that was in charge of --

DR. SHAM: Ron, this is Sam Sham. So the

code boundary between low temperature and high temperature is just like the other or take the stainless steel that is 800 degree Fahrenheit.

CHAIR RICCARDELLA: Okay

DR. SHAM: And the maximum use temperature is 1750 degrees Fahrenheit.

CHAIR RICCARDELLA: Okay.

DR. SHAM: So it's around 154 degrees Celsius.

CHAIR RICCARDELLA: Okay. Thank you.

MR. POEHLER: Thanks, Sam.

MEMBER BROWN: Pete, can I ask a question on this? This is Charlie.

CHAIR RICCARDELLA: Sure. Go ahead.

MEMBER BROWN: Yeah, Ron popped up and said this new alloy is what, nickel, chromium, iron, cobalt?

CHAIR RICCARDELLA: Yes.

MEMBER BROWN: Is there a reason we're reintroducing cobalt into a radiated material such that we -- in my old program, we tried to get cobalt out of everything.

MEMBER BALLINGER: Yeah, this 617 is not used -- would not be used in a neutron environment.

MEMBER BROWN: Oh, okay. All right. That

wasn't clear to me. Pardon my question then. Thank you.

MR. POEHLER: Okay.

MEMBER BROWN: That's it.

MR. POEHLER: All right. Next slide, please. Okay. So this slide talks about the materials that are allowed for Class A metallic materials in Division 5. There's a limited set of materials. There's only six materials and not included Alloy 617.

But those are Type 304 stainless steel, 316 stainless steel, Alloy 800H, 2.25Cr-1Mo, and 9Cr-1Mo-V which is commonly known as Grade 91. And just a note about the two stainless steels, Division 5 specifies the minimum carbon content of 0.04 weight percent for those alloys to give them better high temperature properties. And they are commonly called Type 304H and Type 316H for that reason.

But that designation is not used in Section III, Division 5. But you will hear 304H and 316H. And the design parameters for the alloys are mostly in Division 5. But some of them are also contained in Section II and listed at the bottom of this slide. Next slide, please.

MEMBER BALLINGER: This is Ron again.

Sam, you said that the limit is -- for 617, the boundary is still 800 Fahrenheit?

DR. SHAM: Yes, going from Division 1 rules of the light water reactor. The design rules for high temperature is 800 Fahrenheit --

MEMBER BALLINGER: So that just --

DR. SHAM: -- maximum.

MEMBER BALLINGER: -- means the allowable stresses must be higher then, right?

DR. SHAM: The allowable stresses in the creep regime is higher.

MEMBER BALLINGER: Okay.

MR. POEHLER: Okay. Anymore questions on that slide? No? Next slide, please. Oh, you're on -- no, you're on the right slide. Never mind.

So this slide kind of breaks down all the different failure modes addressed by Section III, Division 5, and specifically for the Class A materials which is HBB. So it I didn't say it before, this presentation is going to focus heavily on the Class A metallic materials and also on graphite.

We are going to touch on Class B metallic materials and core supports but to a limited extent. So the majority of this is going to be about Class A metallics. And that's what this slide is talking about, the failure modes that are covered and also the type of -- that they're considered, what analysis -- or what areas of the code prevent those failure codes, where those are located, and the analysis method. So the two major types of failure modes are load-controlled which are just in HBB-3000 and deformation-controlled which are addressed in non-mandatory appendix HBB-T.

CHAIR RICCARDELLA: So Jeff, these are analogous to what we used to call primary and secondary stresses in Section III, Div. 1?

MR. POEHLER: Right. The HPV-3000 rules are going to consider primary stresses.

CHAIR RICCARDELLA: Okay.

MR. POEHLER: So -- and then what we would consider secondary would be addressed more in the non-mandatory appendix HBB-T.

CHAIR RICCARDELLA: Understand. Thank you.

MR. POEHLER: So, load-controlled are those quantities evaluated against the allowable stresses for primary loads. And those are all evaluated using elastic analysis methods. Evaluation of deformation-controlled quantities is called out in HBB-3250, and that allows the provisions of non-mandatory appendix HBB-T to be used. But it also allows alternative methods --

CHAIR RICCARDELLA: I understand.

MR. POEHLER: -- which is why it's not a non-mandatory appendix. But these quantities include strains and deformations, ratcheting and creep fatigue. Buckling is also addressed in HBB-T, and that can be either load-controlled, strain-controlled, or a combination of both. And as I mentioned, in HBB-3000 rules, only elastic analysis allowed whereas in HBB-T, it allows either elastic analysis, inelastic analysis, and also elastic, perfectly plastic analysis which is allowed through the two code cases.

CHAIR RICCARDELLA: Yeah.

MR. POEHLER: So okay. Next slide, please. So this slide attempts to highlight the general characteristics of the HBB primary load design on the left and then the evaluation of design loads versus loads on the right. So generally, HBB primary load design has the following characteristics. It's based on elastic analysis, load-controlled, uses stress classification and linearization, includes design and service level load checks.

It accounts for thermal aging effects with factors on yield and ultimate strength. And for welds, there is a strength reduction factor applied. And then on the right-hand graphic here with respect to design of service loads, so design loads are evaluated in a single temperature, pressure, and set of forces. They're time independent, and they use the allowable stress, S sub 0.

The procedures are very similar to those to the Section III -- I'm sorry, Section I and Section XIII of the ASME Boiler and Pressure Vessel Code. The service loads evaluation accounts for the time history of loading and are compared to time dependent allowable stresses. And that methodology is unique to Division 5. But I'm going to talk about that more on some subsequent slides.

CHAIR RICCARDELLA: For the surface loads, do we have different services levels as we did --

MR. POEHLER: Yes, it addresses Service Level A and B, C and D.

CHAIR RICCARDELLA: Okay. Thank you.

MR. POEHLER: Yeah, thanks. Next slide. Now I'm going to get into the allowable stresses a bit. So you have both time dependent and time independent level stresses. S sub 0 is the allowable stress for design loadings.

The service level loading allowable

stresses include S sub m which is a time independent allowable stress, S sub t which is a time dependent level stress, and then S sub mt, the allowable limit for general primary membrane stress for Surface Level A and B. And that is determined by the lower of S sub m and S sub t. And then also you have S sub r, the expected minimum stress-to-rupture. That's used in the Level D limits and then also in the deformation-controlled analyses of HBB-T. Or I guess I should say used directly in some of those analysis.

CHAIR RICCARDELLA: So is the S sub 0 -- are there values above the cutoff, the 700 and 800 degree cutoff temperatures?

MR. POEHLER: Yes, sir. And I'm going to discuss that a little more on the next --

CHAIR RICCARDELLA: Okay. All right. Thank you.

MR. POEHLER: So next slide, please. Yeah, so the basis for allowable stresses, so both S sub 0 and S sub m are essentially based on Section II, Part D values, either directly or extended using the same methodology for higher temperatures.

CHAIR RICCARDELLA: Okay.

MR. POEHLER: And so the S criteria in Section II-D may be controlled by the 100,000 hour rupture stress or stress to produce a creep rate of 0.01 percent in 1,000 hours. So it takes into account creep to some extent. So I guess what I should've pointed out that S sub 0 is equal to the higher of the S values from Section II-D, Subpart 1, Table 1A, or the 300,000 hour S sub mt value which generally would only be controlling in rare cases.

And then the S sub m is basically from Section II-D, Table 2A, the S sub m values in that table at the lower temperatures and then it's extended to higher temperatures using the same criteria in Division 5. And S sub t as I mentioned is the lower of the S sub m or time independent and the S sub t time dependent allowable stress. I'm going to talk about how S sub t is determined on the next slide.

CHAIR RICCARDELLA: Okay.

MR. POEHLER: So next slide, please. So as I said, S sub t is determined by the lowest of three different quantities. Those are 100 percent of the average stress required to obtain a total elastic primary -- plastic primary and secondary creep strain of 1 percent, or 80 percent of the minimum stress causes initiation of tertiary creep, or 67 percent of the minimum stress to cause rupture or S sub r.

And the determination of S sub t is

inherently conservation because of the 80 percent and 67 percent factors applied to tertiary creep initiation and stress-to-rupture. Also, it has been noted that of those three criteria, only the 67 percent of rupture stress criteria is directly related to component failure. The other two criteria are sort of different, semi-arbitrary points from the creep curves.

CHAIR RICCARDELLA: Yeah.

MR. POEHLER: So it is conservative.

(Simultaneous speaking.)

CHAIR RICCARDELLA: -- have much time until you -- right? I mean, that's when the curve turns up and you have not that much time until rupture, right?

MR. POEHLER: Right, yeah. It's theoretically. But some materials don't exhibit classical creep behavior. And it also can be difficult to determine the onset of tertiary creep in materials that don't have classic tertiary creep behavior. I'm going to talk about that a little more later.

CHAIR RICCARDELLA: Okay. Thank you.

MR. POEHLER: Next slide. And just a few of the other stresses and material properties, you have yield strength and ultimate strength which are self-explanatory. They are extended to the higher temperatures. You have -- the R factors are weld strength reduction factors to account for the reduced strength of welds compared to the corresponding base metal.

You also have tensile and yield strength reduction factors apply to some materials. And those account for thermal aging those materials. You also have isochronous stress-strain curves which provide stress versus strain curves for various times up to 300,000 hours. And those curves are derived from creep data. They're used in the analysis of some of the deformation-controlled quantities and non-mandatory appendix HBB-T.

CHAIR RICCARDELLA: So 300,000 hours is about 35 years --

MR. POEHLER: Yeah.

CHAIR RICCARDELLA: -- for picking that time?

MR. POEHLER: I'm not sure what the reason was. I might throw that question to Sam Sham.

DR. SHAM: Oh, yes. At the time that we sort of look at sort of the design of 40 years, 100,000 hours with availabilities of roughly close to that. And so currently, ASME is looking into extending the allowable stresses to support a longer design lifetime by 60 years.

CHAIR RICCARDELLA: Okay, okay. So it's basically the 40-year lifetime at some availability level or something.

DR. SHAM: Yeah, something like that.

CHAIR RICCARDELLA: I got it. Thank you.

MR. POEHLER: Thanks. Okay. Next slide, please. Okay. So this is talking more about non-mandatory appendix HBB-T and trying to break that down a little bit and just discussing the characteristics and also the evaluation methods for some of these deformation-controlled quantities. So you have limits for strain accumulation of 1 percent average, 2 percent linearized bending, or 5 percent maximum. Also, creep and fatigue have to be -- creep and fatigue and buckling have to be evaluated.

And as we mentioned before, these things are typically driven by secondary stresses. The right-hand side of this slide talks about the different analysis methods that are available. These include elastic, inelastic, and elastic perfectly-plastic analysis.

For elastic and inelastic analyses, they can be applied to all materials. And the rules are in HBB-T, elastic analysis thought to be bounding while inelastic analysis is thought to be more accurate. And inelastic analysis, there are no material models currently in Division 5 for those inelastic analyses.

And then elastic perfectly-plastic analysis supplies right now only to a subset of the materials. And those rules are in two code cases. And it's also considered a bounding analysis. Next slide, please.

Okay. So now I'm going to talk about how creep fatigue is evaluated. So creep fatigue is assessed based on the interaction diagram which you see on the left there. A life fraction of creep damage and a usage fraction for fatigue damage are determined separately.

The fatigue use is just computed similarly to fatigue for Class 1 components in Division 1, except for Division 5 has its own fatigue curves. And those are in terms of strain versus cycles. The coordinates of these two damaged fractions are compared to the interaction diagram, and they have to be inside the lines to pass.

Different materials have different allowable creep fatigue envelopes. You can see 304 and 316 have an intersection point of 0.3 on the diagram which gives it a little more liberal envelope while 2.25Cr and 800H have an intersection of 0.1, 0.1 which is more restrictive. And then 9Cr is very restrictive envelope there.

MEMBER BALLINGER: This is Ron again. Where would 617 -- sorry for keeping to harp on 617. But it's the main high temperature material and it's not on here.

MR. POEHLER: Yeah. So this is just an example. But, yeah, I can't tell you off the top of my head what the interaction diagram looks like. But we can --

DR. SHAM: 617 is 0.1, 0.1, Ron.

MR. POEHLER: 0.1, 0.1. Thanks, Sam.

CHAIR RICCARDELLA: 0.1? Okay. Thank you.

MR. POEHLER: Okay.

CHAIR RICCARDELLA: So it'll be the middle of the three curves.

MR. POEHLER: Thanks. And we'll talk more about how creep damage is assessed on the subsequent slides. Next slide, please.

CHAIR RICCARDELLA: Well, so the red and blue data points on this slide are a pass versus a fail. Is that the idea?

MR. POEHLER: Yeah, I think those are just examples.

CHAIR RICCARDELLA: Yeah.

MR. POEHLER: I think the blue one would pass for stainless steel, and the orange one would fail.

CHAIR RICCARDELLA: Yeah, go it.

MR. POEHLER: Let's go to the next slide. Okay. So this slide goes into a little more detail about how the creep damage fraction is determined in the creep fatigue assessment. So creep damage for different cycle types is based on stresses, and it accounts for stress relaxation.

The upper right figure shows a schematic of a stress relaxation profile. And the isochronous stress-strain curves are used to determine the amount of stress relaxation. The stress rupture curves are used to obtain the rupture time associated with the relaxed stress for the cycle type in question.

The lower right graph shows the stress rupture curves for Alloy 617. And the time to rupture represents the denomination -- denominator and the creep damage term. Welds have a stress rupture factor to account for the reduced rupture strength of welds compared to the corresponding base metal. And that's called out in HBB-T-1715 which requires supplying this to the stress rupture curves when you did a creep damage calculation.

CHAIR RICCARDELLA: But Jeff, the relaxation only occurs for deformation control stresses, right?

MR. POEHLER: Right. It's not -- you don't take that into account for primary --

(Simultaneous speaking.)

CHAIR RICCARDELLA: Right. And -- okay.

MR. POEHLER: Okay. Let's go to the next slide. Okay. Yeah, so a little bit about the buckling rules, there's different buckling limits depending on whether creep is significant or not and also whether the buckling is either strain-controlled or load-controlled. So load-controlled buckling is characterized by continued application of applied load in the post-buckling regime leading to failure, such as, for example, collapse of a tube under external pressure.

Strain-controlled bucking is characterized by an immediate reduction of strain-induced loading upon initiation of buckling and by the self-limiting nature of the resulting deformations. Even though its self-limiting, strain-controlled buckling must be avoided to guard against failure by fatigue, excessive strain, and interaction with load control instability. So figures like the ones shown here provide time-temperature combinations below which the time independent buckling limits may be used.

And this figure is an example provided for one geometry. There's figures for several different geometries in Division 5. For conditions where strain-controlled and load-controlled buckling may interact or significant elastic follow-up may occur, the load factors for load-controlled buckling are also to be used for strain-controlled buckling.

And the term, elastic follow-up, refers to a situation where only a small portion of the structure undergoes inelastic strains while a major portion of the structure behaves in an elastic manner. And in these cases, certain areas may be subjected to strain concentrations due to elastic follow-up of the rest of the connected structure. The next slide. Okay. I'm going to talk a little bit about -- more about the elastic perfectly-plastic or EPP analysis.

So it's a methodology for analysis of deformation-controlled quantities. It's implemented via two code cases as I mentioned. There's one code case for strain limits and one code case for creep fatigue.

The staff is reviewing Rev. 0 of the code cases which only cover Type 304 and 316 stainless steel. However, Grade 91 and Alloy 617 are covered by revisions of those code cases. EPP is intended to be easier to implement than inelastic analysis, but it removes some of the over-conservatism of elastic analysis methods.

And some of the advantages include that you don't have to do stress classification. You can apply it to any geometry or loading. It accounts for redundant load paths, and it's simpler to implement.

It's based on finite element results at integration points. So there's no linearization of stresses. And it uses the concept of a pseudo yield stress which is determined by trial and error.

The trial value will be the lower of the yield strength or the stress to cause an -- Stress X to cause inelastic strain in the time interval as determined from the isochronous stress-strain curves in Section III, Division 5. And that X is the -- so if the component then fails, basically doesn't shake down to elastic action, then you pick a different X, basically. So it's kind of a trial and error process.

Okay. Next slide, please. Question? No?

So, now I'm going to give just a little more background on inelastic analysis methods. So the code doesn't provide inelastic material models right now. So currently this would be left to the designer if he were using the 2017 edition.

Or actually, yeah, the code committees are working on developing these models. There is some historical experience from the Clinch River breeder reactor with inelastic analysis of high temperature reactor components. And this experience showed inelastic analysis is the least ever conservative of the Division 5 options.

It can be necessary in critical locations where designed inelastic analysis is too conservative to produce a reasonable design. And finally, the current status of development of material models for inelastic analysis in the code is that unified viscoplastic constitutive models for 316H stainless steel and Grade 91 have been developed. And an action to add Grade 91 -- the Grade 91 model to the code has just been balloted. Next slide, please.

Okay. So moving on to the Class B rules. So the Class B rules for low temperature components are essentially the same as those for Section III, Division 1, Class 2 components. For Class B high temperature components, the rules do take creep into account but are simplified compared to the Class A high temperature rules.

And there's a lot more materials allowed for Class B high temperature components than for Class A high temperature components. Creep can be neglected for components with non-negligible creep. There is a Mandatory Appendix HCB-III that defines times and temperatures where creep effects can be neglected. Next slide.

A little more about the Class B rules. Basically, they extend the design methodologies of Division 1, Class 2 to higher temperatures. These are designed by rule approach. They don't use the design lifetime concept.

Allowable stresses are based on extrapolated 100,000 hour creep-rupture properties which is similar to Division 1. And fatigue damage from cyclic service is addressed only for piping with creep effects. A stress range reduction factor is used, similar to Division 1, Class 2, but the factors are reduced to account for elevated temperatures. Next slide.

So for metallic core supports, you have

low temperature rules in HGA which are essentially the same as those in Division 1 for core supports. And then for elevated temperature metallic core supports, the rules are essentially the same as those for Class B. I couldn't say Class -- I mean, I meant Class A, Class A elevated temperature components, including the same allowable materials and stresses. Next slide.

Okay. Now moving on to construction rules for nonmetallic components. So Division 5 is unique in that it provides rules for nonmetallic components, including both graphite and composites. Graphite materials are used mainly in core components in certain advanced reactor designs due to their excellent neutron moderation properties.

Rules for composites were added in Division 5 for the 2019 edition. In the 2017 edition, the rules for composites were listed as in the course preparation. So the staff did not review those, the rules for composites. Next.

CHAIR RICCARDELLA: What do you mean by composites? Graphite is one?

MR. POEHLER: No, I think --

DR. SHAM: They are the C/SiC composite or --

DR. WINDES: C/SiC and carbon-carbon.

MR. POEHLER: Silicon carbide maybe.

DR. WINDES: Yes.

MR. POEHLER: Yeah.

DR. WINDES: Yeah, silicon carbide matrix, silicon carbide fiber as well as carbon fiber and carbon matrix. So carbon-carbon and C/SiC.

CHAIR RICCARDELLA: Okay. Thank you.

MR. POEHLER: Thank you. Next slide, please. So now I'm going to talk about some of the characteristics unique to graphite that provides a little background to help understand the provisions of Division 5 for graphite design and materials. So some of these include the fact that there's no single nuclear grade of graphite. Therefore, we can't design around a specific nuclear grade as we can for metals -- metallic materials.

Graphite is heterogeneous by nature and contains significant pores and cracks. Graphite is not ductile. It has brittle or quasi-brittle fracture behavior. And so the graph here on the right of this slide shows an example of turnaround which is basically you have a volume change initially with increasing neutron dose where the volume shrinks up to a certain dose and it begins to expand. And the material's behavior is completely different before and after the turnaround does is accumulated. Next slide, please.

MEMBER BROWN: This is Charlie Brown again. Could you go back to that graphite slide?

MR. POEHLER: Yeah, let's go back.

MEMBER BROWN: I'm not a materials guy, just trying to make sure I'm educated with the advanced reactor somewhat. Very graphically, describe the negative aspects of graphite in the application of the advanced reactors. Is that going to result or do you think it would result in a change of their seismic response? Do we have to change seismic rules to allow these things -- these materials to be used?

MR. POEHLER: That's a good question. I would probably maybe ask Will Windes if he could talk to that a little bit.

DR. WINDES: Yeah, I think it -- first of all, I think it depends upon the design. So as you can see, you're looking at maybe a 5, 6, 7 percent volumetric change macroscopically at the most for whatever grade of graphite. Sometimes you're only looking at something like one -- a half to one percent volumetric change.

So, dependent upon the grade of graphite that you use, the design that you have, then, yeah, you are going to have to maybe consider something like a seismic. But again, it's going to be very, very specifically design oriented. Does that --

(Simultaneous speaking.)

MEMBER BROWN: Go ahead.

MEMBER KIRCHNER: Charlie, this is Walt. These kind of -- this curve we're looking at here certainly was a big factor in the Fort St. Vrain design which used prismatic graphite blocks. And so yes, seismic is one of the issues. Bypass is another issue that was a concern. And subsequent designs of the modular HTGRs that were using prismatic blocks instead of pebbles made various design-specific changes.

For example, they put, like, a cap. And I'm not describing it very well. But instead of just having graphite blocks -- prismatic blocks stacked on each other, they had a little crown that went over -- in the advanced designs over the graphite, a block that was below it so that they didn't have wobbling, so to speak, under flow and then having bypass and other kind of issues also and structural stability to deal with things like seismic loadings and such.

CHAIR RICCARDELLA: So that's the shrinkage concern. So that's in the beginning of this radiation effect when the volume change is actually shrinkage?

MEMBER KIRCHNER: Yeah, it's shrinkage, the first feat that they had to deal with. I don't know that they were looking at exposures that got back up above the curve where it changed. I think in the end reactor, they had those kind of problems, though. That was a production reactor for the weapons program. But they had, I think --

(Simultaneous speaking.)

MEMBER KIRCHNER: -- entire fluences in that. And they did cross the curve that you're looking at.

MEMBER PETTI: So in general, though, for some of these reactors, the design criteria is that you don't design beyond the minimum shrinkage. Others will talk about designing up to the point that you go back to zero. Nobody talks about designing in the swelling region above zero.

The other thing is that the grade sometimes can be used. This is in the middle of the core where the fluence is the highest. The support structure, the fluences are much, much lower. Sometimes other grades are used. It's not all the same grade in the core. So there's a lot of design considerations here. And the HTGR experts are well aware of these things.

MEMBER REMPE: So Dave, back in the days of General Atomics, they -- help me remember. Wasn't it called H-451 or something --

MEMBER PETTI: Yes.

MEMBER REMPE: -- is what we had.

MEMBER PETTI: Yes.

MEMBER REMPE: And had they -- and I know that source is no longer available. Have all these designers -- because there's quite a few folks thinking they're going to do something with a graphite reactor, for the fuel or for the moderator or whatever. And have they identified sources? Where are they?

MEMBER PETTI: Yes, so you see all the data there. All major grades that are available with all the major vendors have been tested in the DOE program. And these are -- let's call them new grades.

They all -- you could tie them back to the old grades like H-451. There was an equivalent German graphite grade. And so there's a lineage, if you will.

But there's a lot of grades out there besides the old German and the old H-451 which was the

American. There's Japanese grades now. China is trying develop their own grades.

MEMBER REMPE: How do they compare if I look at this --

(Simultaneous speaking.)

MEMBER PETTI: At least as good as the historic.

MEMBER BALLINGER: And I think IG 110 is probably better.

MEMBER PETTI: Well, IG 110, yeah, that's the Japanese grade. But if you look at the American grade that replaced H-451, it's at least as good, if not better.

(Simultaneous speaking.)

DR. WINDES: I'm sorry. Yeah, I was going to say, so Joy, just to give you an idea. The PCEA, the blue square, was Graphtec International's attempt to duplicate after 40 years the old H-451 recipe. And we actually had legacy H-451 graphite that we put into their first two capsules of the AGC experiment and did a direct one-for-one comparison between H-451 and PCEA. And at least from an irradiation response and behavior standpoint, they lay on top of each other so well that you can barely distinguish between H-451 and PCEA. And that's --

MEMBER REMPE: And is there a huge amount, Will? I'm sorry to interrupt. But is the amount large? Do they have a huge source? They're not going to have to do this because they're going to run out again or something?

DR. WINDES: No. So that's -- and that his one of the questions that's going on right now. And I'm sure that the NRC is going to be involved in that is that the whole issue of source, let's face it. You're not going to be able to duplicate graphite-like metal because you don't take it down to the atomistic composition.

You take it down to basically its molecular airmatic (phonetic) ring structure. And that is dependent upon where you get your source material. So even if you dig the same coal out of the same coal mine or pump it out of the same oil well, the farther down you go in that coal mine or in that well, you're going to have a geologic change to the source material.

But with that said, I mean, everybody knows this. It's out in the open. This is a potential issue and weakness. But with that said, the graphite suppliers are well versed and have a lot of experience in determining and correcting and changing the formulas so that you get the same response because this has been going on since basically we made synthetic graphite for over 100 years. People want a consistent material. And so they have experience to do that.

And that's what the experiment with PCEA was. It was a completely different source of raw material, completely different facility, absolutely no people that had done H-451 and made it. And yet after 40 years of laying dormant, they were able to resurrect the recipe and show that they could produce a material that had the same characteristics as a material that had been produced 40 years previously, without the same material, without the same source material, or coke source or anything else.

So that's a question that's being debated. I think that most people believe that we can go in and create a grade of graphite that is consistent throughout time. So if you wanted to have a second, third, or fourth core replace the components, I can tell you that the graphite community is very confident that the suppliers can produce a grade even 20 or 30 years later that is consistent with that first core. Does that make sense?

MEMBER REMPE: Thank you. Yeah, thanks,

Will. It's good to talk to you again, even if it's virtually.

DR. WINDES: Yeah, that too.

CHAIR RICCARDELLA: Walt, this is Pete.

MEMBER KIRCHNER: This is Walt Kirchner. How well have they done with a Great Lakes carbon supply? One of the big issues is neutronics and impurities. So how well are they doing when they replicated the H-451? How well did they do on neutronic impurities?

DR. WINDES: Oh, that's pretty --

MEMBER KIRCHNER: It's a side question, but it's an important one.

DR. WINDES: Yeah. No, that's -- the purification process is actually probably a lot better. One of the things that -- while the nuclear industry sort of stayed still and dormant in this area and we really haven't pushed the technology, the IT industry has. And in fact, just as a little anecdote to answer this question indirectly, when we went in and did a quality assurance inspection on one of the graphite suppliers and we told them that this was going to be a nuclear quality assurance inspection and they were all revved up, they called us back afterwards and they said, man, that was easy.

If you want to see what specs are and getting the impurity levels down, you got to go through an IT inspection. So what's happened in the last 20 to 25 years is that the IT, specifically the silicon chip and all of the computer and solar panel folks, they have come in and they have progressed the purification process to the point that we never could have in the past with the nuclear program. So yeah, it's much better even then than we had in the past.

MEMBER PETTI: Walt?

MEMBER KIRCHNER: Thank you. That's good to know. Okay.

MEMBER PETTI: Just so you know, these samples that are irradiated, they can be contact handled.

DR. WINDES: Oh, yeah.

MEMBER PETTI: They're not very hot at all.

DR. WINDES: Yeah.

MEMBER PETTI: That may not have been the case years and years ago.

MEMBER KIRCHNER: Well, back in the '80s, when Great Lakes Carbon was no longer a source of supply, what I was doing was mining older logs.

MEMBER PETTI: Yeah.

MEMBER KIRCHNER: But that didn't bode well for the MHTGR program in circa the '80s. So this is encouraging news.

DR. WINDES: Oh, yeah, yeah. And like I said, it's a lot more -- the purification process is a lot more sophisticated than it ever was for the old 327 and the H-451 graphite grades.

CHAIR RICCARDELLA: Walt Kirchner, in your initial comments, you distinguished between prismatic core elements versus pebble bed. Could you give a little more on why it is that distinction? Is it less critical in a pebble bed reactor?

MEMBER KIRCHNER: Yeah, it's much less critical. Dave could speak to it better than I could. But you don't have such a large structure as you -- those prismatic blocks were typically about a meter high, 12 or 14 inches across the flats in a hex configuration. So you've got an actual structure that is in both a thermal and a radiation field that varies both -- in all dimensions. So that creates a lot more challenges for the core designer than dealing with a nice hard pebble.

MEMBER PETTI: But I will say, though, that the reflector of a pebble bed is quite a challenge structurally. There are different issues.

It's keyed together.

Think of the -- the prismatic is kind of like Lego blocks with straps around them. So it's thermomechanically easier than if you look at the design of the reflector in a pebble bed. And particularly, even the support, you've got to have -- you've got to hold core up and you've got to let the pebbles through. It's quite the challenge.

DR. WINDES: And I will point out that the image in the lower left-hand corner, that is some of the outer reflector bricks that were designed by the -- for the pebble bed modular reactor, the PBMR in South Africa. And if you look at that, you can see what Dave's talking about. They're keyed together, and they have to be interlocked just basically to support those pebbles that are inside there.

And then from a seismic standpoint -- and this is why composites is being considered. But from a seismic standpoint, they had silicon carbide or carbon-carbon belts that wrapped around the core purely for seismic considerations. And they basically provided a tensile restraint during seismic events -- potential seismic events.

CHAIR RICCARDELLA: Understand. Okay. Thank you.

MEMBER BROWN: Can I ask my question in a different way? You all buried me in prismatics and everything else. Let me put this more practically. All the stuff here, it's very brittle. I know people have made advances like you all commented on. But I'm thinking about it in a long-term application, for example, conventional reactor fuels as we has today.

We had an earthquake at North Anna. And within a short period of time after that, it rode through. It started back up and had no -- and operated as if nothing ever happened. If you have a seismic event of that nature with a graphite-type moderator, is there a concern that you'll be able to go right back to operation? Or are you going to have to go in and do something in the plant?

MEMBER PETTI: There will be a safe shutdown earthquake, and they will have to design it, right?

MEMBER BROWN: I'm not worry about safe shutdown, Dave. I'm talking about below safe shutdown.

CHAIR RICCARDELLA: And that would be OBE, an operating basis earthquake.

MEMBER BROWN: Yeah, and North Anna rode through that and nobody blinked. They kept on trucking. Will graphite be able to do that?

MEMBER PETTI: It will have to be.

MEMBER BROWN: How do we prove that?

MEMBER PETTI: Through the analysis.

CHAIR RICCARDELLA: That's what this code is all about.

MEMBER BROWN: Okay. All right. You've answered -- we're not there yet is what you're fundamentally telling. There's a lot of work to be done to prove that we'll ride through that similarly. I'm just looking at long-term performance. That's all I'm --

MEMBER PETTI: Yeah, I mean, Fort St. Vrain had an earthquake they had to survive, as we know, so --

MEMBER BROWN: Yeah, how long was it in operation? Or how long it was built before they shut it down? That's a big difference.

MEMBER BROWN: How long did it --

(Simultaneous speaking.)

MEMBER BALLINGER: When it was above water or under water?

MEMBER BROWN: How long did it operate?

MEMBER KIRCHNER: Well, Charlie, this is Walt. The right answer here is putting Fort St. Vrain aside which was we can go through all the reasons it was shut down. But when they -- certainly when they designed it, they designed for a 40-year life.

And if I remember correctly, they had shake table tests for their core and reflector structure so that they could convince themselves that from the stress and from the mechanical design standpoint that they configuration would meet both the OBE and SSE requirements. So I'm confident that they can design a 40-year core, and if it were exposed to an event like in Virginia, if it's below the safe shutdown or OBE limits, I'm confident that they would be able to restart the reactor.

MEMBER BROWN: Okay. That's all. That's what I'm --

(Simultaneous speaking.)

MEMBER BROWN: You're an expert. You all --

DR. WINDES: May I say one thing?

MEMBER BROWN: Pardon?

DR. WINDES: May I say one thing, please?

MEMBER BROWN: Sure, yes, yes.

DR. WINDES: Yeah. Just so -- let me ask -- let me answer it in two different ways, sort of a Part 1, Part 2. First and foremost, from a material science standpoint, graphite, these components are fairly massive. Putting a crack through those or even chipping an edge off of them so that they may -- during a seismic event so that they would not -- the Legos would not fit into each other would be -- from a material science standpoint, would be highly, highly unlikely.

There would have to have been a major flaw near the edge that was undetected. So if the rules -- design rules are followed and all of the inspections are followed, there should be no reason for these things to -- the individual components to stay completely and totally stable. The graphite is robust enough to do that. We're not making this out of glass. Graphite is a lot more forgiving. So from a material standpoint, that's not a problem.

The second part is, is that remember that the core is made up of individual stacked components. So they're not rigid. So if there is a crack that forms in one of these components, the real question is, who cares, because we already have cracks.

We're stacking individual elements together and the gaps between them is significant. They are huge cracks if you want to think of them that way. So if a small crack occurs, that's not really a problem.

Even if a small chip occurs, that's not really a problem. What's really a problem -- and this is why I answered your initial question with, well, it depends upon the design. The real issue is, can you shut down the reactor in a safe and timely manner? Can you keep the safe -- the fuel safe? Can you keep the safe operation of the core?

And the answer to that is across the Atlantic and that is with the AGR reactors. They have done extensive testing of their core's shake tables, a quarter size, full size reactor cores with a quarter size on gigantic shaped tables. And they have gone in and done up to the maximum expected seismic events that they have in England and found absolutely no problems with their design.

And the last thing I will say is that every single brick right now in the UK is cracked, has at least one, if not two through cracks. And yet they can still operate their reactors safely. And they have done so for 20-plus years.

MEMBER REMPE: But Will --

DR. WINDES: So again -- what?

MEMBER REMPE: -- aren't those cracks why they're shutting down the UK reactors prematurely?

DR. WINDES: No, not really. What they're doing is they're extending the life beyond what the original design life was, which was about 20, 25 years. They're actually extending it beyond.

And as a consequence -- and the real problem is, is that these -- and it all gets back to the design of the actual cores and what you intended. These -- their cores are so keyed and interlocked that they're literally sort of a one shot and they're done. And there's no way you could go in there and pull out a cracked element -- or excuse me, reflector element and pull it out and replace it.

You have to completely disassemble the entire core. And so as a consequence from the economic standpoint, you can't do that because it's so keyed together. Cracks don't really matter to them. They've operated safely for decades with cracked components. But they don't really care because the core is designed to actually withstand that kind of phenomenon. So again --

MEMBER REMPE: To say they don't really care, I know that there's been discussions for decades about those cracks.

DR. WINDES: They care immensely about that. But does it -- is it a critical safety problem?

And the answer is no. They care immensely about it. And there's been hundreds of pounds -- millions of pounds that have been proposed -- or excuse me, been worked on this issue.

So they care immensely about this. But what the question that comes down to is, can they operate their reactor cores safely with cracked components? And the answer is yes, not only in their models, not only in their analysis, but through pure experience. In the last 20 years, they've had a number of issues and it's never compromised the safe operating envelope of a single one of their reactors, even though everybody knows they are cracked bricks.

So cracked bricks is not necessarily a stopping of the entire reactor consideration. So you have to have that knowledge as well when you're designing these cores. And I apologize. I've taken up a lot of time in this.

MEMBER BROWN: No, don't apologize. I'm not a -- obviously not an expert on graphite, and I know we're going to have a lot discussions later. But this has been an excellent discussion. I appreciate your time and the patience --

DR. WINDES: Oh, no. Thank you for listening. I'll talk all day about this.

CHAIR RICCARDELLA: A question on seismic: the UK is not really a high seismic region, is it?

DR. WINDES: No, it's not. What they're talking -- I think, if I'm not mistaken, they're taking about something on the order of five, five and a half is what they're really, truly expecting. But I believe the original question was something that was not a catastrophic shutdown event but basically a small event that could have a restart. The UK is a perfect example for something like that.

CHAIR RICCARDELLA: An OBE, but there's something that gives metallic structures almost an inherent -- makes them inherently forgiving to seismic loads because most seismic design work is now with linear analysis and you're worried about resonance at certain frequencies. And as soon as you exceed the yield strength in a metallic component, you get a little bit of yielding that introduces stamping that changes where you are on the resonance curve. And so the loads go down compared to what the elastic analysis would predict.

I'm not sure if that same phenomenon works in graphite -- in a graphite -- on the slide, it has graphite. It's not ductile. It's brittle or quasi-brittle. To me, it's almost like masonry structures don't respond real well to earthquakes compared to steel or wood frame structures.

DR. WINDES: True, but the design is completely different. In a metallic, you would have a pressure retaining structure whereas in the graphic, we are not a pressure retaining vessel.

CHAIR RICCARDELLA: Yeah, yeah.

DR. WINDES: And so as a consequence, the entire design requirements and the function of the graphite is not to go in and withstand a cracking event. It's to maintain the structural integrity of the core.

CHAIR RICCARDELLA: Okay.

MEMBER BALLINGER: Yeah, this is Ron. I mean, Section V does not account for -- there's an explicit thing in there. It says, we don't count for corrosion. The equivalent for graphite if there's no water in the system is probably wear. Am I correct? Erosion?

DR. WINDES: Yeah. Well, wear and erosion is something that we're considering. But quite frankly, it depends on the molten salt or if you have a gas cooled environment.

MEMBER BALLINGER: Yeah, yeah.

DR. WINDES: The molten salt and the wear and erosion is going to be something. For a gas cooled reactor, the only real issue is probably dust entrained high velocity gas in some of these regions. But again, the wear and erosion is probably not something that's really where we're really worried about.

I think really what the main issue is the -- and this is why it's in the design rules itself is the irradiation effects of the graph on the graphite. So unlike metals where it basically sort of bottoms out, the graphite has this sort of dynamic response and behavior. And it changes, as you can see, as a function of dose.

And that's why turnaround is so critical and important. Once you figure out where your turnaround is, then you can predict and understand what the behavior is going to be like. But it's a dynamic response to the irradiation and the radiation temperature. That's why it's in the design rules and not in Section VIII.

MEMBER BALLINGER: Yeah, I remember sitting in Arkal Shenoy's office where he had a graphite block that was tested for the Fort St. Vrain reactor. And that graphite block after exposure to a test loop had about an inch of wear off of one of those blocks.

DR. WINDES: Right, yeah. It's both soft and hard.

MEMBER BALLINGER: Yeah.

DR. WINDES: My machinist in the back machining samples both loves and hates graphite at the same time. So yeah, it's beautiful. It's easy. It cuts and then it dulls as cutting tools like nothing else, so yeah.

MEMBER KIRCHNER: Yeah.

DR. WINDES: Very, very weird.

MEMBER KIRCHNER: Ron, this is Walt. The design challenges are quite a bit different than using a metal core. And the picture in the lower left is illustrative of some of the things you would worry about. You don't want excessive wear creating dust and contamination in the primary circuit. You don't want large bypass because of the volumetric shrinkage there before you get to turnaround.

You have to worry -- probably the biggest seismic worry is not the blocks as Will was saying, cracking and such. The biggest worry is alignment so that you can ensure that if you're using control rods, you can get the controls rods inserted and achieve a safe shutdown condition. So it's a different set of

-- there are similar issues but a different set of problems that you deal with, especially for the gas cooled --

DR. WINDES: Yeah, that's where the -- that's why I was mentioning where because that changes -- if you have a lot of wear, it might change the seismic response.

CHAIR RICCARDELLA: Yeah, so this is a very interesting discussion, but I think we have to move on. We've got about five more slides, I think, in the overview part of the Section III, Division 5. And then I'd like to take a break. And then we'll get into the staff -- the comments on the staff endorsement of Section -- of Division 5.

MR. POEHLER: Thanks, Pete. Okay. Yeah, so this -- now moving on, talking about some of the code considerations here with graphite. Because all graphite is brittle and contains flaws as we discussed, core components need to be designed to accept some amount of cracking. The upper right figure shows some internal flaws in graphite.

So because of these characteristics, a probabilistic versus deterministic design approach needs to be used because deterministic is generally too limiting for brittle material like graphite. So distribution and possible strengths in the material is needed for a material like this. And a probability of failure in components is based on inherent strength of graphite grades and applied stresses during operation.

So the figure on the left kind of shows distributions of loading on the left-hand curve on that figure and the distribution of material strength on the right-hand curve on that figure. The overlap of those two curves represents the reliability of the part. So let's move on. Next slide.

MEMBER BALLINGER: Is there a Weibull modulus spec on this stuff?

DR. WINDES: Yes.

MR. POEHLER: I don't know the answer to that. I would --

DR. WINDES: Yes, I think there -- that's what you're seeing right here is viable strength curves. And that's --

MEMBER BALLINGER: Okay, okay. That's what I thought.

DR. WINDES: Yeah.

MR. POEHLER: Okay. So those slides are talking about the structural integrity assessment methods that are in Division 5 for graphite components. The upper -- or the figure on the right here shows typical material testing curves used to derive failure probabilities, tensile strength versus failure probability. So the methods that are in the code for assessment, they're three basic methods, the simplified assessment which is a simplified conservative method based on ultimate strength derived from Weibull statistics.

The full assessment is a more detailed assessment that takes into account stresses, temperatures, a radiation history, chronic -- and chronic oxidation effects. Weibull statistics are used to predict failure probability. The maximum allowable probability of failure is determined for three structural reliability classes which related to safety function.

And so those three classes are shown in the table here along with a maximum probability of failure allowed. And then finally, design by test is also allowed by the code. And that involves full scale testing to demonstrate that failure probabilities meet the criteria of a full analysis. I'd like to point out the graphite rules are a process. The designer can't just pick a pre-approved material. The designer has to demonstrate their specific graphite grade selected will consistently meet the component requirements.

CHAIR RICCARDELLA: So this SRC-1, SRC-2, are they somehow analogous to Class A, Class B components?

MR. POEHLER: I believe so. I think it relates. You would designate that based on the safety significance of --

CHAIR RICCARDELLA: Yeah, okay.

MR. POEHLER: -- the consequences for the year of the --

CHAIR RICCARDELLA: Right. And failure doesn't necessarily mean failure of the structure. It just means cracking?

MR. POEHLER: Correct, the probability of a through crack.

CHAIR RICCARDELLA: Okay.

MR. POEHLER: Okay. Next slide, please. So yeah, so anyway, this is addressing some of the special considerations in the design of graphic components, and those include oxidation, irradiation and abrasion, erosion which Division 5 says should be addressed. This figure kind of shows how these special considerations can shift both the loading distribution and the strength distribution in either direction which would change the overlap area for the two distributions. So degradation can change -- or radiation can increase strength or typically increase the strength.

High temperature can increase strength. Oxidation would decrease strength. Molten salt may decrease strength. Irradiation changes also changes the stress loading on the part.

Dimensional changes can increase stress. But irradiation creep on the other hand can relieve stress. So the stress distribution curve here on the left could shift either way due to irradiation. And those shifts could change this overlap here. So those have to be considered. Okay. Next slide, please.

CHAIR RICCARDELLA: On the previous slide where you were talking about the allowable probability of failure, that really refers to the green curve, right?

DR. WINDES: Correct.

MR. POEHLER: Thanks, Will. Next slide. So this slide is showing the data sheet for graphite which is called out in Article HHA-2-2000 material data sheet forms. And this data sheet captures most of the graphite degradation issues. It includes some material properties or physical properties.

It covers irradiation effects, temperature dependence, and oxidation effects. Molten salt issues aren't addressed yet in the Division 5 code. So the cognizant code test group is currently working on modifications to add that.

And let's go to the next slide. So this is the summary for the overview. So just to summarize, Division 5 was issued as part of the 2011 Addenda to the code. The design rules trace all the way back to the 1960s for development of high temperature rules for metallics.

Division 5 covers the rules for design, fabrication, inspection, and testing of components in high temperature reactors. And these construction rules cover both metallic and nonmetallic components with the rules for nonmetallic components being unique among all design codes worldwide. And finally, the ASME code committees are actively pursuing code rules improvement and developing new technologies to support Advanced Nuclear. With that, I'm going to turn it over to Jordan.

CHAIR RICCARDELLA: Okay. So well, thank you, Jeff. That was an excellent summary, and we really appreciate the effort you put into it. I'm going to propose now that we take a 15 minute break. So we'll go into recess into, what is it, 11:10 East

Coast time. Okay.

(Whereupon, the above-entitled matter went off the record at 10:55 a.m. and resumed at 11:09 a.m.)

CHAIR RICCARDELLA: Okay. We are approaching -- it is now 11:10, and so we'll -- the meeting will come to order again.

And I believe we've had a review of just what's in Section III, Division 5, and now we'll have a discussion of the NRC review and potential endorsement of it. And I guess, Jordan Hoellman, are you going to lead this discussion?

MR. HOELLMAN: That's right, Pete. I will --

CHAIR RICCARDELLA: Okay.

MR. HOELLMAN: I will start as long as --

CHAIR RICCARDELLA: Thank you.

MR. HOELLMAN: -- everyone is ready. You guys can all hear me okay, right?

CHAIR RICCARDELLA: Sounds good.

MR. HOELLMAN: All right. Awesome. So good morning. My name is Jordan Hoellman. I am the project manager for the endorsement effort of ASME Section III, Division 5. I work in the Advanced Reactor Policy Branch in NRR, and I'm excited to be here to present the staff's endorsement efforts and review philosophy related to the potential endorsement of Division 5.

So, as you know, the NRC staff is taking steps to develop its regulatory infrastructure for advanced non-lightwater reactors to ensure we are prepared to support the review of future design certifications and other licensing applications.

I want to take just a brief minute to provide some historical context for this effort. In 2016, we issued the NRC Vision and Strategy for ensuring or achieving non-lightwater reactor mission readiness in response to the increasing interest in advanced reactor designs.

To achieve the goals and objectives in the Vision and Strategy document, the NRC staff developed near-term and long-term implementation action plans or IAPs. Under IAP 4, the staff intends to enhance the NRC's technical readiness for potential advanced non-lightwater reactor designs by applying its established process for adapting its regulatory framework to ensure that it facilitates the use of codes and standards.

In 2018, ASME requested that the NRC review and endorse the 2017 edition of ASME Section

III, Division 5, and the staff responded in August of 2018 that we were initiating efforts to endorse with any limitations and exceptions, if necessary, the 2017 edition of the code and a new regulatory guide as one way of meeting the NRC's regulatory requirements.

So we can move on to slide 33.

So the existence of robust and comprehensive rules for design of high-temperature reactor systems and components in the ASME code endorsed by the NRC for use by prospective non-lightwater reactor vendors would improve the efficiency and effectiveness of the NRC's review process.

An integral part of the framework will be the endorsement of codes and standards that are applicable to the construction, inspection, and operation of these designs.

In this portion of today's briefing, we will provide an overview of the review process the NRC initiated for the potential endorsement of the 2017 edition of Division 5 and discuss some examples of likely exceptions and limitations to the NRC's endorsement.

So let's move to slide 34, please.

So the results -- the results of the NRC staff's review will be compiled into two documents that we are currently working to finalize and realize for public comment. NUREG-2245 will document and provide the technical basis for the endorsement of the 2017 edition of the code, as well as code cases N-861 and N862, which Jeff described earlier.

NUREG-2245 provides the technical basis for the staff positions in Draft Guide 1380, which is a proposed revision to Reg Guide 1.87, which is titled Guidance for Construction of Class I Components in Elevated Temperature Reactors.

The staff is currently not planning to incorporate this by reference into 10 CFR 50.55(a), as Section III, Division 1, is. One reason we decided to do this is that the staff expects that there will be continued significant revisions to Division 5 between editions. And in NRC future reviews of those editions, we may take a different approach to endorsement.

By endorsing via a reg guide, our endorsement, with any limitations and exceptions as discussed in the reg guide, would serve as guidance for a method acceptable to the staff for the use of Division 5. Because we are not doing this via rulemaking, an applicant can propose to use Division

5 with different limitations or exceptions, and those reviews will occur in an application-specific basis.

The Draft Guide 1380 does include an appendix, which establishes acceptable quality group assignments of mechanical systems and components for non-lightwater reactors acceptable to the staff for the safety classification methods, including the traditional means outlined in 10 CFR.

Using the definition of "safety-related structures, systems, and components" in -- defined in 10 CFR 50.2, it addresses the risk-informed approach outlined in 10 CFR 50.69, and it addresses the method in the Nuclear Energy Institute Document 1804, which is the licensing modernization project methodology, which the NRC endorsed last year in Reg Guide 1.233.

The guidance in Appendix A is intended to provide guidance on selecting an appropriate design standard once the classification methods are used to determine the classification of each system and component. And I believe there is an ACRS briefing tomorrow that will provide greater detail on the licensing modernization project methodology.

So let's move on to slide 35.

So this slide just communicates the scope of the staff's review of Division 5. As I previously mentioned, Division -- well, yeah. Division 5 and code cases and 861 and 862 were included in the staff's review. The staff did not review non-Mandatory Appendix HBB-Y titled Guidelines for Design Data Needs for New Materials. And there were few portions of the 2017 edition that were in preparation at the time the staff initiated our endorsement effort, and we're not endorsing those portions of the code at this time.

The staff initiated a separate effort, as Jeff was describing, to endorse the Alloy 617 code cases that were incorporated -- or that were approved by ASME last year in 2020. The issuance of those code cases represents a significant amount of work over several years by the Section III subgroup on high-temperature reactors.

The staff is reviewing these code cases separately from the Division 5 endorsement effort included in today's briefing, and we are considering approaches to fold Alloy 617 code cases before we issue the final reg guide endorsing this.

So slide 36.

As Louise was mentioning in her opening remarks, the staff recognized that there was limited expertise outside the ASME code developers on Division

5. To ensure an independent review, we contracted with national laboratories and commercial contractors for peer review on the technical adequacy of Division 5.

We held periodic teleconferences and shared a collaborative SharePoint site to ensure adequate resolution of technical issues raised by the contractors during their independent review.

In addition, we contracted with Argonne National Lab and Idaho National Lab because we recognized that they had the foremost expertise on this -- on the metallic and graphite portions of the standard. And those contracts are set up to provide on-call technical expertise to facilitate the staff's review in drafting the NUREG and reg guide.

They were also used to answer staff questions regarding the adequacy and use of Division 5, and they were used to provide the staff with the technical basis and historical perspectives related to Division 5.

So slide 37.

So this slide sort of provides an overview of the philosophy we use for endorsement. As Jeff was sort of alluding to, the rules in Division 5 have been developed over the years. The NRC endorses ASME

Section III, Division 1, by incorporating it by reference into 10 CFR 50.55(a).

Those rules apply to components that operate at temperatures that are typically 700 degrees Fahrenheit or less for carbon or carbon steels and 800 degrees Fahrenheit for -- or less for austenitic or high-nickel alloys where creep effects are insignificant.

In the 1970s, to facilitate the construction of high-temperature reactors, ASME developed five code cases that were intended to replace or supplement in some cases Section III, Division 1, and those are Code Cases 1592 through 1596.

And it was intended that these code cases could be used as a guide with justification provided by an applicant to supplement other Section III subsections and appendices used to design components operating at high temperatures. They were approved by ASME in the '70s and endorsed by the staff in Reg Guide 1.87 Revision 1.

ASME subsequently incorporated those five code cases into Division 1 with the creation of ASME Section III, Division 1, NH, and the NUREG uses these code cases as a basis for the review of the 2017 edition of Division 5.

MEMBER HALNON: Hey, Jordan. This is Greg Halnon. Just a quick question.

MR. HOELLMAN: Sure.

MEMBER HALNON: Since those code cases and the review was done 45 years ago, did you do any cursory look at it or a deeper look to make sure that in today's standards and with the OE that we've received over the last many reactor years that everything is still good and able to stay with it in this new review?

MR. HOELLMAN: Yeah. So we did do a detailed historical review of the code cases, a comparison between the code cases and what's in Division 5 now, as well as a look at preliminary safety evaluation reports that the staff developed.

We have also been -- the staff has been involved in all of the working groups and subgroups on the ASME code, and so we've been involved and aware of, you know, the changes that have occurred. And so we've looked at any differences and the improvements that have been made over the years to the code. So it was a detailed review of what was in the previous code cases as well as the additional information.

I think we -- I'd say that we definitely looked in more detail at what was added or changed versus, you know, what remained the same.

MEMBER HALNON: And so you have high confidence in the review back 45 years ago, is the same that you would expect today moving forward on materials and stuff?

MR. HOELLMAN: Right. Yeah.

MEMBER HALNON: Okay.

MR. HOELLMAN: And the code, you know, has -- as it has been developed over the years, you know, and incorporated into Division 1 in NH, the rules of the code have, you know, incorporated the Division 1 standards that we have been endorsing via 10 CFR 50.55(a) over the years.

MR. HOELLMAN: Jeff, do you want to add anything there?

MR. POEHLER: I just wanted to add that it was within the scope of the contractor reviews to look at whether the code case provisions were still technically adequate.

MEMBER HALNON: That's what I was looking for, to make sure that there is some -- that it just wasn't --

MR. POEHLER: If that was their basis for recommending something.

MEMBER HALNON: Yeah.

MEMBER BALLINGER: This is Ron Ballinger. I'm encouraged to see that 617 is going to be incorporated into 1380. Was that originally the case?

MR. HOELLMAN: No. That -- well, we had locations that weren't approved by ASME prior to the initiation of our endorsement effort, and since they've been incorporated and due to interest from, you know, potential applicants, we have decided to take on a separate activity to review those code cases.

And because it sort of occurred, you know, as we were getting to the end of our endorsement review of Division 5, we have kind of decided that let's continue with our current effort and take that on in parallel.

And then I'll get to it later in the -- in our next steps slide, but the plan currently is to, you know, do the public comment period on our current effort and incorporate it later and do another public comment period, but limit it to the Alloy 617 code cases.

MEMBER BALLINGER: So that will delay 1380 a little bit, though, right?

MR. HOELLMAN: It will delay the final

issuance of it maybe, but we're hoping that we can sort of tackle that in parallel with the public comment period and the final issuance of the reg guide. But it will overlap a little bit, and that's -- some schedule challenges will have to --

MEMBER BALLINGER: That's a very good thing. I think -- we had a previous presentation where we made a comment of why is 617 not included, and the feedback that we got was that it was too early because it had just been approved. But now it has changed, and that's a very good thing, in my opinion.

MR. IYENGAR: This is Raj. May I interrupt here, Jordan? Raj Iyangar. I just want to tell you, Ron, we had talked about, discussed this topic.

The code case was the -- 617 was passed, approved late last year. So by then our Division 5 endorsement, the staff endorsement effort, had, you know, been going on for a year and a half.

However, I think based on our discussion we had, and based on the feedback we got from industry, we had actually had a conflict with this in a very agile way. I think Jeff and Jordan will talk about it later. So that we don't delay the final relief of the current -- the draft guide we are proposing, but still incorporate the 617, and you know the importance of that because it allows for such high temperatures.

MEMBER BALLINGER: No, no, that's very good. Thank you.

MR. HOELLMAN: Okay. So I'll continue a little bit in describing how we approached the view. So we compared the articles of ASME, Section III, Division 5, HBB, which is the Class A metallic pressure boundary components operating at elevated temperature service. So we compared HBB to the related areas of code cases 1592 through 1596 as an approach to validate that the information present in HBB is for high-temperature Class A components, which is analogous to high-temperature Section III, Division 1, components addressed by the code cases.

The HBB provisions were reviewed with the assumption that the components have safety-significant functions similar to Division 1, Class 1, components.

In sort of the same manner, we compared the HCB rules, which is the Class B metallic components at elevated temperature service, to ASME code NC and HBB since HCB, which is Class B again, is for high-temperature Class B components, analogous to Class 2 components, and NC, but operate at high temperatures like the components addressed by HBB.

So this is where it gets a little complicated, and Jeff's little magic decoder table comes in handy.

So HCB provisions were reviewed with the assumption that the components have similar functions to Division 1, Class 2, components. When we get to HGB, which is the core support structures, we compared or the code sort of compares them to HBB, because core support structures operate at the same high-temperature range as that established for the Class A components under HBB.

When evaluating the provisions of HAA and HAB, which is the general requirements, HAA is for metallic materials and HAB is for graphite materials. We compared these to the 2017 edition of Section III NCA, which the staff endorsed in 50.55(a).

When using -- so one of the limitations or exceptions we're proposing is consistent with Section III, Division 1. Where Division 5 references Division 1, applicants or licensees should follow any of the applicable conditions for Division 1 that are identified in 50.55(a).

I hope I didn't confuse that too much. So we can move on to the next slide, if that's okay.

So this slide just details the contractor assignments and provides links to the specific contractor reports that were used in combination with the NRC staff's independent technical expertise to develop the technical basis for the findings in NUREG-2245.

As I mentioned before, the way we assign the -- well, the way that contractor assignments are set up does have some overlap, so we did ensure that we were scheduling coordination meetings between the different contractors and setting up that SharePoint site where we could all collaborate, because some of the rules, for example, in the 3000 reference, the rules in the 2000s portions of the code.

And so some of the recommendations provided by the contractors in 3000 relied on some of the findings in -- or the recommendations in 2000 that -- you know, for example, PNNL was not reviewing the 2000 portions of the code, and so we needed to make sure that we were all coordinated and could resolve issues between the different contractors.

So we can move on to slide 39, and I'm going to turn it back over to Jeff to walk through some of the expected limitations and exceptions we are proposing throughout our review.

MR. POEHLER: Thanks. Thanks, Jordan. So I'm going to talk a little bit more about the review process for general requirements. Jordan touched on that already.

But the process -- basically, the staff compared the 2017 edition of Division 5 HAA and HAB to the 2017 edition of the ASME code, Section III, NCA, to ensure consistency with what the NRC has endorsed in 10 CFR 50.55(a), or I guess I should say incorporated by reference.

Similarly, the staff compared the 2017 edition of Division 5, HAA and HAB, to the 2019 edition of the ASME code, Division 5, HAA and HAB, to ensure consistency with those items that were corrected in the 2019 edition.

Just a little more background on that, the NRC does participate in the relevant code committees related to general requirements, and the staff recognized that some changes in the 2019 edition of Section III NCA were needed and were not captured in the 2017 edition of HAA and HAB.

The staff, therefore, also identified exceptions and limitations when there were differences between the 2017 and 2019 editions of Division 5, HAA and HAB. Even though the rulemaking to IBR are incorporated by reference, the 2019 edition of HCA into 10 CFR 50.55(a) is not quite final.

So now I'm going to give a couple of examples of exceptions and limitations related to general requirements. The first one is related to a change in ASME Section III NCA to allow certifying engineers who are not registered professional engineers.

The staff conditioned this in its rulemaking to incorporate by reference the 2017 edition of Section III NCA to require the certifying engineers also to be a registered professional engineer. Therefore, the limitation in the draft guide is for consistency with the condition in 10 CFR 50.55(a).

The second limitation is related to standards used for accreditation of providers of calibration and testing services. The ILAC accreditation process relies on the ISO/IEC 17025 standard, and use of the 2005 edition of ISO/IEC 17025 was endorsed by the NRC through an SER with several conditions.

In 2017, ISO issued the 2017 edition of ISO/IEC 17025, which the NRC endorsed again through another SER with some additional conditions.

Therefore, the NRC is proposing a limitation to Division 5 to make it consistent with the NRC's latest SER.

Next slide, please.

Now I am going to talk about some of the exceptions and limitations that the staff is proposing in the area of mechanical design, and these were identified for several reasons. One of those is consistency with Section III, Division 1, conditions in 10 CFR 50.55(a).

An example of that is the condition on socket weld design, and that condition requires a larger leg length on socket welds than Section III, Division 1, allows.

And a second reason would be consistency with Reg Guide 1.87 conditions on Code Case 1592. One example of that is the use of strain-controlled buckling factors, and this limitation is based on a limitation in Reg Guide 1.87 on Code Case 1592 related to the situation where you could have elastic follow up occurring.

And another reason that we identified condition -- or limitations and exceptions is a lack of guidance in Section III, Division 5. And some examples of that are for inelastic analysis for meeting the HBB-T deformation limits.

And as I discussed earlier, there are no material models for inelastic analysis currently in the code. So the staff would want to review any such models that were proposed for use by applicants.

Another example is related to stress relaxation cracking, and I am going to talk about that on the next slide.

So let's go to the next slide, please.

So the limitation here is when using HBB-T-1710, applicants and licensees should develop their own plans to address the potential for stress relaxation cracking in their designs. The basis for this is that stress relaxation cracking is a mechanism causing enhanced creep crack growth in certain materials caused by relaxation of weld residual stresses in components in high-temperature service.

Section III, Division 5, does not contain any provisions addressing stress relaxation cracking. And also, there is a lot of literature on stress relaxation cracking, and there are approaches that can be used to address it that could be used by applicants but they are not in the code. So that's why we included a limitation for applicants to, you know, explain how they are addressing this phenomenon.

Next slide?

So this slide discusses the review process for metallic and graphitic materials. So unlike in the area of general requirements and mechanical design. In these areas, the staff did not primarily rely on previous reviews of the code cases.

For metallic materials, the contractor performed independent analysis of materials properties and allowable stresses. The staff also received additional input by subject matter experts familiar with the development of Section III, Division 5, in the area of materials properties. And we also considered that an input.

With respect to graphite provisions, they weren't in any previous code cases. They were new to Division 5. Therefore, the staff contracted for technical review of the graphite portions of Division 5 by subject matter experts.

I am going to discuss the review of both metallic and graphitic materials in more detail in subsequent slides.

So next slide, please.

So with respect to metallic materials properties, so -- is there a question? Sorry.

Okay. In some cases, contractor

independent analysis determined properties and allowable stresses with lower values than the code, suggesting that code values are non-conservative. And those were -- contractor reports were primarily by Oak Ridge National Laboratory, which covered allowable stresses in Mandatory Appendix HBB-I-14 and also some other material properties in that appendix.

Oak Ridge performed independent analysis of the metallic materials properties and allowable stresses, and that analysis was based on available data from a literature search, and it used the stated criteria for determining, you know, allowable stresses in Section III, Division 5.

Methodology used was ASME standard practice as far as that can be defined.

There is a report by Numark that found -- that looked at the isochronous stress strain curves and suggested some of those could be non-conservative.

We had Argonne National Laboratory assist with the review of weld strength reduction factors, which were found to not be non-conservative.

So lower values of allowable stresses were typically only at higher temperatures and longer times for the time-dependent properties. The NRC staff did consider these findings in a holistic manner, including how these properties are used, inherent conservatisms in the Division 5 design rules, and historical context. And input from ANL provided historical context and perspective on materials properties.

Next slide, please?

So for metallic materials, limitations are typically in the form of a maximum temperature limit that is more restrictive than allowed by Division 5. These limitations are typically on the time-dependent allowable stresses. The table here shows these limits for the materials where those apply, and you can see that the materials involved here, the properties were typically -- the SMT, which is -- can be controlled by the time-dependent allowable stress, the S sub T, which is the time-dependent allowable stress, and the S sub R, which is the stress to rupture.

For non-chrome 1 Moly-Vanadium, we took a different approach. The 2019 Section III, Division 5, properties were endorsed in lieu of the 2017 Section III, Division 5, properties. And that was done because ASME updated, in the 2019 edition, the values for non-chrome. And those compared well with the independent analysis thoughts, while the 2017 values in Division 5 appeared to be somewhat non-conservative compared to the independent analysis.

Next slide, please.

So I'm going to talk a little more about the basis about how the limitation of one type of allowable stress was determined. The example here is Type 304 stainless steel where the independent analysis suggested significant non-conservatism of the Section III, Division 5, S sub T values for most times and temperatures.

At 300,000 hours, non-conservatism was suggested at temperature -- any temperature greater than 850 degrees F or 450 degrees C, but depending on whether you are in the U.S. customary table or the SI table.

This is based on independent analysis values more than 10 percent lower than the Section III, Division 5, values. Most of the apparent non-conservatism here was driven by the tertiary creep criterion for S sub T.

And the use of the time to tertiary creep as one of the three criteria for time-independent allowable stresses is problematic. There is less data for tertiary creep than for creep rupture in general. It's a smaller database. It is often difficult to identify the onset of tertiary creep.

And in materials that demonstrate non-classical creep behavior the onset of tertiary creep can be relatively early, which results in lower times the tertiary creep and a slower -- lower allowable stresses.

So the ASME code has been deliberating modification or elimination of the tertiary creep criterion. I mean, they haven't done it yet.

There is a proposal to revise the allowable stress for Type 304 and Type 316 to be made in the ASME code committees, and it will use a linear multiplier on the rupture time to estimate the time of tertiary creep, which will increase the number of tertiary creep data points.

So this issue for Type 304 was mitigated by ANL performing an alternate analysis using a different approach for tertiary creep data. And this analysis showed significant non-conservatism only at temperatures greater than 1,300 -- or greater than or equal to 1,300 degrees Fahrenheit or 700 degrees C.

So next slide, please.

Okay. Now moving on to discussing the review of graphite materials and design, so Numark Associates provided a technical assessment of Subsection HH, Class A Non-Metallic Core Support

Structures, Subpart A, Graphite Materials.

The staff completed the review of the above report and all applicable sections of Section III, Division 5, and obtained clarifications and feedback from NRC contractors, including Numark and Idaho National Laboratory, in order to come up with the conclusions identified in the NUREG.

The staff's independent review of the code requirements considered the holistic design of graphite core support structures.

Next slide, please.

So I am going to talk a little more about some of the exceptions and limitations the staff is proposing for graphite. So for graphic materials and designs, several of the limitations can be characterized as situations where Division 5 has a numerical parameter limit, but the staff is not convinced the limit is generally applicable to all designs.

And so design-specific justification is requested for the parameter value in these cases as a limitation. And this table shows the provisions where the staff identified such limitations, including the parameter affected in the Division 5 limit, and those include weight loss limit, cohesive life limit, gas flow velocity, allowed repair depth. So that was a common theme for several of the limitations.

Next slide?

MEMBER KIRCHNER: Could you -- this is Walt Kirchner. Can you provide a little more detail on the first one, oxidation? That seems like a substantial amount of oxidation weight loss.

MR. POEHLER: It does. For that I would call on -- if we have either Matthew Gordon or Steve Downey on the line? Or, if not, I would -- I would ask Will Windes if he can chime in on that, if he is still on.

DR. WINDES: Will is here, but I -- if somebody else from the NRC wants to talk about it first, that would be perfect.

MR. POEHLER: Yeah. I mean, Will was not, you know, directly involved with the condition.

MEMBER KIRCHNER: Yeah. It just strikes me as -- boy, that strikes me as a large oxidation loss.

DR. WINDES: Yeah.

MEMBER KIRCHNER: So way beyond anything a designer would probably want to incorporate in an actual operating envelope.

DR. WINDES: Right. So here is the --

here is the issue. And you're absolutely correct. This oxidation -- the oxidation limits in the code are being changed rapidly and dramatically as we speak. We have a task group that is working on coming up with something that is much more -- makes much more sense and is much more usable.

There has been a number of papers written in the last year, so that kind of talks about not so much what is the weight loss, but what is the effect of weight loss.

So 30 percent -- and then, of course, the real issue -- and I think this is -- and I'm speculating now. I think that one of the main issues that the NRC had was, where is the weight loss occurring?

So if it's occurring in the material -- excuse me, the structural graphite that is directly surrounding the fuel, this could be extraordinarily significant. If this is something that's occurring -- these limits are occurring in something in the core support structures, again, very significant.

If it's occurring in the outer reflector blocks, which are just basically outside of the core area, then it may not be as catastrophic. It's obviously going to be beyond what any kind of designer wants. And so I think you're absolutely correct. This number is there.

The other number -- I want to call your attention also to number 2, which is something that is in hot debate. This is what Dave Petti alluded to earlier this morning where this is plus 10 percent over the crossover line for the dimensional change.

And this is something that no -- this is an area that nobody has ever operated their reactors in. And I think that the NRC is quite correct in identifying this one as a problem as well.

So these are very hot topics that we are changing right now.

MEMBER KIRCHNER: Yeah. I just can't imagine, with numbers 1 and 2 there, going anywhere near that in an actual design. Wow.

CHAIR RICCARDELLA: No. That's why this table is requesting design-specific justification for these limits, if they use them.

MEMBER KIRCHNER: Yeah. It could be a lot less for certain locations that could be tolerable, and then it --

DR. WINDES: It could be more for certain locations, because I believe at 30 percent the code says above that you take out -- you just consider the component has no strength basically. None.

MEMBER KIRCHNER: Yeah. That's what you're -- with that amount of oxidation, you probably have no structural rigidity or strength left in the component. Going through that bend in the curve, and then going plus 10 percent on the life limit, my goodness, like I alluded to earlier, in the N reactor, they had issues like that. And it's just -- it's not practicable for an actual reactor design for a number of reasons, not to get into here.

DR. WINDES: Right. And I can sum it up. It's too much risk. You can operate a reactor -- obviously, they have -- and reactors are a great example of it. But, quite frankly, for a civilian reactor, it's just too much risk. We don't know what's going to happen above crossover.

And there is just so little data, and you just cannot go in and really predict what is going to happen. So, again, these are -- these are things that even before the NRC tagged these as hot button topics we were already working on them, because we ourselves have identified these as real gaps in the code, and significant ones that need to be addressed sooner rather than later for the licensee applicants if they are going to use the code.

MEMBER REMPE: So what's motivating folks to want to even go to 30 percent? Because actually weren't the AGRs -- their limits are actually higher for oxidation. But in the U.S., has that been allowed for things like Fort Saint Vrain?

DR. WINDES: Well, yeah. See, and this is where -- Joy, boy, you always put your finger right on the issues. Yeah. The real problem is is that the AGRs in the U.K. have technically suffered much greater weight losses, and they are perfectly safe in operations.

So the -- and then, in the United States, it has been much, much more extremely conservative. You know, nothing more than, say, 10 percent weight loss. But, of course, they don't tell you where that 10 percent weight loss occurs in the code as it exists now, which is, again, an issue we're talking about -- or fixing.

So what we tried to do was come up with a happy medium where we said if you go in -- and anything up to 30 percent, you need to justify with your design that this is okay. But we're just not even going to consider anything over 30 percent. We just can't.

Even though there is examples of other

designs -- namely, the AGRs -- suffering oxidation beyond 30 percent, without any safety consequences, we just don't want to take that risk on. We're going to limit it at 30 percent, and you -- if you get close to 30 percent, boy, you'd better have a really good justification for using it.

Anything -- and, of course, less and less, you don't have to have as much effort to go in and show that everything is going to be safe. So if you're like one or two percent oxidation, then that's not nearly as onerous as, say, 29 or 30 percent. Do you understand what I'm saying?

MEMBER REMPE: Yeah. But I don't think you're understanding my question.

DR. WINDES: Ah. Sorry.

MEMBER REMPE: Why is it proposed to go from 10 percent to 30 percent? Are there some design developers out there that are saying we think we need to go much higher because our design is going to be approaching 30 percent?

DR. WINDES: No. What we were trying to do -- and, again, please forgive us because we were basically designing in a vacuum. There has been no previous designs. What we were trying to do is make it as universally applicable to as many and all designs as we could.

Just like we don't limit it to one grade of graphite. If you want to use a different grade than somebody else, you are allowed to do that. But you have to do certain things to justify the use of using a graphite or going to those kinds of high oxidation.

So it was -- it was basically an attempt to go in and have -- accommodate as many designs as possible.

MEMBER REMPE: Okay. Thank you.

DR. WINDES: Sure.

MEMBER KIRCHNER: I think, too, the distinction with regard to the AGR is that, if I remember right, these are pressure tube reactors. The graphite is not serving a structural function. It is there to be a moderator.

So what happens to the graphite in an AGR is not a good example for, say, a pebble bed or a modular HGGR design. Completely different design construct.

MEMBER REMPE: That's exactly why I was asking is why go so much higher, because I'm not aware, but I don't know of all the designs that are being proposed and what they are thinking of. But I wasn't aware that they would need to go so much higher.

DR. WINDES: Right. And, Joy, I haven't -- I mean, I can only think of one design, and it's way out there. I'm not even sure it is being fully funded at this point. It's just an idea. But nobody -- nobody designs I think their reactors for 30 percent or more oxidation. That would be sort of effectively operating in air with graphite at higher temperatures. So that's kind of crazy.

And so at that point you're right. I just don't -- I'm not aware of any, but we didn't want to limit. The code is there to try to be as universally applicable as possible. We didn't want to limit anybody. And because there is -- there are designs out there that can operate at the higher oxidation, we wanted to make sure that they -- we had a higher than, say, just a very conservative five to 10 percent mass loss. Okay?

CHAIR RICCARDELLA: Okay. So we're reached the published time at -- for the meeting to end. We've got about four or five more slides. I'm going to propose that we continue on and finish. Hopefully we finish in 15 minutes or so.

MR. POEHLER: Yeah. These should go

pretty quick, I think, probably famous last words, but -- anyway, so, yeah, this -- so this slide discusses an exception or limitation that doesn't fit the mold of the ones I discussed from the previous slide.

This has to do with a provision in HHA-3330 that says you have to design to allow for in-service inspection. But, if necessary, you can replace in-service inspection by operational monitoring. And we are not endorsing -- the staff is not proposing to endorse this provision because requirements for in-service inspection are outside of the scope of Section III, Division 5, HHA.

And the provision related to operational monitoring is the one that the staff finds to be out of scope. So that's why we proposed the limitation to not endorse HHA-3330(g).

Let's go to the next slide.

Okay. Shifting gears a little here, so this slide just talks about quality group classifications. Those are covered in Appendix A of DG-1380, and that provides the staff's guidance on quality group classifications. And the approach is very similar to that in NEI-1804.

Quality Group A is safety-related systems, structures, and components. For that, you can use --

use that for components that have safety-related -- or safety-related systems, structures, and components that have safety significance.

Quality Group B is for safety-related systems, structures, and components, but Class B components in Division 5 that have low safety significance.

Quality Group C is for non-safety-related systems, structures, and components, with no special treatment, or, I'm sorry, non-safety-related systems, structures, and components with safety significance. And for that you would use ASME Section VIII, Division 1 or 2 rules.

And then Quality Group D is for non-safety-related systems, structures, and components with no special treatment, and the owner would establish standards for use for those. And Quality Group D can also be described as systems, structures, and components having low safety significance or no safety significance. I think it's no safety significance.

CHAIR RICCARDELLA: So, Jeff, does Section VIII, Div 1 or 2 have high-temperature considerations in them?

MR. POEHLER: Section VIII does, yeah.

CHAIR RICCARDELLA: All right.

MR. POEHLER: Or pressure vessel. So --

CHAIR RICCARDELLA: Just another question for -- I'm just curious as to -- for Division 5, why they got away from Class 1 and Class 2 and then call them Class A and Class B? That's kind of curious to me. You know, everyone has gotten familiar with the concept of a Class 1 component.

MR. POEHLER: Yeah. That sounds like -- I would probably call on Sam Sham to chime in on that because I really don't know. Are you there, Sam?

DR. SHAM: Yes. It was just a distinction that -- when the group puts together Division 5, to distinguish between the rules for the high temperature and the ones in Division 1.

CHAIR RICCARDELLA: Okay.

MR. POEHLER: Thanks, Sam.

CHAIR RICCARDELLA: Thank you.

MR. POEHLER: Okay. Next slide, please.

MR. HOELLMAN: All right. Jeff, I think this is me again.

MR. POEHLER: All right. Thanks, Jordan.

MR. HOELLMAN: Yep. So this sort of just summarizes what I talked about earlier, and I'll try to move through it quickly, because I know we're running out of time.

So we completed our technical review of the 2017 edition, and we're in the process of finalizing the documents for public comment. NUREG-2245 provides the technical basis for the staff positions in DG-1380, which is a proposed revision to Reg Guide 1.87.

Jeff just discussed some examples of the exceptions and limitations we expect to include in the draft guide, so I won't spend much more time on that. So let's move to 52, and this just discusses our next steps. So we're going to finalize the documents for public comment.

We'll address public comments and make any changes necessary in parallel with our effort to review for endorsement the Alloy 617 code cases. We will plan to -- our current plan is to supplement the draft guide with the Alloy 617 code cases, and any limitations or exceptions we think are necessary there, issue that for a separate public comment period, limited to only the Alloy 617 code cases, and then issue the final reg guide, likely in the early 2022 timeframe.

CHAIR RICCARDELLA: So when do you anticipate that the draft -- the original draft guide will go out for public comment?

MR. HOELLMAN: Well, we're shooting for the end of this month.

CHAIR RICCARDELLA: Okay.

MR. HOELLMAN: It does take -- I'm realizing that it takes a little bit more time to issue a NUREG than some other documents. So there's a little bit of process period there, but we're close. And like I said, the technical review is done. It's just, you know, working through the internal reviews, and whatnot, to get the things out the door for public comment. And it will be a 60-day public comment period.

CHAIR RICCARDELLA: Okay. Okay. Well, I thank the staff for an excellent presentation. Very informative.

And I want -- at this point, I'll go around, see if any of the members have any additional comments or questions. I hear silence.

MEMBER REMPE: Pete, this is Joy.

CHAIR RICCARDELLA: Yeah.

MEMBER REMPE: Is NUREG-2245 available for public -- to the public, or what's the status of that document?

MR. HOELLMAN: This is Jordan. Both of

the documents are being finalized internally now. So nothing is publicly available yet. We are shooting for the end of this month to get things out the door and publicly available. We wanted to have everything publicly available before this briefing, but we just didn't quite make it. So apologize for that.

MEMBER REMPE: But when it is available, please provide a copy to Kent, so he can -- of each document for us, please.

MR. HOELLMAN: Definitely. Yep. Thanks, Joy.

CHAIR RICCARDELLA: Thank you. Any other member comments or questions? Okay.

So then, at this point, we'll turn to the public and see if there are any public comments. Can someone confirm the bridge line is open?

MR. DASHIELL: The public bridge line is open for comments.

CHAIR RICCARDELLA: Okay. So if there is anybody from the public out there that would like to make a comment, please state your name and make your comment. Hearing none -- I'm sorry. Go ahead.

MS. BOUDART: Could I ask a question? I'm a member of the public.

CHAIR RICCARDELLA: Yeah. You can make a

comment, yeah.

MS. BOUDART: I can make a comment. Okay. Well, I didn't want to make a comment. I wanted -- I was so fascinated by the discussion of graphite, and of course everybody was. We really -- the discussion really got kind of stuck there.

I am very interested in the explosion at Chernobyl and the fact that graphite was considered a moderator of the neutron flux there. And that when the negative coefficient was reached, I guess that the liquid moderator turned to bubbles, so that the neutron flux was full force on the graphite and it couldn't handle it.

I'm wondering if somebody could -- if there is any comment on the quality of the graphite, because we went -- you went into so much detail about the quality of the graphite and how important that is. Do you -- does anybody think that a different quality of graphite could have prevented that explosion?

MR. MOORE: This is Scott Moore for the ACRS. Could the member of the public please state your name for the record.

MS. BOUDART: Oh, I'm sorry. I'm Jan Boudart, and I'm a board member of the Nuclear Energy Information Service.

MR. MOORE: Thank you, Ms. Boudart.

CHAIR RICCARDELLA: Does anybody -- we normally don't answer questions, but does anybody wish to make a comment that knows more than I do about what happened at Chernobyl? I think -- I think --

MEMBER REMPE: Pete, this is Joy. There is a bit of confusion in the comment that was provided with respect to what this --

MS. BOUDART: Yeah. I do --

MEMBER REMPE: -- what is the moderator. And, again, we don't respond to public comments at this meeting, but I strongly suggest that the member of the public obtain a general overview article about the Chernobyl reactor design.

CHAIR RICCARDELLA: Yeah. Perhaps you could send that question to Kent Howard, the public official -- the government official for the meeting, and he could maybe coordinate a reply.

MS. BOUDART: Okay. I appreciate it. Thank you.

CHAIR RICCARDELLA: Any other members of the public?

MS. WALKER: Yeah. Can you hear me?

CHAIR RICCARDELLA: Yes.

MS. WALKER: Hi. Kayleen Walker, a member of the public. I was wondering if the ASME code cases can be made public. We're not able to access the code cases.

CHAIR RICCARDELLA: Well, they are available for purchase. The codes generally are available for purchase by ASME. It's an ASME product.

MS. WALKER: Right. But we thought, you know, it's a standard, so I was just wondering -- so you have to -- you have to pay to know the actual standard.

MR. HOELLMAN: This is Jordan.

MS. WALKER: That won't be made available.

MR. HOELLMAN: This is Jordan Hoellman. I think when we release the documents for public comment there are instructions on how you can obtain a copy of the code. I think the public document room does have a copy for public inspection during public comment periods, but that will all be included in the Federal Register Notice issuing the documents for public comment.

MS. WALKER: I have a -- I'm particularly interested in the code case regarding the inspection of the nuclear pressure vessels for storage. And there was a code case that was just published, right, as an approval of an inspection/maintenance program was approved for the canisters at San Onofre specifically.

But anyway, I wasn't able to get the current code case. And I did purchase one, but I don't think it listed the current one. So maybe I could email somebody there, just to verify whether what was published that I purchased is the most current. Would somebody be willing to do that?

CHAIR RICCARDELLA: Yeah. That --

MS. WALKER: It's a little bit -- it's a little bit challenging being a member of the public and these code cases being referenced, but we can't access them.

CHAIR RICCARDELLA: That code case is totally separate from this meeting, which is on high-temperature code cases.

MS. WALKER: I understand.

CHAIR RICCARDELLA: There's probably --

MS. WALKER: I understand, but it's about --

CHAIR RICCARDELLA: You know, it's probably more appropriate to contact someone from ASME about whether that's the most current code, not the NRC.

MS. WALKER: I'm having a hard time

getting through to them or getting the information, so -- anyway, thank you.

CHAIR RICCARDELLA: Okay. Any other members of the public that would like to make a comment?

Okay. With that, I will close the meeting, and I thank everybody for their participation and all. And for the members, we'll see you shortly for the meeting on probabilistic fracture mechanics this afternoon.

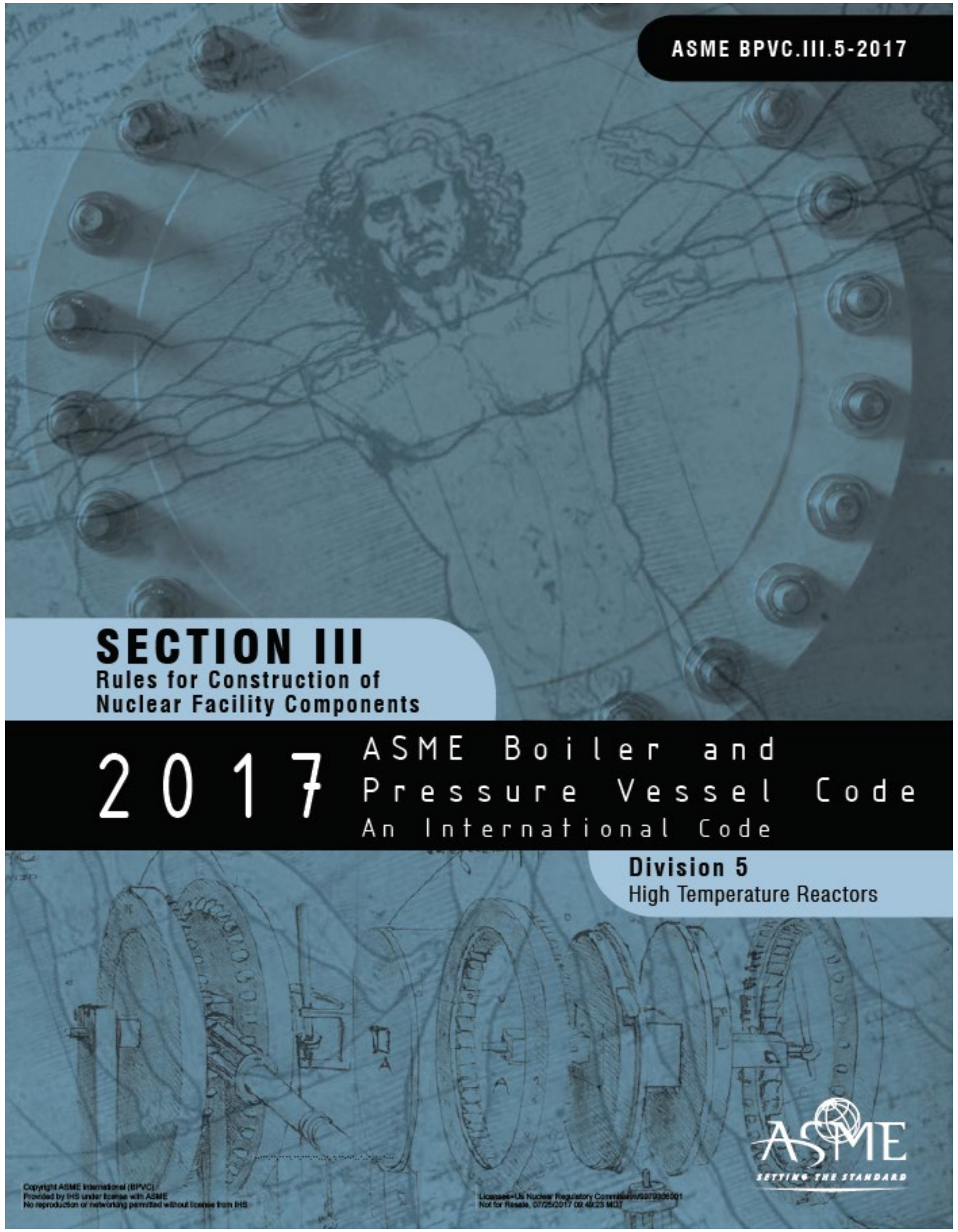
(Whereupon, the above-entitled matter went off the record at 12:15 p.m.)

Overview of Section III, Division 5

Advisory Committee for Reactor Safeguards

July 20, 2021

Jeff Poehler,
Sr. Materials Engineer
Reactor Engineering Branch
Office of Nuclear Regulatory Research



ASME Section III, Rules for Construction of Nuclear Facility Components - Division 5, High Temperature Reactors

- ASME Section III Division 5 Scope
  - Division 5 rules govern the construction of vessels, piping, pumps, valves, supports, core support structures and nonmetallic core components for use in high temperature reactor systems and their supporting systems
    - Construction, as used here, is an all-inclusive term that includes material, design, fabrication, installation, examination, testing, overpressure protection, inspection, stamping, and certification
  - High temperature reactors include
    - Gas-cooled reactors (HTGR, VHTR, GFR)
    - Liquid metal reactors (SFR, LFR)
    - Molten salt reactors, liquid fuel (MSR) or solid fuel (FHR)

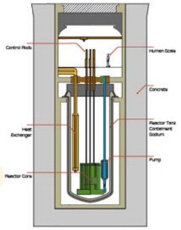
Examples of Different Advanced Reactor Designs Being Developed By Industry

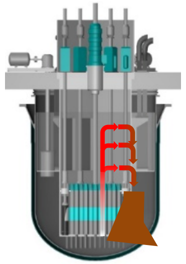
Fast Reactors

GE Hitachi PRISM

TerraPower, TWR

Advanced Reactor Concepts, ARC-



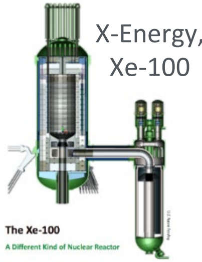


Westinghouse, LFR

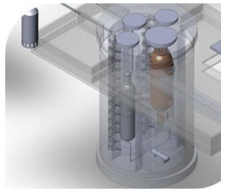
TerraPower & GEH Natrium

Oklo, Aurora

Gas Reactors

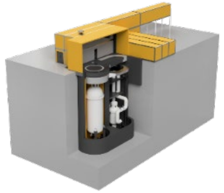


X-Energy, Xe-100



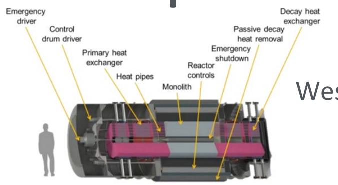
Framatome SC-HTGR

General Atomic EM2 (Gas-cooled Fast Reactor)



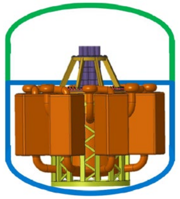
Ultra Safe Nuclear MMR

Heat Pipe Reactor

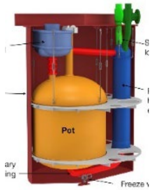


Westinghouse eVinci

Molten Salt Reactors

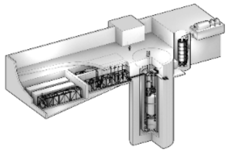


Elysium, MCSFR

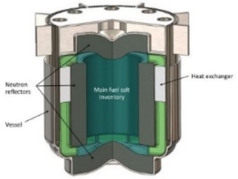


ThorCon

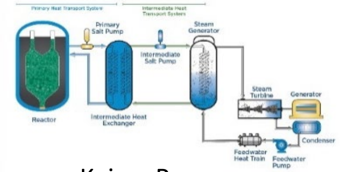
Terrestrial Energy IMSR



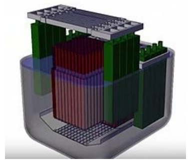
Flibe Energy LFTR (thorium)



TerraPower MCFR



Kairos Power KP-FHR



Moltex Energy, SSR

Division 5 - A Component Code

- Division 5 is organized by Code Classes:
  - Class A, Class B, Class SM for metallic components –
    - Class A is analogous to Class 1 in Section III, Division 1
    - Class B is analogous to Class 2 in Section III, Division 1
    - Class SM is for metallic core supports
  - Class SN for non-metallic components – e.g. graphite core supports
- Division 5 recognizes the different levels of importance associated with the function of each component as related to the safe operation of the advanced reactor plant
- The Code Classes allow a choice of rules that provide **a reasonable assurance of structural integrity and quality** commensurate with the relative importance **assigned** to the individual components of the advanced reactor plant

Section III, Division 5 Rules for Metallic Components do not address

- Deterioration in service due to
  - Corrosion
  - Mass transfer phenomena
  - Radiation effects
  - Other material instabilities
- Continued functional performance of deformation-sensitive structures such as valves and pumps

History of Construction Rules for High Temperature Reactor Components

- 159X Code Cases - complete construction rules for elevated temperature pressure boundary metallic components in early 1970s
- Regulatory Guide 1.87 (Rev 1, June 1975) endorsed 159X Code Cases with conditions
- Code Case series 1592-1596 converted to Code Case N-47, which later formed the basis for Section III, Division 1, Subsection NH
- Division 5 first published in 2011, combined NH, other high-temperature code cases, and rules for graphite core components (new).

Section III Division 5 Organization

Class	Subsection	Subpart	Subsection ID	Title	Scope
General Requirements					
Class A, B, & SM	HA	A	HAA	Metallic Materials	Metallic
Class SN		B	HAB	Graphite and Composite Materials	Nonmetallic
Class A Metallic Pressure Boundary Components					
Class A	HB	A	HBA	Low Temperature Service	Metallic
Class A		B	HBB	Elevated Temperature Service	Metallic
Class B Metallic Pressure Boundary Components					
Class B	HC	A	HCA	Low Temperature Service	Metallic
Class B		B	HCB	Elevated Temperature Service	Metallic
Class A and Class B Metallic Supports					
Class A & B	HF	A	HFA	Low Temperature Service	Metallic
Class SM Metallic Core Support Structures					
Class SM	HG	A	HGA	Low Temperature Service	Metallic
Class SM		B	HGB	Elevated Temperature Service	Metallic
Class SN Nonmetallic Core Components					
Class SN	HH	A	HHA	Graphite Materials	Graphite
Class SN		B	HHB	Composite Materials	Composite

Temperature Boundaries for Class A Components

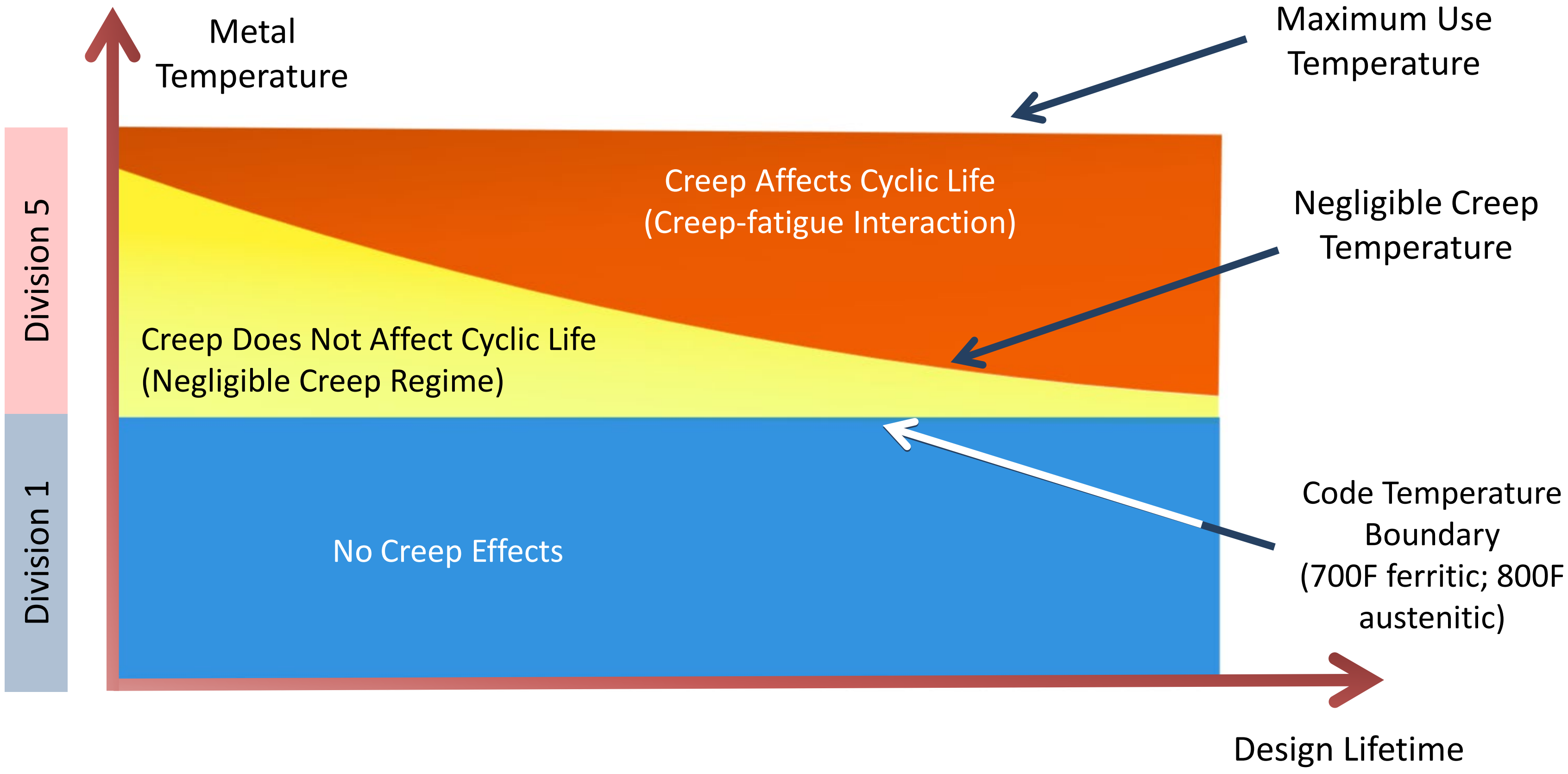


Table HAA-1130-1
Values of T_{max} for Various Classes of Permitted Materials

Materials	T_{max}, °F (°C)
Carbon steel	700 (370)
Low alloy steel	700 (370)
Martensitic stainless steel	700 (370)
Austenitic stainless steel	800 (425)
Nickel–chromium–iron	800 (425)
Nickel–copper	800 (425)

HBB Materials and Design Data

- **Limited set of materials:**
  - Type 304 Stainless Steel*
  - Type 316 Stainless Steel*
  - Alloy 800H
  - 2.25Cr-1Mo
  - 9Cr-1Mo-V (Grade 91)
  - Alloy 617 (Code Cases N-872 and N-898)

Minimum carbon content of 0.04 weight % required for better high temperature properties – "Type 304H" and "Type 316H" – this designation is not used in Section III-5.

- **Design parameters are mostly self contained in Division 5, except the following contained in Section II:**
  - Elastic constants
  - Thermal properties
  - Part of yield strength (S_y) table
  - Part of ultimate tensile strength (S_u) table

Failure Modes Addressed by Section III-5

Failure Mode	Type	Prevented By	Location	Analysis Method(s)
Plastic collapse	Load controlled	Primary load design	HBB-3000	Elastic
Creep-rupture	Load controlled	Primary load design	HBB-3000	Elastic
Creep-fatigue	Deformation controlled	Creep-fatigue rules	HBB-T	Elastic, Inelastic, EPP
Gross distortion due to incremental collapse and ratcheting	Deformation controlled	Strain limits	HBB-T	Elastic, Inelastic, EPP
Buckling due to short-term loadings	Load controlled or strain controlled, or both	Buckling limits (time-independent)	HBB-T	Elastic, Inelastic
Creep buckling due to long term loadings	Load controlled or strain controlled, or both	Buckling limits (time-dependent)	HBB-T	Elastic, Inelastic

HBB Primary Load Design

- Based on elastic analysis.
- “Load-controlled”
- Uses stress classification and linearization.
- Design and service level load checks.
- Accounts for thermal aging effects with factors on yield and ultimate strength
- Welds: Strength reduction factor applied

Design Load

Single temperature, pressure, and set of forces

Time-independent

Uses allowable stress S_o

Very similar to Section I and VIII

Service Load

Time-history of loading

Time-dependent

Uses the allowable stress S_{mt}

Unique to Division 5

HBB - Allowable Stresses

- Both time-dependent and time-independent allowable stresses included.
- S_0 – Allowable stress for design loadings
- Service Level Loading Allowable stresses
  - S_m - Time independent
  - S_t - Time dependent
  - S_{mt} – Allowable limit for general primary membrane stress for Service Level A and B
  - S_r – Expected minimum stress-to-rupture. Used for Level D limits and in deformation-controlled analyses (HBB-T)

HBB - Basis for Allowable Stresses

- S_0 – Equal to the higher of S values from Section II-D, Subpart 1, Table 1A, or 300,000 hour S_{mt}
- S_m - From Section II-D, Table 2A, S_m values at lower temperatures, extended to higher temperatures using same criteria
- S_{mt} is the lower of S_m (time-independent) and S_t (time-dependent)

HBB - Basis for S_t (HBB-3221)

- The lowest of:

  (a) 100% of the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1%;

  (b) 80% of the minimum stress to cause initiation of tertiary creep; and

  (c) 67% of the minimum stress to cause rupture (S_r).

- Determination of S_t is inherently conservative because of the 80% and 67% factors applied to tertiary creep initiation and stress-to-rupture.

Other Stresses/Material Properties

- S_y - yield stress as function of temperature
- S_u - ultimate strength
- R – Weld strength reduction factors
- Tensile and yield strength reduction factors for longtime services (Table HBB-3225-2)
- Isochronous stress-strain curves (ISSCs)

Deformation Controlled Quantities (HBB-T)

Characteristics

- **A subset of the design limits:**
  - Strain accumulation
    - 1% average strain
    - 2% linearized bending
    - 5% maximum strain
  - Creep-fatigue
  - Buckling
- Typically are driven by secondary (self limiting) stresses

Evaluation Methods

Elastic analysis

- All Class A materials
- Rules found in Nonmandatory Appendix HBB-T
- Bounding analysis

Inelastic analysis

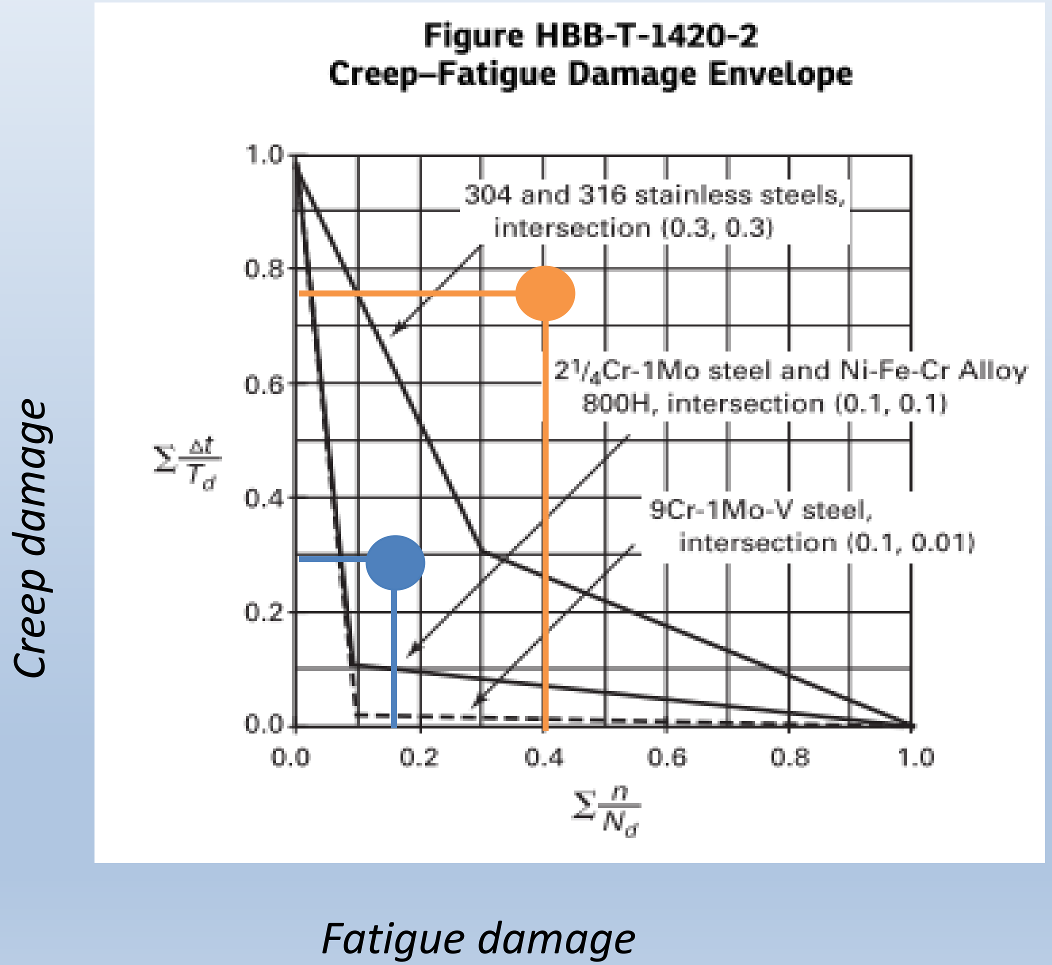
- All Class A materials
- Rules found in NMA HBB-T
- But no material models in Code (currently)
- "Exact" analysis

Elastic perfectly-plastic analysis (EPP)

- Subset of materials (304 and 316 SS, A617, soon to be Grade 91)
- Rules in N-861 and N-862
- Bounding analysis

Creep-fatigue (HBB-T-1411)

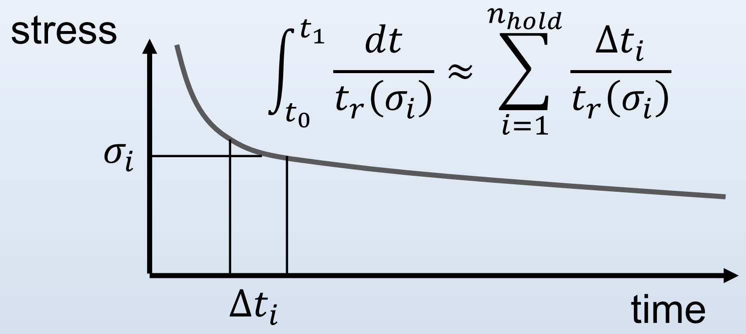
- **Basically:**
    1. Compute creep damage based on life fraction: D_c
    2. Compute fatigue damage based on a cyclic life fraction: D_f
    3. Consult interaction diagram for pass/fail
- **Welds:** same interaction diagram, factors on damage



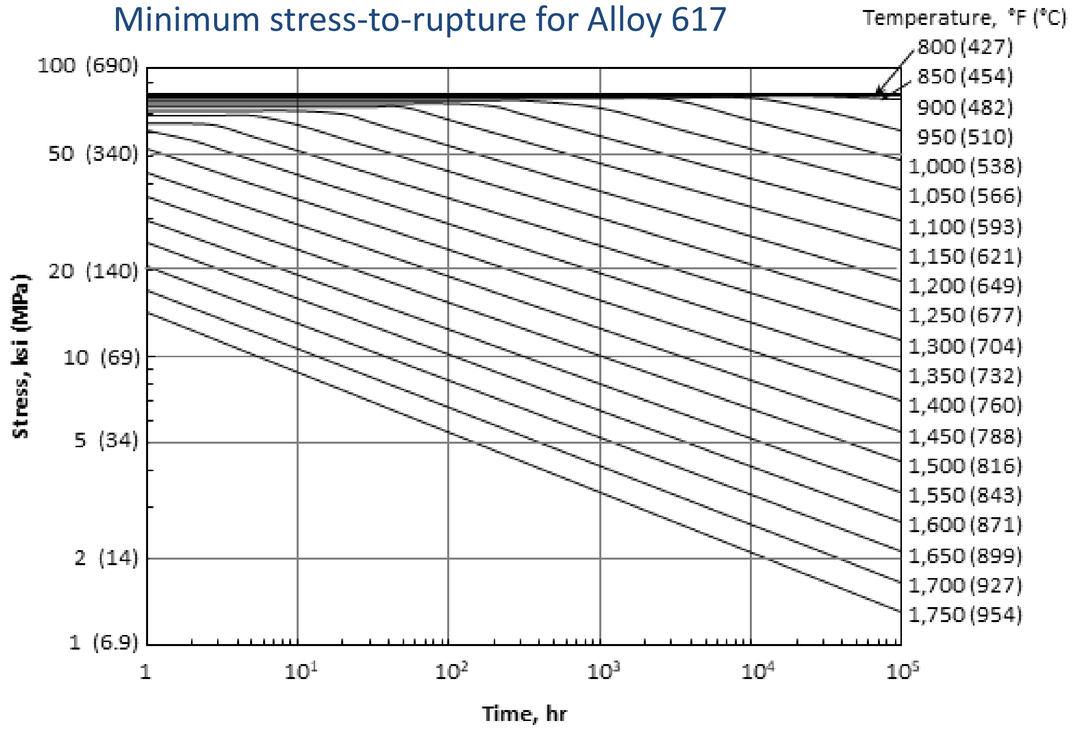
Creep Damage (HBB-T-1433)

- Construct a stress relaxation curve for each hold in each cycle type
- Determine creep damage with a time fraction rule for each time interval $\sum_{i=1}^{n_{hold}} \frac{\Delta t_i}{t_r(\sigma_i)}$
- Sum creep damage for all time intervals needed to represent the specified elevated temperature service life $D_c = \sum_{k=1}^{q}(\Delta t / T_d)_k$
- Database: creep rupture tests
- Welds: use stress rupture factor to reduce the creep rupture strength of the base metal

Stress relaxation profile



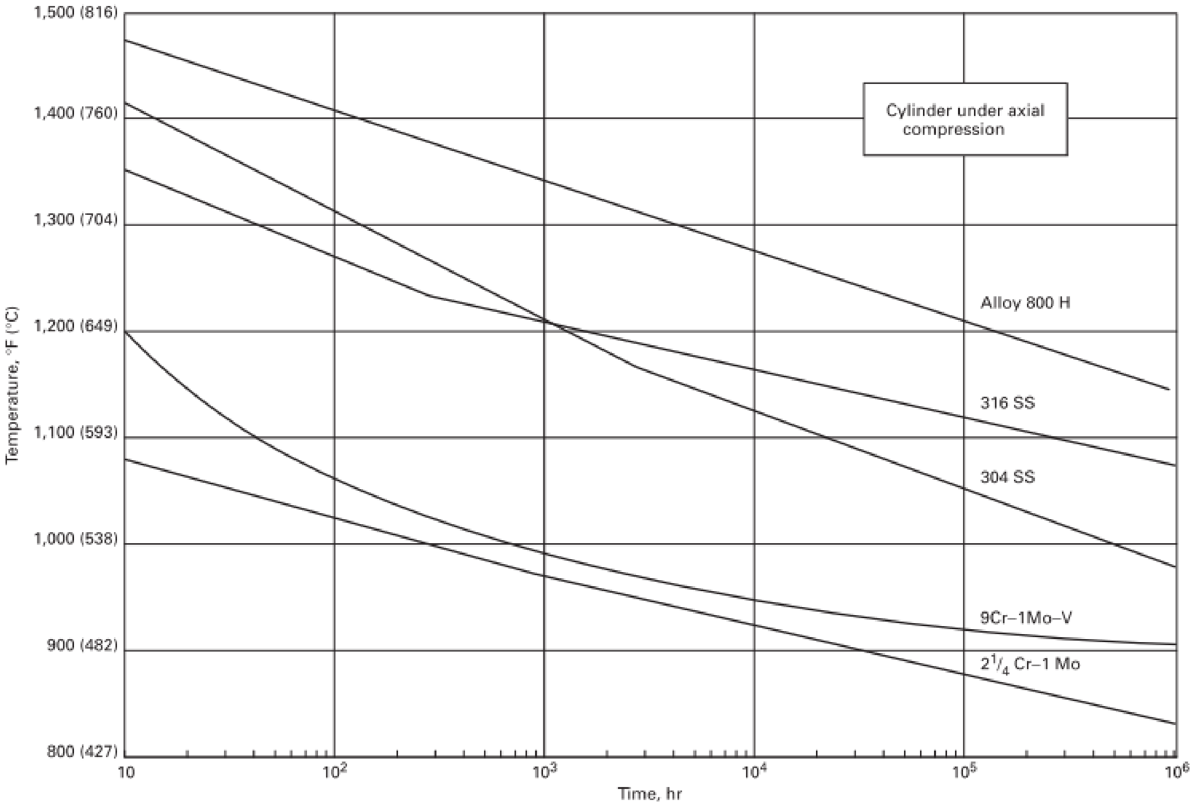
Minimum stress-to-rupture for Alloy 617



Buckling and Instability (HBB-T-1500)

- Limits for both time-independent (creep not significant) and time-dependent (creep-significant) buckling are provided.
- Load factors for both load-controlled and strain-controlled bucking provided.
- Figures provide temperature/time combinations below which the time-independent buckling limits may be used.
- For conditions where stain-controlled and load-controlled buckling may interact, or significant elastic follow-up may occur, the load factors for load-controlled buckling are also to be used for strain-controlled bucking.

Figure HBB-T-1522-1
Time–Temperature Limits for Application of Section II External Pressure Charts



Elastic, Perfectly Plastic (EPP) Analysis

- Use different allowable stresses as pseudo yield stress in EPP finite element analysis to determine different bounding characteristics for different failure modes
- Intended as simplified "screening" tools in place of elastic analysis methods
- No stress classification
- Any geometry or loading
- Accounts for redundant load paths
- Simpler to implement
  - Based on finite element results at integration points, no linearization
- Current status

Grade 91, Alloy 617 covered by revision of code cases. Not reviewed by NRC

EPP Design Check	EPP Code Case	Materials Currently Covered
Primary Load	Under development	All Class A materials
Strain Limits	N-861	304H, 316H, Grade 91, Alloy 617
Creep-fatigue	N-862	304H, 316H, Grade 91, Alloy 617

Inelastic Analysis Methods

Currently the Code does not provide reference inelastic models for any of the Class A materials

- Specification of the material model left to owner's Design Specification or designers
- Limits application of the inelastic rules

Historical experience on the Clinch River Breeder Reactor Project shows that inelastic analysis is:

- The least over-conservative of the Division 5 options
- Necessary in critical locations where design by elastic analysis is too conservative to produce a reasonable design

Current status

- Unified viscoplastic constitutive models for 316H stainless steel and Grade 91 steel have been developed
- Action to add Grade 91 model just balloted.

Class B Rules

HCA – Class B Low Temperature

- Essentially reference III-1, Class 2 rules

HCB – Class B High Temperature

- Allows more materials than HBB
- Mandatory Appendix HCB-II contains allowable stress values
- Different allowable stresses for:
  - Negligible creep
  - Non-negligible creep
  - Mandatory Appendix HCB-III defines times and temperatures where creep effects can be neglected.

Class B Rules

Extend rules of Division 1, Class 2 (Subsection NC) to elevated temperature service.

Based on a design-by-rule approach. "Design Lifetime" concept is not used.

Allowable stresses based on extrapolated 100,000 hour creep-rupture properties.

Fatigue damage from cyclic service is addressed only for piping with creep effects (HCB-3634).

Core Supports

HGA- Low Temperature

- mainly references Section III-1 rules.

HGB – Similar to HBB rules.

- Same materials and allowable stresses.

Construction Rules For Nonmetallic Components (Class SN)

- Section III Division 5 is the only design code that provides construction rules for graphite.
- Graphite materials are used in thermal spectrum advanced reactors because of their excellent neutron moderation properties

Graphite

- There is no single "nuclear" grade of graphite – therefore, can't design around a specific nuclear grade as metals can (i.e., 316H)
- Graphite is heterogeneous by nature, and contains significant pores and cracks.
- Graphite is **not** ductile - Brittle or quasi-brittle fracture behavior

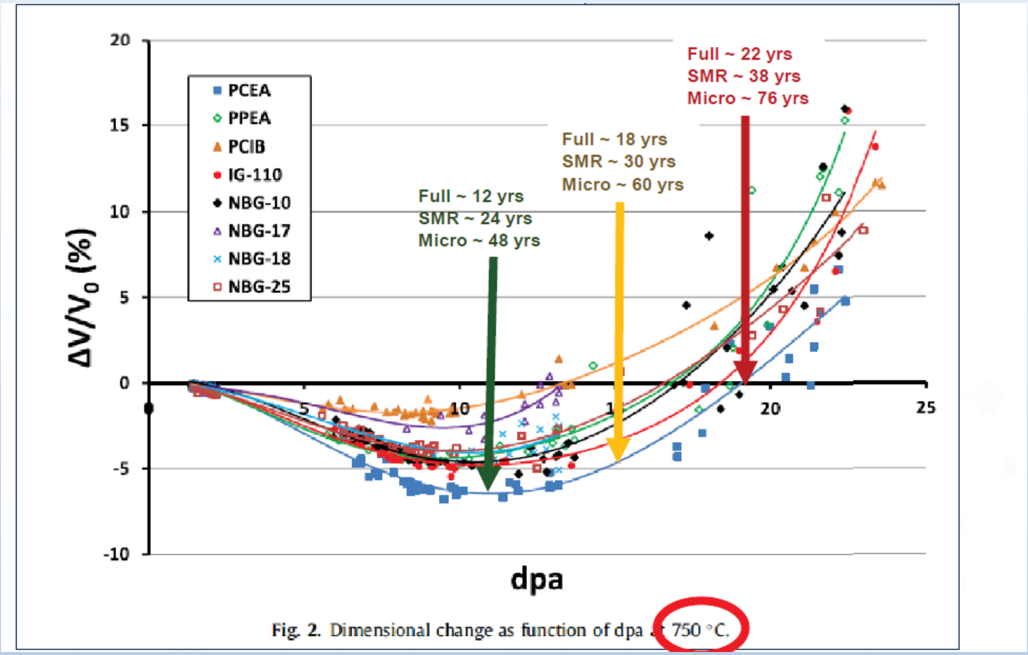
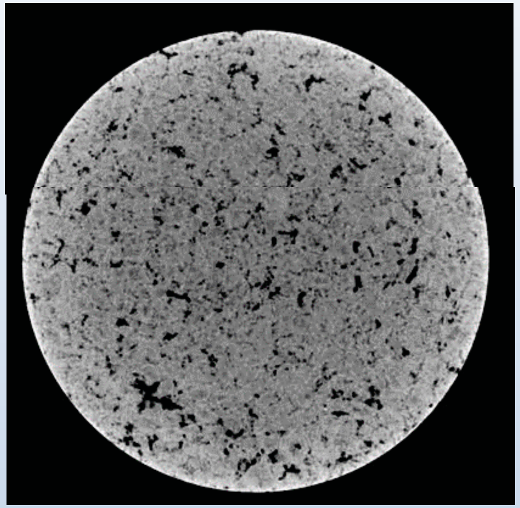


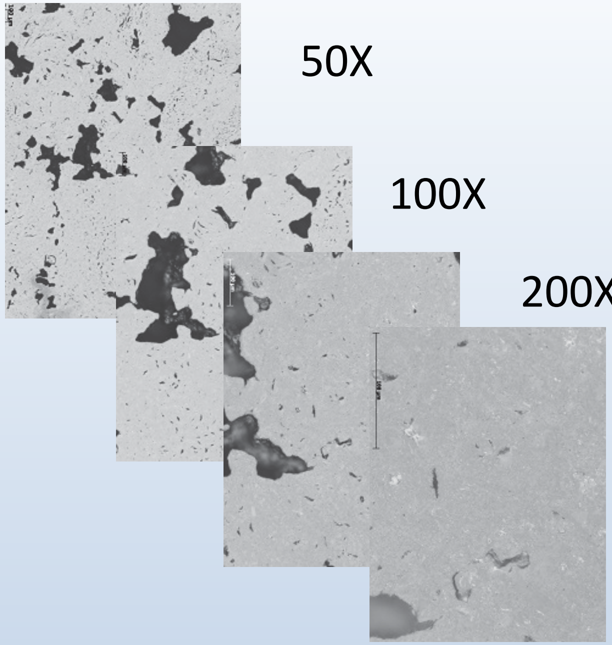
Fig. 2. Dimensional change as function of dpa at 750 °C.

Irradiation significantly alters the graphite behavior - Behavior is completely different before and after "turnaround" dose is achieved.

ASME Code Considerations

- Because all graphite is brittle and contains preexisting flaws,
- Core components need to be designed to accept some amount of cracking.





50X

100X

200X

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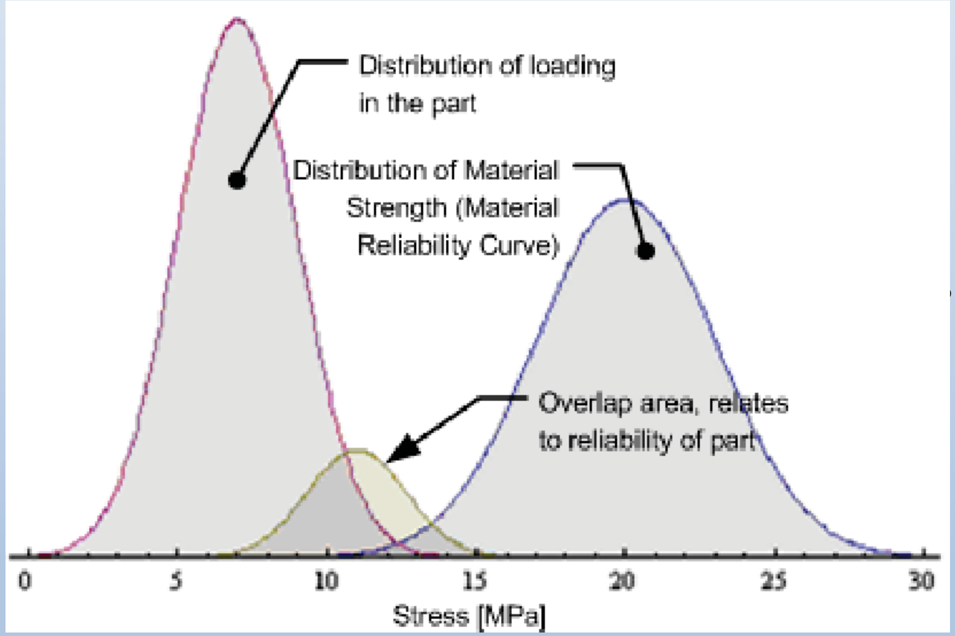


Probabilistic versus **deterministic** design approach

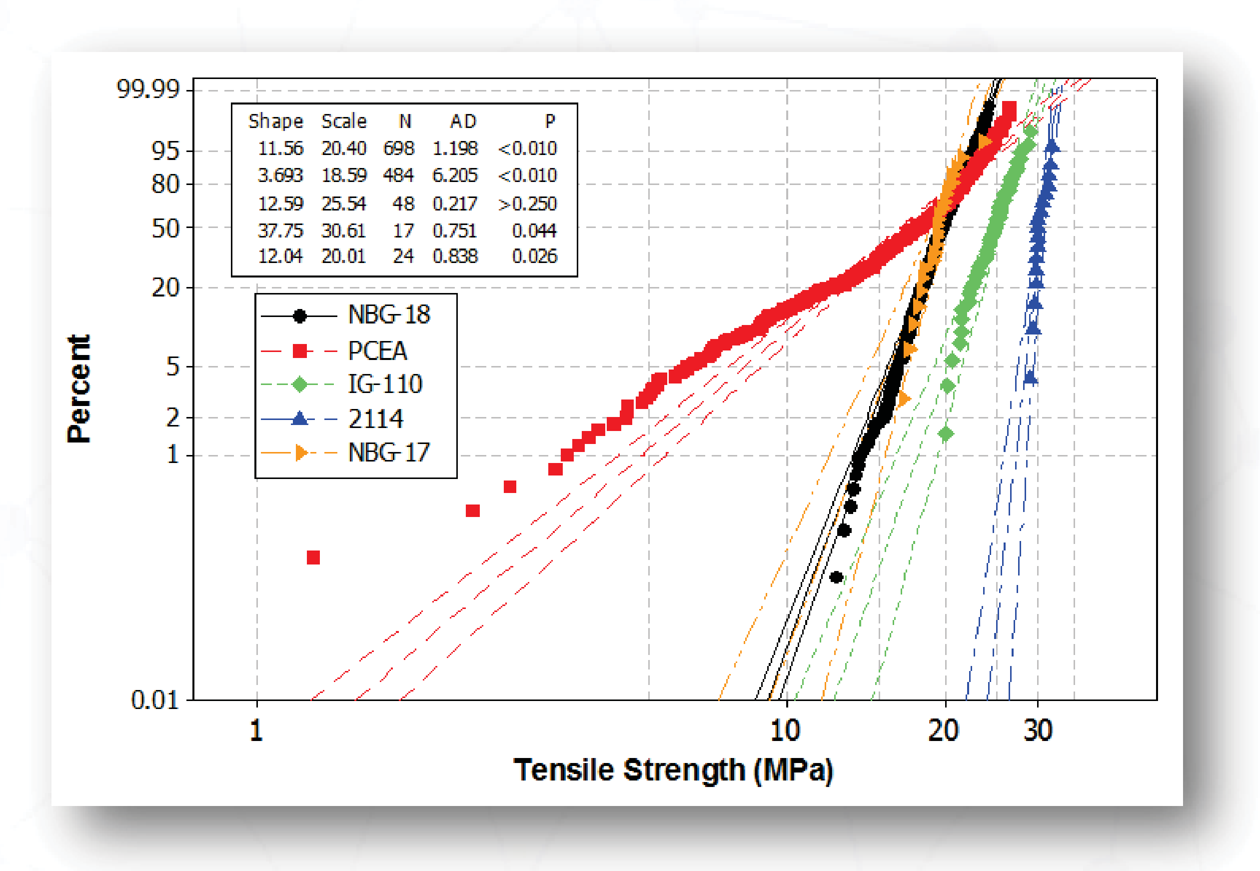
- Deterministic is generally too limiting for a brittle material
- A distribution of possible strengths in a material is needed for quasibrittle materials (i.e., flaw size for graphite).
- Probability of failure in component based upon inherent strength of graphite grade and applied stresses during operation.

Structural Integrity Assessment Methods

- Simplified Assessment (HHA-3220)
  - Simplified conservative method based on ultimate strength derived from Weibull statistics.
- Full Assessment (HHA-3230)
  - Weibull statistics for failure probability
  - Maximum allowable probability of failure defined for three Structural Reliability Classes (**SRCs).**

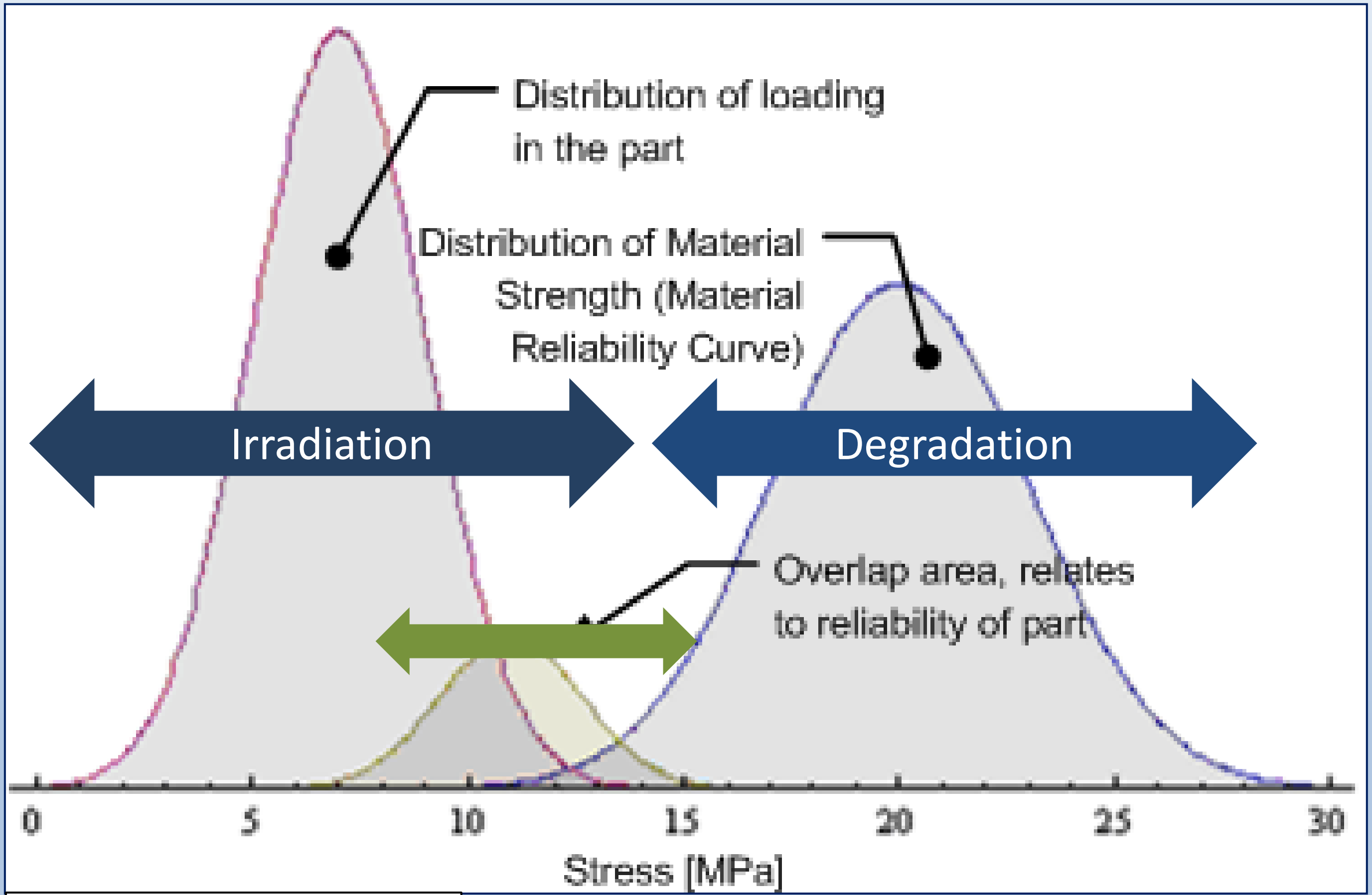
Structural Reliability Class	Maxi. Prob. of Failure
SRC-1	1.00E-04
SRC-2	1.00E-02
SRC-3	1.00E-01

- Design by Test (HHA-3240)
  - Full-scale testing to demonstrate that failure probabilities meet criteria of full analysis.



Graphite code is a "process."

Special Considerations in Design of Graphite Core Components

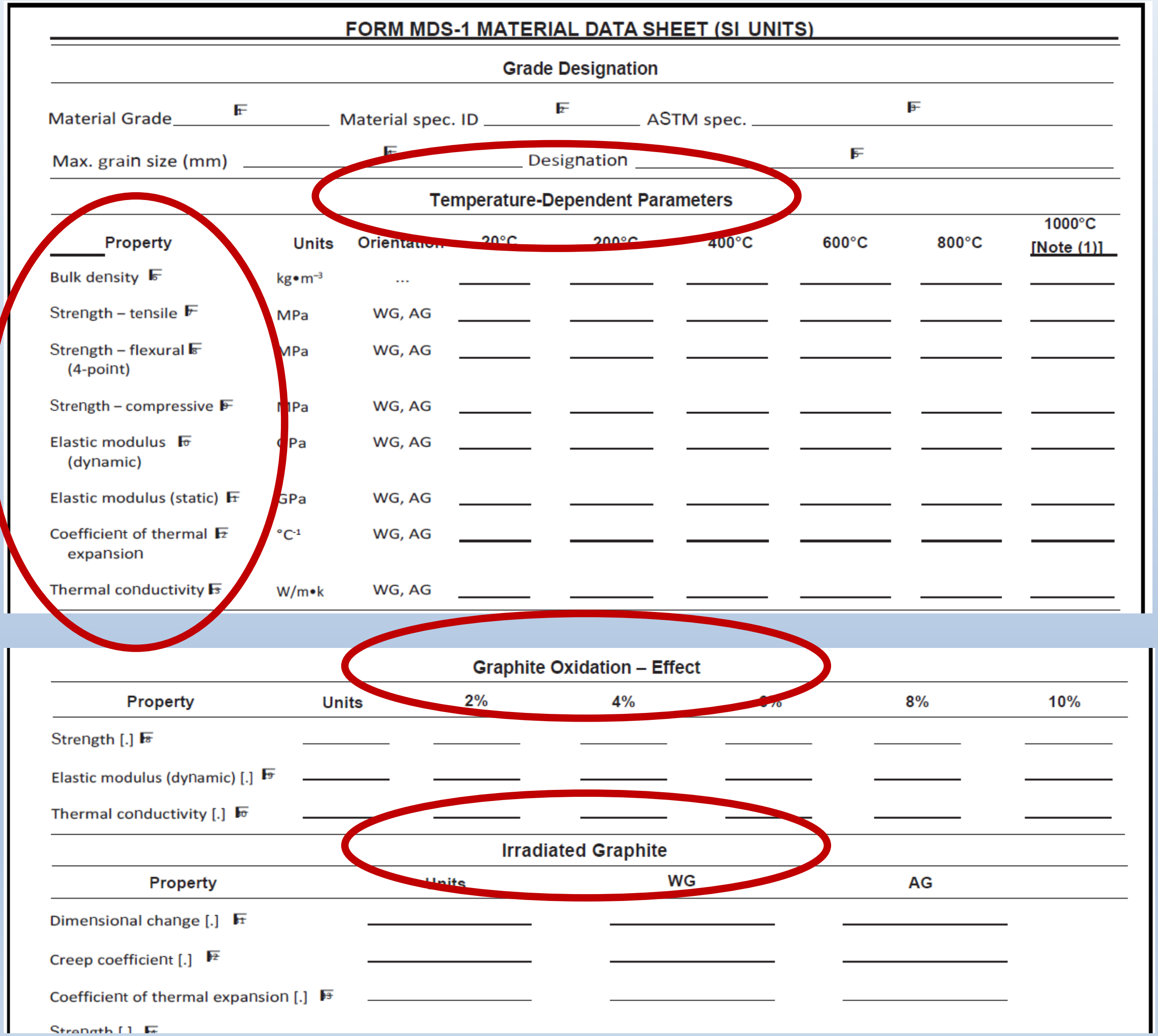


From Dr. Mark Mitchell – PBMR Inc.

- Oxidation (HHA-3141)
  - Loss of strength and geometry changes to be considered
- Irradiation (HHA-3142)
  - Property changes to be addressed
- Abrasion and Erosion (HHA-3143)
  - To be considered when there is relative motion or high gas flow rate in gas-cooled designs

Designer should determine the specific changes for their selected graphite grade

Graphite Degradation (Form MDS-1 Material Data Sheet)



FORM MDS-1 MATERIAL DATA SHEET (SI UNITS)

Grade Designation

Material Grade ______ Material spec. ID ______ ASTM spec. ______

Max. grain size (mm) ______ Designation ______

Temperature-Dependent Parameters

Property	Units	Orientation	20°C	200°C	400°C	600°C	800°C	1000°C [Note (1)]
Bulk density	kg•m⁻³	...						
Strength – tensile	MPa	WG, AG						
Strength – flexural (4-point)	MPa	WG, AG						
Strength – compressive	MPa	WG, AG						
Elastic modulus (dynamic)	GPa	WG, AG						
Elastic modulus (static)	GPa	WG, AG						
Coefficient of thermal expansion	°C⁻¹	WG, AG						
Thermal conductivity	W/m•k	WG, AG						

Graphite Oxidation – Effect

Property	Units	2%	4%	6%	8%	10%
Strength [.]						
Elastic modulus (dynamic) [.]						
Thermal conductivity [.]						

Irradiated Graphite

Property	Units	WG	AG
Dimensional change [.]			
Creep coefficient [.]			
Coefficient of thermal expansion [.]			
Strength [.]			

ASME BPVC Data sheets capture:

- Material properties
  - Strength
  - Elastic modulus
  - CTE
  - Conductivity
  - Thermal conductivity (Diffusivity)
- Irradiation effects
- Temperature dependence
  - Temperature affects everything
- Oxidation effects

Summary

Division 5 was issued as part of the 2011 Addenda to the 2010 Edition of the BPV Code

Though the design rules development for metallic components traced all the way to the 1960s

Division 5 covers the rules for the design, fabrication, inspection and testing of components for high temperature nuclear reactors

Construction rules for both metallic and nonmetallic components are provided

The rules for nonmetallic components are unique among all design codes world-wide

ASME Code committees are actively pursuing code rules improvement and developing new technologies to support “Advanced Nuclear”

NRC Review and Potential Endorsement of ASME BPVC, Section III, Division 5

Advisory Committee for Reactor Safeguards

July 20, 2021

Jordan Hoellman,
Project Manager
Advanced Reactor Policy Branch
Office of Nuclear Reactor Regulation

Jeff Poehler,
Sr. Materials Engineer
Reactor Engineering Branch
Office of Nuclear Regulatory Research

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Purpose

Provide an overview of the process for NRC's review and potential endorsement of 2017 ASME BPVC Section III, Division 5, "High Temperature Materials" (Section III-5)

Discuss likely exceptions and limitations to NRC's endorsement.

NRC Guidance Documents for Section III-5 Endorsement

NUREG-2245 "Technical Review of the 2017 Edition of ASME Section III, Division 5, "High Temperature Reactors"

- Document the staff's technical evaluation of the 2017 Edition of Section III, Division 5 and Code Cases N-861 and N-862 for acceptability and endorsement. Provide technical basis for DG-1380.

Regulatory Guide (RG) - Acceptability of ASME Section III, Division 5, "High Temperature Reactors" (DG-1380)

- Describes an approach that is acceptable to the NRC staff to assure the mechanical/structural integrity of components for use in in elevated temperature environments, which are subject to time-dependent material properties and failure modes.
- Contains exceptions and limitations to the staff's endorsement.
- The regulatory guide will update the guidance of RG 1.87.
- Appendix A of DG-1380 contains staff guidance on quality group classification for high-temperature reactors.

Scope of Staff Review

1

Section III-5, 2017 Edition

- Did not review Nonmandatory Appendix HBB-Y, so not endorsing.

2

Code Cases N-861 and N-862

3

Alloy 617 Code Cases

- Separate technical basis document being developed
- Will merge results into final DG-1380

Contractor Expert Recommendations

- To ensure an independent review of the technical adequacy of Section III, Division 5, NRC used contractors not directly involved with Division 5 code development
- NRC also used contractors more involved with code development on a limited basis to provide historical perspective on Division 5.

Review Process - General

Relied on previous reviews when possible.

- Code Cases 1592-1596.
- Section III, Division 1.

The NRC staff's review was augmented by input from several national laboratories and commercial contractors.

See NRC's Advanced Reactor Public Website: https://www.nrc.gov/reactors/new-reactors/advanced.html#endorev

Contractor Reports

Contractor	Topics	ML #
PNNL	Design, Fabrication, Examination, Testing (HBB/HCB/HGB-3000, 4000, 5000, 6000) Mechanical design appendixes for metallic core supports (HGB-I, HGB-II, HGB-III, HGB-IV)	ML20269A145
ORNL	Materials (HBB/HCB/HGB-2000) Tables and Figures (Mandatory Appendix HBB-I-14) Guidelines for Restricted Material Specifications (Non-Mandatory Appendix HBB-U)	ML20269A125
NUMARK /EMC^2	Mechanical Design Appendixes for Class A and Class B components (HBB-II, HBB-T, HCB-I, HCB-II, HCB-III)	ML20349A003
	Technical Requirements – Graphite Materials and Design	ML20358A145
	Code Cases N-861 and N-862 (all aspects)	ML20349A002
ANL	Historical Context and Perspective on Materials Properties	ML21090A033

Review Process – General Requirements

Staff compared the 2017 Edition of ASME Code III-5-HAA and -HAB to the 2017 Edition of ASME Code III-NCA to ensure consistency with what the NRC has endorsed in 10 CFR 50.55a.

Similarly, the staff compared the 2017 Edition of ASME Code III-5-HAA and -HAB to the 2019 Edition of ASME Code III-5-HAA and -HAB to ensure consistency with those items that were corrected in the 2019 Edition.

Exceptions or limitations proposed where there are differences.

General Requirements – Examples of Exceptions/Limitations

Limitation: Staff does not endorse use of a Certifying Engineer who is not also a Registered Professional Engineer.

Basis: Consistency with a similar condition in 10 CFR 50.55a on 2017 Edition of Section III-NCA.

Limitation: When using HAB-3126(b), HAB-3127(b), and HAB-3855.3(c)(2) and (d)(2): The procurement documents should specify that the service will be provided in accordance with the accredited ISO/IEC 17025 program and scope of accreditation.

Basis: This is one of several limitations included for consistency with the updated ILAC accreditation process that is called out in NCA-3126 and also in the 2019 edition of Section III-5.

Mechanical Design – Exceptions and Limitations

- The staff identified exceptions and limitations related to mechanical design (HBB-3000, HBB-T) for several reasons:
  - Consistency with Section III-1 conditions in 10 CFR 50.55a
    - Socket weld design condition.
  - Consistency with RG 1.87 conditions on Code Case 1592 –
    - Use of strain-controlled buckling factors.
  - Lack of guidance in Section III-5
    - Inelastic analysis for meeting HBB-T deformation limits .
    - Stress relaxation cracking.

Mechanical Design – Exceptions and Limitations – Stress Relaxation Cracking

Limitation:

When using HBB-T-1710 applicants and licensees should develop their own plans to address the potential for stress-relaxation cracking in their designs.

Basis:

Stress relaxation cracking is a mechanism causing enhanced creep crack growth in certain materials caused by relaxation of weld residual stresses in components in high-temperature service. Section III-5 does not contain any provisions addressing stress-relaxation cracking.

Review Process – Metallic and Graphitic Materials

Class A Metallic materials (HBB-I-14)

- Did not primarily rely on previous reviews.
- Independent analysis of materials properties and allowable stresses by NRC contractor.
- Additional input by subject matter experts familiar with the development of Section III-5.

Graphite (HHA)

- Did not rely on previous reviews.
- Graphite provisions were not in 159X Code Cases – New to Section III-5.
- Technical review of Section III-5 by subject matter experts.

Metallic Materials

In some cases, contractor independent analysis determined properties and allowable stresses with lower values than the code, suggesting code values are nonconservative.

Lower values were typically only at higher temperatures and longer times for time-dependent properties.

NRC staff considered these findings in a holistic manner, including how these properties are used, inherent conservatism of the Division 5 design rules, and historical context.

Input from ANL provided historical context and perspective on materials properties.

Metallic Materials – Exceptions and Limitations

- For time-dependent allowable stresses, staff placed limitations on endorsement for several materials.
- Limitations in form of maximum temperature limit for several materials.

Material	Properties	Temperature Limit
Type 304	S_{mt} , S_t , S_r	1300 °F, 700 °C
Type 316	S_r	1300 °F, 700 °C
2-1/4 Cr-1 Mo	S_{mt} , S_t , S_r	950 °F, 510 °C

- For 9Cr-1Mo-V, 2019 Section III-5 properties are endorsed in lieu of 2017 Section III-5 properties.

Example of Basis for Conditions on Allowable Stresses

For Type 304, ORNL independent analysis suggested significant non-conservatism of Section III-5 S_t values for most times and temperatures. At 300,000 hours, non-conservatism was suggested at temperatures ≥ 850 °F or 450 °C. This is based on independent analysis values more than 10% lower than Section III-5 values.

Most of the apparent non-conservatism driven by the tertiary creep criterion for S_t .

Tertiary creep criterion for S_t is a known issue in the Code. It was not intended that this criterion should control most time-dependent allowable stresses.

ANL performed an alternate analysis using a different approach for tertiary creep data. This analysis showed significant non-conservatism only at temperatures ≥ 1300 °F or 700 °C.

Graphite Materials and Design

- Numark Associates Inc. provided a technical assessment of Subsection HH, “Class A Nonmetallic Core Support Structures,” Subpart A, “Graphite Materials.”
- Staff has completed the review of the above report and all applicable sections of ASME Section III, Division 5 and obtained clarifications and feedback from NRC contractors (NUMARK and INL) in order to come up with the conclusions identified in the NUREG.
- The staff's independent review of the code requirements considered the holistic design of graphite core support structures.

Graphite Materials and Design – Exceptions and Limitations

Limitations identified by staff where Division 5 has a numerical parameter limit, but staff not convinced the limit is generically applicable to all designs. Design-specific justification is requested for the parameter value in these case:

Paragraph	Parameter	Limit in Section III-5
HHA-3141, Oxidation	Weight Loss Limit	≥ 30%
HHA-3142.4, Graphite Cohesive Life Limit	Cohesive Life Limit	+10%
HHA-3143, Abrasion and Erosion	Gas Flow Velocity	100 m/s (mean)
HHA-4233.5, Repair of Defects and Flaws	Allowed repair depth	≤ 2 mm (0.079 inch)

Graphite Materials and Design – Other Exceptions and Limitations

Limitation: The NRC staff is not endorsing the provisions of HHA-3330(g).

Basis: HHA-3330 (g) allow for access to performing inservice inspection. If necessary, inservice inspection may be replaced by operational monitoring

Staff is not endorsing this provision because requirements for inservice inspection are outside of the scope of Section III-5, HHA.

The provision related to operational monitoring is the one that the staff finds out of scope.

Four Quality Groups and associated standards (from DG-1380, Appendix A)

Quality Group A

- Safety-related SSCs
  - Use ASME Section III, Division 5 Class A for safety related SSCs that have safety significance

Quality Group B

- Safety-related SSCs
  - Use ASME Section III, Division 5 Class B for safety related SSCs with low safety significance

Quality Group C

- Non-safety-related SSCs with safety significance
  - Use ASME Section VIII, Division 1 or 2

Quality Group D

- Non-safety-related SSCs with no special treatment
  - Owner to establish standards for use

Summary

The NRC staff has completed its initial review of Section III-5 for potential endorsement.

The NRC's review is documented in NUREG-2245.

DG-1380 contains the staff's regulatory position on Section III-5, including some exceptions and limitations.

Exceptions and limitations were generally identified when the staff found that additional guidance was needed to augment the provisions of Section III-5, or where material properties and allowable stresses are potentially nonconservative.

Next Steps

The NUREG and DG will be issued for public comment.

Alloy 617 Code Cases technical review (in progress).

Make changes as necessary to NUREG and DG to address public comments.

Reissue DG for a second public comment period incorporating Alloy 617 results and resolution of public comments.

Issue draft Alloy 617 technical basis document concurrently with DG.