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NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR RESEARCH

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EXPERT PANEL WORKSHOP ON DEGRADATION OF CONCRETE IN SPENT NUCLEAR FUEL DRY CASK STORAGE SYSTEMS

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PUBLIC MEETING

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TUESDAY,

FEBRUARY 24, 2015

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The meeting was convened in the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., Sheila Ray and Christopher Jones, moderating.

PANEL MEMBERS PRESENT:

NEAL BERKE, Tourney Consulting Group

LAURENCE JACOBS, Georgia Institute of Technology

RANDY JAMES, Structural Integrity Associates

JOHN POPOVICS, University of Illinois

YUNPING XI, University of Colorado

NRC STAFF PARTICIPANTS:

SHEILA RAY, NRC/NRR, Facilitator

CHRISTOPHER JONES, NRC/RES, Moderator
GREG OBERSON, NRC/RES, Materials Engineer
RICARDO TORRES, NRC/NMSS, Materials Engineer
BOB TRIPATHI, NRC/NMSS, Sr. Structural Engineer
AL CSONTOS, NRC/NMSS, Branch Chief
MARK LOMBARD, NRC/NMSS, Division Director
BRIAN THOMAS, NRC/RES, Division Director

NRC CONTRACTOR PARTICIPANTS:
LEO CASERES, Southwest Research Institute (SwRI)
ASAD CHOWDHURY, Center for Nuclear Waste Regulatory Analyses (CNWRA)

T-A-B-L-E O-F C-O-N-T-E-N-T-S

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

(8:30 a.m.)

MS. RAY: Good morning everyone. Thank you for attending the Concrete Expert Panel Workshop. My name is Sheila Ray, and I'll be serving as your meeting facilitator for this morning and this afternoon.

My role is to help the meeting go smoothly and to achieve a common objective. My approach will be to set a few ground rules, discuss the agenda and lead the public comment period.

Chris will be handling the technical portion of this meeting. I just wanted to note: This is a Category III public meeting, so public participation is actively sought for this meeting to fully engage with the public.

Just in terms of logistics, there are restrooms. You exit this door, past the elevators. Left to the men’s, and women’s is on the right.

In case there is an exit we will meet out in front of Two White Flint Building. Please be aware of any tripping hazards in the room.

And I just wanted to let you know: There is a telephone bridge. So please, for those on the phone, please mute your phones so we can have a continuous discussion with no interruptions.

In terms of ground rules, I would like to remind everyone to silence all of your electronic devices. We would really appreciate that.

And also please have one speaker at a time for folks on the phone to be able to actively listen. And also note that there is a transcription being taken of this meeting to help record the notes.

So if you can please introduce yourselves before you speak so we can have an accurate record of the discussions today.

We'd like to also be considerate to follow the agenda so we can stay on time. And also, please stay on topic so we can finish the meeting on time.

So the purpose of this meeting is to enhance the existing technical basis related to dry cask storage systems, to identify relevant knowledge and practices from non-nuclear concrete structures, and to identify potential information need.

The agenda today, we'll start with introduction and opening remarks followed by discussions of degradation mechanisms, prevention and mitigation strategies, inspection techniques and technologies, followed by a public comment period this afternoon.

At this time I'd like to start with opening remarks. Mark.

MR. LOMBARD: Thank you. My name is Mark Lombard, I am the director of the Division of Spent Fuel Storage here. Spent Fuel Management, sorry, Spent Fuel Management, we have a new name since last October; I'm still getting used to it, here at the NRC.

And I just want to welcome those in the room, especially esteemed members of our concrete expert panel, thank you for coming today, those other members of the public and members of the NRC and members of our consulting crew here and those on the phone for joining us.

This is another very important topic part of our approach or putting together an approach for extended storage and transportation.

There are several potential degradation mechanisms that can affect dry cask storage systems. And as we all know, for many of the systems out there today, concrete is a very important material in those systems.

So we look forward to this panel over the next two days and the results that it will give us in helping to find that regulatory framework going forward in extended storage and transportation.

When you look at the work we've done the last 16 months on license and certificate renewal, we have built really a totally revamped regulatory framework for potential material degradation mechanisms. Ricardo Torres and Bob Tripathi as well as our consultants at the Center down in San Antonio have helped us to build that regulatory framework.

But that helps us for that first renewal period of which we've approved one system, one independent spent fuel storage insulation renewal at Calvert Cliffs. We're working on the Prairie Island renewal now and also the VSC 24, that Steve is very familiar with, here from Energy Solutions today, and I appreciate you coming.

So we've looked at regulatory framework for that first renewal period of 40 years after the initial 20 years of storage. Extended storage and transportation takes over at that second renewal period.

So we're really looking to look at those longer term potential material degradation mechanisms. And, again, this is one very important piece of that.

So again, we look forward to the results of the concrete expert panel over these next two days. And again, thank you all for coming. And thank you members of the public for attending as well; we look forward to your input later this afternoon.

MS. RAY: Thank you.

MR. LOMBARD: Thank you, Sheila.

MS. RAY: Chris, would you like to make some opening remarks?

MR. JONES: Yes, so this has been a cooperative effort between the Office of Research at the NRC and the NMSS Office, Nuclear Materials Storage and Safeguards.

We support the technical basis, as you mentioned earlier, and so it's been an effort that's brought in a couple different components. We have the staff at the CNWRA, Southwest Research in San Antonio. We have the concrete expert panel as well, and so it's been a fairly large and far reaching effort. The concrete panel has been sort of one component of this.

There's been some additional work in other topics. And so this has been a broad effort, I guess, that Research has been helping to lead for the NMSS.

So I do want to thank everyone for being here as, you know, as done by everyone else. I think there's a lot of good discussion to be had over the next two days.

And I also think that, you know, that discussion will lead to, you know, a real product that will be of use to the licensing activities that the Nuclear Regulatory Commission is undertaking with these dry cask facilities.

I guess with that, do we have any other introductory --

MS. RAY: No, we'll start with introductions --

MR. JONES: Yes, that's great.

MS. RAY: -- of the panel please. Neal, if you'd like to introduce yourself?

MR. BERKE: Okay. I'm Neal Berke, I'm with Tourney Consulting Group. My background is primarily corrosion and concrete durability.

MR. XI: Yunping Xi from the University of Colorado. I've been working on durability of the concrete; I'm also working with concrete structures.

MR. JONES: Great.

MR. TRIPATHI: I thought we were going to go through the Panel first, no?

MS. RAY: Okay.

MR. TRIPATHI: Larry?

MR. JACOBS: I'm Larry Jacobs, I'm at Georgia Tech. I'm with Georgia Tech University, with Georgia Institute of Technology.

And my background is in non-destructive evaluation, wave propagation. I've been working in NDE of concrete for about 20, 25 years.

MR. POPOVICS: I'm John Popovics, I'm from the University of Illinois. Urbana-Champaign.

And I'm also interested in testing, imaging, sensing of structures and also degradation of concrete structures.

MR. JAMES: Good morning, I'm Randy James. I'm three years with ANATECH Corp. And we were acquired by Structural Integrity a year and a half or so ago.

My background is structural engineering. So I'm really interested in the analysis and assessments for the performance of degraded concrete structures.

MR. TRIPATHI: I'm Bob Tripathi, senior structural engineer with Nuclear Material at Safety and Safeguards. And I work for Mark Lombard in Division of Spent Fuel Management.

MR. TORRES: Ricardo Torres. I'm a materials engineer for the Division of Spent Fuel

Management.

I'm background here at the NRC has been on review of transportation and storage systems, ensure compliance with the Title 10 Code of Federal Regulations, Part 71 and Part 72 in regards to storage.

I've worked on the enhanced renewal strategy that we've been working on for the last year and a half at SFM and with the particular emphasis on concrete.

MS. RAY: Thank you.

MR. CASERES: My name is Leo Caseres. I'm a senior engineer at the Southwest Research Institute in Materials Engineering and Development. I'm primarily engaged in concrete degradation and degradation of metals.

MR. CHOWDHURY: I am Asad Chowdhury from Center for Nuclear Waste Regulatory Analysis in San Antonio, Texas.

I'm a structure engineer. I work on many NRC projects dealing with nuclear facilities with emphasis on concrete structures.

MS. RAY: Thank you. And for those of you in attendance, please be sure to sign the attendance sheet so we can have an accurate record of those who attended.

And for those of you on the phone, please email Greg Oberson, to provide your contact information. That's, greg.oberson@nrc.gov. The email address is also on the meeting agenda.

And with that we'll turn it over to Chris.

MR. JONES: Okay, thanks, Sheila. So we have, I guess, a few objectives for this workshop. And I guess the main one is this first bullet.

And that is to enhance the existing technical basis for dry cask storage systems. And we'll do that, I guess, in a few different, I guess, in a few different areas.

One of those is degradation mechanisms. We'll spend actually quite a bit of time on that characterizing, understanding the significance and the mechanisms at certain degradation modes.

We'll spend some time on concrete inspection and monitoring techniques, an important aspect of insuring the, you know, the safe storage of these nuclear materials.

And then similar, but different, the functional assessment of the potential state of these dry cask storage facilities.

We've assembled a panel that has representation from Industry from academia and some other technical fields, transportation, you know, basic concrete research, things like that.

So we hope to leverage existing experience from non-nuclear concrete applications that similarly degrade.

And, as a third objective of these two days, we hope to identify some information needs that, you know, could be explored a little bit further. Both from the NRC perspective, but also it is expected that some of these degradation modes, phenomena, inspection techniques, functional assessments are lacking in the overall sense.

There may be just a gap in understanding, for example, of a certain degradation mode that we just don't have as a human race, the understanding how certain things work. So identifying those will be an important outcome of the meeting as well.

We have a somewhat busy two day schedule that looks like this. This morning from 8:45 to just before lunch we'll work on degradation mechanisms for concrete.

We will have a short break there at 10:15

to 10:30 to go grab a coffee or use the restroom, things like this. So after lunch we'll talk about prevention and mitigation strategies, things that can be done to help prevent or mitigate degradation in the concrete components.

And then at the end of the day, today, we will work on inspection techniques and technology. And so that's specifically looking at a certain UT technique or, you know, the technique itself.

Tomorrow in the morning we will look at how we could use those techniques in inspection and monitoring schemes and in programs and things like that.

At the latter part of the morning we'll look at aging management programs. So AMPs so to speak for dealing with how to handle the aging of these components from a strategic standpoint.

After which we'll look at time limited aging analyses for TLAAs, so to speak. And the remediation and repair and replacement will conclude the day.

At the end of each day we will have a public comment period of about 45 minutes. We anticipate a significant number of comments and questions. And we're kind of excited to have those helping us, you know, come to a better technical basis.

And so nominally each day we'll run from 8:30 to 4:30 in the afternoon. So a good full day but not a grueling too painful of day.

Thanks to anyone on the West Coast calling in at this time of day too. I appreciated that.

So we've gone through this briefly, but we've, you know, selected some expert panelists. Neal Berke from Tourney Consulting Group, expert in concrete technologies and corrosion.

Larry Jacobs from Georgia Institute of Technology. Professor and associate dean for academic affairs, a real NDE expert.

Randy James from ANATECH Technologies, or Structural Integrity more recently. An expert on analysis of degraded concrete structure. A computational analyses.

Hamlin Jennings. I suppose we should stop. Is Hamlin Jennings on the phone now?

He's, I believe, had some health, personal issues that prevented him from calling in, but he's worked with through this process. He is at Massachusetts Institute of Technology.

John Popovics, UI-UC. Also an NDE exert, particularly for a wide range of concrete applications.

And Yunping Xi from University of Colorado, Boulder who's done some recent work for the DOE on the durability and degraded concrete structures in the power reactor side of the house. So we, you know, are excited to hear what you can teach us on this side.

So, just briefly, the motivation for this Concrete Degradation Panel effort is the fact that these dry cask storage facilities are going to be required to operate longer than anticipated, originally it was a relatively short license period. And, due to a number of factors, primarily the absence of a long-term repository, they're being asked to perform a little bit longer.

And so we're considering this problem in two specific timeframes, up to 60 years. So what we would call the first license renewal period.

And then also an additional sort of indeterminate nominally capped at 300 years, but from 60 on, which is for the application for extended storage and dry casks.

It's believed that concrete structures may degrade in these timeframes. And NRC will require an adequate technical basis to demonstrate and ensure the safety of these structures in that timeframe and during those licensing periods.

So this is sort of our central question that will guide us throughout the next two days. How do we wrap our minds around this problem, if you will. This is the question, the issue that's before us.

Great, welcome.

So as I mentioned, just briefly, just a few moments ago, we'll spend the bulk of the morning here on the discussion of degradation mechanisms. So we'll start our first block of that immediately here. Right on time.

So this effort began some years back with the writing and the concept of the technical information needs report. A so-called ML numbers listed there on the slide.

This was a Commission directed investigation on the extended use of dry casks storage systems. And just have taken a little quote out and I'll read that now.

The report presents the results, the NRC staff evaluation of the technical information needs for continued extended dry cask storage. And it focuses on the degradation phenomena that may affect dry storage systems and how these phenomena may affect the ability of systems to fulfil their regulatory functions.

So this TIN Report, so called, the, T-I-N, Report was, I guess, the first or jumping off point into this broader question of extended storage and dry cask facilities.

And prior to coming today we've addressed with the expert panel the findings of the TIN Report with respect to concrete degradation. I've summarized those in a very, very succinct way. Please refer to the full report for the full details.

But the concrete degradation modes and mechanisms and understanding and severity and is sort of summarized in this table. And let me just talk about that briefly.

On the left-hand column we have specific degradation modes identified by the staff in the TIN Report. And then the next three columns discuss initiation rate, excuse me, initiation time, propagation rate and mechanism termination, if you will, so do we know when the mechanisms will arrest on its own. Finally, the inspection capability is listed on a fourth column.

The three columns, in the middle of the table, are populated with H’s, L’s and M’s for high, medium and low knowledge and significance. So it's sort of a blended metric of, do we think that this is an important critical thing to be dealing with.

So we won't go through, line-by-line, but this is certainly the list that was generated by the NRC staff and the Office of Research and also of NMSS in the writing of this TIN Report.

And so it is from this point that the expert panel sort of steps forward. And we identified a lot of confirmation, a lot of correct information in the TIN Report. And we identified some areas that maybe there was a little bit less assurance of.

So moving to the first mechanism of the day, the first degradation mechanism, I want to talk about sort of the structure.

On the left-hand column of these slides I have sort of organized the observations that the experts have made over the course of these panel activities.

And then on the right-hand column there are a few questions that I have generated to stimulate discussion. And these aren't by any means the only questions. But hopefully this will get us talking about the issues before us.

So jumping in. And at this point I'll open it up to the panel, but it was observed by several of the panelists that salt scaling, as a mechanism, was not identified in the TIN Report.

The mechanisms are not tremendously well understood. There's active research in this. There are some prevailing theories. Crystallization pressure of the salts themselves or an interdependence with the ice formation pressure.

So interplay with the freeze/thaw activities. And we do know that it causes primarily surface deterioration because it's an outside in approach.

So again, let me engage the Panel at this point and ask. The first question is, is salt addition required? We certainly see it on our sidewalks in DC. Or is environmental salt, are those sources enough to initiate these degradation mechanisms?

So, Panel, would anybody hazard the first comment --

MR. POPOVICS: So you're talking about salt scaling in particular?

MR. JONES: Correct. Yes. And maybe I've characterized the title of the slide incorrectly. If we need to talk about that too, but --

MR. POPOVICS: No, I just was wondering.

MR. JONES: Sure.

MR. POPOVICS: I am not an -- I think other members of the panel are in better positions to talk. I'll just say that I think the mechanism, salt scaling, is pretty well developed recently.

MR. JONES: Okay.

MR. POPOVICS: I can think of George Scherer at Princeton who's done a lot of work on this. And kind of explaining this pessimism effect. Meaning that the salt scaling only occurs when you have a certain concentration in the solution that's ponded.

MR. JONES: Okay.

MR. POPOVICS: And he has done some work, and others, I'm probably forgetting other people who have done it.

So it does require certain, as far as I understand, as certain concentration of ions that are ponded and then frozen for this to occur. And I think it's pretty well established. But I'll leave it at that.

MR. BERKE: It's mostly to prevent it when you have the ice in salts, which I don't expect are going to be used in any of these applications by --

MR. JONES: Correct. Yes.

MR. BERKE: -- point if you were right next to the ocean. Flat surface it's possible.

MR. TRIPATHI: John, did you just mention that it's not just the salt but you have to have ponding --

MR. POPOVICS: Yes.

MR. TRIPATHI: -- simultaneously --

MR. POPOVICS: That's my understanding.

MR. TRIPATHI: -- simultaneously, otherwise this thing is not really --

MR. POPOVICS: Right. This is a problem for bridge decks that have poor drainage or sidewalks, paving areas, that there is a certain level of salt concentration in the solution.

If you have a very high concentration you don't have this effect. If you're very low you don't have, you have freezing and thawing, but not this salt scaling. There's a pessimism value and it should be ponded.

That's my understanding. I'm not very well versed on this topic, but believe that's the fundamental requirements of this mechanism.

MR. JONES: okay.

MR. POPOVICS: And I would point to George Scherer's work, from Princeton, who's done a lot of work on this.

MR. JONES: Thanks.

MR. CHOWDHURY: Neal, you mentioned the surface near the sea water. So this will be very important for the concrete bed on this --

MR. POPOVICS: It's more the pad.

MR. CHOWDHURY: Yes.

MR. BERKE: It's not going to be the vertical surfaces.

MR. POPOVICS: Exactly.

MR. BERKE: So the best way to help your pad is to make sure you don't puddle.

MR. JONES: Right.

MR. BERKE: And ideally not put it close to the ocean though. Close to the ocean we get into the geographical things will depend on what part of -- which coast you're on and where you are on that coast.

MR. JONES: Yes.

MR. BERKE: So basically it's going to be a pad problem not a vertical surface problem.

MR. CHOWDHURY: Okay.

MR. JONES: So that, unless someone has a different opinion, that tackles my third bullet. Which, can this occur on a vertical surface?

And maybe let's just talk about the second one for a moment. Do we believe that this is more a cosmetic or does this have structural significance? Obviously we're talking about depth, basically. So I'll just lob that out there.

MR. POPOVICS: It's definitely cosmetic, but --

MR. BERKE: Well over a period of time you'll lose -- you'll continue to lose surface. So it's, you know, it's the question, you can see how much it's deteriorating, you can figure out how much steel you have behind it and whether or not it's going to be a problem later on.

But obviously if you've got salt there and it's deteriorating your cover, I guess chloride ingress is decreasing.

MR. JONES: Okay. So not only is the chloride kind of ingressing, but it's also sloughing away until you're getting an accelerated chloride ion front, if you will.

MR. POPOVICS: I think, yes. Neal brings up a good point; it depends on your timeframe. If you had a number up there, 600 years -- well 600 years is a really long time.

MR. JONES: Yes.

MR. POPOVICS: I think in the course of 20 years -- maybe this is not, you know, it's just more on the cosmetic side.

MR. JONES: Yes.

MR. POPOVICS: But longer than 20 years, you know, we're losing cover and we're -- the chloride ion concentration.

MR. BERKE: Now, this would be parallel.

MR. POPOVICS: Yes.

MR. BERKE: So if you start doing that you dry wedge, you can treat the surface to minimize that.

MR. JONES: Great.

MR. JACOBS: And since it's on the surface you can --

MR. BERKE: You don't get to it.

MR. JACOBS: You can get to it.

MR. BERKE: Right.

MR. JACOBS: It's not -- you don't need a fancy monitoring technique.

MR. TRIPATHI: So the only structural significance would be loss of cover of that top rebar, right?

MR. POPOVICS: The structural significance.

MR. TRIPATHI: Structural significance.

MR. POPOVICS: Yes. You're losing material.

MR. BERKE: Chloride ingress has increased but the corrosion of the bars could cause your material to be --

MR. POPOVICS: Yes, that's an indirect structural --

MR. BERKE: Right.

MR. POPOVICS: Yes.

MR. JONES: Okay. So we'll spend some -- you guys have done a great job of setting up subsequent questions, but we'll get to the issue of coupled mechanisms.

And I think that this is one that has a high degree of coupling, both with temperature issues with the freezing and then also with the corrosion, of course, as we brought up.

So that's a known shortcoming of the TIN Report, and maybe the industry, in general, is that, you know, we don't maybe have a great way of addressing some of these coupled phenomena. You know, for something initiating something else.

So, John, can we go back to the -- you mentioned the notion of George Scherer's research and this idea of a pessimism effect. So there's sort of a critical --

MR. POPOVICS: Yes.

MR. JONES: -- salt concentration that causes this happening below, such as freezing, thawing, potential and above sea.

MR. BERKE: Yes, it's a funny behavior. For a while it was observed but could not be explained very well.

And I think George, and I may be missing other researchers who have done the kind of foundational work that lead to it, but George kind of put, is the person I want to say that put it all together. And it really is explained by the relative thermal expansion of the concrete in the ice changes. Ice changes with salt content.

MR. JONES: Right.

MR. POPOVICS: And so when you've got this differential expansion, at this pessimism effect, you had more differences in expansion of heating it quick, and it just basically rips off the layer.

MR. JONES: Just sort of a --

MR. POPOVICS: It's bonded and then rips off.

MR. JONES: Just sort of on the notion that (inaudible) with however far it penetrated.

MR. POPOVICS: And this is a very rough --

MR. JONES: Sure.

MR. POPOVICS: -- description of it, but. So I think he kind of was the first one to kind of put some understanding to that effect.

But yes, if you have very low salt concentration or very high salt concentration, you don't see much surface scale. I mean, you see other problems, but.

MR. JONES: So we basically optimize that with the amount of salt we throw on our sidewalks, is just about right --

MR. POPOVICS: Yes.

MR. JONES: -- to get to this to happen.

MR. CASERES: Based on that definition, it appears to happen only on northern -- on cold weather --

MR. BERKE: Sure.

MR. CASERES: -- climates. Not from southern points.

MR. BERKE: Yes. You have to be below freezing for this to happen. But this can't -- in the lab you can adjust your salt level. In the field application your salt level will hold from high to low, everything in between.

MR. JONES: Sure.

MR. BERKE: So you always risk the chance that even some part of the time --

MR. JONES: In a window so to speak.

MR. BERKE: -- window.

MR. JONES: Asad?

MR. CHOWDHURY: And since this would have been primarily on the flat surface, so it would be a location surely we can inspect --

MR. POPOVICS: Exactly.

MR. CHOWDHURY: -- and then take the remedial action --

MR. POPOVICS: Exactly. Yes.

MR. CHOWDHURY: There is that remedial action.

MR. POPOVICS: Yes.

MR. JACOBS: I mean assuming you can see it and it's not shielded.

MR. CHOWDHURY: Yes.

MR. BERKE: They're not underneath --

MR. POPOVICS: Yes.

MR. BERKE: -- you can find them.

MR. POPOVICS: Yes.

MR. BERKE: The only other place you might have a problem is you might have standing water in the soil.

MR. JONES: Oh, below.

MR. BERKE: -- Right below the surface.

MR. CHOWDHURY: Okay.

MR. BERKE: Or puddling right next to the side. If it's sitting in standing water even though it's kind of on the side. That could be saturated.

MR. POPOVICS: Oh, yes, that's true.

MR. BERKE: But that issue you would be able to see. You'd be able to see too.

MR. CHOWDHURY: Okay. So standing water is a critical factor?

MR. BERKE: Right. With salt in it. Right.

MR. TORRES: And this can also be an issue for a horizontal system and --

MR. JACOBS: And temperature. And temperature.

MR. BERKE: Yes. Temperature.

MR. JACOBS: A lot of different mechanisms. This is not one that moves to the top, but I agree.

MR. JONES: Did you have a question?

MR. TORRES: Yes. My comment is, this could also be a problem -- it seems like it might be a problem for a horizontal system where drainage could be blocked. And you might not have, you know --

MR. POPOVICS: Yes. If you have a flat horizontal like this, then they --

MR. TORRES: Horizontal path.

MR. POPOVICS: -- whatever it is, I don't know.

MR. JONES: I think that is a good treatment of maybe not as important issue, but an issue nonetheless.

Another issue raised by the panelists that was not maybe specifically called out in the TIN Report, but was in a way I guess, is this notion of acid or aggressive ion attack.

And there's a host of ions that could be considered aggressive. And furthermore many other mechanisms could be correctly termed ion attack because they're a specific kind of ion that manifests in a specific way.

Specifically identified were magnesium ions of various valences. The acids and then chloride of course manifests as corrosion usually, but it's another thing that could be lumped under this.

It appears to be tightly coupled with transport properties of the concrete. So the permeability, the vicinity of those covered layers appears to be the critical parameter, if such ions are present.

So that was one observation. I guess the counterpoint to that would be the exclusion of the ions is another critical parameter. If you don't have the ion in the first place you're not susceptible to it.

So let me ask my first generic general question.

How widespread is this general issue? And I guess my excluding things like DEF, ASR, you know, the other named ones. But sort of this generic acid or ion attack. How widespread do you feel this is for other problems in structures?

MS. RAY: Before the Panel answers the

question. Just for the folks on the phone, we're on Slide 16.

MR. JONES: Thanks.

MR. CHOWDHURY: Is Dr. Jennings with us now?

MR. JONES: Dr. Jennings, are you by chance on the line?

MS. RAY: We will attempt to get him.

MR. JONES: Okay.

MS. RAY: We will call him from another line.

MR. JONES: Great. Panelists, how widespread do we feel that this sort of generic ion attach is, acid attack?

MR. XI: What do you mean by other structures? Other chemical structures?

MR. JONES: I guess I mean other than DCSS structures. You know, bridge deck or a non-nuclear, let me say it that way.

MR. POPOVICS: I think magnesium ion attack is relevant for bridge decks and deiced areas because magnesium chloride was, and still is, a commonly used deicing agent.

So the magnesium ion can come from the sea, it can come from groundwater. But the big problem is that it's liberally applied as a deicing agent.

MR. JONES: Okay.

MR. POPOVICS: So if you don't use magnesium chloride as a deicing agent, you're likelihood of magnesium ion exposure is probably pretty small. But there is magnesium in seawater and marine environments.

MR. BERKE: There could be a potential for getting magnesium from dolomite aggregate area.

MR. JONES: Okay. So an internal source.

MR. BERKE: Internal source. And it's -- now I don't think it's much a problem here, but it's been found to be problem sometimes in silica in concretes.

There's less calcium. And --

MR. JONES: Oh, so we drop the --

MR. BERKE: -- magnesium is easier to get in the less calcium that's there. Magnesium, you know, has similar valence, that calcium is more reactive.

MR. JONES: Okay.

MR. BERKE: That's where the problem comes from, magnesium replaces the calcium very quickly. So if you have a source of, if you have less calcium there it's easier.

MR. JONES: Okay.

MR. BERKE: And they do have problems in that we don't have anything like this underneath our open storage places in the Dead Sea, which is rich in magnesium.

MR. JONES: Okay.

MR. BERKE: It's because of magnesium sulfate.

MR. JONES: That's interesting.

MR. XI: To continue from John's comment. So magnesium chloride has been used actually as a anti-icing agent. So just before snowstorms --

MR. BERKE: Hold up --

MR. XI: -- so you put out magnesium chloride, that's a liquid, first --

MR. BERKE: Yes.

MR. XI: -- on the ground. So there will be no ice formed. And then after the snowstorm you use the calcium chloride and that's a deicing agent. So you then use a lot. I mean in Colorado it's very heavily used. Magnesium chloride.

But sometimes -- let's see, when the broadcasting says there will be a snowstorm tonight, then the charge just go out and then it turns out to be no storm.

So all liquid magnesium chloride stay on the pavement, on the bridge decks. And there's no snows to wash them out.

MR. JONES: So it's --

MR. XI: And that create a lot of damage.

MR. JONES: So it's applied as a brine to a highway or an airport prior to --

MR. XI: Yes.

MR. JONES: -- this? Okay. Okay, so again we see a possible important trend that if you're not applying these chemicals you're in a little bit better --

MR. BERKE: Exactly.

MR. POPOVICS: Yes, I think so.

MR. JONES: -- situation.

MR. POPOVICS: The groundwater can have magnesium in it. And sulfates make the, sulfate attack the companion ion. It's important that magnesium sometimes, in the western part of the United States, is common cation in sulfate in the groundwater.

But yes. There has to be some source of the magnesium. And I think the biggest one is the deicing agents.

MR. JONES: Okay.

MR. POPOVICS: Although there are other possible sources.

MR. JONES: Great. So what -- so magnesium -- well maybe we'll just go to the next one I have on my list and we'll pass that.

But acids do we -- I guess I'm assuming this would have to be some kind of chemical spill or something like this?

MR. TORRES: Before we move on to that.

MR. JONES: Sure.

MR. TORRES: Is there a consensus on the threshold from groundwater were magnesium could be a problem for below grade structures?

MR. POPOVICS: I'm sure there is, I don't know it offhand. We could probably find it. You know, actually I don't know. I'm looking at my notes. Maybe I did put something in there.

MR. JONES: I guess magnesium is not one of these usual actors like chloride, sulfate and so --

MR. XI: So actually there are two different types of sulfate attacks.

MR. JONES: Okay.

MR. XI: So one kind is a magnesium sulfate.

So this is actually the worst one.

MR. JONES: Yes.

MR. XI: The source is underground water.

MR. JONES: Okay, so there's a below grade structure, anything --

MR. XI: Yes.

MR. JONES: -- that in contact the ground water would be susceptible.

MR. POPOVICS: That's probably in the Western part of the U.S. more. From what I'm understanding this magnesium sulfate attacks.

MR. XI: yes.

MR. POPOVICS: But it can happen anywhere. But I'm trying to look through my notes to see if I wrote whether there are some threshold levels and I don't think I wrote them down.

I bet Hamlin Jennings is probably well positioned to answer that question.

MR. BERKE: The old ASTM sulfate test method used to have magnesium and sodium sulfate. And I would suspect that magnesium levels lower than what they use there are probably accurate --

MR. JONES: Okay.

MR. BERKE: So whatever they're using for sodium sulfate, I think it was half sodium and half magnesium on a global basis. So I think if it's less than that value, it's probably not going to, for the most cases --

MR. JONES: So that's -- to the left of, I think, upper limit.

MR. BERKE: Upper limit.

MR. JONES: So we would probably set --

MR. BERKE: A little bit lower.

MR. JONES: Yes, a little much, but lower than --

MR. BERKE: Well it's not -- it wasn't a very large amount. It was like, I don't know, was it 0.0250 or something.

MR. JONES: Okay.

MR. BERKE: But it's lower.

MR. TORRES: And I think my follow-up question is, is most of this sampling rounds are probably five to 20 feet below the surface. Is it realistic to even measure those levels at that depth, considering where the magnesium, the source of the magnesium would be?

MR. XI: Usually people only check the sulfate concentration. It's like normally 60 PPM.

That's the upper limit. So nobody checks magnesium. Or sodium.

But when then sulfate comes, so it's negative so the positive ion also comes together, it is a sulfate. So that's why the magnesium concentration should be checked. But usually people do not do it. They only check the negative ions, the sulfates.

MR. TRIPATHI: So to summarize, I think what I heard from the expert panel here is, that unless you do deicing, it's not a major problem.

MR. POPOVICS: Or groundwater.

MR. XI: Well, above ground.

MR. TRIPATHI: Right. But there's an issue with the underground water.

MR. XI: Yes.

MR. TRIPATHI: And is there -- are there any mechanisms to detect that underground water concentration of the magnesium, sodium? I mean what I'm saying that, how do you prevent this thing occurring?

MR. XI: Oh. Let's say if, so before the construction. For a new structure.

MR. TRIPATHI: Oh, before construction.

MR. XI: For a new structure is --

MR. TRIPATHI: Before anyone digs the

ground and pours the concrete.

MR. XI: Yes. Yes. If the sulfate content is higher than 60 PPM --

MR. TRIPATHI: Okay.

MR. XI: -- you use a Type 5 cement.

MR. TRIPATHI: Right.

MR. XI: That's --

MR. TRIPATHI: Does that eliminate this problem?

MR. XI: Yes. It will eliminate the sulfate problems.

MR. TRIPATHI: Eliminate the problem.

MR. POPOVICS: The sulfate problem.

MR. BERKE: Sulfate. But it's a magnesium problem.

MR. XI: Not the magnesium.

MR. BERKE: But you could if you have bad, a new construction is easy.

MR. XI: But now you have --

(Simultaneously speaking)

MR. BERKE: Yes. You get a sacrificial concrete property. It was an easy problem though.

MR. JONES: Sure.

MR. BERKE: On going, you might de-water

around it a little bit.

MR. JONES: Draw down the water table a little bit.

MR. BERKE: Yes, drop the water table.

MR. CHOWDHURY: Now if I understood correctly that monitoring the magnesium in groundwater monitoring would be an important part.

MR. BERKE: But I think most systems for groundwater, usually we'll measure sodium and magnesium and calcium contents.

MR. CHOWDHURY: Right.

MR. BERKE: Just because they got approvals on what we're supposed to drink. So it should be able to -- those numbers should be available.

But I think it has to be a fairly high quantity too, rather than small quantities. Slow, probably in the time span of 20 to 60 years is not going to matter. If it's a high concentration.

MR. JONES: Right.

MR. BERKE: Like this deicing solvent for or something.

MR. TRIPATHI: Are there any acceptance criteria that you know? You said high content.

MR. BERKE: Yes.

MR. TRIPATHI: Do you --

MR. BERKE: I mean I said for starters. Certainly what they use to test in ASTM.

MR. TRIPATHI: Yes.

MR. BERKE: It is below that number. And then I think they took the magnesium out of the testing, for some reason, about 15, 20 years ago.

But looking at what their current sulfate content is in the sodium, the magnesium is nowhere near that level. So it was half that level. So if you put it that level or below you should be okay.

MR. JONES: So magnesium is, you know, one of the ions. I think that maybe we have a few others.

There's acid situations that we're raising concern about. Hydrogen ion. Could we talk about that for a little bit? Is that --

In fact maybe we should even go back a little bit. But, with the acids, let me concentrate on that for that right now. Could we talk about how this affects the concrete and what the mechanism is, you know, and then we can engage in some of these others things.

MR. POPOVICS: Are --

MR. JONES: Does anyone care to jump in --

MR. POPOVICS: -- you talking about the

acid or the magnesium?

MR. JONES: Acid right now, since I've already moved us on.

MR. POPOVICS: Acid, sure.

MR. JONES: But magnesium I think we didn't really do a good job with that. So I mean we can circle back to that.

MR. POPOVICS: So acid?

MR. JONES: Acid.

MR. POPOVICS: Again, I think Hamlin's really well positioned to address this.

MR. BERKE: Yes, he is.

MR. POPOVICS: But, you know, acid counteracts base. And the pore water in concrete is basic very pH. So it undoes that.

So it puts into solution a solid product, calcium hydroxide, which is part of the hydration reaction. So it removes that there, increasing the porosity.

It's lowering the pH of the pore water system, which is bad, for protecting the steel. And also for the stability of the cement. The hydration products are stabile at high pH. When you lower the pH they are not stabile and they break down.

So acid attack has kind of a multiple bad affects. So it affects corrosion, increases porosity and it destabilizes the hydration products of the cementing agent.

MR. BERKE: Typically you if you're above, like five and a half it's not that bad.

MR. JONES: If the acid is above five and a half pH?

MR. BERKE: Yes. I mean it's only at the -- you have to be -- with the exception of some very bad ions.

MR. JONES: Okay.

MR. BERKE: So if we had phosphoric acid, even in a relatively high pH or an acid, it's highly aggressive. And some acids are much less aggressive, but it depends on what acid you have.

MR. JONES: Okay.

MR. POPOVICS: And probably also the exposure term. You know, long term or short term.

MR. BERKE: And if you have a abrasion, if you have wetting and drying of the acids sometimes it can be worse. This happens constantly.

MR. JONES: And that's the type to improve penetration.

MR. BERKE: Yes.

MR. JONES: The cycling sort of drives the ion.

MR. BERKE: Right. But the concrete itself will, you know, we cut all that aging process, this is neutralizing the acid around the outside of the concrete. So it's an issue if you have a lot of groundwater, there would be more acid in it or something.

MR. JONES: okay.

MR. BERKE: In an event it should seal after a while. Unless it's extremely acidic.

MR. POPOVICS: Or rain.

MR. JONES: The acid rain, right.

MR. BERKE: Well acid rain won't hurt concrete usually, unless it's pH three or four. But usually above four or five it's not.

MR. POPOVICS: In polluted areas --

MR. BERKE: Yes.

MR. POPOVICS: -- the rain can be quite acidic.

MR. BERKE: Oh yes. They have pH 2 in Italy in some places.

MR. POPOVICS: So.

MR. BERKE: 2.4.

MR. JONES: Okay.

MR. POPOVICS: It's real fitting by the pollutants, the SOx and NOx's compounds, they really push nitric acid, sulfuric acid contents up.

MR. JONES: Okay.

MR. POPOVICS: In the rain.

MR. BERKE: And the salt beds.

MR. POPOVICS: And the salt beds.

MR. JONES: So, this is all -- we should have done it before, but let's circle back to magnesium ion. How does that manifest? Is it a, it replaces calcium or is it -- can we talk about that just a little bit?

MR. BERKE: Yes, definitely replaces calcium in the structure.

MR. JONES: So how is that bad just from a --

MR. BERKE: Somehow weakens it. I don't know the exact mechanism, but the structure becomes weaker.

MR. JONES: Are we talking -- we're talking about calcium silica hydrate becomes a magnesium --

MR. BERKE: Yes.

MR. JONES: -- silica hydrate and --

MR. BERKE: Exactly.

MR. XI: And it decompose as CSH.

MR. BERKE: Yes. The magnesium version is not as hefty as the calcium is.

MR. JONES: Okay.

MR. BERKE: It's straight up calcium.

MR. JONES: Is there a volumetric component that goes along with it as well?

MR. BERKE: Yes, I think there is. It's in different sizes.

MR. CASERES: It's micro-cracking as the concrete expands, probably.

MR. TRIPATHI: Well, I'm a little bit confused now. About the magnesium, Neal, you said the ASTM or ACI --

MR. BERKE: ACI.

MR. TRIPATHI: -- they used to have, but now --

MR. BERKE: You still have the test method for sulfate resistance.

MR. TRIPATHI: And --

MR. BERKE: There used to be a combined sodium sulfate, magnesium sulfate solution.

MR. TRIPATHI: Right.

MR. BERKE: They basically kept the sulfate content the same, but they took out the magnesium.

MR. TRIPATHI: And for what reasons?

MR. BERKE: You know, that I don't, that I don't know. I mean I just thought it was strange that they took it out. Maybe because there was not a lot of magnesium attack in the U.S.

MR. TRIPATHI: Oh, I see.

MR. BERKE: With sulfate. But I mean that, say once again, normally you have a lot of different groundwater. If you're near Salt Lake City, perhaps you got a lot of magnesium in the soil. Evidently, you know, in most cases it's not as and as the sodium, but if it ever gets to the point where it's high, then you got --

MR. TRIPATHI: So it's a more local regional problem rather that widespread problem.

MR. BERKE: Yes.

MR. TRIPATHI: As far as magnesium goes.

MR. BERKE: Yes.

MR. TRIPATHI: Okay.

MR. JONES: So let me -- I guess we could potentially list some more ions, but let me jump ahead to a more general question. That is my third bullet.

What ionic criteria, so anything that's alpha earth metal I guess is potential for replacement. Transition metals perhaps as well, what ions, I guess, are we --

MR. BERKE: Well the ones that are going to be the worst are the ones that are like +2. So calcium is not going to hurt anything because you've got calcium there already.

MR. JONES: An abundance of testing, yes.

MR. BERKE: Sodium's not going to be replaced because it's a monovalent calcium, so it's the one that's preventing it out there. I hope you don't have any of the higher cations that are +2 in the salt water.

MR. JONES: Okay.

MR. BERKE: If you had those, and they also have a harder time with magnesium. And it actually infuses into the concrete easier because it's small.

MR. JONES: Okay.

MR. BERKE: So I mean it's going to be -- that's probably the key one.

MR. JONES: Okay.

MR. BERKE: The other ones don't matter. But the amount of the anions matter.

MR. JONES: Okay, let's talk about anions.

MR. BERKE: Things like phosphates are, well, even concrete are neutral. I mean, so phosphates, sometimes the ammonia, things like that. Those can have a lot of negative effects.

MR. JONES: Okay.

MR. BERKE: On concrete. Some type of perchlorates is extremely corrosive.

MR. JONES: Okay.

MR. BERKE: The concrete not so much, it's that constant, an acetic acid forming in sulfates that's --

MR. JONES: So are there -- you mentioned the criteria of anything that has a, you know, +2 balance can initially replace calcium, potentially. Are there other criteria on the anion side that we could, you know, look to to maybe spot an important one?

MR. POPOVICS: Any halite ion --

MR. JONES: Okay.

MR. POPOVICS: -- will promote corrosion.

MR. BERKE: Chloride --

MR. POPOVICS: So chloride is one, bromide will also. Halites you don't normally have a lot of bromide exposure --

MR. JONES: Sure.

MR. POPOVICS: -- but definitely -- any halite ion will promote corrosion.

MR. BERKE: Or halite-type like bio cyanide, cyanate or something like that. Not likely to have those.

MR. JONES: Okay.

MR. BERKE: Unlikely you have those.

MR. JONES: Unlikely yes.

MR. BERKE: Even if you have bromide or iodide, your diffusion of the concrete is substantially less the chlorides, so if you have chloride phosphates, it will lower --

(Simultaneous speaking)

MR. BERKE: -- before that, that is going to be your problem.

MR. JONES: Yes.

MR. BERKE: But that's more a corrosion problem --

MR. JONES: Yes.

MR. BERKE: -- than possibly a deicing problem, the scaling problem.

MR. JONES: Sure.

MR. BERKE: I just think that it's

chlorides --

MR. JONES: So the observation I've sort of made here is, you know, we have, and this is outside the Panel activities, but we have a few ions that we kind of look for. Chloride, sulfate, things like this.

But it occurs to me that there's maybe a larger set that could potentially cause problems.

MR. BERKE: Sure.

MR. JONES: And, you know, how much effort we need to put into that. I don't know if there's an answer, but we should be aware that there are other potentially aggressive ions that, you know, could be down in the soil or could come from rain. Things like this. So.

MR. TORRES: So this magnesium attack, does it manifest, say with a specific pattern cracking, or how do you decouple it from other mechanisms that might be --

MR. POPOVICS: It's usually a softening.

MR. BERKE: Yes.

MR. TORRES: Okay.

MR. POPOVICS: I mean in extremely cases I've read where you can excavate a concrete structure with a shovel, after magnesium attack, you can set down a cementing agent. It's cementing properties of the CHS. But that's an extreme case. But it's basically a softening, weakening.

MR. XI: So the strength of the concrete will be reduced.

MR. TORRES: So it will require some sort of core testing to identify the magnesium?

MR. POPOVICS: Probably. Yes. Extracted pore water or around the core.

MR. TRIPATHI: When you say strength of the concrete, we're talking about the, primarily compression strength.

MR. XI: Yes.

MR. TRIPATHI: Okay.

MR. XI: The, you know, the magnesium chloride -- the magnesium sulfate is worse than the sodium sulfate is because this compound can react with the CSH. So CSH glues everything together, provides the strengths. And the one thing about it is CSH agent is reduced so the strength is reduced a lot.

MR. JONES: Over a period of time.

MR. XI: Yes. The sodium sulfate only reacts with calcium hydroxide -- the CSH crystals. So it also reduces strength but not as much. That's why magnesium sulfate is the worst case.

MR. TRIPATHI: Also, can someone elaborate the fourth bullet on the left-hand side, the observation? It says, this mechanism is only tied to concrete transport properties.

MR. JONES: So that was me. I don't know that it's -- not that it appears to be the critical parameter from the concrete side in resting --

MR. BERKE: Well in the case of magnesium, it will actually attack, if you have real high magnesium contacts, because it reacts to CSH, it does appear with the porosity.

Meaning, what's making the low porosity is the good tight structure. It attacks that structure.

MR. JONES: Yes.

MR. BERKE: So that -- it will go fast if the concrete is more porous, but doesn't matter if the concrete's, it's actually a chemical effect on the concrete.

That's what the acid does too. The acid doesn't have the, fuse into concrete, it destroys the surface on the outside.

So that's what makes these things bad. Things like normal chlorides or sodium. They have to fuse into the concrete. That takes time.

You're just, you know, it's kind of if you're trying to get something to run through or something that dissolves the sponging outside. So you have something that is a sponge on the outside doesn't mean you have to make it into the sponge and cause damage.

MR. JONES: Yes.

MR. CHOWDHURY: It seems there's a larger set of acid, or ion attack, instead of one these sulfate or chloride ions. Does the panel have a recommendation about what other acid or ion attacks may be?

MR. POPOVICS: Well I think Neal mentioned phosphates.

MR. BERKE: Yes, phosphate is --

MR. CHOWDHURY: Phosphate is one?

MR. BERKE: Phosphate is probably one of the worse things. You can -- I mean if you got concrete tools you want to wash them off in phosphate solution.

And use that to dissolve concrete strong sugars. You know, which you're not going to have. But, you know, there are things that, you know, but things that might be present due to farming or something else.

MR. CHOWDHURY: Okay.

MR. BERKE: But varying, you might have

phosphates present. The same with some fertilizers.

MR. JONES: Yes, the chemical ammonium nitrate.

MR. BERKE: Ammonium nitrate.

MR. JONES: Is sort of a unique one.

MR. BERKE: And you could have, you know, and then if you have fog action going, you know, the bugs make formic acid.

MR. JONES: You're talking, micro --

MR. BERKE: Microbes, so you can make formic acid. And that's not a great effort.

But usually the pH has to drop on that. So if your soil is above five and a half, most of these things won't cause a problem. Phosphates can cause a problem. And ammonium nitrate can cause a problem --

MR. JONES: Okay.

MR. BERKE: -- at a higher pH.

MR. JONES: Okay.

MR. BERKE: But, you know, my guess is you don't have these around most of your sites. It's easy to test for.

MR. JONES: Sure. As a general comment we're sort of looking at the approach. You know, everything is --

MR. BERKE: So it's a good reason not to put plants around it and fertilize them.

MR. JONES: Okay, let me jump ahead a slide here. Anyone that's on the phone, we are on Slide 17 now.

Usually delayed ettringite formation was admitted specifically by title from the Panel, although it was sort of alluded to in, you know, sort of the way that sulfate attack was talked about. It, you know, could potentially have been considered to be DEF.

So I guess let me just sort of summarize what I observed. The sulfate phases are prevented from forming or curing, forming during the curing and then later, you know, reform as ettringite in some way.

And it appears to be tied to temperature somehow that the high temperature, usually encountered during steam curing or in a very massive concrete structure, is sort of what kicks this off.

And so I guess logically let's separate this from sulfate attack, which is where the sulfate ion comes from the outside and forms an ettringite crystal. And let's confine that to the naturally occurring sulfate that is in the cement that we, you know, purchase at our local Home Depot.

So let me ask my first, this general question here. Are any of the components, do we know, are any of the components steam cured, precast kind of things, that could be, you know, could have that temperature criteria met?

Or we would expect them to have a, maybe this question for you, Bob, do you know if --

MR. TRIPATHI: Well, I'm trying to understand your question here. Are any components precast.

MR. JONES: I would expect, like for example, the slab is not going to be precast, but maybe some of the --

MR. TRIPATHI: Right, right. But some of this horizontal storage modules, which it comes in three separate units. The base unit, the side unit and then the roof unit.

And I'm not quite sure if all of them are poured concrete or some of could be casting or precast rather.

MR. JONES: Okay. So there's --

MR. TRIPATHI: I'm not positive on that.

MR. JONES: So it's not a definite no but a maybe.

MR. TRIPATHI: Yes, there maybe some precast unit which they might ship it to the plant and then assemble it at the plant on the actual pad.

MR. JONES: Okay.

MR. TRIPATHI: As far as steam-cured, I'm not familiar with any of these storage units which are steam-cured.

MR. JONES: Okay.

MR. TRIPATHI: But there may be.

MR. JONES: Okay. So again, I jumped ahead of myself. Let me backup. This is -- I'll need to take this down, but let's talk about the manifestation of this DEF.

Does anyone want to speak to this? How it, you know, when you walk up, how would you identify the DEF degradation? How does it manifest in the concrete.

MR. BERKE: I mean you get cracking. Internal cracking. Because it expands.

MR. TRIPATHI: It expands.

MR. BERKE: It expands.

MR. TRIPATHI: Yes.

MR. BERKE: You get a monosulfate that turns into ettringite which has a much larger volume and also forms these needles that just causes concrete to crack as part of its entry process.

MR. JONES: Okay.

MR. BERKE: And that's where the degradation comes from. For new construction, in whether or not it's a large massive pour or re-stress where you would heat it, you flash the temperature. So it's very easy to control as far as --

MR. JONES: It stays below the --

(Simultaneously speaking)

MR. BERKE: -- stable 65 degrees C or 70 degrees C, depending on what your concrete is. But stable at 65. If you're not then usually you're not going to have -- it's not going to usually fall itself.

The problem that I think we have identified is that we have some locations in the canisters that can go above that percent, above that temperature. I think we have quite a few.

MR. JONES: Okay.

MR. BERKE: And they could potentially dissolve when concrete was made.

MR. JONES: Okay.

MR. BERKE: And then when it cools off, in 20 years or so, velocity goes back to expansive reaction. And then it would be okay if it did it in the same place where it was at. But it tends to travel.

MR. JONES: Okay.

MR. BERKE: It tends not to be dissolved in one place, if it came back in the same place, okay, It has the space to go into but it doesn't do that. It really ends up going somewhere else. So you will get cracking, but the hardest part is to see it.

MR. JONES: It's on the --

(Simultaneously speaking)

MR. CHOWDHURY: Regarding precast and steam-cured components, there is some positive efforts because they are mainly have better quality control than probably casting in the site. So there's some positive benefits there.

MR. BERKE: On the -- I don't think you'll get it from -- if you do it right, you won't get it in making of the material.

MR. JONES: Sure.

MR. BERKE: It's the exposure to the hot fuel canister inside of it that could potentially cause it.

MR. TRIPATHI: So the end result, Neal, what you're saying is that there could be some internal cracking, which are not detected --

MR. BERKE: Right.

MR. TRIPATHI: -- even while pouring this on site or --

MR. BERKE: Not so much on site --

(Simultaneous speaking)

MR. TRIPATHI: -- reaction.

MR. BERKE: Well you get it on site if you're not careful about the design. But I think you can build it without doing that.

The problem that will happen is, is when it heats up in use above 65, 70. Say it gets up to 80 degrees C in some place.

MR. TRIPATHI: Oh, okay.

MR. BERKE: That ettringite that formed in the initial concrete hydration process will dissolve, become monosulfate.

When it drops then below 65 degrees centigrade, thermodynamically it wants to go back, ettringite again. That's an expansive reaction. That's where the cracking comes.

Now it's all -- thermodynamically this all that occurs.

MR. JONES: Okay.

MR. BERKE: Kinetically, how fast it

happens, you know, depends on a lot of things. But the problem is it's going from hot to cold at some point.

MR. TRIPATHI: But these cracking, so called cracking, internal cracking that you're mentioning, are sort of hairline cracks? Or are we talking about like structural cracking might affect the strength of the --

MR. BERKE: It will affect the strength a little bit. That's one of the concerns. Because it causes micro-cracking of --

MR. TRIPATHI: Micro-cracking.

MR. BERKE: -- the distributing --

MR. POPOVICS: Distributive cracking, yes.

MR. BERKE: I mean like ASR.

MR. TRIPATHI: Yes.

MR. POPOVICS: Not unlike ASR.

MR. BERKE: Yes, not unlike ASR where it's distributed.

MR. POPOVICS: So it would be unlike -- you mentioned the structural crack where you have one localized crack because tensile stress is building up. It's not.

MR. BERKE: That will be a heavy load for that. And within that section there would be temperature change.

MR. TRIPATHI: Sure.

MR. JONES: You can tell me if I'm wrong, but some ASR you've got a volumetric expansion that's happening, distributed throughout the concrete. And so to relieve that volumetric expansion there's going to be some level of micro-cracking, mini-cracking, I don't know, some level of relieving of that stress through new surface formation.

MR. TORRES: So it seems like, from the description of the mechanism, it's likely that there will be a cold front moving as -- because you're going to have the inside surface of your outer pack much hotter, sometimes close to 150 degrees Celsius outside with the ambient temperature.

So as the canister cools down, it seems like that will have some sort of precipitation. I'm wondering if that will manifest in some sort of pattern cracking that would be identifiable from the outside or does it require core testing at potentially different locations within the wall?

MR. BERKE: You'll have to talk to one of your structural guys to find out if the shell around is thick enough to contain any cracking that takes place, maybe inside, four or five inches.

Because I guess the temperature of the packing is going to drop off. It won't get that high once you get -- you guys saw how far you got to get inside so when it drops below 70 degrees.

Once it's in that area that's never -- that's not going to get this kind of cracking. So the question is: is that enough concrete and steel over here to contain a little bit of cracking that takes place? That might not matter if it cracks on the inside.

MR. JONES: If that had been confined of only the surface, let's just say that there's sufficient sections --

MR. BERKE: Yes. Because the inside might just be there, you know. It might be lost and it might not make any difference.

MR. JONES: Yes. Let me ask a sort of blunt question. Has there been any -- so I think this is a really interesting theory, I think Neal brought it forward.

Has there been any, I'm thinking of maybe like an industrial application, have we seen this kind of thing where heat load induced DEF, in a structure, is there any evidence from another --

MR. BERKE: Well they've certain seen it from structures that were made too hot.

MR. POPOVICS: Yes.

MR. JONES: Sure.

MR. BERKE: So they had beams in Texas that went through, got well above the heat temperature. They went well above the --

MR. JONES: Yes.

MR. BERKE: -- and when they cooled down they formed the (inaudible).

MR. JONES: Okay.

MR. BERKE: Everywhere. I'm not sure of any cases that they actually had on it where the concrete goes into high temperature use. And they observed that when they used different types of concrete lots of times --

MR. JONES: Yes. So it sort of seems interesting because this critical threshold, 65, 70 C, is not so high that you're getting into deterioration of mechanical properties.

MR. BERKE: Yes.

MR. JONES: So it's, you know, potentially that there may be some -- I'm wondering if this, you know, occurred somewhere in --

MR. BERKE: Well if you stay in a heat spot.

MR. JONES: Sure.

MR. BERKE: It's coming back down to 60 that causes your problem.

MR. JONES: Okay. So DEF, we can, you know, we mentioned it on the salt scaling. We kind of skirted around it in different ways.

We asked them, how do we feel -- is this a, you know, is this a big potential show stopper or is this a relatively minor effect we think or I guess characterize the severity of this mechanism.

MR. POPOVICS: I would put it on the lower --

MR. BERKE: Yes.

MR. POPOVICS: -- lower end of the scale.

MR. JONES: Okay.

MR. BERKE: In addition --

(Simultaneously speaking)

MR. JONES: Lower end.

MR. TRIPATHI: For both short terms and long term obviously.

MR. POPOVICS: Compared to other mechanisms.

MR. TRIPATHI: Sure.

MR. JAMES: Understanding it's more of a worry during initial construction.

MR. POPOVICS: That's right.

MR. JAMES: Not with mature concrete, but --

MR. JONES: We need to protect the canister at the end of the day, probably --

MR. BERKE: Yes, it's very important in initial construction because then it's not just with the interior. You're going to get it everywhere.

MR. JONES: Yes. Okay. I'll hop us ahead one more here.

So the notion of thermal effects, you know, temperature causes a potential application for the DEF, which we just talked about, but there are other ways that the high temperature, moderately high temperature, can affect the concrete.

And one of those, I sort of called it thermal desiccation, you may have seen other phrases. And I think that that language was not used in the TIN Report. I think it was thermal dry out maybe or thermal something.

So I observed that temperatures, you know. Not high enough to, let's say dissolve the CSH or, you know, at least the gel water, but high enough where it could start to desiccate out the core water. Or is basically what we're talking about here. This drying could, you know, potentially be coupled with other mechanisms. That seemed to be a theme that came up.

And there's some potential that, you know, the differential thermal expansion or degrading it through the thickness. So two things, either, you know, with the regard to differential thermal expansion or just this gradient through the thickness could cause some sort of cracking, you know, if the conditions were right.

Let me ask this question. How do we usually see sort of these moderate temperatures manifest in a problematic way? The structures, Yunping I think had, you know, you commented on the ways to kind of freeze/thaw in, you know, your responses here about --

MR. XI: Yes. This has actually happened in water tanks I mentioned in my answer in Canada. So there are probably 40, 30 water tanks damaged in that way.

It's not surface cracking. It's inside. It's inside the walls. We cannot see from the surface. But that's related to, not just the thermal gradient, and also the moisture content.

MR. JONES: Also moisture content.

MR. XI: Yes.

MR. JONES: Okay.

MR. XI: The moisture content. So because the coefficient of thermal expansion of concrete depends on moisture content --

MR. JONES: Sure.

MR. XI: -- those are dependent on temperature. So under different temperature ranges and the CTE is different.

MR. JONES: Okay.

MR. XI: And sometimes there is a reversal. So let's see, everything expands, but concrete does not do that all the way when you cool the structure down. See it's going to shrink and then expand and everything depends on the mix design of the concrete.

MR. JONES: Okay.

MR. XI: So that's why -- let's see, so what happens in those water tanks similar to the dry cask.

MR. JONES: In geometry, yes.

MR. XI: Yes, in geometry. Inside -- so the inner surface is hot, the outer is cold. In the winter.

MR. JONES: Okay.

MR. XI: And then -- but the problem is that the inner concrete start to shrink at a certain temperature rate. But the outer temperature starts to expand. And then if you look at the radial direction there is tensile stress in the middle part. Somewhere in the wall.

MR. JONES: Yes, somewhere through the thickness.

MR. XI: Yes. And then you see -- so that's why there is a maximum happening in the wall.

MR. JONES: So --

MR. XI: And this may also happen in some of the containment structure.

MR. JONES: Okay. So that's the gradient issue, this thermal induced cracking. Let's talk about sort of the drying side of things.

Is that -- can we talk maybe on how that would manifest? We would say a liberation of some of the larger core water, which would -- I mean, dry cells, not necessarily, but what would come along with that?

If I can throw that question out to the Panel? Wasn't a very good question, but how did this manifest, is what I'm getting at. What would we see?

MR. POPOVICS: Shrinkage cracking, drying cracking.

MR. JONES: Okay.

MR. POPOVICS: And if you had sustained temperatures in the 60 to 100 C range, sustained temperatures. So you have a lot of moisture being driven out.

And the moisture is held at different kind of levels of strengths. Some are free to move and some are physically bound and some are chemically bound. And as you continue to sustain these temperatures, you're driving the water out that are held at these various strengths.

MR. JONES: Okay.

MR. POPOVICS: When you start moving the physically and chemically bound water, then you're making micro-structural changes.

MR. JONES: Okay.

MR. POPOVICS: Small micro-structural changes. Again, Hamlin is very well positioned to --

MR. JONES: Yes, but wanted to answer this question.

MR. POPOVICS: But there has been some research about the micro -- small porosity changes, capillary pore changes due to sustained temperature.

Because the water is being driven out, the structure kind of reorients a little bit.

I don't think it's a significant change in like -- it doesn't strengthen anything, certainly.

MR. JONES: Sure.

MR. POPOVICS: Porosity is increasing in the rearrangement. I don't think it's very significant.

The bigger problem is that if it's restrained, you have a lot of shrinkage stresses that are built-up, can lead to cracking.

MR. JONES: Okay.

MR. BERKE: Yes, I think that's the biggest problem is the shrinkage. Because we, you know, we've taken bridge decks and heated them up and dried the water out going well above boiling.

MR. JONES: Okay.

MR. BERKE: And once you're done with it the strengths are all back once you refill it with the water or whatever. It doesn't lose strength.

MR. JONES: Okay.

MR. BERKE: If you're not careful though you'll crack the pipe.

MR. JONES: So what, you say be careful,

what, you know, if we did apply --

(Simultaneously speaking)

MR. BERKE: -- in that case you're actually heating up on purpose. You have to cool it slow.

MR. JONES: Okay.

MR. BERKE: Cool it slowly so you don't, you minimize thermal stresses.

MR. JONES: Okay.

MR. BERKE: But drying shrinkage is always a problem if it's dryer on the outside then obviously it will shrink a little bit.

MR. JONES: Okay.

MR. BERKE: But I think the real problem is, as I mentioned, probably a little bit later on. If you're relatively low yield growth at the surface. In the ocean floors you have a big wave --

MR. JONES: Yes.

MR. BERKE: -- suck them up with the other portion.

MR. JONES: Right, bring into question ions potentially.

MR. TRIPATHI: Is this problem less or more where we have high humidity? You believe that's reasonable?

MR. XI: Yes. So when you have, let's consider a wall. So inside is hot and it's dry and the outside is wet, all with high relative humidity. So there is flow of moisture from outside to inside.

MR. JONES: So you have a moisture gradient --

MR. XI: Yes.

MR. JONES: -- that could drive transport. Also there will probably will be some stress associated with that gradient as well.

MR. XI: Yes, there will be some stress from the shrinkage strain. But the main, from what I have seen in the containment structures, is basically the moisture will drive in from outside, penetrate into the structure. So the outside surface will have a higher moisture content.

And then when the winter comes, the high moisture content will create, will freeze outside then.

MR. JONES: Because you have this sort of saturated outer layer --

(Simultaneously speaking)

MR. JONES: Yes.

MR. XI: Yes. You -- usually the thickness of the wall is not very big. For the residential structures, commercial structures. So the moisture is really is not big problem.

And also the temperature gradient is not big. But in the dry cask the inside and outside, the temperature is gradient is large. And also the moisture gradient is large.

MR. TRIPATHI: I agree that it's large, but it's not as high as in containment. You know, you refer to the containment structure.

MR. XI: Yes.

MR. TRIPATHI: Here you have a much higher thermal gradient then what we have in the dry cask storage. So there's much difference between -- and again, containment structures are ultra thick walls.

MR. XI: Yes, yes.

MR. TRIPATHI: You know, as compared to --

MR. XI: But you need to divide the temperature difference by the thickness of the wall. So that's a gradient.

See, if you do that, and the gradient in the dry cask wall is actually larger than the gradient in the containment.

MR. JONES: Because of the reduced thickness.

MR. XI: Yes.

MR. JONES: Yes.

MR. TORRES: Touching back on your operating experience here on the Canadian water tanks, was shrinkage cracking a precursor to this delamination and that's how it was identified or how was the delamination identified?

MR. XI: Okay, over there is different. Because in the water tank, the inside is not dry. the inside is all water. It's wet. So with a dry cask inside is dry, so there is a difference there.

MR. JONES: So your question remains, how did the --

MR. TORRES: Yes.

MR. JONES: -- how was it identified that this --

MR. TORRES: Was it through leakage or I mean of the structure. What, I guess, NDE was performed to identify the delamination?

MR. XI: Oh, yes. Yes.

MR. TORRES: Okay.

MR. XI: Just like in some of the containment structures in the U.S., they cut the wall. Drill, actually it's not, drill small hole. They cut a big opening. And then you can see it from the wall, is there delamination there.

And then the question is what is the mechanisms to cause delamination crack.

MR. JONES: But was --

MR. XI: So this temperature dependent CTE have been considered as a main driving force for the formation of the delamination crack.

MR. JONES: The discovery was sort of opportunistic though. They were --

MR. XI: It was opportunistic.

MR. JONES: They were drilling through it for something else and then noticed, oh hey, look here. Am I correct in saying that?

MR. XI: Yes. All the things that happened here --

MR. JONES: Sure.

MR. XI: -- seem to increase research in the field. Do not cut that big opening, nobody knows there's a delamination there.

MR. JONES: Yes, the --

MR. XI: You know.

MR. JONES: That's a complicated --

MR. TRIPATHI: So to summarize what you

just said that this a problem with the containment, but it's a bigger problem for dry cask storage because of the --

MR. XI: We do not know unless you cut.

MR. TRIPATHI: Well --

MR. XI: The probably --

(Simultaneously speaking)

MR. XI: -- ultrasonics. We can use ultrasonics to see if there's any delamination cracks in there.

Let's see, if you put a -- what is causing the problem tomorrow. So you have ultrasonic sensors inside and outside the wall and if there is delamination, and then that way a signal transmit time will be significantly deeper.

MR. TRIPATHI: But the end product will be shrinkage cracking, right?

MR. XI: No.

MR. TRIPATHI: Whether you cut a core or you do the ultrasonic, you will detect that shrinkage cracking. My question is, is this a big concern for the dry cask storage system or not, relative to the containment in the water tank and other structures?

I mean, you have seen our, you know, makeup of dry cask storage, vertical, horizontal.

MR. XI: Yes.

(Simultaneously speaking)

MR. TRIPATHI: -- and what have you. So what you're saying is it's unknown whether it's --

MR. XI: It is unknown.

MR. TRIPATHI: -- bigger problem or equal or --

MR. XI: It's unknown.

MR. TRIPATHI: I see.

MR. JAMES: My feeling is that the thermal gradiants on cask are in the design basis of the cask. And it's probably not a big problem at all.

MR. TRIPATHI: That's my feeling. But I'm just trying to understand the issue.

MR. JAMES: Concrete is going to crack, for sure, so through the design basis they're covered for that. For the casks. I don't know about specifics on the design basis, but I'm sure that thermal gradients are part of the design basis.

MR. TRIPATHI: Yes it is. And I mean according to the ACI 318 and 349, if they address this issue then it's definitely within design basis.

So, Randy, what you're saying is that it may be a problem, but probably from what you know about these dry cask storage systems, it's not a significant -- it may not be a significant problem too.

MR. JAMES: That's my feeling.

MR. TRIPATHI: Considered on its own. Okay.

MR. JONES: So that's the gradient side. And then we have the, sort of this desiccation itself. And that potentially couples with other mechanisms that may, you know, improve transport or that may, you know, make you more susceptible for an ion ingress later.

Do we want to talk about that at all? I think it's interesting that the warm side, the dry side, is on the inside, which, you know, seems like a sort of favorable orientation from that regard. But does anyone want to comment on that particular topic?

MR. POPOVICS: Well cracking has structural implication, which is what you're mentioning here, but it does also have ingress implication.

MR. JONES: Okay.

MR. POPOVICS: And that's probably a more important thing for the long-term requirements. But the cracking, if we have a lot of drying shrinkage, cracking would likely be on the inside where the heat source is and where it's dry.

MR. JONES: Okay.

MR. POPOVICS: And so the cracking is bad for ingress.

MR. JONES: Sure.

MR. POPOVICS: You know, but you expect that.

MR. JONES: That seems to be the better side to have, but, you know.

MR. BERKE: And it would be on that side because you also are hotter there so it's expanding. It's kind of interacting to shrink. But you got a thermal expansion on the dry and shrinkage.

MR. POPOVICS: Yes, but it's very dry --

MR. BERKE: Perhaps that's a --

MR. POPOVICS: -- right inside.

MR. BERKE: But still, you're -- it's also fairly hot. I mean if you want to talk shrinkage for when you're heating inside, if you crack outside it's, you know --

MR. POPOVICS: And again, these are reinforced structures.

MR. BERKE: Yes.

(Simultaneously speaking)

MR. POPOVICS: -- cracks are being held --

MR. BERKE: -- stay a certain size because of the design for that. So the only -- probably I think your only real problem on this that might act synergistically with any outside environmental --

MR. JONES: Okay.

MR. BERKE: -- you know, things that don't want there because it will make the concrete more willing to --

MR. POPOVICS: To ingress.

MR. BERKE: Ingress will --

MR. POPOVICS: Exactly.

MR. BERKE: And unless you're in a bad location, that's not going to matter.

MR. JONES: Okay.

MR. CHOWDHURY: Now the cracking of concrete is not new and it is what is widespread. And as Randy mentioned, those are covered mostly by the design basis.

MR. POPOVICS: The structural element.

MR. BERKE: They're not a structural problem.

MR. POPOVICS: Not ingress. We're talking about hundred year, you know --

MR. JONES: The idea I think is that you could, you know, increase the variability, increase the diffusivity, through this drying. And also through the potential formation of micro-cracks, and that could lead to a subsequent --

MR. BERKE: So through an industrial rain environment or a marine environment --

MR. JONES: Yes.

MR. BERKE: -- it's a potential problem.

MR. JONES: Potentially lead to a second -- and we'll cover it, we'll get to that in a specific slide later, but again, this is another one we can think about for potential coupling.

So let's jump ahead one more slide here. And I think we can probably get this one tackled and that will put us on good pace for our break in the subsequent half of the morning.

Creep, certainly individuals have made a career out of this issue for concrete structures that, the observations from reading through literature and, you know, panelists responses, the creep rate appears to be the critical parameter. So if you have a, you know, exceedingly slow creep rate, you know, maybe that's less problematic than if you have a very fast rate.

There's this concept of sort of a, whatever the mechanism of creep is in the concrete, the sort of an arresting of that rate to a certain load. But if you were to do a repair or change the load for some reason, that you might see a, you know, re-energization resuming of this creep.

It seems to me there that there's potential for coupling with other mechanisms on this one. So some apparent creep effects for moisture and drying, things like that.

And I think it's generally accepted, although maybe we want to debate that, that creep rate is going to slow with age. So you're going to see your, the majority of the time-dependent deformation early in the life of the structure.

And then as it goes along, you know, because of this sort of asymptotic effect, you're going to see less time dependent deformation later on the rate. The rate will slow later on.

So does that seem like I've characterized things more or less appropriately? Folks at the table here?

MR. XI: Let's see, you know, the creep depends on two time scales. One is age, another one is the loading period.

MR. JONES: Okay.

MR. XI: So let's say it's for a 40-year-old concrete, if you suddenly put on a load, the creep could be very large.

MR. JONES: Okay.

MR. XI: Let's say if you load it only for two months. So within the two months, the creep could be very large. Although it's old concrete.

MR. JONES: Okay.

MR. XI: So these are true and independent parameters, the age and the loading, the loading time.

MR. JONES: Right. So there's the coupling of the mechanisms themselves with the age of the concrete.

MR. XI: Yes.

MR. JONES: And then there's also the time spent loaded that of course defines the --

MR. XI: Yes.

MR. JONES: -- creep itself.

MR. XI: So this is exactly what happened on some of the containment structures. So once they cut the hole, they basically cut all the prestress tendons, and then there's the stress reversal.

MR. JONES: Okay.

MR. XI: And the creep is very large. And those are for large-span concrete bridges, concrete structures.

MR. JONES: Bridge girders, or something like this?

MR. XI: Yes. But this is under -- let's see, it's not investigation. It's help -- there's a big bridge, pre-stressed infrastructure in Poland collapsed. So the ones who saw is due to a creep, quantified of the concrete.

MR. JONES: Okay.

MR. XI: So it basically reduced the pre-stressed levels so finally the bridge collapsed.

MR. JONES: So you kind of addressed my first question here, do we feel like this is a significant degradation mode for these dry cask storage facilities? Certainly a long spanned girder is perhaps more exposed to it. These, you know, fairly blocky structures that sort of sit there.

MR. BERKE: Bridge structure is --

MR. JONES: So you --

(Simultaneously speaking)

MR. JONES: -- losing them, yes.

MR. BERKE: I think in a concrete cask they're, I think they must design for a certain amount of creep when you design it. I don't know what extra load you're putting on it other than what you start off with.

MR. JONES: Yes.

MR. BERKE: So I mean the pad might get extra load as you drop canisters on it, but basically I don't think creep by itself is going to be a major problem after a couple years.

I mean you'll see in the first couple years, the first year or two. And if you don't have a big problem in your first two years, it's probably not going to happen.

MR. JAMES: As long as you don't change the load on it.

MR. BERKE: Right, don't change the load.

MR. JAMES: And you --

MR. BERKE: I don't see how you're changing the load unless you got 20 feet of snow fell on it or something.

(Simultaneously speaking)

MR. POPOVICS: Yes. Creep needs sustained load. And I'd imagine that the design met the sustained high levels of load.

MR. BERKE: Yes.

MR. POPOVICS: Compared to its ultimate strength. And I just can't imagine that any design would kind of allow high levels of sustained load in your structure over the long term.

MR. JONES: Yes.

MR. POPOVICS: You know, if you have -- but the structural life.

MR. CHOWDHURY: Yes.

MR. POPOVICS: If you have that case, then creep could be a problem. But I'm kind of --

MR. CHOWDHURY: Yes, and let me ask it in one question.

MR. POPOVICS: Can't imagine it.

MR. CHOWDHURY: If you apply certain amount of sustained load to a 60-years-old concrete versus 2-years-old concrete, would that degrade the same?

MR. POPOVICS: No. But I think it --

MR. XI: No, it's different.

MR. POPOVICS: Yes.

MR. XI: As I said, there are two independent parameters, one is age.

MR. CHOWDHURY: Yes.

MR. XI: So if your load, the same loading period, let's say one year.

MR. CHOWDHURY: Yes.

MR. XI: But this is 140 years old, the other one is only 2 years old. So the 2-year-old concrete will have a lot more creep.

MR. CHOWDHURY: Okay, that means, for long-term, the creep may not be a problem because none of it take place in the other years.

MR. XI: Unless you reverse the load and suddenly there is an overload. If the sustained load, keep it as a constant, and the answer is yes. After 40 years it's not a big deal.

MR. BERKE: You can have a sustained load just from the height of the canister.

MR. XI: Yes.

MR. BERKE: That's your pre-creep. As long as you're not putting any extra weight on it.

MR. JONES: But is it high enough compared to the designed strength of the slab?

(Simultaneously speaking)

MR. BERKE: -- and if you have a creep problem it's going to pop up early. But you don't see it right -- if you don't see it in the first year or two, probably in the first year, you're not going to see it.

MR. JONES: So that leads us into a question then, do you feel that the, I guess standard design techniques, I'll just use that in the general sense, are adequate for addressing creep issues or, you know, certainly you mention a bridge falling down, that would suggest that, you know, maybe they're not.

MR. XI: Well that's a special case. That's --

MR. JONES: A special bad case.

MR. XI: -- in Poland it's a large span --

MR. JONES: So that's --

MR. XI: -- concrete. And this will be -- neither of them, I don't think that's a problem.

MR. JONES: So I guess I guess there's evidence of, you know, maybe prestress loss, for example, being higher than what was predicted at investigations. You know, later into the life of the structure.

Which would suggest to me that maybe we don't understand creep as well as maybe we think we do or is that -- I don't mean to speak for the panelists here, but I'm asking the question, do we feel like generally it's well enough handled by the design methods?

MR. JACOBS: In this application or?

MR. JONES: I'm speaking generally. And then a subsequent question is what you alluded to. You know, for this application, do we feel fairly comfortable to --

MR. JAMES: I don't think creep is a degradation issue. But I don't think it should be ignored if you're looking at the functional, you know, assessment of a structure. Because it does play a role in --

MR. JONES: Yes.

MR. JAMES: -- what happens structurally and functionally for that structure.

MR. JONES: I tend to agree. I think it gets lumped in because of it's kind of a signature and so, you know, so it gets associated for -- yes, I agree, it's distinct from some of the other mechanisms. So maybe is the answer from the previous question.

MR. CHOWDHURY: Yes, in the prestress concrete, the importance of creep is rarely coupled with the loss of prestress.

MR. JONES: Yes.

MR. CHOWDHURY: That is a big factor.

MR. BERKE: Yes.

MR. CHOWDHURY: Now in this case, that kind of inspection --

(Telephonic interference)

MR. CHOWDHURY: -- discussed.

MR. JONES: Yes.

MR. CHOWDHURY: So this is very different from the --

MR. JONES: It is, sure.

MR. CHOWDHURY: -- these structures.

MR. JONES: Sure.

MR. CHOWDHURY: Is there reason to be concerned in this situation?

MR. POPOVICS: My feeling is that the structural engineers are best positioned to handle that. I don't see it being a big problem.

MR. CHOWDHURY: I don't see that.

MR. JONES: Okay.

MR. BERKE: Now they had to do the original design model on it.

MR. CHOWDHURY: Yes.

MR. BERKE: They had that problem --

MR. CHOWDHURY: Right.

(Simultaneously speaking)

MR. TRIPATHI: Well as Randy said, as an expert in structural engineering, if you don't see it in the first couple of years, you might as well assume that the creep is not going to be a problem beyond that.

MR. JAMES: Yes. Unless you change the load on your structure later.

MR. CHOWDHURY: Of course. Of course.

MR. JAMES: You know, previous --

MR. CHOWDHURY: If you have sustained a high load --

MR. JAMES: -- you know, it goes up and you take the load off, it comes down and it should act to your --

MR. TRIPATHI: Yes, when there's a reversal.

MR. JAMES: -- your creep rate.

MR. CHOWDHURY: But still, the rate will go down as the years are becoming larger.

MR. JAMES: Not if you change the load. You get back to primary creep.

MR. CHOWDHURY: Yes. But primary creep is still, slow down as it is -- the concrete it getting older and older.

MR. POPOVICS: Yes, the material's ability to creep goes down with age.

MR. XI: Yes. With increasing time.

MR. POPOVICS: But of course there's loading.

MR. BERKE: Which makes it pucker up.

MR. XI: Well actually from that point, creep has some positive effect. It can release those stress concentrations.

MR. JONES: Yes.

MR. XI: So either is this creep law of crack is achieved if the materials can creep a lot in the release --

(Telephonic interference)

MR. XI: So that's the benefit.

MR. TRIPATHI: So other than what Neal just mentioned that maybe 20 inches or 20 feet of snow, like they had in Boston, if it's a sustained high load, you don't need to really worry about it.

And I mean I would not expect any other sustained high load on these storage systems sitting out there.

MR. JAMES: Well you're not going to stack one on top of the other --

MR. POPOVICS: Well yes.

MR. JAMES: -- for example.

MR. TRIPATHI: Say that again?

MR. JAMES: You're probably not going to stack one on top of the other for any reason.

MR. BERKE: Yes, you just know not to let that happen. That's not allowed, you're fine.

MR. JONES: And I'll note that just for a minute, if anyone on the phone, if you're phone is not on mute that be great if you could press that button and make it muted. Thanks.

And so there's this issue of timescale. So you get a large snow load but then the snow, we presume, it will be off in days. But seems to be much, much shorter than the timescale we're usually talking about for these creep effects. So.

MR. XI: Yes.

MR. JONES: So we've covered five mechanisms. Three that were in the TIN Report and two that weren't. Reverse that. Two that were in the TIN Report and three that were not.

So I just wanted to sort of summarize here briefly, what we've covered. That is salt scaling, which was not covered in the TIN Report.

Acid or aggressive ion attack, which was not specifically identified in the TIN Report but was in specific cases.

Delayed ettringite formation similarly was not addressed as a separate mechanism by itself, but was in a way through sulfate attack.

Thermal desiccation or dry out and creep were both mentioned in the TIN Report and addressed somewhat.

So that covers the, I guess the first half, of the degradation mechanisms. We're a little bit ahead of schedule and I wanted to sort of take that time to sort of talk about these five mechanisms in whole.

Of these five, what are the panelists opinions on what are the tall tent poles among of these five, what would you be most concerned about, from a significance standpoint for degradation of those five?

So salt scaling, acid ion attack, delayed ettringite formation creep and then thermal -- dry out thermal desiccation.

MR. POPOVICS: I would vote the aggressive ion and acid attack. Just because it may not happen, but if it does --

MR. JONES: The potential consequence is

quite high.

(Simultaneously speaking)

MR. BERKE: Yes, I agree on with John on that one.

MR. JONES: Okay.

MR. BERKE: If you had to pick the one that I had to be most concerned about.

MR. JONES: Okay.

MR. BERKE: It's also the one you can't see if it's underneath the ground.

MR. JONES: So yes, the fact that a lot of the ions are groundwater transported --

MR. BERKE: Yes, it could be.

MR. JONES: -- tends to --

MR. JAMES: It seems like salt scaling is very similar to freeze/thaw damage. I'm wondering if freeze/thaw damage would kind of cover any degradation mechanisms that occurred from salt scaling.

MR. JONES: I agree. I think that they are similar and the manifestation is near identical. So, you know, maybe it matters not as much what would cause it, but, you know.

MR. BERKE: It can't be freeze/thaw durable but not be salt scaling durable.

MR. JONES: Okay, so that's --

MR. BERKE: Now if you, you know, but if you have freeze/thaw damage, you don't have to worry about the scaling attack because that will be -- that will override it.

MR. JONES: Okay.

MR. BERKE: But you can't --

MR. JAMES: But you can have salt scaling damage without freeze/thaw damage?

MR. BERKE: You can be -- you can pass a freeze/thaw testing and not pass scaling. Usually, the scaling usually requires a little bit quality of concrete. A little bit stronger maybe for freeze/thaw.

MR. JONES: So we put acid ion attack at the top of the list. Would be put all the others together in sort of a lower, less important, category or is that -- is there a ranking that you can observed, panelists? I mean maybe that's not even useful, but if they're all very low significance. But.

MR. POPOVICS: I don't know if I'd rank any of them insignificant.

MR. JONES: Okay.

MR. POPOVICS: I mean if I had to pick one that was insignificant, I personally would pick creep.

MR. JONES: Okay.

MR. POPOVICS: But --

MR. JONES: Because of design floor?

MR. POPOVICS: I just did this application.

MR. BERKE: In this case. Yes.

MR. POPOVICS: In this case, right.

MR. BERKE: Right.

MR. POPOVICS: Because I imagine that design covered that --

MR. JONES: Okay.

MR. POPOVICS: -- in any realistic situations. The other ones are, you know, not insignificant but also less significant. I would lump them all together.

MR. JONES: They're not keeping you up at night basically.

MR. POPOVICS: Yes.

MR. JONES: Okay. It doesn't have to be a consensus, but I see a lot of heads nodding, you know. Okay.

Well, let's take this opportunity to break for just a little bit. We're ahead of schedule by about, little less than ten minutes.

We'll go ahead and resume at the previously scheduled time of, let me make sure I get that right, 10:30. So that gives us, you know, several minutes to go to the restroom or get a coffee or whatever.

So we'll be back in here a little bit before 10:30 and then kick off then. So thanks everyone.

(Whereupon, the above-entitled matter went off the record at 10:08 a.m. and resumed at 10:32 am.)

MR. JONES: So I hope everyone got a chance to sample the delicious NRC coffee. Chance to get up and stretch your legs.

We'll resume our discussion of degradation mechanisms.

MR. JAMES: You need a gavel.

MR. JONES: I need a gavel is what I need. I'll bang my Altoid box maybe. For anyone on the phone, this is the Concrete Expert Panel Discussion hosted by the NRC, if you've dialed into the wrong number. I don't know how you got here, but --

If you all on the phone, if you can mute the phone so we can, you know, not hear your music in the background, things like that, that would be good.

So we spoke at the first part of the morning about degradation mechanisms. We'll spend the second half doing the same thing, although we'll talk about different degradation mechanisms.

We covered, I guess just by way of summary, covered the issue of salt scaling, the issue of acid or ion attack, the issue of delayed ettringite formation, the issue of thermal desiccation or dry out and then creep. Which is the slide that's on the screen right now.

We'll go ahead and jump ahead to the big bad boogeyman, alkali-silica reactivity. This is Slide 20 for anyone on the phone probably, on the slides.

Similar to before we have this sort of construct of observations on the left hand side and questions on the right hand side. And so we have observed that ASR has received a good bit of attention.

The Seabrook Plant has, you know, brought that forth to the NRC. And then also numerous transportation structures, airport pavement, things like this, have experienced this issue. And so it's an issue that on the one hand I think is well, maybe I shouldn't say well understood, but better understood than some of the others.

But it's also a bit of a bigger issue because we've seen it a few more places. And so I think there will be some good discussion here.

I wanted to mention that there's ongoing NRC sponsored research at NIST up in Gaithersburg. And there has been much research over the years. Various DOTs and Federal Highway, things like this, have sponsored projects over the years.

You going to close the doors Greg? So maybe let's just start with a quick general question.

Can I ask the Panelists, can we talk about how ASR typically manifests? How would be see the degradation mode present itself in a concrete component or structure?

MR. BERKE: We'll see map cracking. So it will look like, you'll see a lot of cracking where almost looking like a map. And you'll see sometimes a gel coming through that.

MR. JONES: Okay.

MR. BERKE: So that's, you know, if you see that it's pretty severe at that point. So that's basically how it will, overtime, it will manifest itself like that.

MR. JONES: Okay.

MR. BERKE: Initially you can look at cores, you can see -- you might a crack aggregate here.

Usually you'll crack right through the aggregate.

MR. JONES: Okay.

MR. BERKE: The face of it there. So you'll see that. You might see a gel around some of the aggregates before you see cracking in the concrete.

So you can the early signs of it, potentially, in a core. But if you get the whole overall map cracking, which you might see on an old dam wall or some very old structures. Typically, you know, it's like 20 to 40 years before you start seeing the real bad results.

MR. JONES: Okay.

MR. BERKE: So it's inside something that happens on day one, unless you have a -- you know, you'd have to have everything against you to have that. So usually it shows up slowly.

MR. JONES: Okay. So there's a longer time horizon on this.

MR. BERKE: Yes. And I guess that's the easy thing about the aggregate. I know you got a question here, but you know, you can probably detect it in, you know, if it's going to be a problem and weren't doing something on what you got in there already.

But, you know, this is something that

prevention is the biggest way. You screen your aggregates before you do anything.

MR. JACOBS: Yes.

MR. BERKE: Make sure you don't have aggregates that could be a problem.

MR. JONES: Okay.

MR. BERKE: And you can modify your concrete design too.

MR. JONES: Okay.

MR. BERKE: But the best thing is just not to use bad aggregates. You work several bridge projects and, you know, they'll ship aggregates up from somewhere else.

MR. JONES: Okay. I hear some mm-hmms and amens from this side.

MR. JACOBS: The expansion, like the DEF you were talking about, this addition of the gel. Again, there are ways to rapidly or screen the aggregate.

MR. JONES: Right.

MR. JACOBS: Again, the example I know is there were concrete ties, concrete railroad ties in Metro North in New York that baffled a guy like this.

MR. BERKE: Well it's all fun fortunately.

MR. JACOBS: Yes.

MR. BERKE: The railroad tie at DEF and ASR for each --

MR. JACOBS: Yes.

MR. BERKE: -- demand compensation figures from each other for all that took place.

MR. JONES: Yes.

MR. JACOBS: But it was, again, it was an aggregate. There's a loss here, but again, what's that.

MR. BERKE: Well that one ended up kind of getting settled for --

MR. JACOBS: Okay.

MR. BERKE: -- yes, $100 million on legal fees, $100 million on --

MR. POPOVICS: Per tie, yes.

MR. JONES: Per tie. Undetermined report of per tie, so.

MR. CHOWDHURY: So does the reactivity increase with time? The reactivity.

MR. BERKE: Well usually it takes some time to manifest itself to the point where you get this massive cracking in the concrete. But you'll see it within, you know, you'll see signs of it taking place relatively early if you do a -- take a core and do petrography on it.

MR. JACOBS: You can see it with the petrography.

MR. CHOWDHURY: Yes, okay.

MR. JACOBS: Because of the gel.

MR. BERKE: Yes. So you can see the signs. But it takes a while for that to manifest itself where you got the general cracking.

And sometimes it might not, other than looking bad, it's not always -- mean that, you know, it doesn't always result in a lack of function.

MR. CHOWDHURY: Okay, so structurally it is not -- it doesn't have significant negativity if --

MR. BERKE: No, it can.

MR. JACOBS: Yes.

MR. CHOWDHURY: It can?

MR. BERKE: It depends, once again, depends on the particular structure and the loading on it. So sometimes it's perfectly, you know, it's there, it looks bad and the structure is still functional.

And sometimes it doesn't look quite as bad and the structure loses some of its function. It's all on the structural engineer to determine how, you know, whether or not it's going to cause that kind of problem.

MR. JONES: So maybe let's take just a

second here and talk about, maybe from a fundamental standpoint. So we have a potentially susceptible aggregate, which is siliceous phases, silica phases, that in the present of the high pH, concrete can actually dissolve silica ions.

But the silica ions combine, in some sort of way, with the alkali, also present. Although can also be transported in to form some sort of gel that wants to imbibe water. And then in so doing expands.

MR. BERKE: Expands, right.

MR. JONES: And so you have sort of, you know, a three sided thing. You've got to have the silica, you got to have the high pH and you got to have moisture to drive the expansion.

You know, in other words, if you take away the moisture, for example, you don't get the expansion. If you take away the silica you don't get the --

MR. BERKE: If it's dry you're not going to have a problem.

MR. JONES: Okay.

MR. BERKE: By definition.

MR. JONES: So --

MR. XI: So this way, sometimes if the structure stays there for 30 years under dry condition, nothing will happen? In terms of ASR.

MR. JONES: Yes.

MR. XI: But suddenly the structure is wetted, as you mentioned stable, that's the case.

MR. JONES: Yes.

MR. XI: And then with a high content in the moisture, you see a lot of damage. Suddenly.

MR. JONES: Okay. So --

MR. XI: So this is to answer a salt question. So the whole structure can see suddenly accelerated ASR because of the change of moisture content.

MR. JONES: So I guess, let me ask my first question, which is perhaps the most controversial and open-ended. Can we competently exclude aggregates through aggregate testing?

Do we feel that the state of aggregate qualification is adequate to say we will not have a problem?

MR. JACOBS: No. I mean I think it takes time, you know, to really quantify the aggregate, right. Because you have to wait. It's accelerated test, but it still takes time.

But yes, I think, you know, they do the ASTM standards and put --

MR. BERKE: Yes, mostly the accelerated test are trying to give you a false positive rather than a false negative.

MR. JONES: Okay.

MR. JACOBS: I think that's a good example.

MR. JONES: Okay.

MR. BERKE: So if you pass, almost like a freeze/thaw test. If you pass freeze/thaw you're probably going to be okay because the test is more severe.

MR. JONES: Okay.

MR. BERKE: Than anywhere other than maybe Treat Island. And the same thing goes with the ASR aggregate test.

The accelerated testing, especially if you take the ASTM test, which I think is like 14 days. If you extend it to 28 days, and you pass that, you're pretty much going to be okay.

MR. JONES: So it's the, I guess for more context, two more of our methods. Which are the accelerated. And then there's the bigger one, the prism that takes --

MR. BERKE: Yes, prisms takes a year.

MR. JONES: -- a year or --

MR. BERKE: One to two years, depending on what you're trying to do. And then there's -- you can modify, you know.

And as an added insurance, you can add a fly ash or a silica fume or slag to your mix. As long as it's Type F fly ash. Or a lot of C.

But I mean, so the right, you know, so that can also give you an extra margin of safety.

MR. JONES: Yes.

MR. POPOVICS: So I think there's, you know, the accelerated tests are accelerated because once a year. The year test is more reliable.

MR. BERKE: Right.

MR. POPOVICS: Accelerated test is less reliable, but more reasonable in terms of timeframe.

MR. BERKE: I think the accelerated test will fail things that will pass on a lot of stuff.

MR. POPOVICS: I think that's fair. It's a concern --

MR. BERKE: So if you're real anxious to fill -- you have to do something now, you can't wait a year, yes, use the accelerated test. If it's average, then you have to brought it from somewhere else, it's going to cost you extra money, you'll run the one, and you have the time, you'll run the one year test.

MR. JONES: Okay.

MR. BERKE: Because, you know, if you can save $5, $10 a ton on your aggregate you want to do that.

MR. JONES: Yes.

MR. BERKE: But basically the accelerated tests are designed, especially if you extend the time on the running of them just a month to, you know --

MR. JONES: There's a certain --

MR. BERKE: -- really bad --

MR. JONES: -- sort of conservatism in the --

MR. BERKE: Yes.

MR. JONES: -- break. I thought maybe you were going to --

MR. JAMES: I guess I'm a little less confident about us being able --

MR. JONES: Okay.

MR. JAMES: -- to rely on testing, given the timeframes we're talking about. Three hundred years is a long time.

And at the time Seabrook was built, as I understand it, it passed all the ASR testing at that time. And it those tests weren't quite predictive of longer terms ASRs.

So I'm just a little worried --

MR. POPOVICS: Yes.

MR. JAMES: -- that we're not confident on testing ahead of time.

MR. POPOVICS: Well that's -- I mean the ASR test doesn't, if you pass, it doesn't mean you don't have ASR expansion.

MR. BERKE: No.

MR. POPOVICS: It means you're at a lower level.

MR. BERKE: Lower level of it.

MR. POPOVICS: Now over the long-term, how long is the term needed to cause some damage.

MR. BERKE: Yes.

MR. POPOVICS: Well I guess if you test -- expose it long enough --

MR. JONES: Within the 300 year horizon we're potentially getting in there.

MR. BERKE: Well you also have to see where you are in the test method. If you're right at the -- I mean if you're at the bottom where nothing's happening, you'd feel a little bit better than if you're right at, you know, you're right just passed.

Okay, so something like this, you don't want to just pass maybe. And I think, you know, and I don't know, I have no idea what the original ASR testing was for Seabrook, so I don't know if they just passed or they pass, you know, pardonably.

MR. TRIPATHI: So the answer to the first question on the right hand side is no?

I mean we are talking about excluding this problem. And even if you do testing, what you're saying that all the tests at Seabrook they passed, and still we had a problem.

So by doing more testing or accelerated testing, we cannot completely exclude this problem. Correct?

MR. JAMES: That's kind of my feeling given 300 years of, you know, life on these casks that you're looking at.

MR. POPOVICS: But the technology at the time of Seabrook testing may not be that --

MR. BERKE: I think we're a little --

MR. POPOVICS: But the question really is, it depends.

MR. BERKE: Right.

MR. POPOVICS: Depends how long --

MR. JONES: If we use a limestone aggregate probably.

MR. POPOVICS: How bad is the aggregate. You know, even though it passes --

MR. JONES: Right.

MR. POPOVICS: -- how long was your design on it.

MR. BERKE: Yes, I don't think accelerated tests weren't around when Seabrook was built.

MR. JONES: Yes.

MR. BERKE: The other thing is -- the question is, if you pass today, you know, if you got a large project, the quarry is big. You can have one part of your quarry that's perfectly okay, you just go -- you'd be further down.

MR. JONES: Yes, some mineral opportunity.

MR. BERKE: And now you've got a totally different behavior. So you just can't test and say, boy I'm all done. You got to -- every time you go into a new section, you have to do the testing again.

MR. JONES: Yes.

MR. TORRES: So there's core testing done for design basis when the system first comes in the house? Right now there is no requirement from us to do periodic testing.

And so that seems to be something that there's agreement here or there needs to be some periodic testing for aggregate reactivity. During this time.

MR. XI: I agree. I should make your requirement. So they already mentioned the test done 40 years ago for Seabrook and then for also other concrete structures.

The freezing method is totally different. I'll give you one example. For example, the freeze/thaw test.

So 40 years ago it was 15 cycles. But now ASTM is a 300 cycle. There is a huge difference. So that's why they may pass the test 40 years ago, but if you use a current standard, the result may be different.

MR. JACOBS: I think you asked a slightly different question. I agree with you, but I think you asked a slightly different question.

If you have a system in place now. The test we're discussing are either you have to build a mortar bar or a prism, right. It's not a core.

It's not like you're going in and pulling out an existing structure.

MR. XI: Yes.

MR. JACOBS: You know, that's a different set of tests to say you're looking at is, you know, do you have ASR.

MR. BERKE: You can do that. You can take a core --

MR. JACOBS: Core.

MR. BERKE: -- make a prism out of it --

MR. JACOBS: Yes.

MR. BERKE: -- or put pins on it and test it -- do the same type of testing. Core petrographic.

MR. TORRES: So considering the --

(Simultaneously speaking)

MR. TORRES: All right. Considering that the systems are temperature -- the thermal gradient across concrete, what was the reasonable area to first start looking at?

And then, you know, what general concentrations should we think about? And this might be something that we discuss in the next session.

But if the licensees perform core testing, is it sufficient to do it on the outside wall? And then supplement --

MR. POPOVICS: Well I think you should do it where there's moisture.

MR. BERKE: Yes, where there's moisture.

MR. POPOVICS: So if you're on -- one side of the facility is closer to a body of water, some of them have poorer drainage, some of them have higher water table. Water is the key for a lot of mechanisms.

So I think anything that's damp more often than dry, would be the one that could be more susceptible. Regardless of the internal material.

MR. BERKE: The other thing you need to look at, in addition to the aggregate, is your alkalinity of your cement and how much cement is there. So I mean typically nowadays, if you're worried about, you'll build a low alkali cement along with an aggregate that passes.

And if you pass aggregate in one cement that's not the cement you're using at your job, you might have -- typically you try to use the same cement that's going to be used in the job.

MR. JONES: Is cement content important factor or are they all --

MR. BERKE: Well both. I mean if you have a high alkali cement it might still be useable if you have very little of it there.

MR. JONES: Okay.

MR. BERKE: Because then -- but usually you're going to have a certain amount of cement. And the more alkali content -- higher alkali content in the cement, the higher the alkali content in the concrete.

Now there's a new testing coming up that tests the alkali content that's, you know, that's very high. And even the prism test tests at 1.4, over one percent alkali in the cement.

They actually add sodium oxide to the cement to get the alkali out. If you have a low alkali cement, you're in a much lower alkali level than that, you might not, you know, use it.

So if you have aggregate to test on the low side and you have a low alkalinity system, then you can make the system lower. There's a new ASTM method for adding pozzolan cement. Supplemental cement. They're just materials.

MR. JONES: Specific with ASR issue?

MR. BERKE: Specifically with ASR issues. So you take the cement, you mix it up. Cement pozzolan mix that you're going to use and you test the aggregate in that.

So that's typically used if you have a

marginal area and you're trying to get it to come through. But I mean it will definitely help on a good aggregate if it passes.

MR. JONES: Okay.

MR. BERKE: It will just give you an extra margin of safety.

MR. TORRES: Given the timelines of evolution of this specific topic --

MR. JAMES: You mentioned core samples on existing dry cask storage systems where you -- I don't think it's necessary to go just start testing existing systems with core samples. I mean if that's what you were implying.

MR. TORRES: Yes.

MR. JAMES: If it's there it's there. I don't see there's a reason to go start core testing, you know, existing systems.

I mean you can wait until you see some outward signs, if it ever develops, and then, you know, maybe do more testing. But I don't think there's any reason to go make all the existing systems start doing core samples.

MR. POPOVICS: Unless you had a core for something --

MR. TORRES: Not all systems. But should there be any to do -- look at the worst case scenario and use some petrographic examination. And it need be to one extent conditional elevation.

And then -- but not just look at once, once there's cracking. Is there a need to look at certain periods --

MR. JONES: So you're asking sort of a hypothetical question. If you took what you thought to be the worse ASR susceptible corner of one of the casks and took a core then would there be utility in doing a petrographic analysis or other testing on that --

MR. TORRES: Yes.

MR. JONES: Am I characterizing your question correctly?

MR. TORRES: Yes.

MR. BERKE: I think it would make sense if all those things were casked at about the same time.

MR. JONES: Okay.

MR. BERKE: But if you had one concrete system put in this year and next year you had another fuel thing, if you brought another one out, it's not the same concrete anymore.

MR. JONES: Mainly tied to the aggregate

issue --

MR. BERKE: Yes. It could be different. The cement can be different. There's -- so I mean unless you know that the aggregates are the same and the cement alkali contents and quantities are the same, you can't necessarily make that.

MR. JACOBS: What would you do with that information? I think it's going to be important to tie it back to the performance of the component.

And the question with ASR is, where are you along that timeline? Where are you, you know? And you don't really know, you know. You just got incident time.

And so how is, you know, in a way the core is going to be more detrimental to the performance of the component then. You know, and the information you can get about, specifically ASR.

MR. TRIPATHI: That brings us to the second question. Does it affect the structural performance, ASR?

And if the answer is no, then no matter whether you take the core or do, you know, accelerated testing, it doesn't matter. If it does not affect the functional requirement from the structural point of view. And what you're alluding is that probably not.

MR. JACOBS: Again, I'm saying in this particular application you might do more damage with the core then you would --

MR. BERKE: Before you see the map cracking on the surface.

MR. JACOBS: Yes.

MR. BERKE: You haven't developed enough ASR damage, necessarily, to compromise the structural quality. Maybe you did, but you probably haven't.

So if you're taking a core just to look at that, that's kind of -- I wouldn't do that. But if you're taking a core to look at some other things, you might as well look at as many things as you can. Once you take a core.

So if you're taking a core for strength, take a piece of it off when you're done. Look for ASR, look for chloride contents, look for DEF, look for everything, you know, at that point.

MR. JONES: So that's sort of a best practice kind of.

MR. BERKE: Yes.

MR. TRIPATHI: You're doing a visual screening. If you don't see this kind of map cracking, then it's safe to assume that you don't have this ASR problem?

MR. BERKE: No, it's safe to assume you don't have a -- it's not serious yet.

MR. TRIPATHI: Serious yet.

MR. JACOBS: We're again, you're on a timeline. And I think that timeline is, you know, very long, at 300 years.

But I also think, from a structure -- let's take the concrete ties. Those are very highly loaded. You know, the stresses in those are incredibly high.

Again, are you getting those kinds of stresses in this particular structural system? And I think we've -- I think the answer is no. Right?

This is not my area but you all tell me. I mean this is --

MR. JAMES: Well I guess my experience is if you start taking core samples, you've figured out you've got some problem that you need a lot more information on. You don't generally take core samples as a probe to try to look for information, right.

MR. JONES: Yes.

MR. JAMES: So you need to wait till you have outward signs, I think, of ASR before you go taking core samples to try to figure out how bad it is.

And as far as the second question, I think it can cause structural issues. But generally not in structural concrete where you have a lot of reinforcement that, you know, contains the cracking.

I've had some experience in mass concrete structures and it certainly causes severe problems in mass concrete structures.

MR. TRIPATHI: From the practical point of view, Randy, I tend to agree with you. That unless there is this strong evidence that it's going to affect the structural performance.

I mean, you can take a core sample from a support that affects the corner, this is not a problem. But here we are talking about taking a core sample from the actual storage module. Vertical, horizontal, doesn't matter. That is a different ball game.

So unless we have strong evidence that this is indeed going to be later on, if not now, a structural strength problem or functionality problem, I tend to agree with you that there's no need to have the applicant or the licensee take core samples. Am I reading you correctly?

MR. JAMES: That's correct. Yes, I think

you found a problem and you need to assess the long-term functionality of that component.

So you really need, you may need to go take core samples to get a better idea of the growth rate, the swelling, the material properties, you know, those sorts of things.

But until there's a serious structural problem, you know, there's no reason to go take core samples. In my opinion.

MR. JONES: It's kind of inhumane to just poke holes --

MR. XI: So I have some experiences with containment. So they did take some samples cores out of the structure and we ran the test for them.

This is for license renewal. Because if there is no problem now, you don't see any map cracking on the surface.

But you don't know what will happen in the next 20 years. Either you -- when you have license renewal for the next 20 years. So --

MR. JACOBS: It's 40 for us.

MR. XI: Yes, 40. So that's even worse. So unless it either is a high moisture content in the surrounding environment, that can cause accelerated ASR problem.

So that's how I think, for license renewal, you shouldn't ask the owners to provide core samples to run the ASR test. Like ASTM C 1260.

MR. TRIPATHI: Core samples of the storage unit itself.

MR. XI: Yes. Yes.

MR. CHOWDHURY: Randy, you mentioned that this is more of a mass concrete problem then reinforced concrete problem.

MR. JAMES: Well the structural effects can be worse in mass concrete, which is not, you know, reinforced. You, typically, just thermal reinforcement on the surface.

MR. CHOWDHURY: Okay. That depends quite a bit on the compressive strength of that concrete in the compression zone. If that zone is affected by this reactivity.

MR. JAMES: If you have significant compressive strength degradation?

MR. CHOWDHURY: Yes.

MR. JAMES: Well again, it's kind of a, you know, system dependent, problem dependent issue I think. But generally some swelling can be accommodated because you have lots of reinforcement in these systems.

You know, if you start seeing serious structural cracks developing, then I think you need a functional assessment. What's really going on? And something that you can use to assess, you know, the long-term performance of that structure.

MR. JACOBS: Not to disagree, but the containment, the performance of the containment structure is very different than what we're talking about here. The performance of the systems that we're looking at.

Again, I look at it -- let's say the creep. You know, going back to the creep. Creep I think is a huge problem with the containment structure.

But not necessarily here. I mean a creep is stressed, you have a lot of other things going on.

Here, again, if -- by coring you're really doing more damage than you're potentially going to solve by, you know, okay you're -- because again, you're taking a point, you know, in -- there's a lot of variables involved in this here.

You're taking a specific spatial point that is specific time point and from that test, you're going to have to infer a lot of things on a large system.

I think there are other smarter ways to do it that would not be as destructive to, you know, to get better information.

MR. TRIPATHI: I'm glad you pointed as an expert, Larry. Because I think there's a big difference, as you and I were discussing during the break, that containment is a different ball game then what we are dealing with here.

There are no active systems, of course, moisture content from the outside can affect. But I mean there's absolutely no apple to apple comparison with the containment structures and these dry cask storage systems.

These are passive systems. They just sit there, sit there for 40 years and even beyond.

So there's a different application. And taking a core sample from such a system, might prove to be even more detrimental than what you're trying to achieve by taking core.

I tend to agree --

MR. JACOBS: Unless there's something -- there could be a reason. You need the core to answer a bit of information.

But to go on, I'll call it a fishing trip, to determine if you have. And then from that single core, to try to infer, you know, find the worst case and try to infer on a whole large system.

That is a real -- there's a lot of stretches involved in that, you know, that I reported about.

MR. TRIPATHI: Yes.

MR. CHOWDHURY: But instead of coating, it will do NDE.

MR. JACOBS: Again, there are --

MR. CHOWDHURY: Will you get the same information?

MR. JACOBS: Yes, I think the map cracking is -- you really don't need to go into that fancy cracking.

And this could go in the case of where a good visual inspection, you could tell a lot of information. And then from that, in the map cracking area, then you might have to go in and get further and further.

I mean I think that's a different conversation for this afternoon. But, you know, I think you can design a plan like that, pretty easily, where sort of last case scenario is, oh yes, you know, we had this, we had this, we had this, now we need additional information, let's go in and come up with a core. Or something like that.

MR. JONES: Let me interrupt real quick. If you're on the phone and you have the ability to mute your phone, that would be excellent. Thanks. Please continue.

So I guess tied up in this discussion of the core, there's the notion of a false positive I guess. You get some information from this core that may or may not mean anything about the rest of the system. So there's a --

MR. BERKE: Yes, I wouldn't run it on the accelerated, I'd run the slower method if I took a core. Because now you actually have -- you don't want to put a high, one molar of sodium hydroxide solution around it.

MR. JONES: Yes.

MR. BERKE: Which it's not really seen to tell what it's doing in the field. That's a test to decide if your aggregate is bad.

MR. POPOVICS: It's an aggregate check.

MR. BERKE: You want to find out --

MR. JONES: Yes, right.

MR. BERKE: You want to find out if your

system is bad. So you just might take the darn thing, if you have it or for whatever reason, and I agree we shouldn't take it just to fish.

MR. JAMES: Yes.

MR. BERKE: But if you happen to have one and you want to put pins on it and stick it in a room at, you know, at an elevated temperature for a year at high moisture content to see how it grows, that's fine. But I wouldn't put it at -- I wouldn't do an aggregate check on it per say at this point --

MR. JONES: Yes.

MR. BERKE: -- rest of the system. You can try and predict how long it's going to do.

MR. JONES: So let's also say, you know, Ricardo's asking a question, we're not -- this is just sort of a hypothetical situation that we're talking about here.

MR. TORRES: Yes.

MR. JONES: But I think it's brought some good discussion as well. Let me just ask this last question here, without getting into the details of the specific license items that must be met.

Would we expect that ASR would be functional limiting for these systems? You know, could it be the, you know, could it take us out of functionality, I guess?

MR. POPOVICS: I think it depends on the second question. Certainly ASR is a serviceability problem.

Is it a structural problem? I don't know. How many structures have been taken offline or declared insufficient because only the ASR? I don't know. Maybe not so many.

MR. JONES: Yes.

MR. POPOVICS: But when we consider the long-term performance of these, it could be.

MR. XI: It could be, yes.

MR. POPOVICS: It's definitely a certain serviceability problem.

MR. BERKE: 300 years is a long time.

MR. POPOVICS: Yes, it's a long time.

MR. BERKE: And your concrete is basically swelling.

MR. POPOVICS: Well but, you know, it's more -- I think it's 300 years of serviceability issues. You got cracking and you're allowing the ingress of every bad actor to come in. And moisture, it's usually in a moist area.

So it's -- by itself, I don't know. But, you know, it will promote cracking just like shrinkage cracking, allows cracking. And DEF allows -- promotes cracking.

So I don't know the answers to this. It's, I think to be -- you have to be cautious because we're looking at long extended periods of performance on this.

MR. JAMES: Sure.

MR. POPOVICS: And, you know, I think --

MR. XI: It may depend on the degree of the damage. For dry cask I do not know. But for other structures, it generally, in the ASR, generally it's severe structure damage.

MR. JONES: Okay.

MR. XI: So for example, for the Logan International Airport. The runway got severe ASR damage. They had to re-pave the runway.

MR. JONES: The idea of an airport pavement came to my mind too, but my understanding, and tell me why I'm wrong, if I am, it was more that they didn't want chunks of airport pavement getting sucked into the engines, you know.

MR. BERKE: Well it's a serviceability issue.

MR. JONES: It's not such much that it

wouldn't, you know, not be able to carry the load.

MR. POPOVICS: Right.

MR. JONES: It's a little bit of a different --

MR. POPOVICS: But it is, it's performance. It's designed to not do that.

MR. JONES: Yes.

MR. POPOVICS: So it's not meeting the structural performance.

MR. TRIPATHI: Now you mentioned functionality. You know, there are other safety functions, I mean me being a structural engineer I'd love to talk about structural, but there are other functions.

For example, from the shielding criticality point. Containment, heat transfer. So your question, last question is, does it affect functionality from the safety point of we need to keep all these other functionality requirements also in mind. Not just structure.

As I said, I love to talk about structure. But there are other functions --

MR. POPOVICS: Yes.

MR. TRIPATHI: -- which these safety

systems are supposed to comply with. And is there any affect on some of these other requirements.

Shielding for example. I don't know, because I'm not an expert on shielding. Or a containment.

MR. XI: They definitely increase the permeability, the serviceability. So that will increase the shrinkage or increase the chloride penetration process.

And that, from a structural point of view, one of my colleagues is working on an NRC project. On the shear strength reduction by ASR.

MR. JONES: So that's a --

MR. XI: Just getting starting, the NRC project. So we just need to wait and see.

MR. JONES: So we could maybe talk about this all day, but I'm going to jump us ahead. To the next other, I think pretty interesting issue, and that's radiation.

So, and I'll list my observations. The mechanisms of radiation damage seem to be somewhat, I used the word poorly and that maybe strong, But somewhat less well understood then some of the other mechanisms.

We also know that the dose levels in these dry cask storage systems are far less than the radiation dose that's seen in the bioshield walls, in a PWR for example. And so that's probably a good thing.

There's a recent NUREG/CR that's been published from the Oak Ridge folks. Numbers listed there.

And there's some evidence, from the Japanese guys, that the -- that was pretty vague. From some Japanese researchers that there is some coupling with ASR.

And so you can morph the, what would otherwise be non-soluble silica phases, into something that is soluble. And that, you know, there maybe a coupling effect there. So that again brings up this little coupling thing that we have in the back of our minds.

So here again, and you know the best question first, are total lifetime fluence limits adequate to ensure performance?

MR. POPOVICS: I would say no. Because those limit -- that assumes that the limits are well established and well understood. And I don't believe they are.

And there are other factors besides

fluence. There's temperature, there's what, flux. There's a number of things that, again, I agree the level are low here. But I, you know --

MR. JONES: Yes.

MR. POPOVICS: -- sort of say, okay, here's a number. Let's say with ASR. Okay, here's the number. It's a reasonable number from expansion, because you know formation cracks, you can define it on something physical.

I have a hard time saying, okay here's the single number and define that. You know, that can capture all the cases.

MR. XI: You know, in my answers, so I provided two different answers. One is if you ask within 40 years period. So the ACI specified value is fine.

It's about --

MR. JONES: In the shorter timeframe.

MR. XI: Yes. In the seven years, 40 years. About six orders of magnitude lower than the critical value identified in the paper by Hilsdorf.

MR. JONES: Yes.

MR. XI: Published in 1978. So worldwide the standard was based on that paper.

So you can talk about 300 years and that's different story. Because it's another rate, is a total of both.

MR. JONES: Okay.

MR. XI: For neutron radiation. So that's why for 300 years the answer is I don't know.

MR. JONES: Okay.

MR. XI: Actually, you mentioned that report recently published. That's what I did with my colleague.

MR. JONES: Right.

MR. XI: So we searched all the literature. And actually we analyzed all the references cited by Hilsdorf.

So a lot of test done in the past is not reliable. So --

MR. JONES: For numerous reasons, as I recall, some were --

MR. XI: Yes.

MR. JONES: -- strange aggregates or strange cements.

MR. XI: Yes. Sometimes it's done, even for cement. The results are included in the paper and used worldwide by many countries. Including here.

So that's why 300 years is, I don't know.

MR. JONES: Yes, maybe.

MR. XI: 30 years, that's fine. The ACI standard is fine.

MR. JONES: Somebody was talking, I don't know if there was some more?

MR. JACOBS: No, Larry just -- well I'll let you. So there was a paper that just came out, two papers, out of the Oak Ridge folks.

MR. JONES: Sure.

MR. JACOBS: A very nice summary. I saw this after I printed my response.

MR. POPOVICS: Yes, I found this yesterday.

MR. JACOBS: Again, one of the authors I know, Yann Le Pape.

MR. POPOVICS: Yes.

MR. JACOBS: And it's a very nice summary and it does a very good job. And I literally was reading it on the plane on the way in last night.

And I don't have my arms around it quite honestly, but I think this is one -- this is one of the reasons I said, gee, a single number doesn't make sense. They're too many variables going on.

MR. JONES: Okay.

MR. JACOBS: But I think it echoes a lot of the things we're saying. Yes.

MR. POPOVICS: The reason that I kind of don't have a lot of confidence in the total fluence on this is because even, you know, Hilsdorf paper, regardless of, you know, the problems that may be associated with it.

I think over the years, and in the different documents, it's interpreted differently. So these numbers don't have the same meaning to all people.

So for example, I pointed out that in Hilsdorf paper, he cited some levels as critical levels of fluence. Above which you're causing damage. That's what I understand it to be.

Whereas in the ACI 349 document, that's taken as an ultimate lifetime limit. These are two very different things.

And also there's a little bit of confusion about the units in those. So for example, I think Hilsdorf uses, I think it's neutrons per square meter. But --

MR. XI: It's per centimeter.

MR. POPOVICS: No -- well ACI is using square centimeter and Hilsdorf is using square meter.

MR. XI: No, no. Hilsdorf's using --

MR. POPOVICS: So maybe I switched it. But one -- they're not using the same units.

Now it's reading that two, I started to be concerned like, maybe someone didn't catch that in ACI so that when they put the limit. Because actually the lifetime limit they put on, because they're using differences much higher than Hilsdorf's limit, if I read correctly.

So these kinds of things give me concern that we hang our hat on a limit when these are old data as far -- I mean we should -- I should look through Le Pape's paper. I haven't -- I just found that yesterday, to get a better handle on that.

But otherwise there hasn't been a lot of, that I've seen, a lot of research on radiation exposure, since Hilsdorf's. And that was around '78.

MR. BERKE: There was a Japanese paper that I found, I don't remember the names of the guys, that looked at this. And they also looked at, they were a little bit -- they were okay on the neutron flux, but they seemed to think that the radiation was a little bit too low.

MR. JONES: You're talking about the --

MR. BERKE: It should be lower.

MR. JONES: -- gamma part?

MR. BERKE: The gamma part is probably lower than what's typically done. But it's our -- but that was all by calculation, the gamma.

But what they intended to show was that there was a big -- what the effect is was there was a combined effect with the radiation and the heat temperature of the concrete.

So if the concrete stayed below a certain temperature, these levels were fine. But if the concrete temperature was higher, these levels were --

MR. JONES: The levels changed with --

MR. BERKE: Yes, they were not necessarily fine.

MR. JONES: So let me go back to the -- so you're bring up kind of a second point. So I asked a very generic question, intentionally.

But you're actually thinking that maybe the fluence limits themselves may have issues in the way they've been interpreted and --

MR. POPOVICS: I don't want to accuse anybody --

MR. JONES: Sure. No, no, no.

MR. POPOVICS: But they cause me a lot of confusion.

MR. JONES: Okay.

MR. POPOVICS: That first of all, one is listed as a critical limit of fluence for material breakdown whereas the other is listing that limit as an acceptable lifetime dose.

MR. JONES: Okay.

MR. POPOVICS: These are two different things.

MR. BERKE: Well that's more conservative. The second one.

MR. POPOVICS: Right. And that the units that are presented, as far as I can read, make the opposite sense.

To one, ACIs that list as acceptable lifetime, is orders of magnitude higher because it's units of neutron per centimeter square, not meter squared. But yet the same number is quoted.

So I'm wondering if there is some accounting error. A typo there.

MR. XI: No, no. Actually I did the same analysis.

MR. POPOVICS: Okay.

MR. XI: And I convert the ACI number to the same unit as he used. It's a neutron per centimeter square. And the ACI number is more conservative.

MR. BERKE: It is more.

MR. XI: It is fine.

MR. BERKE: Yes, the meter squared number is much bigger than the 70 square meter squared number.

MR. POPOVICS: Yes, but Hilsdorf --

MR. BERKE: It had to be at least 10,000 counts larger.

MR. XI: Yes, I analyzed in my answer.

MR. POPOVICS: Okay.

MR. XI: It's fine.

MR. BERKE: Yes, I mean I looked at that. Because they have like, the ACI I think was 10 to the 17 neutrons per meter squared.

MR. XI: Yes.

MR. JONES: Neutrons per meter.

MR. BERKE: Neutrons per meter squared. And --

MR. JONES: So it --

MR. BERKE: -- these Japanese guys came up with 12 times 10 to 22 neutrons per meter squared.

MR. XI: Yes.

MR. JONES: Yes, we can have this issue where we're concrete guys that are not as well prepared for the transition of radiation topics.

MR. POPOVICS: So you're right. Here's I'm looking at, this is the Hilsdorf paper. So the units, he's talking about the order of 10 to the 19 neutron per centimeter square.

MR. BERKE: Now you multiple by 10,000.

MR. POPOVICS: But now the ACI limit is the same.

MR. BERKE: Yes.

MR. POPOVICS: Right?

MR. BERKE: Yes. The 10 to the 17 neutrons.

MR. POPOVICS: Yes, so they do make that conversion. Okay. Yes, so the order of two should be the change.

MR. TRIPATHI: Have any of the experts had a chance to look at the recent, by recent I mean a couple years ago Brookhaven National Lab, BNL, did a nice report on this.

And from what I recall, I reviewed that report for the research folks and I recall that probably for the dry cask storage system, because of the radiation level compared to the main power block containment are so low, that we don't need to really, you know --

MR. POPOVICS: That may be, but the question is, can we rely on lifetime limits.

MR. TORRES: That's --

MR. POPOVICS: I think that's a different question.

MR. TORRES: That's not necessarily the case for up to 100 years, Bob.

MR. POPOVICS: Yes.

MR. TRIPATHI: They can get pretty close. In the gamma dose rate. It's pretty close to the limits.

MR. BERKE: Yes, I think the gamma one was the one that --

MR. TRIPATHI: The gamma was --

MR. BERKE: -- take the neutron --

MR. JACOBS: It was the gamma. At least in the Le Pape, which was a summary of all of these.

MR. JONES: So I guess let me ask my second question with a couple of different flavors. So there's some that couple with ASR, do we think that it might couple with other things? That's one question.

Do we think that the neutron and gamma act independently or should those be considered in a coupled sense? Is there any evidence that is important?

So they're sort of two separate questions there that I'll draw out.

MR. XI: Now it's acting independently.

MR. JONES: It's not independent?

MR. XI: Yes. Because when you have a neutron and then the neutron radiation generates gamma radiation.

MR. JONES: Sure. Yes.

MR. XI: Yes, so that's why when you run the test for a neutron radiation, and then at the same time you have a gamma ray.

MR. JONES: Okay.

MR. XI: So in the literature, people already realized that. So it's very difficult to separate the two effects.

MR. JONES: So the basis for making these limits sort of include the coupled effect?

MR. XI: Yes. These are already included in the coupling effect. Coupled between the two --

MR. JONES: Yes. Right.

MR. XI: -- radiations. There are also other couplings. Coupling with ASR, coupling with freeze/thaw. So that's a different coupling.

MR. JONES: So let's go into that a little bit. Do we -- so I mean you've answered my question, but are there any other examples that come to mind that radiation is expected to interact with, I guess, or --

Is that question clear? That what other mechanisms you expect radiation to interact with, I guess?

MR. BERKE: One of these guys said there was a strength degradation if the temperature was already hot.

MR. JACOBS: And there seems to be an expansion mechanism to -- from an aggregate. And it seems to be very aggregate dependent.

MR. JONES: Yes.

MR. JACOBS: So again, you can see a lot of the, like the ASR. Even the DEF could be something, you know.

There's possible for the -- so you could talk about our friend freeze/thaw, yet either, which would be another one that, you know, sounds like.

MR. JONES: So you're getting to the fact that since the aggregate expansion, you know, the most commonly identified mechanism --

MR. JACOBS: Yes.

MR. JONES: -- does the same thing in

something like DEF or does the same thing as ASR. There could be a stacking of --

MR. JACOBS: It will be a linear.

MR. JONES: Yes.

MR. JACOBS: It will be a, you know, they'll --

MR. JONES: Okay.

MR. XI: So it appears the coupling with a similar stress. So that's why it's difficult to analyze the test data in the literature.

So if some people, when they run the radiation test, they also run the temperature test. So the temperature will follow exactly the thermal history of the concrete, in the concrete, under the radiation.

And then they subtract the thermal --

MR. JONES: Subtract off the thermal effect?

MR. XI: Yes.

MR. JONES: Just get --

MR. XI: And then you get the net effect formulation.

MR. JONES: Okay.

MR. XI: But most of the test data of the meters, they don't do that. So that's why it's all --

MR. JONES: So you're --

MR. XI: -- mixed together. So first is a gamma ray and neutrons mixed together.

MR. JONES: Okay.

MR. XI: And then mixed together with a similar effect.

MR. JONES: Okay.

MR. POPOVICS: Then you get the effects on the bound water, internal water?

MR. JONES: Yes.

MR. CASERES: How about the formation of or the affect of carbonation induced by radiation?

I read some papers that talk about internal carbonation not being on the air gas phase or through a normal carbonation through the air. But rather carbon induced radiation that promotes carbonation.

MR. POPOVICS: I don't know that.

MR. BERKE: I wonder what the mechanism would be.

MR. CASERES: Iron 3 calcite reacts, I mean you have to have water in the system as well. But there's a -- transformation affects transformation of calcite into the formation of CO2, carbonation induced radiation.

MR. POPOVICS: So you're deliberating gas?

MR. CASERES: In theory.

MR. BERKE: Okay, that might be the case of a limestone aggregate or something versus a siliceous aggregate. Or I can see if you get a high enough temperature your limestone aggregate starts to break down.

MR. POPOVICS: That's pretty high.

MR. BERKE: Well --

MR. POPOVICS: You have to --

MR. BERKE: Localized flux, you know, maybe.

MR. JONES: Yes.

MR. BERKE: I mean that might be where the high temperature effect comes in. I don't know.

It's something that takes place ahead of your -- if you're at a high temperature then when this happened, you're more likely to have this. Whereas high flux or low temperature doesn't have the energy to do that.

MR. JONES: So in a very generic sense, suffice to say that dumping all this extra energy in may have effects on other mechanisms that are dependent on thermodynamic equilibria, things like that. It's, you know, not beyond the realm of possibility for a lot of the mechanisms. Maybe you can say it that way.

Let me play cattle driver and heard us along a little bit. To freeze/thaw. Thanks for the transition.

And so this, you know, I think we have a general sense of this from our, you know, understanding about how rocks erode and things like this. But, you know, water gets into the pore network, freezes, expands. There's a differential expansion thing going on that causes a tensile stress and, you know, can degrade the concrete.

We typically link this with cycles of freezing. In other words, just freezing once.

A very cold climate where it just freezes once, stays cold all winter, and then warms up. It's not as penalizing as like the Great Lakes in the Midwest where you get a lot of cycles throughout the course of the winter.

MR. POPOVICS: Or here.

MR. JONES: Or here. The mid-Atlantic. There's this issue of micro-diffusion, pore size distribution versus saturation.

So as freezing is going on it's a fairly complicated -- mechanisms are going on. You know, moisture is maybe moving around a little bit in response to the stress gradients and things like that.

Below some saturation threshold, you know, that this doesn't happen. Above which we start to see it.

Yunping I think brought up this notion of differential coefficient thermal expansion. So, you know, for differing moisture levels you'll have a, you know, stress getting induced by this effect.

And we talked about it a few slides back, but this, I'm going to my questions now, but there appears to be some integration with salt scaling. These two are similar, they're cousins maybe. Maybe brothers.

But not the same, from what we talked about earlier. Am I accurately characterizing that? I see some heads nodding.

MR. CHOWDHURY: This is primarily mechanical effect. Depends on other parameters of the mechanical structure of the concrete.

MR. BERKE: This can significantly affect the structural capability of the concrete. The concrete just basically loses all its strength.

MR. CHOWDHURY: Yes.

MR. POPOVICS: But by mechanical effect you mean the process of the degradation?

MR. CHOWDHURY: That's right.

MR. BERKE: Yes. Yes.

(Simultaneously speaking)

MR. POPOVICS: It's not chemical.

MR. CHOWDHURY: No, it's not chemical.

MR. BERKE: No, this is not chemical. This is totally mechanical.

MR. CHOWDHURY: Yes, all mechanical.

MR. BERKE: And this goes back to how they were testing freeze/thaw many years ago. They used to freeze in air and thaw in water. That's a much more mild test.

MR. JONES: Yes.

MR. BERKE: Than freezing in water and thawing in water, which is done today. But the advent of the so called freeze/thaw testing, where people freeze and thaw in water.

But the old machines used to thaw with the use of freeze in air and thaw in water. You can get 300 cycles on one of those and not get past a hundred in the current Method A method.

MR. JONES: And so that's related to the saturation issue I assume?

MR. BERKE: Right.

MR. JONES: Yes. So that leads us into our sort of second generic question here. What concrete parameters influence freeze/thaw?

We know from the ACI design method that you put a little bit of air into the mix to --

MR. BERKE: Yes, for your strength.

MR. JONES: -- effect, you know.

I'm trying to prevent this, but I guess what are the key concrete parameters that get us into trouble here?

MR. BERKE: Well you need strength. You need a minimum strength to pass. Ideally ACI will tell you your water to cement ratio is going to be above 0.4 or 0.5.

But 0.50 will do okay. And you should have the right air-entrainment, which is based on the size aggregate you have. So there's a table for that.

And then the other thing that you don't talk about much, because most of the time it's not a problem, but your aggregate itself can be freeze/thaw susceptible. So you have to make sure you use an aggregate that is sound. Totally --

MR. JONES: Is that getting the porosity of the aggregate I guess or --

MR. BERKE: Yes, I think it's related to porosity in the type of --

MR. POPOVICS: It's the microstructure of the aggregate.

MR. BERKE: Some aggregates will hold water.

MR. POPOVICS: The worse possible pore structure.

MR. BERKE: And I've run into that in actual experience where we've gone in a different part of the quarry and an aggregate’s perfectly okay. Turned out that everything was fed in freeze/thaw. And we found out that the DOT took it off its approved list because the section of the quarry where they're at.

MR. JONES: So it happens.

MR. POPOVICS: Some people argue that you can -- there's no defense ultimately against freezing and thawing that you can make any material, under the right conditions, have this damage. But, you know, proper design and proper air-entrainment, in some cases, that's the usual way to do it.

But there are cases where you have extremely dense strong concrete that does not have any air-entrainment and it doesn't suffer freeze/thaw --

MR. BERKE: Yes, but that's not our case here.

MR. POPOVICS: No. But I mean my point is --

MR. BERKE: That will solve a lot of problems if they don't occur in that kind of concrete.

MR. POPOVICS: But saturation is pretty much everything. If you fully saturate the pore structure, you know, it's hard to let the material survive for very long.

MR. BERKE: Yes. And that's why vertical surfaces do much better. It's very hard to saturate vertical surface. Especially if you got a heat source on the other side that's trying to suck the moisture out.

So it's really almost always seen on horizontal surfaces. Or some surfaces, if you're buried in soil with water and you're above the -- everything in the soil is above the -- you're above the frost line, you can go up and down with freezing. With the surface.

Those are the places you're going to see it. Ocean where you have the waves will come in and get it wet, it will freeze. Then the way the water will come in and thaw it out. So the water will also -- so tide is always very bad.

But it has to be someplace where the concrete is saturated.

MR. POPOVICS: Saturation is really bad.

MR. CHOWDHURY: Yes.

MR. BERKE: When the concretes dry, you're not going to, in most cases, you're not going to induce thawing. I won't say it will never happen, but if it's dry it's unlikely.

MR. CHOWDHURY: So a lot of similarity between salt scaling and this one.

MR. BERKE: Yes. Well --

MR. POPOVICS: That requires freezing and --

MR. BERKE: -- they both require freezing --

MR. POPOVICS: -- moisture.

MR. CHOWDHURY: Yes.

MR. BERKE: And saturation. But I mean, water is saturated.

But you can get, as mentioned earlier, you can get scaling without getting freeze/thaw. If you get freeze/thaw you're probably going to have a scaling problem.

If nothing else the freeze/thaw, when it's severe, will cause scaling on its own. Without the salt.

MR. JONES: You know, it points up another thing. Construction practice is very important.

MR. BERKE: Yes.

MR. JONES: So if you have poor construction practice, poor finishing, you can promote this kind of surface damage.

MR. BERKE: Absolutely.

MR. JONES: Because you have a surface layer, a poor layer at the surface, that can be avoided by proper practice.

MR. BERKE: It's also when you place the concrete. I mean if you can place concrete, like in the end of the, normally you're not going -- in this type of weather or like the end of the fall, and it's still saturated from all the water that's there and goes through freeze/thaw cycles then, you can't develop any strength.

Even a good air void system or anything else, it can fail. So you have to watch when that first freezing cycle is going -- freezing cycles are going to start relative from when you make the concrete.

So it is -- I mean structures made in the spring, tend to do better than structures made in November or October. Right before it -- and in a region where you don't freeze and thaw.

MR. JONES: So let me ask you about this, my third bullet here, the coupling. I can envision how, you know, this, like many others, micro-cracking increases transport of other things.

Do we -- that's obvious to me. Otherwise you can couple, you know, as Larry, you mentioned it during radiation discussion. I don't -- was that --

MR. JACOBS: I was just putting that as an example.

MR. JONES: Okay.

MR. BERKE: But if the concrete disintegrates this is bad. Doesn't matter what else is going on.

I mean, let me show you pictures at 100 cycles in the freeze/thaw category out at Treat Island. Where they got big blocks. And after three, four years, this block that was a cubic meter, as a meter cube or something, is a lot smaller.

MR. JONES: Yes. From outside in penetration of --

MR. BERKE: Outside in. So I mean this is -- if you have freeze/thaw problems, yes it's going to let stuff in faster. But you might not have any cover because the concrete itself is going to, especially if it gets any type, you know, concrete softens and falls off, come off.

MR. JONES: Okay.

MR. JACOBS: Again, this should be from the outside in.

MR. BERKE: It's outside in, yes. I can't imagine if you have anything on the inside of one of these.

MR. XI: Actually, John mentioned that the degree of saturation is very important. So I want to share with you some of the bad examples.

Let's see, because the inside is very dry. It's a high temperature, is dry. But in the summer, actually the temperature difference between inside/outside is pretty small.

MR. JONES: Yes.

MR. XI: Because outside in the summer you can go to 50, 60, as a low.

But the outside is very wet. The relative humidity could be very high. In a lot of gradients.

So that's why actually the moisture is sucked in from the outside surface and stays there. And then in the winter it will serve as a source of water to create a freeze/thaw damage. And this happens in some of the structures.

MR. JONES: Okay.

MR. XI: Now, so what's the critical level of relative humidity inside the concrete? That's very important.

And a lot of people say if something were wrong that 80, maybe 89, 90 percent, that's actually not true. So the test I get, for the moisture level inside the concrete, is less than 90.

Let's say around that level. But then you still have a freeze-thaw damage. So --

MR. JONES: So, yes. So certainly this is -- your moisture in a pore network is a complicated one. People have -- certainly people have looked at it in a lot of different ways.

So, you know, relative humidity of some

level gives you a sort of gross number. But there could still be liquid water in smaller pores.

MR. XI: Let's see because even if I did the statistical analysis of the weather station in the Midway Station. Midway Airport.

The average, year average is 70 percent. In the summer it's much higher than that.

MR. JONES: Okay.

MR. XI: So that's why the surface layer of concrete, the pore relative humidity, could be 90 percent.

If you go to Florida, no, Florida is a bad example. There's no freeze/thaw. So let's see --

MR. JONES: El Paso.

MR. XI: The humidity in Chicago in the summer, could be very high. So that's why the surface layer humidity inside, could be higher than the critical value.

So I'm talking about the structures in our nuclear power plant along Lake Michigan. So they do have a problem.

MR. JONES: So certainly it's common for a power plant and a storage facility to be located near a body of water. So that's not an unusual thing.

MR. XI: Yes, but almost all reactors are next to the water. Bigger water.

MR. JONES: Well what is big, I don't know. But, yes.

MR. BERKE: Well that's the reason why you have your air void system. But it's also the reason why you don't want too high water-cementitious ratio.

Because you don't want a continuous pore system in your concrete. Because then it's more likely to have this, areas where you'll have the interconnection. You have that problem.

So you really need to have -- if you're in freeze/thaw, you really should file a minimum ACI.

MR. JONES: Yes.

MR. POPOVICS: I would say this is the degradation mechanism where we had the most control of. I'd say in terms of preventing it, proper material selection, proper dosing of air, proper construction practice goes along way of curing.

MR. BERKE: Right.

MR. POPOVICS: You know, more than other mechanisms.

MR. BERKE: And then, you know, if you have puddling in the area, you know, you know you have a problem. You know, you can try to keep it a little dryer in those areas.

MR. JAMES: You know, so for detecting and -- it usually happens on visible exterior surfaces. So it's easy to find.

MR. JONES: That's nice.

MR. JAMES: You can see it. And if you have to it's fairly easy to fix. Knock off the cover layer and put some more on.

MR. JONES: So let me just go ahead and move us ahead. We've got sort of two more topics to cover before lunch and about 20 minutes to do it. So.

MR. TRIPATHI: So can I --

MR. JONES: Sure, absolutely.

MR. TRIPATHI: Neal, I think what I heard from you is that freeze/thaw could be a bigger problem relatively for a horizontal storage module than vertical.

MR. BERKE: Yes.

MR. TRIPATHI: Am I --

MR. BERKE: Yes. Because you're more likely to be water saturated.

MR. POPOVICS: Right.

MR. BERKE: However, you know, if you're

sitting on the face of the rain for certain amount of time and it freezes, then that's a whole different story. But in general water, you know, doesn't stay out --

MR. POPOVICS: Or under the ground.

MR. BERKE: Or under ground, as I mentioned. Running into freeze/thaw and then above the frost line, if you have water underground. Those are the two places you'll see it.

But if you're, you know, the vertical surface where it's, John, you're much less likely to be saturated with water other than somebody --

MR. TRIPATHI: Well luckily we don't have many in Oregon and Washington State where it rains 100 percent of the time. So.

MR. BERKE: There are a few places that will do that. And usually those places don't see frost.

MR. JONES: Yes.

MR. TRIPATHI: So it's more of a problem to consider on a horizontal storage model, in general, than --

MR. BERKE: Oh yes. And if for some reason it pops up on your vertical, as Randy mentioned, you're going to see it. This is something that the results are, you know, you'll see some sort of degradation on the surface.

You might not get to analyze what's causing it, but it will show up on the surface. It's not something that will occur on the inside of your casks.

MR. JONES: It's more straight up.

MR. BERKE: Yes. So this is visible.

MR. TRIPATHI: Thanks.

MR. JONES: So I'm going to jump us ahead here to corrosion. Neal, I'll expect you'll have -- I think you'll have some things to say about this particular topic.

We observed that steel corrosion manifests in a couple of ways. In advanced cases of the section of the rebar is reduced.

And then you also have sort of this covered delamination because the corrosion products for iron are expansive. They tend to pop off the cover.

Typically correlated with medium, the higher water cement ratios. Again, tied with this kind of transport issue, permeability issue.

I sort of added this but, you know, it's unlikely that covered thickness in the ACI methods are thinking about a 300 year design license. So, you know, I'm bringing in this, you know, our longer timeframe.

You know, maybe is interesting here. And I thought maybe it's coupled with thermal desiccation.

So I think I've sort of hit one, but are some of our key parameters for initiation and progression of corrosion, as our first bullet?

MR. POPOVICS: Let me clarify. Here you're talking strictly about internal embedded steel. Not exposed steel.

MR. JONES: Yes.

MR. POPOVICS: Okay.

MR. BERKE: Okay, for the general corrosion problems, tell me -- say stuff coming in from the outside.

Certainly, you know, if you get a critical amount of chloride next to the bar, it could go into corrosion. And dependent on how much oxygen's in the concrete available, you can have a fairly high corrosion rate once that takes place.

The box will be in relatively good shape, but the cracking, the expansive -- corrosion products are expansive, so they'll cause cracking and then you could get, if you don't do anything, you can end up with delaminations and swelling, and swelling. Then the whole thing just starts to take off on you.

So that would be chloride coming in. Could be carbonation if you have the concrete, for some reason, carbonates from outside. That can cause it.

Carbonation is a slower process --

MR. JONES: Yes.

MR. BERKE: -- then the chloride process.

MR. JONES: It's an effort by dropping the pH.

MR. BERKE: It drops the pH down.

MR. JONES: It takes the rebar out of the passive --

MR. BERKE: Yes. And typically get, for some reason, you have a lot of -- either the concrete is very poor. So if you have, or a crack, it can get --

But the carbonation, usually goes at a much slower rate than a chloride induced corrosion.

MR. JONES: Okay.

MR. BERKE: Also it's more uniform so you don't get, the localized areas, a lot of corrosion product coming out. So it's longer to crack with carbonation. So those are pretty much controllable.

I probably -- so much worried about that we don't hear why, because I don't think, you know, that's important when you, you know, you get the bridge decks. When you're throwing deicing salts on them or you got a marine structure that's sitting in splash tidal zone.

You know, if you got a, depending on how far you are from the ocean. Because there should be no deicing salts coming anywhere near this concrete.

So you got to assume that it's got to be a marine-type chloride in that. If you're, you know, you got to -- I mean if you have a certain amount of cover, how far you are from the type of loading you get, you can certainly get the 60 years if it's reasonably good cover.

MR. JONES: Okay.

MR. BERKE: 300 years is -- depending on where it might be. But for the most case, in carbonation, if the concrete stays reasonable moist, it's not going to carbonate. Because this concrete is going to dry out, so it's more susceptible to carbonation.

MR. POPOVICS: I think carbonation is maybe more of an issue --

MR. BERKE: I think it might, other than the marine environments, the carbonation might be a problem.

But then you need to have moisture for that.

So if there's no moisture, you know, these 70, 80 percent relative humidity in the concrete, they have corrosion going on.

MR. POPOVICS: But I think cycling, it helps it out.

MR. BERKE: Yes, it helps.

MR. POPOVICS: Like drying when it rains.

MR. BERKE: But carbonation, you know, if the concrete’s between 40 and 70 percent RH, which is quite possible with this bridge, that's ideal carbonation conditions.

And over a 300 year period you could, especially just since this concrete is not ultrahigh performance concrete. We're talking about, it's in the 0.52 ratio range, which can carbonate, you know, a certain amount under those conditions in the 300 year concrete.

So for the 300 years you might get some of that. There are mitigation techniques you can use, I believe, to, you know, to make that unlikely. And -- so I mean I think that's the --

That and the structural thing. Not, initially, not too bad. But if you let it get to the point where you start getting delamination --

MR. POPOVICS: Yes.

MR. BERKE: -- spalling, then you have a problem. Little bit of corrosion actually helps the structural ability, the first -- before it causes the cracking and the delamination and spalling.

MR. JONES: Those products increase the bond for a period of time.

MR. BERKE: Yes. So a little bit of initial --

MR. JONES: Yes.

MR. BERKE: That's very short lived. So no corrosion --

(Simultaneously speaking)

MR. BERKE: You know corrosion, I wouldn't count on that for anything splitting. But I mean, once you know corrosion starts, you know, now you've got to do something to mitigate it.

MR. JONES: Okay.

MR. BERKE: Because that can cause, not left alone to do its thing, it will cause a problem. It certainly can lose all the concrete outside of the steel, so if that was offering any type of containment, that's gone.

MR. JONES: Okay.

MR. CASERES: You're assuming contamination coming from the gas phase, from the outside. But again, I'm pointing out the induced carbonation from radiation.

MR. BERKE: Oh, you got -- yes, if you get carbonation anywhere the mortar, I mean the steels protected in concrete because the pH is above 10.

MR. JONES: The concrete protecting the steel is --

MR. BERKE: Yes, the concrete's protecting the steel. The pH, the high pH surrounding the steel will be passive up to about 11, 10. In that range.

MR. JONES: Yes.

MR. BERKE: If the pH drops to 10 or below, then the steel could corrode just naturally.

MR. JONES: Yes.

MR. BERKE: It's not a -- it's a more uniform corrosion spread out, so it takes longer to see the damage.

MR. JONES: Yes.

MR. BERKE: But it can happen.

MR. JONES: Passively basically.

MR. BERKE: Yes. Another one I worry

about, as I said in one of my important things, is if you're where it's really hot and you're moist, then you're a different part of a Pourbaix diagram.

A Pourbaix diagram has a potential pH. Looks at what phases are stable. So at a high pH, if you're really high in temperature, you run into a -- you end up with an iron oxide that's on the surface not being passive. So it dissolves.

So you could potentially have a high corrosion rate at a high pH and a high temperature.

MR. JONES: Okay.

MR. BERKE: It's one of the reasons why our steam generators don't operate in -- say high pH rate, so why don't we operate all our steam pipes, you know, heated water for steam, you know, at pH 13 liquids.

MR. JONES: And this is the reason --

MR. BERKE: They don't do it. Yes. They run stuff down around nine so that they go nine to ten, so they don't have that problem.

So it's a potential problem. Once again, it meets, you know, by knotting up. But that's something -- that part's bad because the bar dissolves. The corrosion products are solid.

MR. JONES: And you don't get the benefit of a rust streak or --

MR. BERKE: Yes, you don't see --

MR. JONES: -- popping, cracking.

MR. BERKE: -- cracking at the surface you don't know what's going on. Matter of fact, if we had corrosion going on in this under low oxygen conditions, you would have non-expansive products and it's the same thing.

MR. POPOVICS: Green rust or whatever it's called. Black rust.

MR. BERKE: Yes. But it's like you might see it under something with a system with a membrane over a hundred years or something.

We saw it under a bridge in England that just totally caved in. No indications at all.

Epoxy rebar in the Florida Keys. They found underneath, inside the epoxy when they cut it, they found a pH 4 liquid oozing out.

MR. JONES: Hmm.

MR. BERKE: Because they got a little bit of corrosion, took under here and it was -- so it was covered. You had a cap somewhere else and it was acidification. So it was hydrolysis process that can take place. But that usually doesn't happen.

MR. JONES: Kind of unusual, yes.

MR. BERKE: Yes, that's a very unusual case. So I don't think you'll see it here expect possibly in a -- so the one I'm worried about here is the high temperature --

MR. JONES: Okay.

MR. BERKE: -- under moist conditions. I'm not worried about the other one. Because I think you'll have oxygen coming.

MR. JONES: Is that -- anyone else want to add to --

MR. POPOVICS: I would say anytime temperature goes up corrosion will go up. It's --

MR. BERKE: Well it's a funny thing. It goes up and then it doesn't go up anymore.

MR. POPOVICS: But you're talking about the --

MR. BERKE: This is a totally different process.

MR. POPOVICS: Yes, you're talking about kinetics. Because the product changes that temperature.

MR. BERKE: Yes.

MR. POPOVICS: But I'm talking, anytime

temperature goes up, molecules are moving faster, corrosion will go up.

MR. BERKE: Yes. But the problem is there's an oxygen content too. So the normal -- you get to some point, yes. If you go from 20 degrees to 30 degrees, the corrosion, goes up.

MR. POPOVICS: Yes.

MR. BERKE: You get the 40 it might actually drop a little bit because the amount of oxygen, the solubility of oxygen is less the higher --

MR. POPOVICS: Yes, that's like a balance issue.

MR. BERKE: So balance it balances out. It's always tricky. Nothing's so simple.

MR. JONES: Sure.

MR. BERKE: That's why I have a job. But then you get to something like 65, 70, 80 degrees C and you have a whole different process taking place.

Okay. Now you don't have -- now the ferric oxide is not stable. You form an Fe2 hydrogen, Fe2O3 or Fe2O2 or Fe2O4, at least with hydrogen on it. Which is soluble.

MR. POPOVICS: Which is --

MR. BERKE: And so it's not acting as a

passive layer to protect the steel. That doesn't need chloride, it just needs the high temperature and the high pH.

MR. JONES: That's acting chlorine.

MR. POPOVICS: Yes, that's an acting chlorine.

MR. TRIPATHI: Neal, everything you discussed so far pertains to rebar. You know, there are other embedments.

MR. BERKE: Ah. If it's steel it's steel.

MR. TRIPATHI: Steel is a steel.

MR. BERKE: Steel is steel.

MR. TRIPATHI: But the rebar steel is slightly different than say structural steel. For example we have channels embedded --

MR. POPOVICS: For corrosion it's --

MR. BERKE: Not a whole lot. Unless you're putting stainless steel in there or some kind --

MR. POPOVICS: Yes, so higher alloys.

MR. BERKE: -- or higher alloy contents. Even in concrete a lot, you know, I don't know even if they even, they don't go to the low alloy high strengths, low alloy steels too much.

But I mean yes, if you have --

MR. TRIPATHI: Carbon steel. Any carbon steel.

MR. BERKE: Carbon -- any --

MR. POPOVICS: Any low alloy --

MR. BERKE: -- 35 steel. You know, the normal carbon structural steel and rebar are going to be fairly similar.

MR. TRIPATHI: So you're saying you have observed this mechanism? Even with the bars were coated with epoxy, you still see the --

MR. BERKE: Well epoxy coated bars can't fail. Especially over a long period of time.

MR. TRIPATHI: Of course. Yes.

MR. BERKE: I mean the problem in all these things is, what type of accelerated test do you use? Most the accelerated tests for black bar are not that accelerated for epoxy coated rebar.

I supposed rebar is better than non, you know, black bar. So I don't want to be sitting here knocking it, it's still important.

MR. TRIPATHI: The main issue with epoxy is that that's not a perfect coating.

MR. BERKE: Yes.

MR. TRIPATHI: I mean it always have flaws in the coating.

MR. BERKE: Yes.

MR. TRIPATHI: Accelerate corrosion.

MR. BERKE: Yes. If you get breaks in the coating over a long period of time, under the right conditions, you can get corrosion occurring underneath the coating.

But coatings a little bit better now, that's less likely to happen. But everything, you know, it's got a time effect.

MR. TORRES: This is a radiation environment, so that's epoxy weathering.

MR. BERKE: I don't think the bars are getting, you know, or from what I read, I didn't see the bars getting really bad. But unless they heated up I guess they would be -- there could be a problem. You know, localized heating of the bar due to the radiation flux.

MR. POPOVICS: You're talking about the embrittlement of the polymer. Yes.

MR. TRIPATHI: Embrittlement of --

MR. BERKE: Of a polymer? No, the polymer has all sorts of aging affects that you don't see in most --

MR. TORRES: Wait. You're suggesting that it might be unlikely to see an epoxy rebar of this application because --

MR. TRIPATHI: That relaying on the coating is --

MR. TORRES: Yes, I'll let --

MR. BERKE: I agree with you on this case. But I mean any structural steel behaves generally the same.

Matter of the fact, the boiler steel is, you know, is probably a little bit better quality than rebar. That's when they first noticed the problems with the high pH.

MR. JONES: So I think --

MR. POPOVICS: I think it's good practice to consider any low alloy steel or anything below carbon steel as the same. As corroding the same.

MR. BERKE: Yes.

MR. POPOVICS: And you can't really count on corrosion protection unless you go up to the higher alloys. So like weathering steel or stainless.

MR. BERKE: Well maybe the top weathering steel might do something, but I mean typically --

MR. POPOVICS: And anyway you don't use

weathering steel for reinforcement.

MR. BERKE: Yes, exactly.

MR. POPOVICS: That's an external steel.

MR. JONES: Right.

MR. BERKE: Yes, you might -- you maybe go to like a nine percent chrome bar, at the bare minimum. That might give you some benefit.

MR. JONES: So we're kind of getting into some prevention mitigation issues, which is, you know, we'll have some time to come back to that. But let me jump us ahead just to this last item here, which is coupled mechanisms, which we have also covered a little bit as we've gone along.

I've observed that it seems like there's sort of an underdevelopment or under treatment in the literature for studies with coupled mechanisms. You know, you sort have this idea that micro-cracking will enhance, whatever, but, you know, there's maybe a lack I guess you might say.

Or just, you know, researchers tend to try to exclude things to focus on the things they're researching on, you know. So again, this micro-cracking linked to transport appear to be a very common one.

And then the couple that are stimuli might also be relevant. And this I'm talking about, you know, radiation or maybe stress, you know, tolerates the thing.

And I guess I would, you know, we don't have a time of time anyway but I don't think we need a ton of time, is there any active research that anyone's aware of looking at any kind of coupled mechanisms that would be relevant to --

MR. BERKE: Some were down in Florida looking at cracks. Shrinkage cracks and corrosion.

They have a much, and this is actually good for here, they have a much more profound affect to small cracks on high performance concrete then they have on normal concrete.

MR. JONES: Did you go from impermeable to much, much more permeable.

MR. BERKE: Yes. Because I mean it turns out that, you know, if you got a concrete in a 0.5 water cement, especially a 0.5 or even 0.4 water cement ratio, the pore structure is not necessarily too much different than what you have in a fine crack.

MR. JONES: Okay.

MR. BERKE: So you don't see a big change.

But if you go to a real high performance concrete, you have a -- that microcrack is actually a big path than, a much bigger path, than the concrete around it.

MR. JONES: Okay.

MR. BERKE: So really it comes into what size crack.

MR. JONES: Okay.

MR. BERKE: So if you have a large crack it's going to matter to you. If it's a, probably if it's under 0.1 millimeter, it's under 0.2 millimeters --

MR. JONES: You're similar to the pore network at that.

MR. XI: You know, I had a project about a coupling affect sponsored by NSF.

MR. JONES: Okay.

MR. XI: Several years ago. Actually two. Two projects. So it's about the coupling between positive and negative ions because they move together.

MR. JONES: Okay.

MR. XI: But what if you people try to, let's see, analysis the chloride, they focus on chloride. But actually if you look at sodium chloride, calcium chloride and magnesium chloride, so will they penetrate into concrete at different rate. Because of the factor of positive ions.

MR. BERKE: Yes.

MR. JONES: Because of the --

MR. XI: So I had a --

MR. JONES: -- limits along with that.

MR. XI: Yes, I had a project on NSF. And also another priority is about the covering. Let's see, if we have a freeze/thaw and at the same time we have a chloride concentration.

So I know there's some mechanical damage covering the chloride.

And the current research is on the effect of the concrete. On the penetration of a moisture. You know, they talked about that.

MR. JONES: Yes.

MR. XI: So when the temperature gradient and a moisture gradient in the same direction --

MR. JONES: Yes, or opposite direction.

MR. XI: -- opposite of doing that. And actually I just talked with, I don't see her, your colleague.

MR. JONES: Are you talking about Mita?

MR. XI: Oh yes. We made a proposal yesterday to NEUP. So where the proposal is about the multi-phases problem.

MR. JONES: Okay.

MR. XI: So it's the coupling of everything. Positive and negative ions, temperature, moisture --

MR. JONES: So proposed for development?

MR. XI: Yes.

MR. BERKE: And actually, you have a good point. I had a paper I did with Carolyn Hansen back in the '80's looking at magnesium chloride, calcium chloride, sodium chloride as far as how they come in. You know, on the chloride.

There's a big difference in the chloride ingress, you know, based on the salt. So it's not so bad because it holds up a lot of the water on -- it takes a lot of water on. And so it slows down the chlorine movement a little bit.

MR. JONES: But --

MR. BERKE: Magnesium is bad and the calcium is bad also.

MR. JONES: Okay.

MR. XI: How would we use your test data? Very helpful.

(Simultaneously speaking)

MR. BERKE: And it was an MRS meeting back in, I think back in --

MR. JONES: So this is going to wrap up our discussion of degradation mechanisms. You know, we haven't hit on everyone, but, you know, I tried to identify the ones that maybe there was more to talk about.

Some of them, you know, were maybe better settled or whatever. But I want to invite Brian Thomas up. He's our director of the Division of Engineering and the Office of Research. Just to say a few words for us here. So.

MR. THOMAS: Good morning.

MR. JAMES: Good morning.

MR. BERKE: Good morning.

MR. TRIPATHI: Good morning.

MR. XI: Good morning.

MR. THOMAS: I do know some of you. How are you doing, Mark?

MR. LOMBARD: Good.

MR. THOMAS: Good. Randy, how are you?

MR. JAMES: Hi.

MR. THOMAS: First members of the Panel, thank you very much for giving me the opportunity to say to you -- to express to you my appreciation for your participation in this process.

I know it's your lunch time and I'm taking five minutes out of it. Maybe five minutes. But I think it's a well worthwhile opportunity and I'll take advantage of it.

I do truly want to express our appreciation in the Office of Research, and in the Agency, for your, you know, being a part of this process.

As you all know this is a very significant, key significant area for us. We're looking at, you know, plants that are interested in subsequent license renewal and what we call life beyond 60. Extending their lives.

And so, you know, we're charged by the commission to look into what are the key significant degradation mechanisms associated with concrete.

You know, over the past few years your concrete has, you know, it's surfaced in terms of problematic. In terms of problems. Problems that can develop over years.

So we're really concerned about exactly what aspects of the degradation that we focus on in terms of, you know, licensing after -- that are interested in extended life.

So thank you again. I particular get interested in and get excited when it's a panel composed of, you know, members from the industry and from different venues get together and share their views, share their experience, their knowledge.

It -- you know, I came in about a half an hour ago. And just sitting back there and all the issues that were bubbling up, I got a little excited about that.

It takes me back to, we had a panel process involving the AP-1000. You know, a shield, the steel plate composite concrete modular wall design. We had a panel process in that.

And it takes me back to those days when there were a lot of huddling time. A lot of -- we spent a lot of time huddled up in various venues. Various rooms trying to figure out what are the key significant issues we should be concerned about.

Of course we're looking at design. And we were thinking about constructability and accessibility, inspectability, monitoring and so forth.

Not once did it cross our minds that, hey, we ought to look at, you know, will the structural integrity of these structural components be -- still be intact 40 years down the road, 60 years down the road, 80 years down the road.

So now you're really looking at the other end of that whole design process. And bringing to bear that knowledge that you have with regard to that is very, very much important to this. And we really truly appreciate it.

MR. TRIPATHI: Besides the industry experts, don't forget the professors from academia.

MR. THOMAS: Yes, yes. And thank you. And I'm really thinking of --

MR. BERKE: Mention them.

MR. THOMAS: -- members from all venues. I really truly appreciate it. That's it.

MR. JONES: All right.

MR. THOMAS: Thanks a lot.

MR. JONES: So we have come to lunch, which is a pretty unique time in the day. We will -- let's see. Look here.

We will come back at -- right at 1 o'clock for prevention and mitigation strategies. So we have just right at an hour from now.

So there's a cafeteria downstairs. If you feel like you can get off campus and back in time, that's fine too. So we'll meet back here at 1 o'clock. Thanks.

(Whereupon, the above-entitled matter went off the record at 12:00 p.m. and resumed at 1:01 p.m.)

A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

(1:01 p.m.)

MR. JONES: Okay, it's 1 o'clock. We will start to ease back into the afternoon session here. I hope everyone found a delicious morsel downstairs, that you're all thoroughly nourished and ready to take on the afternoon.

I guess just a little minor housekeeping. If you've come and have not signed the attendance sheet in the back, we'd appreciate that. Also, if you are on the telephone line and have a mute button available, that would be great so that we can, you know, if we're hearing your telephone ring, music, that sort of thing.

And this morning we covered degradation mechanisms in a fair amount of detail, maybe not as much, maybe too much. But that's what we did.

And now we'll move on to some additional topics, namely prevention and mitigation strategies and then inspection techniques and technologies.

I should point out that I think that there's another meeting going on next door that's not related to concrete. So if you find yourself in this room and don't want to hear about concrete, now may be a good time to --

(Laughter)

MR. JONES: Okay. So I sort of conceptualized this topic, prevention and mitigation strategies, in light of, so it goes hand-in-hand with the degradation mechanisms that we talked about this morning.

In fact, often when you talk about ASR, for example, the first thing that comes up is how to exclude aggregates and stop the problem. And so they're sort of naturally linked, but I wanted to spend some specific time on them.

And maybe it won't take the full hour and a half I had allocated. But maybe it will. I did want to distinguish between the notion of, and this is arbitrary, this is me doing the distinction, but distinguish between prevention and between mitigation.

So prevention is something we might do during the construction phase or early on to prevent a problem. And then mitigation would be, of course, something that, you know, once the map cracking is detected or whatever, how would we, you know, maybe try to help ourselves out a little bit by taking actions to mitigate further acceleration of the degradation.

The prevention strategies could be

considered so-called best practices. You know, we, I guess, in the concrete industry, you know, you hear sort of the same things come up again.

You know, like low water cement ratio or use supplementary cementitious materials or, you know, sort of these best practices that aren't necessarily targeted at any specific degradation, but are in general good things that sort of improve the health of your, and then frankly durability of your concrete.

And of course the notion of prevention is informed by the notion of design life. And so, you know, if you're designing for X-years, you know, maybe you don't need to worry about some things.

We find ourselves in the situation where the design life has maybe lengthened on us a little bit. And so we're sort of in an odd situation of not being to prevent everything just because the structures are already built.

So mitigation, as I mentioned, is our actions once we take, you know, once we've gone a little ways or detected a problem how might we mitigate that.

And I do want to distinguish between a separate topic, in my opinion, which is repair and remediation replacement. So we're kind of splitting hairs here but, you know, mitigation's maybe something you do to arrest the acceleration of a mechanism, and then that's different than maybe a repair or replacement, remediation activities. So we'll try to confine ourselves in that way.

So I don't have as many slides for this section. I just sort of put some ideas here. And I wanted to talk with the experts about just what you thought about prevention strategies.

I've listed a few here, water/cement ratio, I should say to people on the phone, we're on Slide Number 27, supplementary cementitious materials, aggregate selection, admixtures, things like this. Construction practices we mentioned in passing earlier as well.

So I guess maybe if we could, if there's anyone that wanted to offer a general comment on prevention strategies, maybe we could start there and then see where that leads us. And if not, you know, we'll see which direction to go from there, I guess.

MR. TRIPATHI: I'll make a general comment.

MR. JONES: Sure.

MR. TRIPATHI: I think, between the prevention and mitigation, I would put more emphasis on mitigation. The fact is, because more than 2,000 cask storage units are sitting out there.

MR. JONES: Sure.

MR. TRIPATHI: Some for 20 years, some even exceeding 20 years. Now, prevention is nice and fine, but this is all for new construction which is still in the making.

MR. JONES: Right. We're somewhat limited in our ability to prevent --

MR. TRIPATHI: Exactly, exactly. So I would like to hear more about the mitigation strategy than prevention. I'm not saying don't talk about prevention. But relatively, it's more important. More than 2,000 units are sitting out there.

MR. JONES: Yeah.

MR. TRIPATHI: And we need to worry about those.

MR. JONES: See what we can do with those, yeah. So that's a great comment on the narrower topic of prevention. Would anyone else care to share a thought or --

MR. POPOVICS: I think all of the, you know, I think we discussed this already in the telephone -- got caught talking off his head last month, but almost all degradation mechanisms rely on moisture. And if you don't have moisture, you don't have the mechanisms.

So if you mitigate moisture, you're going a long way towards extending the life, not in every case, of course, but whether it's by proper drainage, detailing, coatings --

MR. JONES: So let's drill down on that a little bit, obviously. As we know, water is mixed with cement to create the concrete. So there's a certain amount that's present. You're specifically talking about the ingress of moisture --

MR. POPOVICS: Right.

MR. JONES: -- the water coming from an external source and getting in.

MR. POPOVICS: Yeah, water goes from being concrete's best friend to worst enemy in the span of its life.

And I think water, you know, the first two concrete mix design strategies are specifically to reduce capillary porosity and ingress, so diffusion and heat transfer mechanism, basically, you know.

MR. JONES: So again, these are just starting points. Let's maybe think about construction practices. You know, John, earlier you mentioned the finishing of concrete can affect the results of stability.

MR. POPOVICS: So there's certain detailing, certain practices that may be important, curing, with curing it, any of it, like, exposed surfaces are important.

MR. JONES: And that works by refining the pore network, getting, you know, less transport to susceptible --

MR. BERKE: What it is is your 28-day compressive strength and 28-day properties are only real if you cure the concrete properly so you can get to something like that. Otherwise, it's going to be more like a one-day property or two-day property.

MR. POPOVICS: Yeah, the more you cure it, the more, you know, especially surface conditions you're protecting. You know, you're reducing shrinkage stresses by impelling the dry out your, I'm talking about moisture in --

MR. BERKE: Yeah.

MR. POPOVICS: Providing external moisture for continued hydration. It's a very simple practice, but a very important practice.

MR. BERKE: Sure. And allowing time for concrete like this, it'll be moist enough on the interior. It's the outside part that benefits the most.

MR. JONES: Yeah, they're kind of erased between how fast you can migrate the moisture out from the deep points of the pore and the curing, or the hydration that's going on naturally.

MR. TRIPATHI: According to ACI 318 and 349, both I think it's a 28-day strategy.

MR. BERKE: Yeah.

MR. TRIPATHI: Not the day after, not after 20 years. I mean, after 20 years, you know, the 3,000 PSI is no longer 3,000 PSI. It's more like 6,000 PSI. But you can only rely on the design strength.

MR. BERKE: But the 28-day design strength in sitting in a moist --

MR. TRIPATHI: Exactly.

MR. BERKE: -- environment. But if the concrete's not sitting in a moist environment --

MR. TRIPATHI: That's what counts.

MR. BERKE: -- then it doesn't have that 28-day strength at 28 days.

MR. TRIPATHI: There is a separate issue which we'll discuss probably tomorrow. The concrete, as it ages, is harder. We all know, concrete hardens. And there are some requirements which we'll discuss tomorrow.

But what about hardened concrete. It's no longer 3,000 PSI. And certain design features relied on that 3,000 PSI. But now, all of a sudden, you've got 6,000. What do you do with it? We'll talk about that tomorrow.

MR. BERKE: It could be a problem in some cases.

MR. TRIPATHI: They're separate issues.

MR. BERKE: Sometimes, too much of a good thing is bad for you.

MR. JAMES: So you mentioned up front on the slide that prevention strategies usually depend on your design life that you're specifying.

MR. JONES: Sure.

MR. JAMES: I'm probably not supposed to ask questions, but are we thinking for new cask systems you're going to increase the design life, required design life for the systems?

MR. JONES: Well, I don't know that we are or we aren't. But, you know, we find ourselves in the situation where something that was designed for X is now being asked to go, you know, at least two-X if not, you know, so there's a bit of an incompatibility there.

MR. TORRES: I think that an example of where we can use your feedback is, from what I gathered from the previous session, for instance for ASR, ASR aggregate reactivity, it seems like there's a consensus that the extended tests should be the preference for design.

So that's the kind of information I think that would be useful. But at this point, I don't think that we determined that we're going to be imposing rigid requirements to the same design there.

MR. BERKE: Because the current design limits on bridge decks, for instance, pretty much the minimum is 75 for bridge decks, whereas you're seeing in the news now like Tappen Zee and Goethals, and they're talking 150 year design-wise.

Now maybe some repair, moderate repairs that they can get to things in that time, but basically it's going to last 150 years. And that's what they're talking about.

And, I mean, it's not rocket science or nuclear science to do that. It's pretty, they're pretty straight forward methods that could be used.

And a lot of the things that might have kept it from being used 40 years ago such as you had to have that low water cement ratio, and you couldn't have workable concrete. That's all, you know, pretty much, you know, been taken care of.

Now thermal grade, thermal controls, or not controls, thermal conditions so that you don't have thermal cracking in massed concrete, you can control that and still have low permeability durable concretes, you know.

So one of the considerations is that, at least when we're building new stuff, is to have a little bit better, you know, a longer design life. And then the committee would be getting together 25 years from now to decide whether or not to put another 50 years or 100 years, you know.

But I do agree with my friend here that if you've got 2,000 out there now, you've got to do something about those. That's going to matter, you know, because you have to handle those.

But on the new, we had, like, this is the new construction. And new construction, that can even be taking the things that are being used for the wind structures and bridges and use that technology to try to, you know, at least get a design life that's closer to 100 years or longer.

MR. TRIPATHI: See most of the modules sitting out there, Neal, are, as I said earlier, are, that's what I'm seeing, 3,000 PSI.

MR. BERKE: Oh, yeah, I know.

MR. TRIPATHI: Okay. Maybe in some instances maybe 4,000. We're not talking about here high strength like --

MR. BERKE: Oh, absolutely.

MR. TRIPATHI: I mean, you can buy 10,000 PSI concrete. My question is if we impose that upon them to use higher strength concrete, would some of these mechanisms disappear --

MR. BERKE: Yes.

MR. TRIPATHI: -- or minimize?

MR. BERKE: Well, the problem is that, and here's the biggest problem they have, at least the bridge guys, bridge and parking structures, we tell them you have to design a low permeability concrete.

So it used to be in the old days, you said I want these types of permeability requirements, and they needed 4,000 for structural, and they were getting 8,000. So they looked at the 8,000. Well, I'm way over. They'd drop it down to 4,000, less durability.

So the problem is, if you design for

durability, you're going to end up with a higher, in most cases, you're ending up with a higher strength than you need.

Now, that's an opportunity too, to redo the structural designs to take advantage of that higher strength concrete or at least have it so that it's not detrimental to you. So you end up, there might be actually a cross savings that come about or extra margins of safety --

MR. TRIPATHI: Right.

MR. BERKE: -- by having that. But, yeah. I mean, the durability and strength have to be separated. Because --

(Simultaneous speaking)

MR. BERKE: -- doesn't matter.

MR. TRIPATHI: Risk and reward, if you are not getting enough for the extra money that you spend, then it's not probably worth it. You know, current modules are designed from strength worries to take the tornado missiles.

MR. BERKE: Oh, yeah.

MR. TRIPATHI: I mean, all kinds of natural phenomena, including size, make-up, what have you. So if they're good enough with 3,000 PSI, what do we have substantial to go back and tell the vendor --

MR. BERKE: Possibly --

MR. TRIPATHI: -- to use a higher --

MR. BERKE: Possibly a little thinner wall to seek in the envelope, you know, radiation aside, possibly a little thinner wall. But once again, durability and strength have to be separated. Strength might be overkill.

MR. TRIPATHI: But as I said earlier, besides structural discipline, we have to worry about also shielding, criticality, containment, heat transfer. So all this framework --

MR. BERKE: I hear you. But what I'm saying is that all those things might be over-designed for it. But if you're looking for 100 year design life, that's typically the case.

If you can use that extra strength somehow in your design, that's fine. At least make it so it's not detrimental to you. Because sometimes too brittle a structure is bad too. But if you want durability, in most cases you're going to end up with more of the other things that, you know, you'll be way beyond your structural design limits.

But that's the durability now that's

running it rather than strength. Because you can hit the strength and have totally now a durable concrete. It's easier in 3,000 PSI, 4,000 PSI.

MR. JONES: So just to summarize, there's sort of a different design criteria that might be met if we're talking about durability. You started my sentence for me but, you know, designing for durability might yield a different result than designing for structural performance or field --

(Simultaneous speaking)

MR. BERKE: Almost always, almost always.

MR. JONES: And so that could potentially be, you know, your bridge deck example, that could potentially be a different way to approach the same problem.

MR. BERKE: Well, they don't utilize it. They say they have the same problem with the bridge deck. They don't want 8,000 PSI concrete in most cases in the bridge deck. If they get it in the girders, they'll take it.

MR. JONES: Yeah.

MR. BERKE: In the girders is great if they have that extra strength. But in the bridge deck, if they had 4,000 it would be ideal for them.

MR. JONES: Uh-huh.

MR. XI: I can give you an example following what you just said. So, let's see, 15 years ago the highway industry was shooting for high strength concrete.

MR. JONES: Yeah.

MR. XI: And in Colorado were using 10,000 PSI concrete. And now they find out that the strength and toughness was two different things.

MR. BERKE: Yeah, absolutely.

MR. XI: So toughness is resistant to cracks. So concrete only strong between cracks. So you have a higher strength and then long cracks, does not mean anything.

And then the industry switched to a high performance concrete. I mean, the strength will be adequate. And the durability should be higher. So what we did, many projects were for CDOT, Colorado DOT --

MR. JONES: Sure.

MR. XI: -- was that so there's a -- 28 days -- for the project, and then you add the chloride permeability up. So this is the ASTM --

MR. JONES: Right, rapid chloride permeability.

MR. XI: Yeah, rapid chloride, actually is conductivity.

MR. JONES: Yes.

MR. XI: So this is one. And then also add another one is a shrinkage test, so to make sure the shrinkage is low. And then the shrinkage cannot be totally removed from concrete. So we add another test. It's a ring test.

MR. JONES: Uh-huh.

MR. XI: What I forgot --

MR. BERKE: 1581.

MR. XI: -- actual number.

MR. BERKE: There's an ASTM 1581, the AASHTO, a slightly bigger ring. But they're basically the same idea.

MR. XI: Yeah. So to make sure the shrinkage is low and also the resistance to shrinkage rate is high. So combine these four tests so we can make sure the concrete will be, that the strength will be enough and the durability will be high.

So actually we used this, and we developed, mixed in lines with CDOT, one can be used in the summer, one used in the winter.

MR. TRIPATHI: So maybe this is something which we can think about for future storage --

MR. BERKE: Absolutely.

MR. XI: Dry cask.

MR. TRIPATHI: And then there is room for, if NRC goes along with it and if it's blessed by the management and the technical expert, to even change the regulation. Right now, Part 72 which governs the storage may not require, I'm saying may not require, the durability requirements, just the strength.

MR. BERKE: Right.

MR. TRIPATHI: But it it's worthwhile, especially for a long term, 100 years and beyond, then this durability --

MR. BERKE: Yeah. And you do the shrinkage and the cracking resistance in conjunction with it, as he said, so that you can counteract some of the brittleness that would come from the outer restraint --

MR. TRIPATHI: There's a potential candidate for rule making --

MR. BERKE: Yeah.

MR. TRIPATHI: -- in terms of, you know --

MR. XI: Changes the conformance for future --

MR. BERKE: Yeah, future. It won't help you on the stuff itself.

MR. XI: More change. And there's another thing I will mention, because that was a big loss, that was one of the MVPs.

So because the people mentioned about coating, because coating is very important to prevent the penetration of moisture into the concrete in general, just measured. But when you apply a coating, you must be very careful. Because there are more than 200 regions have coatings on the market. So what you need to use is called breathable coating.

MR. JONES: Breathable?

MR. XI: Yeah. So it will block the liquid water getting into the concrete. But it will allow the vapor phase of water get out of the structure. That's very important. Otherwise, you know, there was a structure up. And I don't want to mention the name. They used a coating, and then the moisture could not get out.

MR. JONES: Uh-huh.

MR. XI: So when we drilled the core, later the internal moisture distribution you can see on the surface, the relative humidity is super high. The reason is because the moisture is driven by the temperature gradient from inside to the out surface. It cannot get out the walls by the coating.

And mostly, when you use the right type of coating, the thickness is very important. You know, in the industry it's about six to eight millimeters. But when the contractor try to apply it, they want to do a better job --

(Simultaneous speaking)

MR. XI: Yeah. So coating is usually very thick. So again, that blocks the moisture to get out of the structure.

MR. TRIPATHI: So we are talking about the coating on the concrete surface?

MR. XI: On the --

MR. TRIPATHI: External?

MR. XI: Yeah, yeah.

MR. JONES: Let me engage maybe the other half of the table. What do we think about the notion of, I guess, designing for durability as opposed to designing for strength, or shielding or something like this?

MR. POPOVICS: I think Yunping and Neal stated it very well. It's a different set of design criteria for durability or serviceability as opposed to the strength and loads, dynamic response.

MR. JONES: Uh-huh.

MR. POPOVICS: But the code does recognize both. So, you know, so I think the new buildings, you know, new structures should, with proper materials and design, should last as long as expected. I don't know if we have a 300 year design yet, you know --

MR. BERKE: You go to Moscow and Abu Dhabi for 300 years.

MR. POPOVICS: Okay.

MR. BERKE: I'm hoping it'll last that long.

MR. POPOVICS: In Abu Dhabi, you said?

MR. BERKE: Or to Moscow.

MR. POPOVICS: They have corrosion problems there.

MR. BERKE: Yeah. Well, it was mostly in the ground that we were protecting, of course. So it would be great for the underground stuff.

MR. POPOVICS: But it's, I think, I think they've stated it pretty eloquently.

MR. CHOWDHURY: So the potential is that duration of licensing is significant, 100 years, higher strength, higher toughness, those are some of the potential -- in this.

MR. BERKE: Yes. I would say you get the higher toughness and resistance to cracking. The strength problem's not going to be a, the strength, you're going to have more than you need.

MR. JONES: Uh-huh.

MR. BERKE: It's almost impossible to mix concrete like that that's not strong. You can do it, but you have to work at it.

MR. XI: But I want to add a little bit. I mentioned high toughness. But I know finally I will not make any recommendations for Federal Highway, CDOT. The reason is because in the US there is no standard.

MR. BERKE: Yeah.

MR. XI: In the highway community, people fight with each other, finally no standard in the US. But in Europe, there are a series of recommendations. So it's not an easy job to test --

MR. BERKE: Yes. In Europe they have a big test that they do.

MR. XI: So that's why we didn't make any recommendations.

MR. JONES: For durability in general or

for --

MR. XI: No, for --

(Simultaneous speaking)

MR. BERKE: Definitely you want crack resistance. When your toughness is ideal, then you have a crack resistance as a bare minimum.

MR. POPOVICS: Uh-huh. You're talking about the notch beam?

MR. BERKE: Well, they've got a one notch beam square thing they use in Europe. And then they've got a regular, they use a regular box beam. But, you know, they do it in, you know, displacement control.

MR. POPOVICS: Displacement control.

MR. BERKE: And they have a certain value they get at, prime, that C3 or something, I forget exactly how it goes.

And they can actually figure out what the flexural strength, the toughness is at a certain point. And they have all the design code that was designed for that. So he has fibers now --

MR. JONES: Well, let's shift gears a little bit, not forgetting prevention, but let's switch to mitigation strategies. And again, I've just thought up a couple here. But there's probably many more.

As Al points out, this is probably the more interesting issue. Because we do have a large number of examples in the field, weathering, aging, et cetera. And so, you know, this could potentially see, you know, work its way into the inner space.

So de-watering, of course, and that could be, you know, a well to reduce the water table. Or that could be a, you know, many ways to remove the water, I guess, is what I'm getting at, exclusion from the, you know, lake front or whatever. Moisture barriers, coatings, we just talked about.

I think some of these chemical mitigation things are interesting. I don't know how applicable they are. And maybe we can shed some light on that, but some of these chemical application ideas for mitigating ASR, cathodic protection for rebar. Then I'm certain there'll be many others.

So I may have to start it the same way, does anyone have a generic comment on the notion of mitigation for degradation? Or maybe I'll ask this question. Is there good experience with mitigation, or are they all just kind of delaying --

MR. BERKE: I think there's good experience. They're using some materials that are, you know, at least on bridge decks where they applied them. And the rates can go down, and the same with parking structures. We see things like that.

We've got a new ASTM, not an ASTM, but we have a Bureau of Reclamation test method that we just developed to actually look at repair techniques. And we basically had, it was a one meter square slab that has two layers of rebar on it.

We get it into corrosion with chloride, and at Point 5, so it's very applicable to infrastructures that we have there. And you get it into corrosion, and then you apply a repair and mitigation technique to it, either a topical sealer, or a corrosion inhibitor or a coat.

And/or you have a hot spot that you have extra chloride in, and you use that for embedded analog. And these methods are showing that -- some of these methods look like they actually will mitigate corrosion.

And, you know, it might buy you ten years, and then you'd reapply it, you know. But in all cases that we're seeing, the things that work are much better than the controls, controls of slabs that go on and crack, because they've been treated.

When you do your electrochemical

measurements, the corrosion rates were high and they stopped. You open it up, you've still got the rust on the bars --

MR. JONES: Sure.

MR. BERKE: -- because the rust doesn't disappear. But the whole process just slows down. So you could buy considerable time. They're relatively inexpensive. And we're doing some work with ASR with that. It looks like at least one of these things works with ASR too.

MR. JONES: Are they electrical methods or --

MR. BERKE: Just basically drying the concrete out.

MR. JONES: Uh-huh.

MR. BERKE: You know, we're seeing a couple of advantages of that. We're seeing a reduction of the strain gradient between the top bar and the bar further down which is also good.

Because one of the things that caused -- not the bar, this is the concrete -- the other thing that causes cracking in concrete is the strain differential. So if it's that the shrinkage is the same near the top as it is in the middle, you know, you're most likely to get cracking.

MR. JONES: Uh-huh.

MR. BERKE: So we're seeing that. We'll probably publish this pretty soon. We had like an initial thing at last year's TRP.

MR. JONES: Uh-huh.

MR. BERKE: But there's a couple of papers at NACE on some of these. But the new test model is very good. We're testing several so-called repair products. Now, most of them were designed for bridge decks and parking structures. But I don't see why they wouldn't work on the concrete in this application.

And so I think -- and they have the advantage of what Asad was talking about. They're water repellant, some of these. But they let the moisture out. So they don't trap moisture in.

Trapping moisture in, I think, as he pointed out, is something that can be really bad. That's where you get a tenth of the corrosion under low oxygen conditions. You don't get a lot of expansion products. I mean, you don't want a slab that's 100 percent wet. So you need to get the lithium. That works, but it's, quite frankly, it's hard, you know, the company that used to sell it, it doesn't get in.

MR. JONES: So it's difficult to --

MR. BERKE: It'll protect the outside of the concrete. But it's, you know, it's a reality. So it's used as an admixture now more than it's used as, I mean, you can't get fly ash, you're stuck with everything you got. And you can't get fly ash. It's used more in new construction.

It can be used on a thin section confidently. But if you've got a section that's a foot thick, you're not going to get this stuff in a foot, I mean, no matter what.

And the CP definitely works for corrosion, but one of the things CP does is increases the alkalinity next to the bar that's being protected. So if you have an area that was marginal, and your concrete had a relatively low alkalinity content --

MR. JONES: For ASR?

MR. BERKE: -- for ASR, you're okay. But now all of a sudden, you've increased the pH at the bar. So you could get attack on that area. You could get in front of the --

There's been some reports of that with electrochemical removal systems with a pH around -- which is cathodic protection on steroids, more or less, when you're trying to drive chloride out. There's been some reports in Europe that you get pHs above 13 at the bar, 15, 16, you know, really high hydroxide contents.

Now, cathodic protection is a much lower current. But over time, it will build up, so it will be higher. And one of the ways it protects is by raising the pH around the bar as well as driving chloride away.

So that would be -- it could work if you have the right, if you did the -- that's where the core would be useful to find out do you have the right area. If you have an area that's not susceptible for --

MR. JONES: Uh-huh.

MR. BERKE: If you have an area that susceptible, you might want to think about it. And then of course, you know, I think these things can, you know, all of these things here would work, what you have there.

But underground the water, again, there's no water, there's no stuff causing it to corrode, outside problems with the concrete.

MR. JONES: I'm trying to think, kind of first but, you know, what other, excuse me, I've listed others. But, you know, what other methods have I not mentioned or that are relevant in the industry, that have shown up on --

MR. POPOVICS: Well, the most basic one is chipping out bad concrete and recasting it, replacement.

MR. JONES: Yeah.

MR. POPOVICS: But that's maybe too obvious to put up there.

MR. BERKE: Well, sometimes rather than just total replacement -- I don't know if this is repair but, I mean, you might be able to put a thin overlay of concrete or mortar on the outside. That could help you sometimes with, if you had carbonation problems it could help you. Other than that, it could seal it up and keep other things from coming in.

MR. JONES: So add just more material to --

MR. BERKE: Yeah. A little bit on the outside, you know, and that --

MR. JONES: Like stuccoing, if you will, to the --

MR. BERKE: You know, the same general idea. But that could potentially work.

MR. CACERES: How about liquid inhibitors, you --

MR. BERKE: Oh, yeah. I mean, if you got the right thing. If the concrete's dry enough you can certainly get, you know, the standard inhibitors in.

I mean, they don't penetrate a whole lot either, right away. But if you dried it, the concrete is dry, then they'll penetrate farther.

There are some inhibitors that are silane type treatments that penetrate a little bit farther. We've seen some go an inch and a half in. And those, there're just not some of the ones you might be familiar with.

And they actually, because they have a low -- the trick there is a low viscosity and a very low surface tension. You need a real low surface tension to get in. And mostly, if you have a low surface tension then they can impregnate.

MR. POPOVICS: That's the inhibitors that are vapor barriers?

MR. BERKE: No, they don't make it. They don't get in that deep.

MR. POPOVICS: No. But, I mean, that's their role?

MR. BERKE: Right. They're supposed to do that. But --

(Simultaneous speaking)

MR. BERKE: Well, even a silicon based waterproofer, if the concrete's dry, we've shown that can get in three inches if the concrete's dry. But you have to go out there and dry the concrete out which may be, in this case, isn't so bad, because you've already got the heat coming in from outside. It might be you get it at the point before it rains, it might be dry enough.

But there are some of these -- there're some organofunctional silanes, for instance, that could possibly penetrate some things. And helping us, they dry the concrete out, and they help on that end. So there's new technologies out there that could possibly do wonders for this.

MR. JONES: So you've hit upon an issue that I think is important to the NRC. And that's that some of these things are new. And so, you know, in an ideal world we would have an ASTM standard for everything that we could, you know, rely on.

But could you give us an idea of sort of the maturity, if you will, or which are the more accepted mitigation techniques or, I mean, there's always a new idea, I guess, is what I'm getting at.

MR. BERKE: It can be about a year from now. Right now, we're testing about five, about three, about six commercial products, six or seven commercial products right now for this application, not necessarily for it -- but we'll know a year from now which ones work.

Now, the ones you know that will work are the ones that publish the data, but you won’t know the ones that don't work.

MR. POPOVICS: They're vapor barriers, or what are you testing?

MR. BERKE: A lot of them are based on either acting to keep water out and letting moisture -- keep new water out and let moisture out. And some of them have combinations of that with an inhibitor in it.

MR. POPOVICS: An electrochemical?

MR. BERKE: Yeah. So it was a combination of electrochemical and sealer type technology --

MR. POPOVICS: Okay.

MR. BERKE: In some of them. But we've also tested, as part of developing the test method, membranes and CP anode and stuff. Yes, if they do it right, they all have some promise.

MR. POPOVICS: I think, well, CP is quite an established --

MR. BERKE: Yeah.

MR. POPOVICS: -- mitigation strategy. It has problems. You know, hydrogen development, if you drive the temps too low, can release hydrogen-2 which is sort of the case --

MR. BERKE: Yeah. The problem with the CP is only if you're worried about, have to worry about the potential for ASR.

MR. POPOVICS: Uh-huh.

MR. BERKE: Also it's --

MR. POPOVICS: And the cost.

MR. BERKE: It's also most expensive. These other things are relatively inexpensive.

MR. POPOVICS: Uh-huh. But the sacrificial lamb, the CP, doesn't have those driving potentials, right, the problems?

MR. BERKE: Yeah.

MR. TRIPATHI: So let me just quickly summarize if I understood you guys correctly. John, you said earlier that moisture is the worst factor among all. If you can control the moisture, you can extend the durability and life of the structure. Neal, you said that the drying, external drying which basically will achieve a moisture control.

MR. BERKE: Right.

MR. TRIPATHI: So it seems like that may be the mitigation technique which we need to concentrate most, to keep it as dry as possible, not just in Arizona, naturally it's dry, but even out there by Michigan.

MR. BERKE: One caveat though. You don't want to dry it and have it -- I mean, you have to dry it and make it hydrophobic. Because if you dry it, if I just dry the concrete, I could take a heater and dry the concrete.

MR. POPOVICS: Then the rain would come in.

MR. BERKE: And I drop water on it, that's how you get inhibitor three inches down. It just sucks it up. So you have to make sure that you let it dry. I don't know what your friend was talking about, you have to let it dry but not let water in. So you have to repel the water from coming in. So there's technologies out there to do that.

MR. POPOVICS: Yeah, keep the water from getting in, contain the water from getting in.

MR. JAMES: Not necessarily active drying, but just keeping it naturally drying.

MR. BERKE: Well, I think it'll naturally dry anyway just from the fact that you have a heat source on the inside. So they keep new water from coming in, otherwise it's going to dry out pretty quick all the time.

MR. TRIPATHI: So maybe it's a good idea to let some of these modern techniques which you are working on in the final report so we can take advantage of that.

MR. BERKE: I can talk to you about that.

MR. XI: But before you apply, you want to measure. Because we also deal with other strategy to dry the concrete and seal the surface, actually three different types we use now on our highways.

The penetration sealer is one type of different products, and it seems like it overlays and waterproof membranes. But for this application, it's very difficult. The reason is because of the temperature readings we just talked about several times.

So you seal the outside surface. And then the moisture gets from the air and push from inside to outside. There's no way you can prevent that. And then once the moisture gets to the surface, it accumulates there.

And part of the moisture can dry out, but when you have the coatings on the surface to prevent the moisture from outside to get in, and then some moisture will accumulate on the surface. So this happens in many of the structures.

MR. BERKE: Yeah.

MR. XI: So that's why it's, in theory, that's all right. But in the practice, it's really difficult to implement.

MR. BERKE: Well, I think a sealed membrane is going to trap moisture below it. That's definitely a problem if it doesn't breathe. And there're several products out there that breathe. Those tend to do much better. But, you know, you could use one that doesn't breathe, but you have to have -- everything below it's already dry. And it works fine.

MR. XI: Yeah. The moisture from this room will -- concrete loses a wall and driven to the outer surface. And that accumulates well there.

MR. TRIPATHI: So you're saying that some of these storage modules, especially the horizontal storage module, may have some standing water inside or -- which came through the vent. And that moisture from that water, the moisture will try to get out.

MR. XI: Yeah. There is a lot of moisture in the air.

MR. TRIPATHI: Through the concrete wall.

MR. XI: Yeah. Because the inside is not a vacuum, right?

MR. BERKE: They're the cooling vents, circulating, right? That's why I thought you'd have a breathable surface requirement.

MR. XI: Yeah. But surface is very difficult to achieve.

MR. TRIPATHI: So what you're saying, even if you dry it from outside, it's not going to help so much. Because all that water from inside, the moisture, is trying to get out, from inside out.

MR. XI: No. What Neal said is first you'll dry it out, from outside, external. And then you'll seal it.

MR. TRIPATHI: Oh, seal it.

MR. BERKE: But you want to use a sealer that doesn't let the moisture out, then you have dry it out first.

So you can use an impermeable membrane if it's dry --

MR. XI: Underneath it.

MR. BERKE: -- if you dry it out first. If it's not dried out first, then you have to have a breathable material. So you have to -- what material you use is based on, in most cases, a breathable material will work for your application.

MR. POPOVICS: Well, yeah. But Yunping's saying that it's hard to achieve in practice, the --

MR. XI: Yeah.

MR. POPOVICS: -- balance of --

MR. BERKE: Well, there's actually -- so it's working on bridges, you know, where you've got eight inch thick bridge. And it's at the bottom of the bridge, and the top dries out. It gets water on it all the time. It's horizontal. It may work.

So, I mean, you know, and then our test method would need to be developed. It's the same thing, it's still wet on the bottom.

MR. XI: You know, for bridge decks, the bridge deck is about eight inches thick there. So the top and bottom are the same temperature. So the difference in the dry cask is that the water is much bigger, much safer.

And the inside, the temperature is high almost all the time. So that's why there is a temperature gradient driving the moisture from the inside to outside. But on the bridge deck, you don't have that.

MR. TORRES: These coatings are polymeric?

MR. XI: Polymer-based, yeah, most of them.

MR. BERKE: Well, it depends. The coatings are polymer-based. The other ones are siloxane type materials. I don't know if, you know, siliceous polymers, I guess.

MR. TORRES: So it's likely that they will embrittle or thermally degrade.

MR. POPOVICS: UV, you mean? Are we talking UV degradation?

MR. TORRES: No. Just from --

MR. BERKE: Oh, the polymer ones will have a problem. The silane/siloxanes, they're a problem if you have a wearing surface. See, you have lots of advantages here, because you're not driving cars over it. You're not taking a salt scraper, you're not taking a shovel and taking off a millimeter of the concrete every, you know, a month.

And so it's going to penetrate and stay there in most cases. And it'll have to be redone after a certain amount time. But it's going to do much better than, and it'll last much longer than it would on a surface that's got traffic on it.

MR. JONES: So I'm thinking about your being here discussing the moisture gradient that's driven by the thermal gradient. That would suggest to me that we would not have a great problem with getting ions in. Because the moisture would tend to be moving the other direction, preferentially. Am I thinking about that incorrectly or --

MR. BERKE: Sounds right.

MR. JONES: Well, if you have a concentration of --

(Simultaneous speaking)

MR. BERKE: No, no. Not if the surface is hydrophobic. If the surface is hydrophobic --

MR. POPOVICS: He's being kind of general. I'm saying that --

(Simultaneous speaking)

MR. BERKE: In general, that's why I say, in general, you can't just dry it out. Because the surface will suck up the water because of the concentration gradient.

MR. JONES: Right. So let's say we've forgotten the coatings. But is a moisture gradient inside to out? And so that suggests that, you know, not a lot of the moisture that rains on it or salt spray are going to be tending to work their way into the concrete. Because, in fact, the preferential direction of moisture moving is the other --

MR. BERKE: No. Because if you get that water on it, it's 100 percent. The inside's going to be whatever the outside is from the inside at 100 dropping down to, let's say, 70. Now it rains, it's 100 percent. You're looking at 70. That pulls it in.

MR. POPOVICS: That's true. The chloride diffusion would be driven by the concentration gradient.

(Simultaneous speaking)

MR. BERKE: There's always a concentration gradient no matter what the moisture gradients are.

MR. JONES: Right, that's what I'm trying to say.

MR. BERKE: Yeah, diffusion is different than absorption.

MR. JONES: Yeah.

MR. BERKE: Absorption will be based on the moisture you're creating, while the chloride will be based on the moisture, mostly on the diffusion properties. And it'll get a push from absorption.

MR. XI: And there are three driving forces. There's a temperature gradient, moisture gradient and chloride concentration gradient. So in the period of one year, you need to look at a certain period which driving force will dominate.

So let's say in the summer inside/outside are about the same. So 100 degrees is not a big deal. And then the moisture gradient outside actually is wet, inside is dry. And also outside, the chloride concentration is higher. So these two driving forces both drive chloride from outside to inside. So in the summer, you have that.

But in the winter it's actually reversed. The inside is hot, the outside is cold. And then the temperature gradient will drive everything out.

So really, it depends on the -- within this 300 year period, you'll see all this back and forth. But once the chloride gets in, it cannot get out. It's not like moisture, it can dry out. The chemicals will stay inside.

MR. JONES: So specifically on the notion of having an impermeable membrane on that outer surface, I mean, you've just clearly laid out that, you know, that driving gradient that would give us concern by accumulating moisture on the surface, that situation would change throughout the year, I guess.

MR. XI: Yeah.

MR. JONES: But still you're asserting that's it's a best practice to have a permeable, a semi-permeable coating?

MR. XI: Membrane, yes.

MR. JONES: Okay. That's good, good insight.

Let's talk about the lithium methods just for a minute. I think they're interesting, so sorts of lithium salts have higher activation energies, the higher or lower activation energies than the ASR gel that's forming. And so you've got a replacement. And I guess the theory is that that new compound is volume stable if you don't get the expansion anymore.

The problem appears to be getting that lithium into the form at work to do any kind of mitigation action. So, I guess, has there been any experience where this has worked well? You know, you alluded to that maybe briefly.

MR. BERKE: Well, they are using it in new construction now. And there it does work.

MR. JONES: As an admixture after?

MR. BERKE: As an admixture. It works there. It's expensive, but when they have no other choice, it's used. And it's actually a really good business fund to have. I mean, they sell it for surface supply. People buy it. But, I mean, I just don't think it can soak deep enough to do it.

MR. JONES: Since it's not, like it was --

MR. BERKE: Well, the problem is, if you have moisture in the interior concrete, I mean, if it takes chloride 20 years to go a couple inches in, it's going to take lithium nitrate, just typically the one they used, twenty years to get in, maybe a little faster. Lithium was a little bit quicker than sodium. But it's not going to go down --

MR. JONES: Yeah.

MR. BERKE: -- three, four inches overnight unless you've got really poor quality concrete. Now, you could get it in farther if you actually went about and fried it. So if you take the concrete above 100 degrees C --

MR. JONES: Uh-huh.

MR. BERKE: -- to three inches down, now absorption will pull it in.

MR. JONES: You'll get an accelerated --

MR. BERKE: You'll pull it in through your --

MR. JONES: Is there any --

MR. BERKE: And then it'll only work that way. But that's an expensive process.

MR. JONES: Is there any evidence of concern with the anions that the lithium comes along with? You know, nitrate is maybe not the best thing to be adding in.

MR. BERKE: Yeah. Nitrate by itself isn't so bad. Nitrate with chloride would probably be bad. So if you do corrosion testing on nitrates and concrete, they'll pretty much look like they're harmless, but they combine with chlorides that make that type of chloride a little bit worse.

MR. JONES: I guess I'm getting at sort of similar to what you alluded to with the sort of cathodic protection strategies. You may get yourself into another situation. So in trying to mitigate ASR, you may, I mean, is there anything to what I'm thinking or --

MR. BERKE: Yeah, it's --

MR. XI: Actually, one way to try releasing into the concrete is to use something like whatever is used in the electric field to drive it in.

MR. BERKE: Yeah.

MR. XI: Actually, we made some work with the hydraulic power industry, the Kurobe dams, concrete dams is a massive structure. So over there, we made the condition you can drill through the holes, like not very far away. And then the --

MR. JONES: Essentially point sources of the solution?

MR. XI: The point source and then introduce a current. So the lithium, when you put the lithium compound on the surface you will try to suck in. But I just heard for the dry casks they don't want to drill anything. But what you can try is, let's see, put the current, let's see, positive 90 on both surfaces. And then try, let's see if there's any help.

MR. BERKE: Yes, you could drive an electrochemical. I forgot about it. But that's expensive.

MR. JONES: So similar to the rapid chloride permeability test, you could set up a --

(Simultaneous speaking)

MR. POPOVICS: It's similar to chloride extraction.

MR. BERKE: Yeah.

MR. POPOVICS: It's essentially the same thing. Chloride extraction, when you pond a monovalent cation on the top that pushes it down in the same way that alkali gets pushed down --

MR. BERKE: Right, right.

MR. POPOVICS: -- pushing the alkali down.

MR. BERKE: Yeah. This would actually get some of the chloride out. So you'd have a battle plan. If you ran lithium irrigation, you're kicking the cation towards the bar. And you're taking the chloride to the surface.

MR. POPOVICS: It actually undoes the increased alkali --

MR. BERKE: Yeah.

MR. POPOVICS: -- collection at the bar.

MR. BERKE: Well, you still have sodium going towards the bar. I mean, the sodium's going to go in the same direction as the lithium goes in.

MR. JONES: Uh-huh. And that's maybe not ideal?

MR. BERKE: I think as far as ASR to lithium, on the outer part might help out. But down by the bar or something, wherever the source is, the sodium's likely to be higher there.

MR. JONES: So it seems there's a --

MR. BERKE: And potassium for that matter.

MR. JONES: Potassium, yeah. It seems there's a theme emerging that, you know, while we come essentially with a large number of casks in the field, we have a lot more options on the prevention side of the house than we do for the mitigation.

We have some techniques that are sort of limited efficacy from the mitigation standpoint. So I guess I just throw that out there as an observation.

But I guess let me -- so we focused on the casks, rightly so. There's a, you know, a pad as well that's often, maybe not often, sometimes a safety significant feature.

Does that change things at all? We have a, you know, little bit different situation, no heat load, well, in some places no heat load. Does that make you think of anything else?

MR. POPOVICS: For me, the prevention or mitigation, I didn't quite follow what you said.

MR. JONES: So we've sort of focused on the notion of the casks, the overpack, you know, the cask structure. But there's also a pad that they sit on, a foundational pad. And so that is also an important --

MR. BERKE: There's no reason why all these things wouldn't work on the pad the same way. And there you have the option to, if you have water on the ground around it you find out --

You know, if you want to lower, you know, if you want to worry about freeze delay, you can make sure there's no water in the part of the soil that would freeze. You can do, you know, you can take out some of the, you know, you could do things there to help it out. Yeah, you can have a couple of extra options.

MR. XI: Now, on the pad you can drill, right?

(Laughter)

MR. TRIPATHI: If you have to, only if you have to. Now, I'm not saying that, you know, boring is not allowed. I didn't say that. But we try to minimize it because of other implications.

MR. POPOVICS: Well, I think any kind of action, you'd go on to the unit, that's a big deal, right? Anytime you go into any sort of mitigation strategy on a unit of any sort, that's a big deal for the unit.

MR. TRIPATHI: Yeah.

MR. POPOVICS: Right. So we better get it done right and make sure that it's the right thing to do.

MR. TRIPATHI: Yeah.

MR. POPOVICS: Licensing, protection, and safety and all that stuff.

MR. TRIPATHI: You know, when you get all these techniques, it can extend the life of the structure so much. I mean, if you are at a point where, you know, you've got to do again cost/benefit analysis and say, well, is it worth for me to do further mitigation or further repair, we'll get into that.

At some point, you want to decide that it's not worth it, throw it out with anyone, especially the pad, not the casks but the pad.

MR. JONES: Well, I mean, that's an -- any of these I'm going to say to do, because I don't have to do it, but in theory you could always remove the canister and place it in another unit or, you know, you have some options there as well.

MR. POPOVICS: Some canisters are more transportable than others, right --

MR. JONES: Well, indeed some are transport/storage, you know, they're dual purpose canisters. But I guess it's a little bit different than the reactor side of the house where you have sort of an investment that, you know, you want to preserve as long as possible. There's similar options, I guess, is all I'm saying with the dry cask installation.

MR. XI: Not just little bit different, a lot different.

MR. JONES: A lot different, yes.

MR. XI: We're not dealing here with the reactors.

MR. JONES: Yeah.

MR. XI: And these are storing, just passive system. They are not active systems.

MR. BERKE: Well, I think at any point you can do a cost/benefits analysis.

MR. XI: Sure, yeah.

MR. BERKE: So, I mean, if your mitigation technique buys you five years and costs so much money, in five years you have to do it again. You can look at that.

And that's versus, of course, now a major repair debt that he was talking about where you're removing concrete, putting in new, you know, all that. So, I mean, it's just a simple cost analysis. And it's sometimes pushing a repair back five years when you do a net present value analysis. Money, you know, it's very cost effective.

MR. JONES: Sure. And it's, to some degree, beyond the scope of what we're working on here. But ultimately I think that that will be the deciding factor in a lot of cases, you know, is it cost effective to do that or --

MR. XI: Yeah. Again, in the highway industry, and they use a life cycle cost analysis a lot. So they keep track of the cost for this time, let's say, for the repair and then see the rise of the usability and then draw again.

So after a certain cycle, you can run the analysis for the next repair. And if it's not worth it, then you just change to a new one. That's what they do in the highway industry. I don't do it myself, but my colleagues --

MR. JONES: Sure.

MR. XI: -- all of this.

MR. BERKE: My company does that for the departments --

MR. TRIPATHI: So you're not aware of any cheap mitigation techniques.

(Laughter)

MR. TRIPATHI: At the same time, very effective.

MR. BERKE: Well, somebody has to --

(Simultaneous speaking)

MR. BERKE: -- relatively inexpensive.

You know, inexpensive meaning something for five cents a square foot, I don't think is going to do you any good, you know. But for a dollar or $2 a square foot, you might actually get some good performance. So, I mean, it's just a matter, you know, of what are you looking at. Repair can be $20, $30, $50 a square foot.

MR. TORRES: So I think it's important that, in the area we all just have a money cost, it's obviously occupational dose. And the repair and having someone go in and get close to the system, is that something that we have to keep in perspective?

MR. BERKE: Well, some of the stuff, something you're spraying, you can have a remote -- you can have a crane operator with a spray, and you can spray from far away for a lot of these things. So you don't necessarily have to get close with it. When you repair it, you're going to have a guy right there.

MR. JONES: So let's make a statement, and you can tell me why wrong. So it seems like a lot of these mitigation strategies, there's significant nuance to what is going on, you know, the particular chemicals chosen, or the application technique or the relative permeability/impermeability of the coating, things like this.

Is that a fair statement? In other words, you know, if somebody comes with X coating versus Y coating, you know, we need to know a whole lot more about what's being applied than --

MR. BERKE: Well, that's basically what the Strategic Development Council from, that we heard from the Concrete Institute said, and that's why they set up the fund to develop this test method --

MR. JONES: Uh-huh.

MR. BERKE: Because everybody has the best product.

MR. JONES: Right.

MR. BERKE: So now we have a --

MR. JONES: It's a strange thing. Everybody's is the best.

MR. BERKE: -- to evaluate them. I mean, it's not an inexpensive test to run. But we've got a bunch of people running it, because you have to make the concrete ready-mix trucks. So you have -- You have to make five slats for each condition that are, you know, a meter square and, you know, fairly thick.

So a lot of stuff going on, there so people aren't doing it. If they're starting to do it now then they will eventually, I mean if somebody comes in with a technique and says this is what I want to do, I would say, okay, where's your test results to show that it actually does something?

MR. XI: Now, I suggest NRC do some sort of project on this. Because the highway industry really spent a lot of money, just in Colorado. We put five different sealers side by side on a highway bridge. So monitoring was for several years.

And then it seemed only to overlay side by side the same traffic, the same -- and water pool membranes. And after that it would compare the performances in terms of moisture loss or weight retention.

MR. BERKE: Sure.

MR. XI: Yeah. And that way, make a recommendation, they put the good ones on their referral list so the contractor can use. If the NRC is really serious, want to use coating or any serious --

MR. JONES: Yeah.

MR. XI: -- and a lot of work must be done before that. Because this is totally different, a serious condition.

MR. JONES: Absolutely. So an interesting position would be more of, you know, an applicant comes with X, and we would need to somehow interpret, you know, the efficacy of that X.

MR. XI: Yeah.

MR. JONES: And that appears to me to be an extremely nuanced question.

MR. XI: Yeah.

MR. JONES: So let me circle back around to the prevention side of the house. We got into this a little bit, but I'm interested in a little bit more information.

So, you know, if we were to design for durability what would be, like we mentioned, toughness for example, you know, what would be the kinds of things that we would want to see either in the sense of a test or performance criteria that a mix would meet to -- again, I'm just thinking hypothetically here -- but if, you know, we were to approach this situation of extended storage and dry casks, you know, what would we be thinking about?

MR. POPOVICS: Ingress, I would say.

MR. BERKE: Yeah.

(Simultaneous speaking)

MR. POPOVICS: -- or permeation. And that comes not only from the pore network, but from cracking.

MR. BERKE: Right.

MR. POPOVICS: So if something is very dense but cracks a lot --

MR. BERKE: Yeah, yeah. That's a stress problem.

MR. POPOVICS: -- make it worse, then, you know --

MR. BERKE: I think you got it right. The main thing, you'd do a performance-based standard. Maybe you have some minimums. But you say I'm going to have a rapid chloride permeability or resistivity of the concrete under a certain point. And that relates to chloride ingress and moisture ingress.

Then I'm going to say, then I want to have, on a ring test, I'm going to go so many days without cracking.

MR. JONES: So kind of a toughness, shrinkage --

MR. BERKE: Well, that goes to -- that's a combined shrinkage creep, dry shrinkage, restraint shrinkage test, basically. So it gives you that.

If you really want to go all out, you can go up to a toughness requirement too, that my concrete's going to have this toughness factor running, you know, ASTM, six inch by six inch beam, eight, nine, 20 inches long. That might do it.

But, you know, run on that certain flexural toughness on it as a minimal, if you want to add that. You know, but you might not need that. But those are the types of things you want to do. If you do that, you'll have concrete that's more than strong enough structurally, and it'll be relatively low permeability.

And then you can go to programs. There are programs out there, sophisticated ones like STADIUM, which looks at the concrete drying out, actually. So you can actually look at growth movement through chloride and sulfate movement.

MR. JONES: You're talking computer programs?

MR. BERKE: Computer programs, but the concrete that's not water saturated, not saturated. So it gives you a better condition to what we have here.

Or you can go with the simple ones, like Life-365 and some other ones out there that don't completely handle the water, saturation of water exactly 100 percent but still do a pretty good job.

And you can model how long your system's going to last. You can say, okay, here's my hot wire rod bars on the surface, here's the expected environment --

MR. JONES: When you say last, on the basis if what, concrete strength or what --

MR. BERKE: Well, for whatever problem you're looking at. So you're looking at chloride, you could say, okay, given my chloride environment, my local quarry environment --

MR. JONES: I'll have X concentration of --

MR. BERKE: I'll have so much chloride here in 100 years. Is that as dry as it's going to get to my bar or not? And so you get to the bar, you can say I need to have that. And it's sent to the bar. Well, then maybe I use epoxy-coated steel, or I use a corrosion inhibitor or I use stainless. So you have options.

MR. JONES: So you're getting that, I'm just turning this over here, but generically getting at a computational modeling of the --

MR. BERKE: You get the computational modeling once you -- but you can do a performance specification where the performance requirements can be used in models that exist and/or could be modified to work with your applications.

So now you have, you know, see a little

performance spec. From the specification, you determine how long your material, you know, the special durability. And you can decide what's important.

Now, for things like ASR, those are kind of hard to predict. There you go and say, you know, maybe I want to do prevention.

The Europeans have a method called FIB which is how they do long term concrete design in Europe. And basically, they say just you could either design, you know, take care of the stuff coming in or you can eliminate the problem more or less by itself.

If you have aggregates that doesn't undergo an ASR reaction, you have low alkaline content in your concrete, that's the way to handle ASR problems, don't have a lot of alkali and don't have an aggregate that's susceptible.

MR. JONES: Sure.

MR. BERKE: And that's what they're doing on all the big bridges. You know, they're going to low alkali mixes that are low alkali contents. But transportation agency wants to make it even better and pre-screen inner aggregates. And for free soil; you had air entrainment.

So you handle those things kind of that way.

And for your chloride, your low permeability, for sulfate, maybe low permeability type cements they have tri-calcium-aluminate in them --

MR. JONES: So these design methods are, like, you just mentioned, do you find that they're typically more prescriptive or are they, you know, meet such and such --

MR. BERKE: They do both. I mean, and the same that we do here. We might go prescriptive on ASR. Because it's hard to predict, you know, when ASR's going to happen.

You know, if you have an aggregate that's susceptible and you have the alkali in there, it could happen. You don't know when. You don't know how severe it's going to be.

So the easiest way to handle that is basically eliminate the condition so it doesn't happen, at least hopefully it doesn't happen.

But, I mean, but that's not bad. Because there's enough -- you kind of know if you don't have the alkali in there. The alkali is not above a certain point --

MR. TRIPATHI: Question for you, Neal. Coming back to the original requirements for durability, are you familiar with ACI-318-349, any other consensus code here or anywhere else --

MR. BERKE: Yeah.

MR. TRIPATHI: -- which, in prescriptive form, discusses requirements of --

MR. BERKE: The FIB, for one thing. The European FIB --

MR. TRIPATHI: Which one?

MR. BERKE: FIB, F-I-B.

MR. TRIPATHI: F-I-B.

MR. BERKE: F-I-B, in Europe. The Bureau code in Europe, Life-365, not Life-365, but ACI Committee 365. It has a report. I think I referenced the one in my answers.

MR. TRIPATHI: Yes, I saw that.

MR. BERKE: So, I mean, so that's another place to go.

MR. POPOVICS: Probably the Durability Committee has --

MR. BERKE: Yeah, 222, 201.

MR. TRIPATHI: Now these are --

MR. POPOVICS: This is not, they're not codes.

MR. BERKE: They're not codes per se, but they're guidelines.

MR. TRIPATHI: Risk-informed performance based criteria or just performance-based criteria?

MR. BERKE: I think 365 is mostly the performance criteria. 201 has more prescription.

MR. POPOVICS: Yeah, it's prescriptive reports, not a code.

MR. BERKE: Not a code, yeah. I think it might -- I don't know how much of that's in 318 now.

MR. POPOVICS: Yeah, a lot of it is.

MR. BERKE: So a lot of it's --

MR. POPOVICS: Certain aspects are incorporated in it.

MR. BERKE: Yeah. And a lot of it's in the 349 has some of that stuff from 201.

MR. POPOVICS: Yeah.

MR. BERKE: And 201's getting more strict, 201 and 222. 222's the Corrosion Committee. 201, and 222 and 318 are a little bit different on what chloride levels you should be. But, you know, that eventually will get straightened out.

MR. TRIPATHI: Yeah. As long as it's addressed in some consensus program.

MR. BERKE: Yeah, yeah. Oh, yeah. And

NACE has some things.

MR. JONES: So it's a bit afield, but what about, like, various DOT specifications. Those are not consensus-based, but there is a --

MR. BERKE: Well, there are --

MR. POPOVICS: AASHTO is --

MR. BERKE: AASHTO has some stuff. And then, of course, these new bridges that are going up have very detailed surface life analyses that they have, that the design/build team has to get to the stated owner or the eventual owner has to buy into.

So the Tappan Zee Bridge, the Goethals Bridge, of course, in New York and St. Lawrence Seaway Bridge. They have combinations of both prescriptive and performance-based specifications.

I mean, a lot of times the owners don't want to go totally performance for some reason. But, I mean, so you sometimes will see a -- you usually will see some sort of combination of the two.

MR. TRIPATHI: Yeah, for DOT, because it's a spread very broad, so I see, particularly in Florida, I think Colorado, they have totally different requirements.

MR. BERKE: Sure.

MR. TRIPATHI: So, let's see, for corrosion, deicers, resistant to deicers in 14 states, in western states they have their own standard. And if you go to Florida, Texas, they have their own standard.

(Simultaneous speaking)

MR. BERKE: Florida standard for marine, for fluoride coming in, is probably tougher than some of what the northern states are using for deicing salts, even though deicing salts, you might argue in some cases, it's actually worse.

MR. JONES: Well, it's got to be very carefully applied to the surface.

(Simultaneous speaking)

MR. BERKE: Places like upper parts of the United States and Canada, the amount of deicing salts applied in the winter time actually could be worse than a severe marine environment.

MR. XI: And also the rapid chloride test in the highway industry, it's not just 28 days. It's 14 days, 28 days and 36 days. Because the maturity of concrete has less effect on the strength than on the permeability.

It's a human factor. So that's why they want to predict the 14, 28, 36, the trends, to see what will happen for the long run.

MR. BERKE: Yeah. What typically happens is your diffusion coefficient for chloride not only is a function of the concrete water system, the water to cement ratio, is also a function of concrete chemistry. And it's a function of time.

And over time, it increases kind of a logarithmic relationship. So they'll run it for several times. And they can predict what it's going to be 20 years from now. So 20 years from now, it could be lower than it is today.

MR. JONES: So rapid chloride permeability is brought up as a --

MR. BERKE: That's a simple one.

MR. JONES: It's easy, it's fast, et cetera. What are the panelists' thoughts on that compared to absorption, or compared to permeability or compared to, you know, these other, I'll call them actual transports. I mean, it is diffusion but --

MR. BERKE: Well, the problem with the rapid chloride permeability test is they kind of got the same, when it was developed, they looked at the chloride profile in the concrete. It looked like a normal type, both diffusion chloride profile and they had to run it for six hours.

Really, it's a connectivity test, as Yunping pointed out. And there's a new ACI method now. You just test for one minute, get the contradictory conductivity. And that's directly related to the diffusion coefficient. That's also a --

MR. XI: One minute.

MR. BERKE: -- yeah, one minute. I could tell you off schedule why it's six hours instead of one minute. Because I was a part of the task group. I was a big part.

But the other thing they can do is another test. There's a Nordtest which is from the Scandinavia where they do basically the same test at a lower voltage.

And then they split open the concrete, and they see how far, using silver nitrate, they see how far the chloride came down. And from there they get a diffusion, they can calculate the diffusion coefficient direct, both the diffusion coefficient directly.

They've even got more sophisticated, like, STADIUM, where you do transport testing. And you've got, you measure the porosity of the concrete.

MR. JONES: You're taking real properties and muddling your way through it.

MR. BERKE: And you've got what they call the active diffusion coefficient. And that's a modeling system that takes back to the concrete chemistry, gives you another way of predicting how fast things are, you know, the chloride ingress.

So there're several ways of doing it. I would say the rapid chloride permeability or conductivity methods are used because they're pretty quick.

MR. JONES: Yes, sure.

MR. BERKE: You get the results fast. And they actually do give a good representation of what's going to come then. But, I mean, but they do go more sophisticated.

The absorption tests are very valid. I mean, if you have a cask, they're going to be dry on the outside. So how, you know, how much water gets pulled in through absorption is critical.

So there's two tests now in the ASTM for that. One is a capillary test and another one is a kind of bulk absorption test. The bulk absorption test is a little bit easier to do. They both pretty much tell you if the concrete's going to, you know, pull in things. So that tends to be less dependent on water to cement ratio.

MR. JONES: The bulk test, the --

MR. BERKE: Yeah. Either one of them. I mean, they'll show a -- water to cement ratio drops. You'll see a drop in water absorption. But it's not big.

What affects that big time is if you stick a damp proofing agent in the concrete. If you put, like, a -- what is it I'm thinking of?

MR. JONES: So if you --

MR. BERKE: What was I thinking about? I can't think of it now. But if you put in, like, butyl oleate or something like that, or calcium stearate into the concrete, that'll make it hydrophobic.

So when you run the bulk diffusion or a capillary diffusion test, the water can't come in fast. So that reduces that. That's beneficial. That could be, you know, that and combined with lower water to cement ratios is a way of making what they call water, you know, a way of making water, what's so-called waterproof concrete.

Lowering the water to cement ratio keeps chloride from coming in. And that's the most efficient, that's the biggest thing for keeping chloride from coming in.

But the tests that everybody looks at, these bulk diffusion tests, you see nothing's coming in. So making the concrete a little hydrophobic is something they see real quick. And they say, ah, the water's not getting through. So it's kind of, so it is beneficial, especially when you have wetting and drying conditions. It doesn't matter if it's 100 percent wet all the time --

MR. JONES: It's not going to affect the ionic --

MR. BERKE: It doesn't help you at all.

MR. JONES: -- protection. Yeah.

MR. BERKE: So it has to get a chance to get dry so it could be a hydrophobic, if it stays wet for a long period of time or under a lot of water pressure.

But for things like the casks that are above the ground, they're going to dry out. So we're talking about putting a silane or some sort of material on the outside of an existing one to mitigate. You could put a hydrophobic agent in a new one --

MR. TRIPATHI: But there are some casks which are going to be underground.

MR. BERKE: Yeah. Those you want to do that. I mean, they'll give you -- if it's 100 percent moist, you're not gaining anything by doing that.

MR. JONES: Are those casks fully underground?

MR. TRIPATHI: Fully underground.

MR. BERKE: No.

MR. XI: Not in direct contact with the soil, right, completely buried, all you see is the top --

MR. BERKE: No, no. But they do make sure it's clean --

MR. TRIPATHI: I thought I included one of those pictures in my initial presentation.

MR. BERKE: Now a case like that, I would assume they would put it in the clean soil.

MR. TRIPATHI: Yeah.

MR. BERKE: Clean fill or --

MR. TRIPATHI: Well, some backfill is just the engineered fill. And at some location, due to other reasons, they're going to put some lean concrete instead of all this fill.

MR. BERKE: So, like, global fill concrete.

MR. TRIPATHI: Three thousand PSI lean concrete.

MR. BERKE: That's not, that's --

MR. TRIPATHI: No rebar.

MR. BERKE: That's not fill. Oh, yeah, that's --

MR. TRIPATHI: But there are different reasons why they do that. All I'm saying is that there are some already deployed underground.

MR. BERKE: Well, there you would -- for something like that, if it's going to be 100 percent wet in the surface side, you don't think --

(Simultaneous speaking)

MR. TRIPATHI: Those are underground.

MR. BERKE: Yeah. You don't make those hyrdrophobic. Because that's --

MR. XI: Then what is the line for, the yellow one?

MR. JONES: Say that again?

MR. XI: This yellow layer.

MR. TRIPATHI: Yeah. See, they have a legend there. That's just the cavity enclosure.

MR. BERKE: Are you having to pull those out of the ground then?

MR. TRIPATHI: Eventually.

MR. BERKE: I mean, I know if it's just like a global fill which is only about 150 PSI.

MR. TRIPATHI: Part 72 requirement, one of the Part 72 requirements is that these have to be taken out at some point in time for whatever reasons, either -- I don't want to go into too many details about the regulations, but in future if we decide to take this spent fuel out and do recycling for some other reasons, it would have to be retrievable. The word I was looking for was retrievable.

MR. BERKE: Okay, retrievable.

MR. TRIPATHI: They have to be retrievable. And for that you have to have features that eventually, at some point in time, if they decide to retrieve this, it can be retrieved.

MR. BERKE: Well, I would give you a suggestion. You have your lean concrete on the outside border around everything. And then around each one of these, you put a flowable concrete filler around it so that it's --

MR. TRIPATHI: Any particular vendor has thought about all this, yeah.

(Simultaneous speaking)

MR. BERKE: Because that way you can pull it out easily. And it would still give you the same protection that you had without having to break 3,000 pound -- 3,000 PSI concrete's not easy to knock out in 25 years.

MR. TRIPATHI: Yeah. The majority of them are above ground. But there are some underground. That was the point.

MR. BERKE: Interesting. But talk about -- and the short story is there are design methods out there, there are ways of measuring the permeability of the concrete to use in these design methods.

MR. TRIPATHI: So what is one mitigation technique you would recommend definitely? And again --

MR. BERKE: Well, I mean, assuming, you know, one that might be cost effective would be some of these combination silane, and some of these are, again, a function of silanes or some silane-type treatments from outside with inhibitors in them.

MR. TRIPATHI: Silent type treatments?

MR. JONES: Silane.

MR. BERKE: Silane. Or some are gas that are -- well, there's organofunctional silanes which have very low surface tensions. So they tend to go in pretty well. And then the normal silanes might work too.

And they've had success on these with bridge decks and parking garages. So, I mean, you don't have the wear on it, so you don't really have much in control. So you have all sorts of -- a lot of those things you really don't need.

MR. TRIPATHI: Well, besides local ants and scorpions, nobody's going to walk on it.

MR. BERKE: No. If it's slippery enough, the ants and the scorpions might fall off. Actually, now you've got me scared. The scorpion's crawling out and he starts about this big on the bottom and he's about this big when he gets to the top.

MR. JONES: So this has been a useful discussion, I think. You know, some of it is contrived, and we're just sort of thinking about what, you know, might come to us. But this is a little bit less defined than the degradation mechanisms, I realize.

But I think it's useful to talk about and for us as NRC staff to learn about what things might present themselves at some point in the future. And so that's, I think, a useful discussion.

So let's get some coffee, a little bit early. And we'll work our way back here -- let me check my handy, dandy schedule -- work our way back here at 3:45, I believe.

MR. TRIPATHI: You mean 2:45?

MR. JONES: I'm off a line here, I apologize. 2:30, I was reading the line below.

MR. TRIPATHI: You must be tired.

(Laughter)

MR. JONES: Just about an inch low is really all it was.

(Whereupon, the above-entitled matter went off the record at 2:20 p.m. and resumed at 2:41 p.m.)

MR. JONES: Okay. So we'll resume here. I hope everyone had a chance to stretch their legs a little bit.

So I've found the correct line on the schedule now that I was messed up with earlier. We'll have about an hour long session here. And this is sort of to introduce the notion of inspection and monitoring.

But first, we'll look at just the techniques themselves. And then tomorrow morning we'll get into how this can be used in a more strategic and applied sense.

So again, this section I will be, I don't want to say more technical, but more focused on the techniques themselves, so technical in that sense.

As I'm sitting here looking at the slides, I probably might have put these in different order. But one of the main questions that I think we as the NRC are interested in is helping to understand the usefulness or the applicability of a certain technique.

And so, I just sort of made this little cartoon, this graphic. And so we want techniques that are in the green box, in other words, very mature and give us a lot of good information. And we want to try to avoid techniques that are in the red box which are, you know, brand new, out of somebody's PhD thesis, but also don't give us any direction.

I suspect that we'll have some that are in the yellow boxes, but what we want to understand, I think, is how, you know, what are the limitations, and conversely what is the utility, what is the usefulness of the other techniques.

And so now I'll go back to the slide that I should have put in a different order. So actually I've broken down this, and this is totally contrived, made by me, but if we could stick to it and work our way through, I think it might help us organize our thoughts a little bit.

So the first inspection technique, if you will, is a very low tech technique. And that is a visual inspection. It's also probably the most common inspection technique.

And so I broke that down into imaging and, like, a physical walk-down, you know, a physical looking at the structure where we would carefully go and look at things all around.

So let me ask just if there's any comment on these visual techniques. Maybe we could introduce, you know, if you're familiar with visual or imaging type techniques that are of interest or potentially of interest, we could introduce those now or just talk about the utility.

Again, this slide, you know, what the thought is on -- obviously visual is probably mature, but, you know, what kind of information are we getting.

MR. POPOVICS: I would add, like, sounding on the visual. If it's not a visual technique, it's usually associated with visual, like a sounding or tapping contact, chain drag. Like a --

MR. BERKE: Chain drag, a hammer.

MR. POPOVICS: It's like a loaf of bread when you tap it to see whether it's --

MR. BERKE: Yeah, right.

MR. JONES: So that's distinct from impact, actually what they have is a mechanical technique.

That's where we're looking for a modular or something.

MR. JACOBS: This would be incredibly qualitative. The human ear is very good at telling, you know, the difference between that and, you know.

MR. JONES: So is it good we're looking for a used car, looking for bondo spot, we would come along and --

MALE PARTICIPANT: Pretty much.

MR. POPOVICS: But it's very broadly applied. And I'm not saying that that's what -- but if we're going to list it, you should probably list --

MR. JONES: Okay, that's great.

MR. POPOVICS: -- and that means it's viable --

MR. XI: Yeah, something similar to that is on the bridges. We use chain drags. So it's a big steel chain. And then we just drag it on the surface of the bridge decks. You hear it is hollow, that means there is --

MR. JONES: A delamination of some sort?

MR. XI: This is similar to that.

MR. JONES: So a very advanced sound effect.

(Simultaneous speaking)

MR. BERKE: No. Somebody that's good at that, it's almost as good as a radar.

(Off microphone discussion)

MR. JONES: We're kind of joking, but this is good information, you know.

MR. BERKE: It works. I mean, that's the thing about it.

MR. JACOBS: Is there, so what did we say, imaging or, you know, visual, is there a problem, let's say, is there a part that you can't see? Is there a part where you need to be on a cherry picker, or do you need some kind of, you know, device you hold --

MR. JONES: Selfie stick.

MR. JACOBS: Somebody can hold it up there and, you know, looks at it that way. Is that something we add to this?

MR. TORRES: Yes. And in the inside of this overpack, obviously, the inspections will have to be done remotely, some areas obstructed by, say, the support structure at the canister and so on.

So that's something that needs to be considered, especially when we go further into discussion of this embedment and, you know, there's susceptibility for enhanced degradation because of the connection to the concrete. But not all of it is inspectable. And we recognize that.

MR. POPOVICS: One method that could be listed under visuals emerging is this kind of 3D machine vision mapping, 3D photo mapping. So I've taken many images, photographic images or video and then using computer software to reconstruct that giving a 3D rendering, including texture, cracking and so on.

So it's kind of like taking photographs of the structure on steroids, and you get back a 3D rendering. And with today's imaging technology, your iPhone can produce enough high quality video and -- video still that you can rebuild these things. And it's emerging and becoming easy to do, so far.

MR. JACOBS: So we were talking, let's say, where the ASR, like looking at a map, you know, the map that shows types of cracks. This would be a way you could get an image, relatively inexpensive, documented.

And then you could come back and look at that same one and get another admission. It's low cost. It's, even with a lot of technology involved, it's relatively easy.

MR. JONES: Again, my sort of cartoon, let's talk about the, you know, the utility of what we're getting. Obviously, we're only getting surface information, maybe talk a little bit more about what it could add and what it's not.

MR. POPOVICS: Well, it would be a kind of enhanced visual. You know, it'd be a document, you would have a 3D rendering. I'm assuming you're talking about the 3D mapping.

MR. JONES: I was talking generally, but that's a great place to start, because we were just talking about it.

MR. POPOVICS: Yeah, any visual method, you're only getting the outer surface. I mean, concrete tells you when it's thick, it's cracking, and staining and so on. And the rest is great. But you don't see anything below the surface.

I mean, you can make inferences about what happening below the surface if you've got staining or something, so you're limited to that. It's still a very effective technique, it's first line of defense, it has to be done.

MR. TORRES: How much more effective is this 3D image rendering under visual at, say, giving information, depth of cracking and so on? I mean, it's obviously just surface --

MR. POPOVICS: It won't give you any depth of cracking. I mean, you can get some --

(Simultaneous speaking)

MR. POPOVICS: -- if there's an offset or things like that, shifting.

MR. JACOBS: One is is that it's a record, right. And then you don't have to be there to do the, you know, I mean, one thing you could do is, let's just say, come up with a plan where you have a technician that's relatively trained, goes around and looks, you know, walks around and, you know, this one he sees nothing, or this one she sees nothing.

And then all of a sudden, this one, she sees some map and then, okay, a map wouldn't take the image, you know, take it with the iPhone, you know, take the little visual. And then now you have that image. So what did you say? You had 3,000 of these?

MR. POPOVICS: Roughly 400.

MR. JACOBS: Yeah. So you know what I'm saying. So, you know, maybe one percent, maybe ten percent you would need enhanced visual. And that decision would be based on the regular, you know, the regular visual.

MR. POPOVICS: Good.

MR. JACOBS: And I don't want to give the impression it gives you much more information about what's going on than the regular visual inspection. But, you know, you have a storable document, in a way, that doesn't change. And you can compare it, you move the rendering around. It's very powerful.

And it's emerging. It's only going to get better in one year from now and two years from now. It's really a kind of leading edge. It's one of the things, if we think about this sort of 300 year or even 100 year, this would be something, you know, you could come back to the same image in a year, relatively inexpensive, and there's no change. Oh, my goodness, or gee, now we have this kind of pattern occurring, you know, more and more. And it's just a nice way to quantify in a very qualitative fashion.

MR. POPOVICS: Sure, yeah.

MR. TORRES: And monitoring and trending is obviously a very important part of vision management.

MR. CASERES: How is the area between the two we're just saying monitored? Because I don't know if they had a video screen in between. But how is that concrete being monitored, that water in between?

MR. TORRES: The person signs the -- I don't know that word, getting too much into detail about a specific system here -- but the, I think it's the -- one and two that has that very screen. I don't recall that there have been inspections in between. That's like the inside of the -- screen. That's where it was.

MR. CASERES: Yes, yes.

MR. TORRES: And so all inspections are asking -ob to help with this, so essentially, close to the DSC support structure and obviously the external --

MR. CASERES: Yeah, that's supposed to, I mean --

MR. TORRES: -- area. But that's --

MR. CASERES: -- supposed to be receiving rain or any other, any type of environment that --

MR. TORRES: Yeah, yeah. But, you know, but still, some components that haven't yet been inspected to date, not just that.

MR. JONES: Is there a, I guess, I'm thinking of digital image correlations. Has there ever been any application of that done in monitoring or --

MR. JACOBS: Sure. And that's, to go on your chart, that's, you know, a technology that isn't matured yet. And there's a lot of potential there.

MR. JONES: But potential it gives you some more information?

MR. JACOBS: More quantitative information or, again, some depth, stuff to get that in depth information. But it's hard.

MR. TORRES: I mean, it seems like it would be possible to do some rendering of defects having multiple --

MR. JACOBS: That's why you, to do any kind of subsurface rendering, you need something to penetrate beneath the surface. Your eyes, in this case, that won't give you the penetration.

MR. TORRES: How reliable are the systems with variable lighting, you know --

MR. JACOBS: Some of them have their own source lights, you know, with that. That's all, you know, part of the thing that gets sold. But the technology, you know, John's comment with an iPhone is exactly that. I mean, you can, you know, you can do it with something then.

You know, the technician can adjust it and get -- if all you're looking for is a qualitative image of something to compare to, that variability isn't going to kill you, right? It isn't going to be the deciding factor.

MR. POPOVICS: I guess I should clarify, I'm not saying this is a DIC system, digital imaging. But that's a very expensive, high technology to track strain, mapping and so on. It's not this.

What I'm talking about is the 3D rendering of lots of photographs that kind of build back structures, that you have basically a 3D photograph of your structure that you can store, and reference later and compare.

And the breakthrough is that you use very basic technology and reconstruction software to get this. So it kind of enables many more people to use it rather than the DIC system which you have to buy. And it's very expensive, and it depends on a lot of things.

MR. JONES: Sure.

MR. POPOVICS: But the DIC gives you more, you know, about the strain fields and all of that.

MR. JONES: So visual's clearly got a lot of value, maybe the most value. I don't know.

MR. POPOVICS: It's got a lot of separate tiers in that, you know, the tiered inspection structure in 243. So, I mean, it is the first line of defense. And this could be a nice add-on to that, something to empower visual.

MR. JONES: So I'll drive ahead a little bit, just a general topic of chemical analyses and that --

MR. CSONTOS: Can I ask one question? This is Al Csontos. I'm chief of the Renewals and Materials branch in SFM and NMSS.

The visual, one question is is that do you think that we would need to clean surfaces to inspect those areas for the different degradation mechanisms of choice?

I know I heard these others but, you know, these things are out there for 20 years. There's a lot of dust, debris, cracks that have stalactites on them. So the practical question that I'd like to bring out here is what are the cleanliness requirements that would need to be put out there. Do we need to clean?

MR. TORRES: I will extend that question. Because right now we're using ACI 349 for our acceptance criteria here. When you look at the Tier 2, we're looking for cracks of one millimeter. So this is where, you know, we understand the reliability and --

MR. POPOVICS: Well, I don't know the answer to that, honestly. But one thing's for sure, it's a lot better on concrete than steel. Steel, of course, you know, you have very tight cracks. You have to clean, you have to have some sort of penetrant, or something to see the cracks, to actually see something. You have to do processes.

Concrete, the cracks are more open. And so are there cases where grit, and filth and other coatings are covering cracks? Yeah, sure, there are. But it's a much more -- concrete admits this kind of technology much more than other materials.

So I'm sure there are cases where you would have to do some special surface treatment. But in general, it's not done. For visual inspection of a concrete bridge, they don't clean it.

MR. BERKE: No. You want to look at it uncleaned first anyway, because there are stalactites and stuff --

MR. POPOVICS: That tells you stuff.

MR. BERKE: -- you want to see. Then you might make a decision. This theory looks interesting, what happens? Maybe I want to clean it off when I --

MR. POPOVICS: Look, if you're going to map a crack accurately, you have to go there with a crack comparator anyway, right?

MR. BERKE: Actually, there's a new device out there that I saw last year at TRB where I could stay here and look at a crack over there and see, you know, under it, you know, down to the bottom point one millimeter or so.

(Simultaneous speaking)

MR. BERKE: It was a Japanese company. They had, like, it was in binoculars, the way they measured the distance. And depending on how big it was on the thing, they were able to determine what the crack size was.

(Simultaneous speaking)

MR. JONES: I mean, basically, if you have enough resolution you can --

MALE PARTICIPANT: An optical comparator.

MR. BERKE: Optical comparator. But, I mean, it would allow you -- which would be perfect for these cases if you're worried about some being in harm’s way. They can stand back 20, 30, 100 feet and measure the cracks.

MR. TRIPATHI: So the answer to Al's question is you don't need to clean the outside surface, or you're better if you don't clean it?

MR. BERKE: Initially, you want to see it unclean, because anything that's -- there might be things there that are important that will come off in the cleaning process.

MR. POPOVICS: Provide evidence of what's going on. And I don't think you need to clean in all cases. There may be, of course, some cases where you do need to clean. If you wanted to know the crack map within a certain point, then if you can't see it you have to clean it.

MR. BERKE: Yeah. You might then, based on that, decide where you need to clean but not to clean everywhere.

MR. TRIPATHI: So maybe.

MR. XI: You know, we inspect bridges in Colorado for CDOT, not every one. They have several inspection groups that inspect highway bridges every two years. But if it is a very bad bridge, a lot of cracking, so we will do it.

And so, but see, if you clean the surface this time at this location, next time you need to do the same thing. So if you do not clean it next time, you don't clean it. So it's the same technique must be used every time.

MR. TRIPATHI: I understand that. But I think what I heard is that you will probably detect more degradation if you don't clean it than if you clean it. Is that correct? That's what John said.

MR. JACOBS: The concrete is going to tell us, it's telling us something and take advantage of that, certainly the first time through.

MR. XI: Especially for the dry cask, my suggestion is you clean it. Because for highway bridges, sometimes you just cannot do it. It's so big, you cannot reach there. So you have to, just like Neal said, every year or so they remove, laser or something, to reach the height. But for dry cask, it's 20 feet. So it's much easier to do it.

MR. TRIPATHI: To do what, to clean?

MR. XI: To clean, clean it and then take photos, put in a database. I was actually surprised this has not been done. Because there are only 2,400 --

MR. POPOVICS: But there are health issues. There are health issues involved for the inspectors.

MR. TRIPATHI: Yeah, there are other implications. I mean, you are saying it's easier to clean, but the matter is not whether it's easier or harder. What I'm hearing from John is that you will detect more degradation and further mechanism if you just do it in situ, in whatever condition it is, rather than clean it and then do inspection.

MR. POPOVICS: Well, I think you have more evidence.

MR. TRIPATHI: More evidence. So if you clean it, then you can destroy the evidence, some of it.

MR. XI: No, no. What I mean is that you, let's see here, from today with the health record, so we clean it. And then every two years we go there and we clean a number -- yes. So you repeat the same --

(Simultaneous speaking)

MR. XI: What I mean is the highway industry is not, it's not that they do not want to clean. We just cannot reach there. It's too expensive.

MR. BERKE: And it works too --

(Simultaneous speaking)

MR. XI: I went to several NPPs. I just passed through the dry cask. There is nobody --

MR. JONES: No. I'm sorry, transportation structures, you know --

MR. XI: No, no, no. I mean dry cask. You just said there is radiation. But I don't get anything like that.

(Simultaneous speaking)

MR. XI: I have worked on some these and, believe me, they do have radiation.

MALE PARTICIPANT: Also realize that they might not be able to access some areas --

(Simultaneous speaking)

MALE PARTICIPANT: The risk is taken into consideration.

MR. JACOBS: I guess to -- you're saying consistency. If you're going to clean it the first time, you have to clean it every time. And that consistency makes sense. But I do think, going along with what John said, if you end up cleaning the same area every time, there's information in that that you shouldn't just discard, that you shouldn't just throw away.

MR. POPOVICS: And, you know, frankly a concrete road doesn't need to be cleaned in as many cases to see the issue. It's not required. It is not required. In steel structures, it's required. You have to clean all the surface very well to see the cracks and map them.

MR. JAMES: Well, in the end you've got to meet the 349.3R requirement. So if you can't demonstrate that you're able to detect a 0.1 millimeter crack, you need to clean it.

MALE PARTICIPANT: The one millimeter.

MR. JAMES: Or whatever it is. But if you can, then I don't think you need to clean it.

MALE PARTICIPANT: Yeah, that's pretty tight.

MR. JAMES: Is it 0.1?

MR. TORRES: Going back to this acceptance criteria, and I realize that we're discussing this tomorrow, but is there a benefit on the 3D imaging versus on whether or not the imaging apparatus is attached to the wall versus it being some sort of boroscope that is not exactly at a controlled or precisely controlled location --

MR. JACOBS: You mean the positioning of the camera? Yeah, that's the beauty of these 3D photo mapping, that you don't need to know the position. You take enough photos, and they overlap the software. It stitches them together. It's amazing.

MR. POPOVICS: You don't need the robotic, you don't need to tie one into the other. That's the --

MR. JONES: So just in the interest of time, let me move us ahead a little bit. I think that was a good discussion on what is probably the most important inspection technique we have.

Talking about chemical analyses and how they're -- there's certainly a host of, you know, if you're looking for X ion there's, you know, various lab techniques to do that.

And you're usually going to be having to take some sort of sample or, you know, touch the surface or whatever and so, you know, have surface pH corrosion. But each one's a little bit different. You know, you measure the electrochemical potential there, I guess.

The third one, I guess, is what I was just talking about. If you're able to obtain a small sample, you can do various techniques. And then there's sort of some of these new, you know, LIBS, laser induced breakdown spectrometry. You can get some information by shooting with a laser beam, a really neat technology.

So I guess let's talk in the general sense, you know. Would we envision or are there approaches, maybe I'm thinking about groundwater monitoring since you're doing a broad spectrum monitoring. Is there any evidence of these kinds of things being used?

MR. POPOVICS: You said groundwater?

MR. JONES: Uh-huh. So we sort of have an example there, but are there other widespread application of just sort of broad spectrum chemical testing?

MR. POPOVICS: Well, you can extract pore water also from concrete. But that'd be a sampling type of thing.

MR. BERKE: Yeah, I'm not sure concrete pH, the surface tells you anything. The surface is probably going to be various cells. It's most likely carbonated. So unless you go in a little bit, you're not going to get anything.

And also for a corrosion potential, you've really got to be able to tie on to one of the bars somewhere. So if you drill a hole and tie-on to a bar, then that's a perfect case to get your chloride sample out of the stuff that comes out of that hole.

The PH, you know, when you first get in there and get the pH of that, you know, you can take a -- if you get the hole with a little core drill rather than a bit, you can slice it in half and get, well, you can see how far the carbonation goes down. You can analyze it for chloride. You can look for ASR, and you can look for sulfate. And you can tie-in to the bar and then do the corrosion potential map. So that's, you know --

MR. JONES: That gives you a lot of information?

MR. BERKE: -- out of one little, you know, one little connection. So it's better for taking powder, plus taking powder in the field, it's too easy to carbonate and everything else when you're handling it.

So the core, you can ship it back, and you can analyze it more carefully in the lab. And it doesn't have to be a big core, it can be, you know, two inch diameter, or something like that. And that gives you enough to attach to the bar. Then leave the wire in, so the next time you come back you won't have to do anything.

MR. TORRES: Is there a standardized method for measuring pH of this --

MR. BERKE: There are surface pH measurements that are used in soils which are pretty good. And the ASTM has several methods. There's one in, is it G, I don't know, there's one G method for measuring. That's probably the best, because you measure it as soon as possible so the soil doesn't -- because soil can change. As soon as you take out of the ground, things start to change in soil.

MR. TORRES: In the actual concrete.

MR. BERKE: But for the concrete, concrete you can use litmus paper, but on the surface it's always going to be probably something close to carbonated maybe on the surface just because it's in contact with air.

You could use a normal pH meter if you have the powder up to inspect it under. It tells you the bulk pH. Squeezing the pore water will give you the internal pH if you do it carefully. But I'm not sure --

(Simultaneous speaking)

MR. POPOVICS: I don't know if it's a standard test. It's a --

MR. BERKE: It's not a standard test.

MR. POPOVICS: It's a laboratory process that's quite involved. Not everybody can do it.

MR. BERKE: The standard petrography test, when you take that core slice, you'll break it, and slice it in half and real quickly measure the duo, phenolphthalein and there's now some indicators that do more than just -- or they'll give you various color shades so that you can get the -- in a spectrum from 13 down to, you know, ten.

MR. JONES: So pH would basically --

MR. BERKE: Right, right. So you could do that, that's standard. I think they're in the guides, the petrography guides in both AASHTO and ASTM. So I think they're one of the C methods --

MR. JONES: In a lot of these chemical techniques, in once sense they're mature in that, you know, we can tell, yes, what the pH is with a high degree of confidence. But there're some nuance, I guess, or tribal knowledge on how we go about measuring, and interpreting and --

MR. POPOVICS: What do you do with it? How does it tell you about, you know, the thing you're looking for.

MR. JONES: Yeah. So again, in this sort of context, you know, on the one hand we've got a lot of maturity. On the other hand, it's kind of --

MR. BERKE: Well, the pH does give you something important.

MR. POPOVICS: Sure.

MR. BERKE: Because it certainly tells you, you know, if it's moving towards the bar. I mean, typically if it's a normal carbonation it goes as the square root of time. So if you know the carbonation depth at a couple of times, you can now estimate how long it's going to take to get ---

MR. JONES: How you're remapping it?

MR. CACERES: The same with chloride.

MR. BERKE: Yeah, same with the chlorides, if you know the chlorides in a couple, well actually, chlorides you can do all in the same sample. Plus, you could take, you know how old it is, you know how long it's been out there.

So that gives you something that's semi-quantitative, let's say, to quantitative. So they're not bad on that end. So it's more than just having the knowledge.

And also by looking at that, you can tell if there's sulfate moving in, you can see sulfate attack. And you can see ASR. So you get an awful lot out of that little piece.

MR. JONES: And to get a little piece of the material is important.

MR. BERKE: Yeah.

MR. JONES: So let's talk about specifically the notion of groundwater monitoring. So we get our sample of groundwater, and we do a chemical analyses. Typically, you know, you're looking for chlorides and sulfates.

But as we talked about this morning, there are potentially a larger number of ions that you could look for. The problem to me would be, you know, to what do we compare that. Just because there's a phosphate, a one billion part of phosphate, what do we do with that?

MR. BERKE: Well, we don't worry about that if it's one part per million.

MR. JACOBS: Even if it was higher than that, and I agree with you. I stand corrected on the other statement. There is a deviation, and it is, for me, that multiphysics. But this is one, okay, now you're off the material, and now you know something about the groundwater chemistry. How do you use that in a quantitative sense so that it --

MR. BERKE: When you're looking at a steel piling in the soil --

MR. JACOBS: I agree on that.

MR. BERKE: Okay. And it's very useful. You don't know if they cared that much about whether or not it's magnesium or sodium in that case, but it is usable.

But the other thing you could, of course, do is also get the soil sample and analyze the soil. So you could do the soil value, and you could see how the soil analysis compares to the groundwater analysis. And that'd give you some sort of an idea.

So if there's no relationship between the soil and the groundwater which is unlikely, you know, you could scratch your head and say the groundwater doesn't meet anything. I have to analyze the soil. But if they look pretty close, then it's a lot easier to measure the groundwater.

And now, I just came off a site where the groundwater and the soils weren't, you know, the groundwater had a higher conductivity, naturally, because it was water. But, I mean, the chemistries weren't all that different, you know. So, I mean, if the groundwater looked bad and the soil looked bad and so --

MR. JACOBS: And then you could infer on the concrete from that.

MR. BERKE: Well, we located steel in this case. But, yeah, you could certainly infer on the concrete from that, you know, what the sulfate concentration -- I mean, what's important in the concrete is how much moisture it holds.

So you get an idea of how much, what's the concentration of the sulfate in the water, sulfate and chloride in the water in the soil next to the concrete. Because that's the surface concentration that you got to worry about. Then the bulk water might be a little bit different.

MR. JACOBS: And then that would give you sort of a list of different deterioration or --

MR. BERKE: Possible deterioration in some models.

MR. JACOBS: -- you'll heighten for these as opposed to --

MR. BERKE: Right.

MR. JACOBS: -- these others. That's it.

MR. BERKE: Right now, we're modeling sulfate ingress into, sulfate and chloride into some kind of --

MR. CASERES: Again, the only concern at the moment is what the diffusion coefficient is on those --

MR. BERKE: There are modeling programs, if you know something about the concrete. You could actually model the sulfate ingress into, the sulfate attack into the concrete based on the concrete, the spent chemistry of the concrete permeability features and what's the sulfate around it.

And I'm doing them now for some stuff, and it's looking pretty good. What we predicted it to be like in about four or five years is close. It won't be 100 percent, but it's --

MR. TRIPATHI: So the concrete is a homogenous material, and compared to soil it is non-homogenous. So what do you --

MR. BERKE: Well, you --

(Simultaneous speaking)

MR. BERKE: But the soil is underneath the water, and the soil doesn't, I mean, that's why you --

MR. TRIPATHI: Are you suggesting that it'll be more advantageous to do a soil sampling rather than --

MR. BERKE: A soil sampling --

MR. TRIPATHI: -- the groundwater monitoring?

MR. BERKE: A soil sampling is always more accurate for you than the groundwater somewhere else, because it's exactly what's next to the concrete, however, it is easier to do the water sample than it is to do the soil sample.

The soil samples are already what you're trying to get in the soil. The water sample is what you're trying to get to do something in the soil to get something that looks like the water sample that you pull out.

So if the water sample you pull out is close, so one time you might have to do both. And then after you do both, you can see how they relate. And you can probably just -- you might be able to get just away with the water sample.

MR. TRIPATHI: Well, some of these industry sites for sure were located in a very poor natural soil. And they had to come back and strengthen the soil by driving piles deep down into good rock level and then fill, good fill, engineered fill material. So those kind of sites are probably more susceptible to this kind of --

MR. BERKE: Well, disturbed soil is usually bad for steel. But concrete, I'm not sure if it's -- concrete just more or less cares what ions are there. So if you could figure out what the ion concentration is next to the concrete surface, that's pretty much what you're looking for.

Something like steel cares about how much oxygen is getting there and how, you know, whether or not -- so disturbed soil or backfill is much worse for steel than it is for concrete.

MR. TRIPATHI: No, these were drilled in place concrete piles.

MR. BERKE: Yeah. But they're still susceptible to the soil conditions there. The soil condition is --

MALE PARTICIPANT: Yeah, those are groundwater.

(Simultaneous speaking)

MR. BERKE: But the concrete, the soil's not going to be the same. It's not going to be that much different than the groundwater. It can't be.

MR. JONES: So it seems to me that we still have an issue with, you know, sort of all the soil or groundwater monitoring, you know, if you're wanting to check with these additional ions we don't really have a great reference to compare it to. Is that an accurate --

MR. POPOVICS: You're talking about the threshold levels of the various --

MR. JONES: Yes. It's like we have these nice tables --

MR. POPOVICS: -- layers.

MR. JONES: -- in ACI documents.

MR. BERKE: Well, I'll tell you, if you've got 1,000, 2,000 parts to a million magnesium there, I'd be worried.

MALE PARTICIPANT: All of a sudden, I think.

MR. BERKE: Okay. You know, so there's some numbers that's going to be beyond, you know, you get it all. I got 5,000 parts per million phosphate there, I'm going to be a little worried about that.

MR. JACOBS: Like those expansion tests. It's not going to tell you fine gradations, but if something's way up here --

MR. BERKE: Yeah. But if I see --

MR. JACOBS: -- it'll tell you.

MR. BERKE: Yeah. But if in the noise range, five, ten parts per million, it's probably not a big deal. You have to kind of use --

MR. POPOVICS: But the question is, like, you know, what are those threshold levels that you start to worry about. And, in some cases, there's not agreement about those numbers.

But you're getting a chloride ion, for example, there's a lot of debate about, you know, what kind of chloride and then is it sound. And in sulfate, what's the companion ion, you know, these things.

And you have to be a little bit careful about focusing in on one threshold value when actually you should probably be thinking about a safe range, and maybe a questionable range and a dangerous range, which would depend on the kind of cement you have in your concrete and --

MR. BERKE: Absolutely.

MR. POPOVICS: -- things like that. So it's a little fuzzy.

MR. BERKE: You might be able to do a probably analysis. You know, I'd say this is, you know --

MR. POPOVICS: LIT, risk, yeah --

MR. BERKE: The risk. I mean, even with chloride threshold values, a lot of the models we're doing now that we talked about, you know, originally they all started out as deterministic models. Now we're saying, okay, the chloride threshold value is, let's say, 500 parts to the million. That's the mean. It's got a standard --

(Simultaneous speaking)

MR. BERKE: It's got a standard deviation and distribution around that. And now you run -- so now you've got distribution on the chloride, you've got distribution on the cover, you got distribution on the surface concentration and a few other things. And now you're on, okay, then you do probability rationale.

And you expect there might be, I want 99 percent of the stuff not to be there. The bridges are typically going with 90 percent, for elements, you can't fix these easily. And for things like barriers --

MR. JONES: You could use those.

MR. BERKE: -- 80 percent.

MR. JACOBS: And just for my own edification, you're going to do this groundwater monitoring anyway, right? You're looking for it to fix that.

And you're saying, look, we're in there, let's take the sample, let's try to get, you know, glean as much information out of it. I think that's a very smart way to approach this problem.

MR. BERKE: I agree with you. And if it's really bad, you know it's bad. And if it's really low, you know it's okay. So it does tell you something if it's high. And it tells you something if it's very low. And we have that no man's land in between that you need to do some extra work on. But at least you've got the real disaster case.

MR. JACOBS: Just don't get overly secure. You know, gee, I see nothing in there. Okay, everything is great. You know, let's move on.

MR. TORRES: I think that's the part where the acceptance criteria is very important, so that when the corrective action program kicks in, it evaluates, say, chlorides. What are the complementary cations and, you know, what kind of cement the structure was built?

So I think that, whatever criteria, and this is why we posed the question, the acceptance criteria for the groundwater chemistry program, if that was adequate or if we need to even be potentially more conservative based on this.

MR. JACOBS: This is where sort of just a whole overall holistic monitoring approach, if you want to use the term, multi-physics is one way of looking at it.

You know, you're sensitive here to something that's different than, let's say, with acoustic measurement or with a visual measurement. And then you can, you know, where do you see the overlaps you're expecting?

You know, gee, we're expecting a high, you know, susceptibility to ASR for instance. Then let's try to check back with, you know, a visual inspection. That's the way to sort of move something holistic in there.

MR. JONES: So again, I'm not the fun sponge here, to kill the fun, but to move on to the mechanical here and talk about some of these techniques where, you know, you're sort of trying to measure something like a modulus or some sort of mechanical property. And that is of use as a proxy for structural wellbeing, I guess.

Again, can we, you know, try to help understand, in this sort of context, what these mechanical techniques are going to give us and which ones I've left off of our list?

MR. JACOBS: Do you want to start with impact echo?

MR. POPOVICS: Sure. I mean, yeah. I see ultrasound in two. Oh, I see imaging.

MALE PARTICIPANT: Imaging, yeah.

MR. POPOVICS: Okay, I was wondering what the difference was. You know, impact echo is a method that works for certain defects very well. And it does not work for other defects very well. And it has kind of a limited application scope.

And so, in this case, impact echo's quite good at finding horizontal delaminations, kind of like quantifying the chain drag, quantifying the sounding method and getting more information out of it and repeatable. But beyond that, it's kind of limited.

MR. JACOBS: Would you, again, on the negative too it's a localized measure, but that's okay.

MR. POPOVICS: That's a point.

MR. JACOBS: It's a point measure as opposed to I'll look at things sort of globally versus locally. But just thinking out loud, John, if you, let's just say you wanted to have a monitoring technique that, let's say, forget delamination, it assumes the delamination but monitors stiffness, concrete stiffness.

So, you know, every ten years or something like that you could certainly come up. Impact echo was an easy one to tap into, it doesn't take a lot of technology. But we'll give you gross information that you could potentially use.

MR. POPOVICS: Yeah, I mean, it's kind of a localized resonance test. So, you know, you're able to monitor that over the years. And if you notice a change in that resonance value, something's going on.

If it's going down, there's generally a loss of material stiffness, basically, or a loss, you know, there can be a geometric change. So there is some information that you can get from it.

MR. TORRES: And regarding voids, it's not reliable --

MR. JACOBS: Again, I mean, it's great for delamination. I mean, it's can't miss. You know, voids are, again, we're going to get into things like wave lengths where, you know, if you have lots of voids like this and, you know, this has very long wave lengths, it's not going to necessarily identify them in the sense that you want.

You know, you have in your mind let's get 3D. What you would like best is a 3D image through the thickness of, you know, the porosity, the density of the cask. Is that what we could call -- that would be Nirvana for us here?

MALE PARTICIPANT: Miller Light.

MR. JACOBS: Yeah, right. Something like that. Even if you could do a scanning system, this won't give you all of that information. It doesn't have either the capability. It's not sensitive enough to some of the things that you're looking for.

MR. POPOVICS: There are cases where you could conceivably detect the void. Maybe you got lucky or it's big enough. But I wouldn't say that you will be able to detect voids with that.

There are other methods that are more susceptible to kind of voiding, impulse response, very much like impact echo, but it kind of analyzes the information differently. It's better for kind of like local voiding. But it has to be near the surface. It's still a point measurement. You have to get up there and touch it and feel the test.

MR. TORRES: Is there agreement on the limit and the detection for that delamination, how wide it needs to be? Or is it dependent on the user and, you know --

MR. JACOBS: So, let's say --

MALE PARTICIPANT: It's a big debate.

MR. JACOBS: Yeah. Again, for just a delamination in a plate, we can call this a plate with the curvature. I don't know the answer to that.

MR. POPOVICS: I think a lot depends on aspect ratio, how is that delamination compared to its lateral extent, say, it's square and level extent, you know.

If your aspect ratio is less than three or four, it's going to be pretty hard to see. It's more, regardless of the depth, it's like maybe, you know, one inch down. But it's ten inches across, you're going to find that very readily.

But that's, you know, a very specific kind of case. And I think the impulse response in a way, it kind of gives you more information, the stiffness measurement, local stiffness measurement for that kind of situation.

MR. TORRES: And is there an influence on vertical versus -- it seems you keep saying horizontal delamination.

MR. POPOVICS: Oh, I shouldn't even say the word horizontal.

(Simultaneous speaking)

MR. POPOVICS: We mean bridge decks, so --

MR. JACOBS: Most people use it for bridge decks, but doing it on a vertical piece will not matter.

MR. POPOVICS: Yeah. You won't see any -- which of these were parallel. If it's parallel, the defect's parallel to the freeze surface, that's the surface.

MR. XI: Yeah. I can share some experience I had. You know, I don't do research like John on this, non-destructive evaluation method testing. But we use them. So the sound method, let's see, use hammer or use chain drag. If the crack is deep or it's very tight, then you cannot have a crack.

And then all this ultrasonics is not accurate enough. And we also use the infrared imaging before. It's also not accurate.

So, let's say, today we can apply the infrared imaging, you see original delamination crack here. Because we basically do the test of the whole surface. And then after two months, we come here, you run the same test, it's just disappeared. So it's not very accurate from an application point of view.

MR. POPOVICS: But there's one kind of, in this particular application, there's one possibility of using infrared thermography. And that is you will always have heat flow in this case. Because the inside normally --

MR. XI: Exactly.

MR. POPOVICS: Certainly in exceptional cases. You will have heat flow going out, a constant heat flow. And so IR imaging might be useful for this.

(Simultaneous speaking)

MR. JACOBS: We're going to have to get smart here. I mean, we have a very consistent structure as opposed to a bridge or --

MR. XI: I'm talking about the nuclear containment walls.

MR. JACOBS: But this looks very different. I mean, this is much simpler, it's much smaller. You know, there's a lot more access points.

I mean, again, I could envision, again, and I agree with you, let's say, that what you call the tapping is not exactly but impulse response is doing the same thing. It's just taking that signal and, rather than using your ear as the sensor and your ear to make the interpretation, you have a transducer that captures the signal --

MR. XI: Quite right.

MR. JACOBS: And the interpretation is, you know, it's the same way your iPhone works. I mean, you take that signal, you digitize it, and you extract information from it.

And your ear is very good at telling differences in sound, but if the crack is buried too far and the difference in sound is not in your audible range, of course you're not going to have it.

But I agree there are no silver bullets for this one. But there are ways to go after this and to quantify it in a consistent fashion and come up with a testing plan that I think would make sense.

MR. JONES: So just easing into this area a little bit already, but let's talk about the imaging type techniques we're aware of, you know, trying to make a picture of, you know, the various ways of doing it, ultrasound waves, radar waves, microwaves, things other than light to make a picture, I guess, is what I'm getting at. What are the --

MR. POPOVICS: Infrared light.

MR. JONES: Well, okay.

(Laughter)

MR. JONES: So what are the, again, my little cartoon, what are kind of the gotchas apparently, you know, dimensions are an important thing in concrete. You have a hard time penetrating a lot of it, for example.

MR. POPOVICS: Well, radar is a fantastic tool, because you can collect a lot of data without touching, you know. You can have even an air-coupled antenna and move very quickly and scan.

And you are very sensitive to conductors inside, so you can find metal, in particular, very well. But if you're not looking for metal, then the utility of radar drops quite a bit. So if you're looking for position of ducts, and rebar and so on, radar is fantastic.

But these structures, because they have reinforcement, they tend to shield the other defects from radar. And so radar has a limited application, I think.

MR. JONES: Uh-huh.

MR. POPOVICS: And, you know, I'd like to hear more about Yunping's experience with IR. Because it just occurred to me, that might really work. So I'd like to learn more why it didn't work in your case.

MR. XI: We didn't use IR.

MR. POPOVICS: Oh, you didn't use IR?

MR. XI: Oh. Yeah, yeah. Yeah, we used.

MR. POPOVICS: Yeah, that's what -- infrared is --

MR. XI: Yeah, yeah. Yeah, we used, as I said, so the crack can now disappear. So that's why when you scan this part and we see cracks, and then after two months it just disappears, this is not reasonable. So that's why it makes -- the technique is very --

MR. POPOVICS: So it's not reliable?

MR. BERKE: Well, sometimes cracks do close up. But they don't go away.

MR. XI: Some do.

MR. BERKE: Maybe up here, that's great.

MR. POPOVICS: I think we have to separate sort of a, when you do qualitative image from a --

MR. XI: It's not close --

MR. POPOVICS: -- from quantitative.

MR. XI: A crack is a crack. It's a reversible process.

MR. JACOBS: Why do people use, let's just pick a mechanical like an ultrasound. It's sensitive to mechanical properties, right, which are good things, right?

You know, if you want to measure stiffness, either you want to measure density as opposed to, you know, thermal properties which are important or dielectric properties which are important, you don't typically design -- they're not used a for a mechanical design.

So one’s a more direct measure and the other is an indirect measure. And so that's why you can get fooled. It's, you know, you can get false positives.

And it's very easy to get fooled.

While if you stick to making direct measurements, again, I'll use the term sensitivity, you know, is that you're looking for this. Is the technique sensitive to that thing that you're looking for? And how sensitive is it? You know, that's the way, in my mind, we have to quantify this particular problem.

MR. JONES: That's okay, I'm kind of thinking. Go ahead.

MR. TORRES: I just want to confirm here, so it seems like IR thermography is, it does not seem to be adequate.

MR. XI: In my opinion.

(Simultaneous speaking)

MR. POPOVICS: In that case, I don't know.

MR. JACOBS: I think John's point, that you have a heat source, you know you're going to have a differential, just in this particular example where you know you have, the internal temperature is going to be very different from the external temperature, no matter what.

MR. POPOVICS: The heat flux.

MR. JACOBS: IR requires the --

MR. POPOVICS: The heat flux.

MR. JACOBS: If you don't have that, it doesn't work. That's why it's good to take an IR picture of your house and you'll see, on a cold day, you can see where you insulation is missing. Certainly, I wouldn't throw it out, out of hand.

MR. POPOVICS: But also, you know, not having done it on these kind of structures, I appreciate that it may not work.

MR. JACOBS: And there's a reason why it's not used. You know, it hasn't gained wider acceptance. But this application, because of the heat source in the middle, might make it a candidate. I wouldn't throw it out, out of hand.

MR. POPOVICS: Right. This is a technology whose price is plummeting and performance is skyrocketing, IR cameras. They're not out of anyone's league anymore. They used to be. They used to be very, very expensive.

MR. TORRES: So you guys think this would be useful, even for the two, three foot thick wall?

MR. JACOBS: Well, yeah. I'm not going to sit here and say put it in the dust bin.

MR. JONES: So let's talk about acoustic monitoring. So this is where we, you know, set a bunch of microphones around the facility and listen.

MR. POPOVICS: You're looking for passive.

MR. JONES: Yeah. The cracking events or --

MALE PARTICIPANT: Well, yeah. Right.

MR. JACOBS: And so my opinion is it sounds great, you know --

MALE PARTICIPANT: No pun intended.

MR. JACOBS: No pun intended. But it's just going back to the three feet of concrete. You're never going to be able to extract the information.

Again, this is not under load, there is nothing, this is a passive structure. You're going to listen forever and not get anything. I mean, where a passive technique like that works very well is you have a rotating part, let's say, that, you know, you can look, you have a dominant signature that --

MR. JONES: Sounds the same forever.

MR. JACOBS: Sounds the same. You know, the classic is Hunt for Red October, when you're listening for submarines, that signature is very specific, and it travels very long distances in water.

Here, even if you had a dominant signal, you know, happening on the inside, just because of the amplitude and the frequency content, you would never be able to detect it on the outside.

MR. CASERES: You see them put the transistor on the same side of the wall and do some sort of a measurement, some sort of penetration.

MR. JACOBS: These we're discussing are passive. We're not putting the signal in and looking, it's not --

(Simultaneous speaking)

MR. JACOBS: We're not putting an ultrasonic signal or acoustic signal in and listening for a response. Here we're just listening for an acoustic signal that comes out of, to come out of the structure.

(Simultaneous speaking)

MR. POPOVICS: And if you wanted to triangulate and characterize, you would need much more than two sensors, unfortunately.

MR. JACOBS: Yeah. Honestly, this acoustic emission had so much promise early on. And people jumped on it. And I'm talking in the 60s, and 70s and 80s. And it's so inconsistent.

And in a material like concrete, just because of what makes concrete difficult from an acoustics perspective is your signal attenuates. If you want to find a flaw in this way, you need to have your wave lengths on that basis.

So to find smaller flaws, you have to go higher and higher frequency. And you just, you know, higher frequencies don't penetrate. They attenuate like that. So this is that problem in opposite.

MR. TORRES: Could it be useful then for below grade structures and potentially, you know, monitoring settlement or --

MR. JACOBS: That will happen at, settlement will happen at a time scale, you know, so much longer than, you know, you would look for it here.

MR. POPOVICS: Where I've seen acoustic emission kind of find some utility is in kind of one dimensional structures where you're trying to locate that kind of, also develop fractures and large brittle events, so at least that pre-stress concrete pipe.

So there's water in there, you put an array of sensors and then there's a wire fracture somewhere. And an array can triangulate it back and say it was here, you know, in a line.

And so maybe in pre-stressing, ducts could work for something one-dimensional. But, you know, in a massive structure, you're asking an awful lot of acoustic emission to kind of characterize --

MR. JACOBS: You only use energy, like, with these microfracture events. But something is causing our, you know, again, it's a passive structure, correct? There's not, you know, we're not loading it. It's not getting, you know, there's not these releases of energy periodically going through.

So it's really just sort of sitting there. And any kind of damage, let's say, with ASR or DEF, that's so small, that's orders and orders of magnitude smaller, the type of acoustic signature that would come out of that than you would be sensitive to. And even if we could find, you know, even if it happened, it's not going to come out, you know, to where we're listening for it.

MR. CHOWDHURY: So is it sensitivity issue? Because when pre-stress tendons in concrete fail in tension, that there is more than just a small fracture, so just sensitivity issue.

MR. JACOBS: That's one of the pieces. I'm saying it's a combination of pieces. You're asking me, I'm throwing this one in the dust bin. I mean, the technical -- and they're not technical issues, they're physical issues, you know, they're just so dominant.

And, you know, you have to almost solve three different problems. You have to solve the problem of, okay, let's say you can measure a signal accurately. You know, you need so many sensors to be able to go back to triangulate where it is, okay.

And then, again, a lot of it is the propagation from the source to where your sensor is. Here, we're potentially going through, what, three feet of, you know, concrete.

Now, we can penetrate three feet of concrete with ultrasound, but we'll do it at a very low frequency, very long wave length. Because we have control over that.

This we have no control over. The signal causes, you know, the acoustic signal, the frequency content is from whatever the event is. And it's going to be really high frequency. You know, if it's a very low frequency, very slow tearing, it's not an event that we're interested in.

MALE PARTICIPANT: I would agree with that.

MR. XI: Yeah, to add on that is for durability problems, you have a lot of small distributive cracks happening at the same time.

MR. JACOBS: Yeah.

MR. XI: So the sensors cannot detect which one happening and where. So in the lab, we have one concrete bin with one distributive crack, and then you can see the crack or data, and then the sensors can detect and hear the sound as a correct hit. So that's why, in the prior case for durability problems, it's really difficult to use acoustics, acoustic sensors.

MR. JACOBS: Okay. I would agree --

MR. JONES: So I sort of mismanaged our time a little bit. But the previous section, maybe we should have spent more time to this. But this wets our whistle a little bit for tomorrow. And we'll get into these issues a little bit more.

We're going to transition no, I'll hand the floor over to Sheila to transition into the public comment period.

MR. POPOVICS: Okay. Because I think imaging, there is a lot to pull up for review.

MR. JONES: Yeah, so we'll definitely come back to that.

MR. POPOVICS: Okay.

MR. JONES: So we've gone over by seven minutes, like that. So we'll go into our, you know, our recap, flex conclusion, we'll bleed into that a little bit to make the public comment period, you know, the full segment.

MS. RAY: All right. Thank you. Thanks, everyone, for their participation today. So now we'll start the public comment period. And I'd like to ask, for anyone who does have public comments, please introduce yourselves and state your affiliation for the record.

And I'd like to limit each person to about two to three minutes. Please just mention one or two comments, and then we'll come back to you once we've cycles through everyone, just to make sure everyone has a chance to make a comment.

And there will be some public comment period planned tomorrow as well. And also, please direct your questions to the staff, either Chris, Bob or Ricardo, and not to the panel. And please keep your comments relevant to the topic at hand, dry cask concrete systems, and degradation modes and inspection techniques.

And what I will do, since we do have folks on the phone, is I will alternate between people in the room and people on the phone. And so I'll start with people in the room. Please step up to the microphone if you have a question, yes, sir. And please state your name.

MR. PLANTE: Yes, my name is Paul Plante. I'm from the Three Yankees. I wanted to comment particularly on the inspection stuff, since we're talking about that right now.

If you could go back to your slide with the four boxes, Chris, I'd like to say that the one on the left in the upper corner is also a valid place to be.

MR. JONES: Sure.

MR. PLANTE: Really two types of power plants out there, or I should say ISFSIs out there. There's ISFSIs that are associated with power plants, and then there's decommissioned power plants which are stand-alone ISFSIs.

The guys, I represent stand-alone ISFSIs. I have three of them. And we don't have a lot of high technology tools available to us. But we do cask inspections every year. We use sounding techniques. I have my sounding hammer with me. We have used chain dragging on horizontal surfaces as well.

We had some delaminations at one of our pads, so those are all very good inspection techniques. I'd like to reinforce the panel's opinion of that.

I'd also like to say that, you know, we do have some groundwater monitoring wells in proximity to the ISFSI. There's none right in the middle of the ISFSI itself, but we do look at ones nearby.

And I wanted to mention that the ANL criteria, they published some, as Ricardo's aware, they published some criteria on chlorides, sulfates and pH in groundwater. And we usually test those three parameters.

It would be useful for the experts and for others to know, you know, what additional parameters ought to be monitored besides chloride, sulfates and pH. And I'm not sure that ANL has the right acceptance criteria for those, but that's what we're looking at. And that's what we compare our criteria, what we observe too. So that would be good information, if you could elaborate on that some. Thank you.

MS. RAY: Thank you. Is there a participant on the phone who would like to make a comment? We could open the bridge line. And please un-mute yourself. Any participants on the phone?

MS. GILMORE: Yes. This is Donna Gilmore from California.

MS. RAY: Yes, Donna, please go ahead with your comment.

MS. GILMORE: All right. There was one speaker that talked about a sustained heat range of 68 to 100 degrees centigrade. And, let's see what is was, that would drive the moisture out. And do you have -- are there any real examples of that or is the storage of spent fuel the only thing that's at that temperature range that would give us an example of the problems happening?

MS. RAY: Chris, do you have any --

MR. JONES: So maybe I can clarify what she was asking, if there's another example from something else with a similar temperature ranges, is that how I'm interpreting it?

MS. GILMORE: Well, yeah. I mean, let me ask it another way. The concept that we have of this hot interior, cooler exterior, what's the closest thing we have to that in other components besides, you know, concrete that has spent fuel in it? Is there any other components?

I know bridges wouldn't be the case, but something else that we have this phenomenon where we have all this heat on the inside.

MR. XI: We are talking about dry casks, right? So dry casks, inside is hot, outside is cold.

MR. JONES: Yeah. Did you have a --

MR. JACOBS: I remember, I think the comment came up here. It was a hypothethical statement as opposed to a specific statement about dry casks. It was a hypothetical statement about --

MR. POPOVICS: Yeah, it's based on literature, studies of behavior of concrete exposed to sustained temperatures in that range, not necessarily in the dry cask.

MS. GILMORE: Okay. I mean, but let me simplify the question. So there's really, this is kind of a unique situation. There's nothing even close where we have any actual situations, where we have concrete containers where it's hotter on the inside than the outside. Is that what I'm understanding here?

MR. TORRES: So, this is Ricardo Torres with the NRC. So, Donna, as you probably are aware, the heat from this system is dissipated through conduction, convection and radiation.

So the system might be enclosed. It might be in a support structure. So there's conduction of heat. And then there's convection which is used though the inlets and outlets of the overpack.

The concrete temperatures do not exceed

design basis limits which we have evaluated based on information that we know about thermal degradation and thermal desiccation as well as the ACI 349 limits, upper limits that they suggest. We've evaluated those, but the system --

MS. GILMORE: Now, I'm not sure -- that's not my question. That's not my question. I'm looking to see if there's any -- so this is all theoretical, because we don't have any real live situations, obviously, as in the situation with bridges or, you know, roads.

So we don't have real life situations, it sounds like, where we have the inside of the concrete much hotter than the outside. So that means all of this is pretty theoretical.

Are there -- because I'm trying to get a sense of, like, how quickly we could have failure, especially given this extra issue of the interior being hotter and drawing the moisture, or pushing it out or whatever is going on here.

MR. CSONTOS: Donna, this is Al.

MS. GILMORE: I'm going to assume the answer is that there is nothing close to this --

MS. RAY: Donna, we do have one person here who might be able to shed some light on your question.

MR. CSONTOS: Donna, this is Al Csontos. How are you doing?

MS. GILMORE: I'm fine. Who is this?

MR. CSONTOS: This is Al, Al Csontos.

MS. GILMORE: Hi, Al.

MR. CSONTOS: Hi, Donna.

MS. GILMORE: Yeah.

MR. CSONTOS: So what we're looking at, Donna, is irrespective of the temperatures and what not here, we're looking at performance of the concrete for its intended function.

And what we're seeing is that our inspections that we're looking at here, and that's what this group is looking at, is are we missing any degradation mechanisms that we should be looking for? Are there any things, other performance criteria that we should be looking at?

It's really all about performance for the intended function, whether that be shielding or structural. And then from there, what do we need to be looking for in the long term, okay.

You know, there's nothing, you know, if we do have some sort of difficulties with these concrete overpacks, there's nothing that stops licensees from going out and building a new one and then just shifting and moving the canister from one into another and just replacing them, okay. It's just an added cost for them.

But in reality, there's nothing really that stops or prevents us from letting that happen. So when something gets to the point where it is passed its performance criteria, you can either repair it, mitigate it, replace or, like I said, mitigate.

So, you know, these are things that are out there. We're just looking at, you know, from this group, is there anything that we're missing as part of those performance criteria, the performance metrics that we need to be mindful of going forward.

MS. GILMORE: Yeah. I understand that. What I'm trying to figure out is, you know, one other person mentioned life cycle cost. Who was the speaker that mentioned that, life cycle cost?

MR. JONES: I think it came up from most of the --

(Simultaneous speaking)

MALE PARTICIPANT: A couple of us.

MS. RAY: Donna, we've hit a few minutes. And I'd like to move on to some other commentaries.

MS. GILMORE: Oh, okay, fine.

MS. RAY: But we can circle back to you if you have additional comments.

MS. GILMORE: Okay. All right.

MS. RAY: I'd like to turn to anyone else in the room who may have a comment. Please introduce yourself?

(No audible response)

MS. RAY: Seeing none in the room, are there other participants on the phone that would like to make a comment?

MR. LEWIS: Yeah. My name is Marvin Lewis.

MS. RAY: Yes, Marvin. Please go ahead.

MR. LEWIS: Okay. Really simple one. ASR, alkali silica reaction. You guys were mentioning something about Florida. I only know about Seabrook which is up in, what is it, New Hampshire. And I was wondering what is the site in Florida showing alkali silica reaction please?

MR. JONES: I don't recall that we mentioned that.

(Off microphone discussion)

MR. POPOVICS: We mentioned Florida with regard to higher risk of corrosion.

MALE PARTICIPANT: Corrosion, yeah, corrosion.

MR. TRIPATHI: And again, I think that you were talking about some non-nuclear structure, right?

MR. XI: Oh, I was talking about the bridges.

MR. JONES: Yeah, bridges, yeah.

MR. XI: In Florida.

MR. JONES: So maybe the confusion was we were transitioning quickly between corrosion and ASR. But, yeah, I don't believe we mentioned Florida in the contest of alkali silica reaction.

MR. LEWIS: Do you ever find ASR anywhere except Seabrook?

MR. JONES: Certainly for non-nuclear structures.

MR. POPOVICS: The Atlanta Airport.

MR. JONES: The Denver Airport.

MR. XI: Philadelphia.

(Off microphone discussion)

MR. XI: On bridges, a lot of bridges, and also on gravity dams a lot, worldwide.

MR. BERKE: Dams are probably the worst place.

MR. LEWIS: Thank you for answering that. I wish you could have answered Donna's comment as well.

MS. RAY: Thank you. Other participants in the room who may have additional comments? Yes, Sir? And please state your name, once again.

MR. PLANTE: Yes, Paul Plante, Three Yankees. I wanted to talk about what we do for inspections a little bit. Annually we go out, we do inspections.

Actually we've been recently trying the 349 criteria just to see how that would work in practice. We do go and take pictures. We don't have the sophisticated imaging techniques, but we do take pictures of anything that we see that would be particularly Tier 3.

And we do take them annually. So we take them one year, go back to the same spot the next year, take another picture, look at it, see if anything's changed. And then hopefully that will, in the long term, inform what we wind up doing about some of these.

I noticed that some of the cracks that we have that are larger in nature come from the -- you have outlet vents. And you have corners on them. And we have cracks that come off of those corners where the steel and the concrete meet. And that's the kind of stuff that we primarily are looking at. We also have them down below on the inlets. They come off of the corners of the inlets as well.

MALE PARTICIPANT: Forty-five degrees.

MR. PLANTE: Yeah, about at a 45 degree angle, exactly right. So I just wanted to bring that up to the group. Thank you.

MS. RAY: Thank you. Are there participants on the phone that would have additional comments?

MS. GILMORE: Well this is, if nobody else does, it's Donna Gilmore again.

MS. RAY: Go ahead.

MS. GILMORE: Okay. So it appears that, because of the situation of the interior being hotter, that we could potentially have these cracking or delaminating conditions sooner than other situations because of the different mechanisms that were described in this meeting. Did I understand that correctly?

MR. JONES: Yeah. I don't know that we implied that that would be sooner. Or I certainly didn't get that --

MS. GILMORE: Well, that's why I'm asking.

I'm asking a question. Would it, at least theoretically, be sooner.

MR. JONES: Well, I guess I'm hung up on the notion of sooner. Sooner than what? Without a heat load, is that what you mean?

MS. GILMORE: Sooner than you're experiencing in other situations that have these problems happening.

MR. JONES: I don't know that we hear that conclusion, ma'am.

MALE PARTICIPANT: No.

MS. GILMORE: Well, I'm just kind of, so I guess what I'm trying to figure out is how soon could we have a serious problem in, you know, I know you mentioned that something could be replaced. But we have to pay for that. So, you know, so that's a money issue. And we don't have money set aside for this kind of long term maintenance.

So I'm just trying to get a handle on, you know, do we need to allow a lot more money here? We're right in the planning stages at San Onofre. So this is a big issue for us.

MS. RAY: Donna, is your concern on the inspection?

MS. GILMORE: So how soon would this might happen, is what I'm trying to get at, that we might need to do some kind of major repair or replacement? How early should we prepare for that as a potential, conservatively speaking?

MR. JONES: I think, unfortunately, that's the question that we don't know the answer to. If we did, it would make our lives a lot easier.

MR. POPOVICS: I think good inspection techniques are paramount to all degradation mechanisms, holistically. And really, that should --

MALE PARTICIPANT: First of all --

MS. GILMORE: It doesn't sound like you have one, the testing is just internal to the concrete and not visual on the outside.

MR. CSONTOS: Donna, you know, this is Al Csontos again, you know, we at NRC have to look at all the sites, all 50-plus sites around the country when it comes to this. And we have to make our regulations, you know, uniform for everyone, okay.

MS. GILMORE: Of course.

MR. CSONTOS: We can't go out and make a, you know, we, at this point, have to be thinking about what we can do. And that's what Aging Management

Programs are there for. And that's what ACI 349.3R does, is that we do this through an inspection and assessment of those degradation mechanisms that can challenge the performance of the canisters for its intended function.

And then we either repair, replace or mitigate them. But if we replace them, you know, that's fine too. I mean, you're right. It's an additional cost, but from NRC's point of view, we're worried about those safety functions, okay.

And if a licensee does not maintain their systems where the safety function is maintained, then they will have to replace them, or repair them or mitigate them. And so that's the whole strategy that we're doing here. And we don't have a date that we can give you, because we're looking at this holistically throughout the whole country.

MS. GILMORE: Well, I'm speaking holistically. I'm just, you know, I'm speaking holistically. How soon could this potentially happen in any location? I'm just looking for a conservative range. But if the answer is you don't know, then I'll take that.

MS. RAY: Donna, we have someone who would like to speak.

MR. SISLEY: Hi. My name is Steve Sisley. I'm with Energy Solutions, one of the certificate holders. I'd just like to say that the temperature gradients that we're talking about are a design load. We designed the cask systems with sufficient strength to withstand the highest temperature gradients that the systems can possibly take.

So this is not an aging related issue. This is a design condition that we designed for. And these systems are strong enough to take the maximum temperature gradients.

MS. RAY: Thank you. Donna, could you hold one moment. I'd like to see if there are other participants here in the room that would like to make comments.

MR. XI: Well, I'd like to make a comment about what you just said. So you're talking about thermal stress. So is thermal stress induced by the temperature readings?

MR. SISLEY: Yes, absolutely.

MR. XI: But we've been talking about the temperature gradient driving the moisture movement. So these are two different issues. I'm not saying the thermal stress is not important.

MR. SISLEY: Well, it sounded like the impression was that these systems weren't designed for the temperature loads. And I just wanted to address that. They are designed for these temperature loads.

MR. XI: Yes. From a mechanics point of view.

MR. SISLEY: Yes.

MR. XI: But not from a durability point of view.

MR. TORRES: Yeah. And I think that that's why we're having this discussion here, to identify that there are gaps that we need to potentially do further research or to entice further research, whatever is needed at this point with what we know those design basis limits are adequate and this is our approach. But again, we rely on inspection and monitoring to make sure that that --

MR. CSONTOS: Right. And, Donna, this is Al again. The reason why we're hedging on your answer is because it's so complex, okay. We're looking at various mechanisms, multiple different mechanisms, multiple different heat loads, multiple different locations around the country, multiple mobility paths for water ingress and other types of chemical reactions to occur.

I mean, that's a heck of a lot of things to try to nail down. And so instead, we are focusing on inspection and other inspection technologies to then assess what type of performance we can maintain over the period of the renewed operation for these systems.

So I hope that helps answer your question. Because we've really spent a lot of time on this one question. Is that okay? Are you still there, Donna?

MS. GILMORE: Well, yeah. Maybe if you can at least include in a summary some, you know, key issues that you still need to investigate.

MR. CSONTOS: Sure, okay. We'll do that.

MS. GILMORE: That might just clarify that. Okay, thank you.

MS. RAY: Thank you, Donna. And your comments have been put on the record. So we do appreciate that.

MS. GILMORE: Okay, thank you.

MS. RAY: Are there other participants on the phone that have comments?

MR. HOFFMAN: This is Ace Hoffman.

MS. RAY: Could you repeat your name one

more time, sir?

MR. HOFFMAN: Ace Hoffman.

MS. RAY: Okay. Please go ahead. Thank you.

MR. HOFFMAN: Two quick points. First of all, in reference to what Donna was saying and Csontos' answer, you have to investigate the worst cases and cover all cases. Because you're trying to write a generic proposal or a generic regulation. So I just wanted to mention that.

And the other thing is, earlier somebody mentioned that all decay mechanisms rely on moisture. And so I'm wondering what are the chances that the NRC is going to recommend that these dry cask storage locations all be enclosed in an airtight building to reduce the moisture significantly and also reduce the salts and all the other things.

It just sounds like that's the first line of defense. And we've always had a lot of levels of defense in the nuclear industry, at least we've been told we have those in here in the dry cask storage system. We have one at most. And so perhaps we need more. Thank you. Those are my --

MS. RAY: Thank you. Is there anyone from the staff who would like to respond?

MR. CSONTOS: Ace, thank you so much for those comments. We'll take them, you know, under advisement. But that's, at this point, we can't, you know, there are other mechanisms that may not require moisture. That's a radiation induced type of issue. So those are things that we also look at. But your points are well taken. Thank you, Ace.

MS. RAY: Ace, did you have any other comments?

MR. HOFFMAN: No, thank you.

MS. RAY: Thank you. Folks in the room, any comments?

MR. WALL: My name is Joe Wall. And I'm from EPRI. And I just wanted to point out that we have over 40 years of operating experience with biological shields which have similar heat loads that dry cask storage does. And we haven't seen any accelerated aging in the bioshields.

MS. RAY: Thank you for your comment. Other participants on the phone, do you have any --

MR. DUNCAN: Yeah. Andy Duncan from Savannah River.

MS. RAY: Yes, go ahead.

MR. DUNCAN: In combined aging mechanisms one needs to balance, I think, environment to minimize both the effects of maybe corrosion and carbonation.

I know that in intermediate relative humidities, the carbonation rate peaks out and is much higher than if it's very wet or very dry. So it wouldn't necessarily be the best thing to put all these cask storage facilities in an interior humidity controlled environment, say around 45 percent relative humidity, because that's when the carbonation rate is the highest.

So if you, 200 years from now, if you end up getting a leak and the moisture goes higher, now you've got carbonated concrete and no protective barrier between your rebar and your surface.

MS. RAY: Thank you. Did you have any other comments to add?

MR. DUNCAN: No, that's fine. If somebody else wants to disagree or has an educated comment, I'd appreciate listening.

MS. RAY: Any follow-up comments for this?

MR. TRIPATHI: Well, I think we agree with, in general, we agree with what you just said. But right now, we are not aware of any licensee has any plans to enclose the storage units either vertical or horizontal.

But your point's well taken.

MS. RAY: Thank you. Are there other comments from people in the audience here? Yes?

MR. LOMBARD: This is Mark Lombard. I'm the director of the Division of Spent Fuel Management here at the NRC. And I'm hearing some of the comments from Donna Gilmore and Ace Hoffman.

This is the first time we have engaged an expert panel on concrete. And the reason is that we want to make sure we start to gather that information that would eventually flow into a regulatory framework.

Now, as it flows into a regulatory framework, as Mr. Hoffman brought up a good point, that the regulations are generic, I guess, for lack of a better term. They're the same for everyone.

But the Aging Management Programs, and the title of an aging analysis really starts first in the Aging Management Program, is very specific to a specific dry cask storage system at a specific site.

And if there are issues that we identify that are specific potential degradation mechanisms for a site in a dry cask storage system, certainly the Aging Management Program that we would approve for that system would include inspections and, as Al said, mitigation or replacement techniques for that degradation mechanism.

So we're just kind of starting this effort. This really applies to the second renewal period, at least time equals 60 years of dry cask storage.

And so a lot of your questions seem to indicate that you may be thinking that this is going to flow into requirements immediately. But we're some time away from actually changing either requirements or Aging Management Program requirements.

But I will say that if we identify a safety issue, a potential safety issue at any time during this process, clearly we would go after that safety issue if it is probable that that would apply to, again, a specific system sitting on the ground now at a specific site.

MS. RAY: Thank you. Other participants? Oh, yes? Go ahead.

MR. JUNG: I'm Andy Jung from Areva. I'm not an expert for concrete. But I'm working for corrosion of the metals.

One question is we're supposed to inspect both, like, interior and exterior surfaces on the concrete overpack. Or only we are supposed to go only inspect outside of concrete. Because the, again, I'm not an expert for this concrete degradation.

But if we, like, most likely more benign condition of inside of concrete except for, like, some additional, some radial issues affects can make the moisture some disassociation.

Other than that if, like, inside it's more benign condition, we can maybe go only outside exterior inspection rather than both sides. Because, you know, it is so difficult to go to inside for concrete degradation.

MS. RAY: Is there anyone from the staff who would like to follow-up on this?

MR. TORRES: Yes. At this point, in the Aging Management Program, for the first license renewal period includes inspections of the interior and exterior.

And the justification for doing inspections of the interior, again, is we need operating experience. We want to know how the systems look inside to be able to then have a justification to say systems can only be inspected from the outside.

MR. JACOBS: But, Andy, when you said interior, did you mean embedded, embedded concrete, embedded steel?

MR. JUNG: No. So inside all that.

MR. JACOBS: Okay, all right.

MS. RAY: Please use the microphones.

MALE PARTICIPANT: Exterior overpack.

MS. RAY: Thank you.

MR. TRIPATHI: Let me add to what Ricardo just said. That inspection involves inspection inside or outside, doesn't matter where, anything which affects the functionality of that dry storage cask.

Not just structural, but there are other disciplines which are also affected, shielding, criticality, containment, thermal, what have you. So anything which affects the functionality of that life of the cask or whatever the licensing life is, it's included in the inspection, inside, outside, doesn't matter.

MS. RAY: Thank you for that clarification. Are there other participants on the phone that would like to make a comment?

MS. GILMORE: This is Donna again. I have a quick question for the EPRI person. He mentioned that they have examples of a similar heat load. Could you identify what that is?

MS. RAY: Donna, if you would please, we're taking questions directed to the staff at this time.

MS. GILMORE: Oh, okay. Okay.

MS. RAY: Other participants on the phone that would like to make a comment? Anyone in the room that would like to make any further comments?

(No audible response)

MS. RAY: One last time, anyone on the phone?

(Off microphone discussion)

MR. CSONTOS: Correct me if I'm wrong. This is Al. It was the bioshields, right?

MR. WALL: Yeah.

MR. CSONTOS: In reactors.

MR. WALL: The entire reactor cavities.

MR. CSONTOS: The reactor cavity that surrounds the pressure vessel --

MR. WALL: That's correct.

MR. CSONTOS: -- that has a very large heat load. Because it's actually creating the energy. It's not boiling, but it's very hot. And so that sees the temperature range that you're talking about, Donna. So that's why, you know, I just wanted to make sure we clarified that so you'd have that statement out there.

MS. GILMORE: Thank you.

MR. CSONTOS: Oh, and inside the container.

MS. RAY: Yeah, one more time, anyone in the audience that would like to make a comment?

(No audible response)

MS. RAY: And is there anyone on the phone that has additional comments?

(No audible response)

MS. RAY: There will be additional comment period tomorrow, in case you have burning questions in the evening. But I will turn it back to Chris for concluding.

MR. JONES: Great, thanks. So this pretty well wraps up the first day of our expert panel. We, again, say thanks for the time to come out here and visit with us about these concrete degradation issues.

We, I think, have covered a lot of interesting things. And I think tomorrow is really where we begin to transition into how to act on some of these things with the inspection and monitoring, Aging Management Programs, TLAAs, repair and remediation, et cetera. So, you know, I look forward to that.

I think, you know, frankly we've wrapped up a little bit ahead of schedule which is, you know, great for everyone. So we'll look forward to seeing everyone back at about 8:30 tomorrow morning. And we'll proceed from there. So thanks, everyone.

MALE PARTICIPANT: Thanks, Chris.

(Whereupon, the above-entitled matter went off the record at 4:10 p.m.)