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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

July 12, 2006

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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WEDNESDAY, JULY 12, 2006

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ROCKVILLE, MARYLAND

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The Advisory Committee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, at 1:30 a.m., Graham Wallis, Chairman, presiding.

COMMITTEE MEMBERS:

GRAHAM B. WALLIS, Chair

WILLIAM SHACK, Vice Chair

J. SAM ARMIJO

SANJOY BANERJEE

MARIO V. BONACA

RICHARD S. DENNING

THOMAS S. KRESS

OTTO L. MAYNARD

DANA A. POWERS

JOHN D. SIEBER

ACRS STAFF PRESENT:

MICHAEL JUNGE

JAKE ZIMMERMAN

MICHAEL MODUS

JIM DAVIS

KENNETH CHANG

TOMMY LE

HERMAN GRAVES

TONY SHAW

MIRELA GAVRILAS

ALSO PRESENT:

TIM O'CONNOR

DAVID DELLARIO

PETE MAZZAFERRO

GEORGE INCH

JIM MADOFF

DAN NAUS

LES DOLE

I N D E X

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

8:34 A.M.

CHAIRMAN WALLIS: The meeting will now come to order. This is the first day of the 534th meeting of the Advisory Committee on Reactor Safeguards. During today's meeting the Committee will consider the following: final review of the license renewal application for the Nine Mile Point Nuclear Station; results of the study to determine the need for establishing limits for phosphate ion concentration; integrating risk and safety margins; a subcommittee report on PWR sump performance and the preparation of ACRS Reports.

This meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act. Dr. John T. Larkins is the Designated Federal Official for the initial portion of the meeting.

We have received no written comments or requests for time to make oral statements from members of the public regarding today's sessions.

A transcript of portions of the meeting is being kept and it is requested that the speakers use one of the microphones, identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

There are a few items of current interest. In the handout on Items of Interest, you'll notice some speeches by Commissioners and you'll notice that there's an SRM on the pressurized thermal shock rulemaking place. So those who were here yesterday will note that there is progress, perhaps, in that area.

Sanjoy Banerjee, you will note, is here today. He's joined us as an official member of the ACRS. It's a personal pleasure for me to welcome him. Please join me.

(Applause.)

I note that this is the last meeting for Richard Denning. On behalf of the Committee, I'd like to thank you, Rich, for your outstanding contributions to the Committee in reviewing several complex technical issues. We wish you good luck in your future endeavors. I would note that you have been an exemplary member, offering insightful comments in many different areas and at times helping the Committee to converge to consensus when that initially appeared to be difficult. Thank you very much, Rich.

(Applause.)

MR. DENNING: Thank you and if I could

just say a word, it's been a privilege being a member. It's often been a challenge. I'd like to commend the staff who do just a terrific job in supporting us and it really has been very enjoyable, just working with this Committee. And so I'm just going to pretend that this isn't the last day until I walk out that door today. Thank you.

CHAIRMAN WALLIS: This is a place where assumptions are made. Maybe we should assume that you're still here.

(Laughter.)

On a sadder note, I'm sure you know that Graham Leach, former member and consultant of the ACRS, died on June 22nd after a short illness. We shall really miss him and his wise advice and pleasant company. So we send out sincere condolences to his family.

I'd like to begin the meeting. The first item on the agenda is the license renewal application for Nine Mile Point. Jack Sieber, my colleague on my right, is the expert on this matter and I'll pass the gavel over to you, Jack, to lead us through this one.

MEMBER SIEBER: Thank you, Mr. Chairman. I would point out that P.T. Quo is usually here. He's off on medical leave at this time. I've heard that he much preferred to be here than where he is right now.

The Nine Mile Point Nuclear Station is the subject of today's, this morning's session. We had a subcommittee meeting in April, actually on April 5th of this year where we went through the application and the safety evaluation, both of which are quite thick documents and each of us, I think, got a copy of them. So we've had the pleasure of carrying them around and trying to read them all for some time now.

We did not write an interim letter in April and because things were sufficiently in good shape at that time that we felt that the staff or the licensee did not need any special advice from us as to how to proceed.

So what I would like to do now is to introduce Jake Zimmerman of the staff who will guide us through the license renewal application process and the staff's response to that.

Jake?

MR. ZIMMERMAN: Thank you. Good morning. Again, I'm Jake Zimmerman. I'm the Chief of License Renewal Branch B in the Division of License Renewal, Office of Nuclear Reactor Regulation.

With me today is Mr. Tommy Le. Mr. Le is the senior project manager responsible for leading the staff's review of the Nine Mile Point license renewal application. Mr. Le will discuss the staff's final safety evaluation report after the Applicant has made their presentation.

Also with me today is Mr. Robert Hsu. He's the assistant team leader for the Aging Management Program and Review Audit Activities. Mr. Hsu is here to answer any of your questions related to the audits that were conduct at Nine Mile.

Also, joining us later during the staff's presentation will be Mr. Michael Modus who is the team leader for the Region 1 inspections. He'll be joining us via phone.

Finally, I'd like to acknowledge the staff that's here with us today in the audience that provided us outstanding support throughout this review. They're also here to answer any additional questions that you may have.

This was a challenging review for us and the Applicant is going to discuss their recovery project that they went through. But the staff did conduct a detailed and thorough review of this license renewal application which was submitted in May of 2004.

During that review of the original

application, the staff did identify issues associated with quality of information provided and Applicant's resources to support our review activities. As a result, in March of 2005, the Applicant requested a 90-day grace period to address these issues and they will address that during their presentation of the recovery project.

We believe the Applicant appropriately responded to these issues and in July 2005, submitted their amended license renewal application. The staff resumed its review and as Dr. Sieber pointed out, we did issue the draft SER with open items and discussed that with the subcommittee in April of 2006.

So the staff is here today to present the results of the final safety evaluation report and with that, I'll turn it over to the Applicant, Mr. Tim O'Connor, who is going to lead us through the Applicant's presentation.

MR. O'CONNOR: Thank you. My name is Tim O'Connor. I'm Site Vice President of Nine Mile Point for Constellation Energy. What I'd like to do is introduce the team that I have and staff that again can answer any questions that you may have.

John Carlin is here. He's our Assistant Vice President of Technical Services. He's in the back. David Dellario is to my left here. He's Director of the Calvert Cliffs Reactor Head Project. That's his current title. He was prior to that the Director of Projects for us on this particular effort. Ray Dean is in the background over there. Ray is our Quality Assurance Director for Nine Mile Point. Bob Randall is here in the back with Ginna Licensing. He also was part of our project efforts at Nine Mile. Pete Mazzaferro was the Project Manager. He's to the left of David Dellario. George Inch is one of our -- I call him one of our smartest fellows in the technical area. He's here to answer any particular questions you may have. He's in our Design Engineering Group. Mike Fallin is the Corporate Engineering Technical Consultant. And Jeff Poehler is Corporate Engineering Senior Engineer.

So that's our staff. With that, what I plan on doing is providing an oversight on my slide 3, is to describe a little bit Nine Mile Point, the current Nine Mile Point performance. We'll talk, as mentioned earlier about our license recovery project, the operating history, our planned improvement initiatives, license renewal commitments and then we'll summarizing with closings.

So with that, slide 4. Nine Mile Point is owned by Constellation Energy, but Unit 2 -- Unit 1 is 100 percent owned by Constellation Energy. Unit 2 is owned partially, 18 percent, by the Long Island Power Authority. Constellation Energy acquired ownership of Nine Mile Point in November of 2001. It is the owner/operator of both plants. It's located in Lycoming, New York. The ultimate heat sink is Lake Ontario and GE is the NSSS turbine supplier.

Slide 5. Nine Mile Unit 1 is a Mark 1 containment. It's rated at 1850 megawatts thermal. Rated electrical 615 megawatts electric. Commercial operation 12/1 1969. In its current license operational expiration date is 8/22/09.

Unit 2 is a Mark 2 containment. It's rated thermal capacity is 3467. It's electrical output is 1144 megawatts electric and commercially operated 3/11/88. Unit 2 was granted a 10 CFR 54.17 exemption.

Current performance of Nine Mile, Unit 1 and Unit 2 are in the reactor oversight process performance indicators as green. There are no open inspection findings with status greater than green. Nine Mile, both Unit 1 and 2, are in column 1 license response of the ROP Action Matrix.

Unit 1 and Unit 2 are running very solid and on a performance index against the industry, I would tell you that we are a solid industry average, moving towards top quartile in many functions, many areas.

With that, I'll turn it over to David Dellario to talk about our beginning of our license recovery project.

MR. DELLARIO: Thank you, Tim. Yes, my name is Dave Dellario. I was responsible for the project during the recovery period. I submitted the application back in May of '04, but unfortunately in March of '05, both Constellation and the NRC mutually concluded that there were some quality concerns of the application. At that point, both parties agreed that we would defer and allow a grace period for Constellation Energy to improve the overall quality of the application which would help facilitate the NRC's review.

But the first thing we did is we went ahead and did a root cause analysis to figure out what went wrong. We spent a month looking at the industry, talking to other applicants, bringing in more resources, identifying what we had to change. For example, we re-did the entire MSR scoping effort with the application. We went back and answered all the open RAIs.

What it really came down to is we found there was a couple of fundamental problems with the project itself and that is isolationism. We didn't have enough engagement from the site. Management engagement, their lack of it from both site and corporate. And then lack of resources. When I talk about lack of resources, the pure number of people on the project only went down to two or three people and at that time normally you'd have about 18 people in the project, which then creates a domino effect when you're talking about answering RAIS. The project really struggled from the time we submitted it until the time we put the project on hold.

From corporate changes, they moved the project under fleet licensing and created extensive checks and balances. We're talking about independent assessments were done through recovery period, internal assessments. QPA was doing assessments on the project. We established key performance indicates. Challenge boards were established.

Every section of the application went in front of Nine Mile Point management to make sure that it met the quality level of our expectations for our management. There was also periodic meetings and briefings to the chief nuclear officer.

CHAIRMAN WALLIS: Sounds like a case study in business management to me.

MR. DELLARIO: We certainly made some mistakes.

MEMBER KRESS: Would you tell us a little more about these key performance indicators were. I wasn't at the subcommittee meeting.

MR. DELLARIO: An example of key performance indicator, we wanted to develop program basis documents. That was one area that we were weak in. So we had it was about 40 or 50 -- 43 of those. So we just made a burn-down curve to track for those things we wanted to change in the project, we wanted to track that we stayed on schedule. Because again we only had 90 days to do all this work, so it w as very important that we didn't get behind in anything because it was a very aggressive schedule.

MR. O'CONNOR: Those metrics that they're talking about also had quality pieces with it, not only just the volume and assuring that we're meeting commitment dates, but also had quality elements associated with it and then had various types of challenge boards to validate that the information that's being provided was accurate and I would say complete. That was done through independents as part as part of our lessons learned to ensure that we would deliver on what we had said.

MEMBER POWERS: Could I understand better the 90 days?

MR. DELLARIO: Well, we say we went on hold for 90 days. It was actually overall four months. It was more than that. We spent a month just doing benchmarking. But the overall direction from the NRC was you have one shot at delivering this application, so we took a little longer than the 90 days. If you look at the dates from the time we put the project on hold to the time that we submitted the amended application.

MEMBER POWERS: I'm still struggling with why 90 days. Why one month, why not six months?

MR. DELLARIO: That's just the time it took us to turn it around. I mean --

MEMBER POWERS: Well, you complained earlier that you were time constrained here. I'm just trying to understand why 90 days.

MR. DELLARIO: Because what we did was we did a root cause analysis, figured out where all our weak areas were and then the NRC had asked us how long it would take before we resubmit the application. And that's what we told them. We thought -- we were very confident that we could get this back to them in July. So that ended up being about a 90-day turnaround. Still, I'll be honest with you, at this point it was more work than we had thought. There aren't a lot of resources to do this work. So when I say we were constrained, perhaps that's not the right word. We laid out a plan and it was just a challenging plan.

MR. O'CONNOR: The 90 days I don't think was anything more was our original estimate based on what we believed the problems were. As we did the root cause and started looking into the specifics, we did find that it was a little more extensive than the original estimates. We applied the appropriate resources, did the various reviews and commitments, and when it was ready to the quality that we thought was satisfactory, resubmitted.

CHAIRMAN WALLIS: We're not really reviewing your history. We're reviewing your product, I think. So maybe we should move onto that, should we?

MEMBER POWERS: Yes, I'm just trying to understand the decision-making process here. I'm perplexed. But you're right, I don't need to understand it.

MR. DELLARIO: As I mentioned, we had added resources to the project. And what was key here was we brought in at least a dozen contractors. But what was more important was to get the site engaged. So we wanted to program owners, as a Nine Mile Point as the program owner be involved with the project. They were the ones that developed the program basis documents. They understood license renewal. They were expected to review and understand the goal and when the NRC came to the site during the audit and the inspection, they were the individuals they spoke to.

This is very important because, you know, as the project winds down we didn't want to hand this product over to the site. We wanted to be sure they were engaged along the way. So they were the ones that own the commitments and we'll implement them and that's what they're doing at this time.

Next slide.

MR. O'CONNOR: I think the major lessons learned that Dave is describing is that the decision making the company had made originally was to call this a project and ran it somewhat isolated from the site. That doesn't mean that the site wasn't involved. The site didn't what I would call own it to the degree that was required. But our lessons learned in the root cause was that all projects, whether it is license renewal or anything, belongs and is controlled through the site VP. That's through me. I am responsible for all projects associated with Nine Mile Point.

It doesn't matter who takes on the responsibility of doing the activities, but ownership, the quality, the commitments, and the assurance that it's done to the degree required belongs to the site VP.

In our project review, we determined that sometimes you take actions, but don't necessarily know what are the results that you're looking for. And so we had to go back and review how we pre-establish and determine results, interim milestones, and metrics associated with it to assure that the activities that we're going after, that the outcomes are achieved that we expect.

Nine Mile Point staff was assigned to the team to projects. Each one of the functional areas inside the facility, maintenance, engineering, operations, and the different support groups, all had line management personnel associated and assigned to the project under Dave and Pete Mazzaferro. We believe that was part of the problem is that we did not fully understand how some of these things were expected to take place and we didn't recognize our involvement in the degree that it was necessary.

One of the Constellation fleet initiatives is that validating progress requires results verifications through challenge boards. We have series of challenge boards that are put during various milestones to validate that the expectations are being met and it goes through a rigorous review by independent parties, as I said, to assure that the product quality, the commitments, and the quality is meeting what's expected.

We used an awful lot of intentioned oversight through quality assurance and through independent subject matter experts again to assure that we're bringing in the right industry experience and the right subject matter expertise to support the activities that we're going after.

And probably the other thing that we learned on projects that's critical is engagement of the site. And engagement comes through communication. I think a project of this size, as it is with anyone that has this type of magnitude, is without involvement from the whole station, it's very difficult to be able to make things happen. So one of the keys is to make sure that people are educated and understand what the expectations are and how they are required to involve themselves in order to support success.

We did quite a few communication efforts through first line supervisor alignment meetings, education sessions, training sessions, communication through written versions of project performances. All as ways to try to get people to understand that license renewal is for their success and longevity in the jobs. That was very successful in getting greater engagement. Those are some of the larger lessons learned that we came from this particular project that we've applied in all projects associated with Nine Mile Point.

MEMBER MAYNARD: During your introductions, there were a couple of key members of your team that looked like they have new assignments now. I'm just curious what you're doing to ensure that toward the end of this project and during the transition here that you don't lose some of the momentum and some of the knowledge that you have.

MR. DELLARIO: That's the reason why we really during the recovery period brought the site into the project and that is the program owners. So we thought long term, you know, who is going to have to implement these commitments and it is the program owners. So we have not lost any momentum at this point. Pete is now the project manager and a Nine Mile Point employee and driving these commitments. So again as I mentioned earlier is we didn't want to hand this off and lose that momentum. We needed to get the site engaged upfront.

MEMBER SIEBER: I think your point is well taken. Our experience is the bulk of the work lies ahead of you at this point. You've made a lot of commitments to have things, but you don't have them yet. All that has to be generated and you have a limited amount of time to do that work. It takes manpower to do it. It has to be done right.

MR. DELLARIO: Right, and that's another reason is the decision was made to continue to run this part of the I'll say project as a project. Pete is going to stay involved as a project manager, driving the site to implement these commitments. So the project is not going to go away and just count on a program owner to make this happen. So there is going to be the continued oversight, the continued metrics are going to be in place, and the track and trend is that we're moving in the right direction.

MR. O'CONNOR: The key is transitioning into the normal way business is being done at the site, that people and employees understand how to do day-to-day business. So commitments are in a tracking system that is the same tracking system we use for all other types of commitments and business activities. We have system notebooks that these things are incorporated into, that the system engineers as part of their normal business maintain and watch through various types of plant health committees validate that the commitments that we have in front of us are being tracked and, in fact, being followed and implemented through our work management system. Work management system through the online process as well as the outage process.

And finally, one of the things that Nine Mile I think has learned is that we have to have a solid business plan. The business plan that we have going forward over the next five years has a specific section for license renewal that has tracking expectations, metrics for ensuring that the various items are getting done as well as having a line of sight for the financial commitments necessary to get that done. And I can assure you that the company has supported all of the financial requirements necessary to make those commitments get completed over the next couple of years, clearly in 2007 and 2009 being the two years we have outages that have to get done for these commitments.

MEMBER SIEBER: Constellation Energy owns and operates other nuclear plants like Calvert Cliffs. Is that correct?

MR. O'CONNOR: Yes, sir.

MEMBER SIEBER: And it seems to me Calvert Cliffs has as renewed license?

MR. O'CONNOR: I believe so.

MEMBER SIEBER: Is the Calvert Cliffs license renewal application, did that serve as a model for Nine Mile?

MR. DELLARIO: No, because license renewal has really evolved since the time we submitted that application. So the application themselves were totally different. I mean when that application was submitted, there was no GALL, there was no 95-10. These documents did not exist. So we couldn't use that as a model for Nine Mile.

MEMBER SIEBER: So I can sleep peacefully tonight this close to Calvert Cliffs?

MR. O'CONNOR: Yes, you can.

(Laughter.)

MR. O'CONNOR: Let's go to the next slide.

MR. DELLARIO: All right, so then the results of the project. We resubmitted the amended application in July. We addressed the NRC's identified quality concerns and we accelerated the transfer of license renewal knowledge to Nine Mile Point and that's when I was talking earlier about bringing the program owners in earlier. And the measure really of success for this project is having successful audits and inspections. And they were very successful throughout the fall of 2005.

Next, Pete Mazzaferro is going to discuss the Nine Mile Point operating history and license renewal commitments.

MR. MAZZAFERRO: Good morning. I'm Pete Mazzaferro, and I'm the project manager for the license renewal currently and in the future for implementation. What I want to discuss with you today is the operating history of items we have done in the past. I do address aging effects that have occurred, talk about some of the more recent plan improvement initiatives, and then also talk about implementing our commitments before we get into the period of extended operation.

On this slide you see a number of items

that we've implemented over the years that have resolved aging issues at the station. One item I do want to bring to your attention, the second item on the Nine Mile core shroud repairs. We have both tie rods and clamps at Unit 1 that are installed. Just recently we were the subject of a Part 21 on the tie rod and I'll tell you, we're aggressively working with the other licensees and GE to come up with a permanent fix for that and we'll be taking actions in the upcoming outage, which is in March of 2007 to resolve that issue.

In the next slide, talking particularly about the Nine Mile 1 containment. There's a current interest in the industry on the Mark 1 containments, in particular on the exterior surface of the shell, because that is normally inaccessible. There was a generic letter issued in the late '80s because of an issue at one of the other BWR Mark 1 containments. There were a number of actions that were taken at that point and when we took those actions, what we discovered is that we did not have any leakage that was in contact with the exterior surface of the containment. We confirmed that through remote visual inspections.

We actually went in with remote devices

and physically looked at both the top part, the upper elevations as well as at the bottom or what is called the sand cushion area. We actually have 10 four-inch drain lines that go from the sand cushion area into what we call a torus room, which is an open area that is accessible.

Again, using remote devices we looked up the drain lines, saw that there was not any indication of ever having water flowing through there. We were able to look at the top of the sand cushion area and that was also dry and no indications of any leakage ever occurring.

Since that time, every two years we go in and we do take a look at the sand at the exit point of those drain lines and have not discovered any indications of water at all.

Should that have occurred or if it occurs in the future, because this is an activity that we will continue to do, we would put that indication or that situation in our corrective action program, go through a root cause evaluation, an extended condition review, and take the appropriate actions to one, stop wherever the leak is coming from; and two, evaluate what is the effect on the outside surface of our containment shell.

CHAIRMAN WALLIS: Could you just clarify an item on the slide for me? The fourth little item under first bullet, remote visual observation of water. That doesn't mean that you observe water, does it? That means that you looked for water and didn't see any? The way it's written it looks as if you actually observed water leaking.

MR. MAZZAFERRO: As it turned out, in 1987 we did actually observe water --

CHAIRMAN WALLIS: Did observe water.

MR. MAZZAFERRO: That was leaking onto -- there's a shelf drain, which is designed to collect water and there was water there. What it turned out to be is we actually had a puncture from a maintenance activity in the cavity liner, which is normally not filled with water.

CHAIRMAN WALLIS: Somebody drilled a hole.

MR. MAZZAFERRO: Or hit it with something, yes. So we discovered that and we fixed that and there's been no water there ever since. But even that water, though, was collected on a shelf drain and drained away. That did not come in contact with the metal surfaces of the shell.

MEMBER SIEBER: Typically, if you get moisture there in other plants it would come through the refueling. Is that true?

MR. MAZZAFERRO: That's one source of leakage. Yes.

MEMBER SIEBER: A fix is to put it through the refuelant seal. Is that true?

MR. MAZZAFERRO: Our refuelant seal has always been in scope. We did that right from the beginning.

MEMBER SIEBER: So you already implemented the fix without having had the problem?

MR. MAZZAFERRO: Correct. Yes. The next slide, I talk about the core shroud cracking at Unit 1. As I mentioned earlier, we have installed tie rods back in 1995 to replace the horizontal welds. We also had some vertical weld cracking in two of the welds, and we installed the vertical clamps in 1999.

Following that, we've had our noble metals application in 2000 and instituted hydrogen water chemistry. And we continue to do our inspections of both the repairs and the shroud. So that's something we continue to do. We've been honoring that and as part of the inspection, we do the evaluation obviously to make sure that we're structurally sound and continue to meet our design requirements.

VICE CHAIRMAN SHACK: What will be your

end of life fluence on the shroud or any internal peak at the end of the 60 years?

MR. O'CONNOR: George?

MR. INCH: I guess Unit 1 and Unit 2. Unit 1, on the shroud. My name is George Inch. I'm with the Nine Mile Point engineering. The peak fluence on the unit shroud will be less than 10^{21} through the end of the license renewal term. It's getting close to the 10^{21}. Unit 2 will be less than three 10^{21}. We've exceeded the $3E^{20}$ threshold for both shrouds. So we're accounting for reduced fracture toughness on the Unit 2 shroud which doesn't currently have tie rods.

VICE CHAIRMAN SHACK: What are the top grids going to get to?

MR. INCH: The top guide grid?

VICE CHAIRMAN SHACK: Top guide.

MR. INCH: Those fluences are in -- depending, it's a high gradient. At the bottom of the grid, the fluence levels are in the 10^{22} range. That's neutrons per centimeter squared. And then there's a factor of five to ten shift, they're about a foot high in the fluence.

MEMBER ARMIJO: I have a question on your noble metals. That was first applied in 2000 and I think the concept was to reapply noble metals periodically.

Has Nine Mile done that at both plants. Both of your plants?

MR. O'CONNOR: Both plants are noble metal plants. We do have a reapplication coming up on Unit 1 in December of 2006 here.

MR. MAZZAFERRO: The next slide I'd like to talk about is the control rod drive stub tubes at Unit 1. We've had leakage experienced in the past. We applied for and received approval to institute a role repair through a safety evaluation back in 1987.

Since that time, and in the more recent past, there was actually a code case that's been submitted to the ASME code. That's undergone review. It's been approved through the Section 11 portion of the Committee. It's now at the full Committee for final review and approval. We would expect to get those results here in the next month or so.

During the period of extended operation, if a stub 2 that has been previously rolled leaks again, we'll institute one of three options here. We'll do a weld repair consistent with the BWRVIP-58A document, which has been endorsed by the NRC.

A variation of that weld repair should one become available, and that obviously would have to go through staff approval as well. Or because we're not sure exactly what will happen in the future, there could be another type of mechanical or weld and repair method, but that would also obviously have to go under staff review and approval.

But in any case, if the stub tube that had been rolled leaks again, we will effect a mechanical repair.

CHAIRMAN WALLIS: How do you detect a leakage?

MR. MAZZAFERRO: It's a visual indication that during our pressure tester in an outage, we can see water leaking from the bottom.

CHAIRMAN WALLIS: So you have to see water leaking?

MR. MAZZAFERRO: Yes, that's how we discovered all of them in the past.

CHAIRMAN WALLIS: What if it presumably leaked very slightly and evaporated and you wouldn't see it. So it has to be something which is enough to see it flowing?

MR. MAZZAFERRO: We conducted under hydro-pressure, which is 900 pounds pressure but the temperature is on the order of about 200 degrees.

CHAIRMAN WALLIS: Not like to evaporate.

MR. O'CONNOR: Not likely to evaporate. And obviously the inspectors are VT-2 qualified so we're not talking about personal activity.

CHAIRMAN WALLIS: Thinking more of leaky faucets. If they drip once an hour, I don't bother with them at all. If they drip continuously, then I maybe fix them. There is some threshold where you do something presumably. One drip an hour is that a leak?

MR. O'CONNOR: Yes.

CHAIRMAN WALLIS: It is. Okay. If a guy stands there for an hour and watches to see if there is a drip?

MEMBER SIEBER: You have to do it -- I presume you do that inspection? It's very difficult to see that joint.

MR. MAZZAFERRO: You're right.

MEMBER SIEBER: All these wires and things coming down.

CHAIRMAN WALLIS: So it's not so easy to see the leak then?

MEMBER SIEBER: No.

CHAIRMAN WALLIS: Okay.

MEMBER SIEBER: The repairs either because the surface has to be machine-welded, I presume.

MR. MAZZAFERRO: Right. This would be.

MEMBER SIEBER: That latitudinal position has a different curvature to it. You have to set up for that particular location because it's different from every other location except those in that circle. The whole thing is not an easy thing.

MR. O'CONNOR: No, as part of our license renewal funding, we're beginning the, I would say, the research and development process now to begin the various types of mechanical techniques and testing of those techniques well before we would reach the 2009 point in time where zero leakage is the expectation. But we'll be going through iterations of sort in order to prove that we can perform the activity and test the activity to the satisfaction and expectations required.

MEMBER SIEBER: I just don't want my colleagues to think that this is a simple thing.

MR. O'CONNOR: No.

MEMBER SIEBER: Not a simple thing.

MR. O'CONNOR: No.

MR. MAZZAFERRO: Okay, thank you. Moving onto the planned improvement initiatives. And this is just some examples of how Constellation is committed to an ongoing program of station improvement and especially in the area of aging management. As we've mentioned earlier, we have implemented hydrogen water chemistry and noble metals, and noble metals does require a reapplication and that's in our business plan to do.

CHAIRMAN WALLIS: What does this mean? Does it mean that now everything is much better or something? What's the implication?

MR. MAZZAFERRO: The vessel internals are in much better shape from an aging standpoint because of the noble metals application, hydrogen water chemistry from a cracked grill standpoint.

MR. O'CONNOR: George, do you want to add anything on noble metal, its impacts?

MR. INCH: We've got some excellent data on the effectiveness of noble metals on the subtuse. Pete or Mike, I have a slide that shows how effective noble metals appears to be.

As you noted in our presentation, noble metals was applied in 2000. Prior to 2000, we would see a new leaking stub tube once every refuel outage. We'd get one or two new leakers. And that's our history plot.

We did noble metals. It's marked there

with a black line. That one event in the refuel outage was actually only six months after the noble metal was applied. In the past outages, we've had zero new leakers.

It's been impressive to me that noble metals is an effective mitigation on new leaking stub tubes and we have aggressive plans to reapply. We're looking at all the new technologies for on-line and will be applied over the next two years at both units.

CHAIRMAN WALLIS: Is this something NRC expects to see in all of these Mark 1s and maybe the others that are up for license renewal? They must have no metal chemistry?

It's not required.

MR. INCH: I think hydrogen --

MEMBER ARMIJO: George, is it in the BWRVIP program or is it plant specific, plant management decides to do this or not do this, depending on their assessments?

MR. INCH: The BWRVIP program strongly recommends plants use mitigation techniques, hydrogen water chemistry or noble metals. There's a strong recommendation in the industry. And plants work out which technology works best for that plant. So noble metals -- like the best solution for Nine Mile.

MR. O'CONNOR: Noble metals, if you have a choice between the noble metal or increasing your hydrogen injection, hydrogen injection makes it almost very difficult to operate the plant with personnel because of the sources or the dose rates. So when you look at the balance, it's clearly the right decision to move towards noble metal and reduce your hydrogen injection.

MEMBER SIEBER: On the other hand, there are plants, BWRs who don't use noble metal right now.

MR. O'CONNOR: Right.

MEMBER SIEBER: So it's not a requirement. It's a recommendation.

MR. DENNING: George, I don't think you identified yourself.

MR. INCH: My name is George Inch. I'm with Nine Mile Point Design Engineer, BWRVIP program.

MR. MAZZAFERRO: Some of the other activities that we have on-going for Nine Mile Point Unit 1 in the spent-fuel pool, we're replacing all the boraflex racks with borelle racks. Again, that's because the boraflex racks are aging and losing their capabilities. We're replacing those.

MEMBER SIEBER: You're going to have a lot of radioactive waste in the replacement process, I presume.

MR. MAZZAFERRO: Yes.

CHAIRMAN WALLIS: How is your spent-fuel pool capacity for future? What does it look like?

MR. MAZZAFERRO: The capacity at both units is will run out in the near future. We do have plans to go to dry storage on site that will handle that. That will carry us through the period of extended operation.

MR. O'CONNOR: Those projects of both the rerack is funded and is started, those activities, and so has dry-cask storage. Both those efforts are completely funded to support implementation in the times --

CHAIRMAN WALLIS: The re-rack is not increasing the capacity of the pool.

MR. O'CONNOR: It's not.

CHAIRMAN WALLIS: It's just changing the method of avoiding criticality, that's all.

MR. O'CONNOR: It's to address the aging issue, but it does not increase capacity allowances for the pool.

MEMBER SIEBER: You're just overcoming aging?

MR. O'CONNOR: Yes.

MR. MAZZAFERRO: For both units in our closed cycle systems we will be implementing corrosion inhibitors in the near future. That is something that came out of our review for aging management and we have already replaced the reserve station transformers and the disconnect switches for Nine Mile Point Unit 1. Again, I bring that up because those are components that we take credit for recovery from a station blackout event.

Going forward and addressing our commitments, as mentioned earlier, the commitments we made in our application, we've put in our official tracking system which is called the Nuclear Commitment Tracking System. We have 56 related to license renewal; 43 of those are for Unit 1 and we will implement those over the next two years and then there's 41 that we have for Unit 2 and we'll take the lessons learned from ourselves, as well as the industry on those commitments and we'll implement those for Unit 2 right afterwards.

There's full support from both the site and the corporate management to meeting the commitments. As Tim mentioned earlier, we have full funding, full project support, full site support to implement those, all those commitments and one of the issues that we did foresee is this to make sure we have consistency in the transfer of knowledge from the project that submitted the application and work with the staff on that review to go forward to now implement that into our normal day-to-day process.

And that's, quite frankly, while I'm continuing to be the project manager. I'm the person that's going to make that transition happen and make that successful. We have a regional inspection that will occur in the summer of '08 and obviously, we'll be ready for that.

We continue to have oversight and support from plant management and corporate management through performance indicators' schedules because we want to make sure we're on track and that we're producing a quality product.

MR. O'CONNOR: We want to make sure that it's clear. These commitments aren't off by themselves. These commitments are fully integrated into our normal business processes so that there's no confusion about if an item comes up, it's in the work management system. It's expected to get done. It has commitments with it. It has expectations to do it. We do it. That's the way we do business.

And for an example, in our refueling

outages, since we do have a short amount of time, that you mentioned with Unit 1, we've actually made many of these items as mode restraints for start-up which forces us to make sure that we have addressed the issue and completed it before we can make the mode switch change for start-up. That's the rigor that we are applying to assure that we don't want to miss a commitment or two, find it easier to defer or move out to the future.

MEMBER ARMIJO: Does these particular commitments have any special tag on them that they are license renewal commitments?

MR. O'CONNOR: Yes, sir, they do.

MEMBER ARMIJO: When budget squeezes happen, you have a little bit extra information about that particular commitment?

MR. O'CONNOR: That's correct.

MEMBER ARMIJO: Give it a high priority?

MR. O'CONNOR: Yes.

MR. MAZZAFERRO: We've done that down to the individual work order as well, to put the license renewal tag on it, we call it.

MR. O'CONNOR: And it's part of our process for restart is to give us the assurance that the commitments that were expected. And again, it's part of a normal requirement we do for any start-up for outages, had we completed all of the regulatory or INPO commitments that we made prior to making the start-up. And so that's a rigorous process for us to validate.

MEMBER SIEBER: Let me clarify something. You're not actually committing to using noble metal chemistry as part of your license renewal commitments are you?

MR. O'CONNOR: We're going to do it regardless.

MEMBER SIEBER: No, but I mean --

MR. O'CONNOR: It's a mitigating strategy.

MEMBER SIEBER: We used to follow the water chemistry guidelines.

MR. O'CONNOR: Yes, that's the commitment. That's the commitment. The commitment is to follow the BWR owner's recommendations. That's correct. We believe at Nine Mile that the most prudent approach to mitigating strategy is the noble metal side of the equation.

We are committed to that as our form of implementation.

So from a summary perspective, although we may have had a little bit of a shaky start, we certainly had a great deal of lessons learned. We believe we've appropriately recovered from that and applied those lessons learned. Our commitments are tracked. They're funded. We do have a line of sight for those to assure that they get done in the business plan.

Our programs are in place for effectively managing aging issues. We do have the correct metrics and oversight expectations to assure that we follow through on the items that we've committed. And I can tell you that the ownership rests with me. I am the one responsible for assuring that these activities and these processes that we're presenting in front of you are part of the normal business that Nine Mile operates to and our only commitment is that we operate at a standard of excellence and nothing less than that. That's the way we'll continue to move forward.

That concludes our presentation. Thank you.

MEMBER POWERS: Can I just ask about the downcomer bellows? On your downcomers coming in, do your torus on your Mark 1 containment, are they in the scope of the license renewal?

MR. MAZZAFERRO: I'm not sure -- please repeat your question. I think I'd say yes, but go ahead.

MEMBER POWERS: I can't imagine them not being. The bellow connections, we have a big tube coming in through another tube in the torus and what not?

MR. MAZZAFERRO: Yes.

MEMBER POWERS: Do they show any corrosion?

MR. MAZZAFERRO: I don't believe --

MR. O'CONNOR: George, do you have anything specific on the ISI or other inspections on --

MR. INCH: My name is George Inch. Could I try and repeat back your question to make sure I understand it?

We had the vent system in the Mark 1 system and it goes through some vent spheres with a header and then there are individual downcomers on a centipede, if you will.

MEMBER POWERS: Those downcomers come out of the dry well into the torus, you'll have a bellows connection on them?

MR. INCH: They're flat.

MR. O'CONNOR: Okay.

MEMBER POWERS: So the question is do they corrode or fatigue?

MR. O'CONNOR: I believe that's in our program, but I would need to check to make sure that --

MEMBER POWERS: If you happen to find out, I'd be curious.

CHAIRMAN WALLIS: They might fatigue if they're used.

MEMBER POWERS: They flex all the time. Every time the plant comes up or warms up and cools down, they have to flex all the time and when I looked at them years ago at Brown's Ferry 1, they corrode and they're different for every plant. There are no two the same. And Nine Mile Point has particularly unique ones.

CHAIRMAN WALLIS: They've been there a long time.

MEMBER POWERS: It's a different power plant from Brown's Ferry and built by different guys, built at a different time. It's just always different, so I was just curious.

It has some importance in risk analyses because if they blow out, then you bypass the torus water.

MEMBER SIEBER: Any other questions? If

not, thank you very much.

(Telephone ringing.)

MR. MODUS: Good morning.

MEMBER SIEBER: Mike, this is your phone call for the presentation for Nine Mile.

MR. MODUS: What do you mean this is my phone call?

MEMBER SIEBER: Tommy Le told me you were going to participate in this.

MR. MODUS: No, I am not participating. I am standing by in case ACRS has questions.

MR. ZIMMERMAN: Hey, Mike, this is Jake Zimmerman.

MR. MODUS: Hi, Jake.

MR. ZIMMERMAN: We tied you in via phone to the ACRS room. Tommy's coming up to the mic now to give the presentation and so yes, we do have you available to answer any questions relative to the Region 1 inspections that were conducted at Nine Mile.

CHAIRMAN WALLIS: Who is it that we have on the phone?

MR. ZIMMERMAN: We have Michael Modus who is the Region 1 Team Leader for the inspections that were conducted at Nine Mile.

But yes, Michael, Tommy will be leading

the entire discussion. Okay?

With that, I'll turn it over to Tommy Le, our Senior Project Manager for the Nine Mile Point license renewal application review and also with him again is Mr. Robert Hsu, who is the assistant team leader for our Aging Management Program audit activities.

MR. LE: Thank you, Jake. My name is Tommy Le. I am the NRR Project Manager for the staff review of the Nine Mile Point license renewal application. I have the honor to represent the staff this morning to be before you to discuss and brief you the result of the staff review of the license application for Nine Mile Point Nuclear Power Station Unit 1 and Unit 2.

As Chairman Sieber said, the final SER is bulky and this is a result of the great effort from the NRR staff who are with me here today to support me to answer all your questions. And their dedication and continued review despite the up and down of the application are hereby appreciated. I also want to extend from the staff to the Applicant and management and their staff who have responded to the staff during the review period and their cordiality and cooperation during our visit and our questioning.

With that, I'd like to go to the next slide, please.

I also, by the way, have Michael Modus on the line to answer any question as well.

I would like to walk through the four areas, the overview of the staff, the process and the highlights of the review and also the TLAA and then the final conclusion of the entire staff.

Again, I am a project manager and I rely on my staff and all the work they do and I count on their effort. I thank you again.

The Applicant submitted the application on May 26, '04 and as you are aware, Unit 1 is Mark 1 GE 2 and Unit 2 is Mark 2 GE 5. I believe that at the time that the application was submitted, this is the first time it had been submitted to the staff.

Again, the reason for the bulkiness of the review is because the two units had different designs. They have different BOP and so this is two reviews in one. And I think the Applicant got a good price for it.

MEMBER SIEBER: In spite of the fact that the units are quite different, you're applying the same aging management programs. And that's for the simplicity that evolves from that from the standpoint of the licensee's administration of the program.

MR. LE: Yes. Some of the aging management are different for different units.

I forgot to note that most of the Applicant's personnel here have been promoted since the review of Nine Mile.

(Laughter.)

Again, the Unit 1 operating license is going to expire on August 22 of 2009 and Unit 2 operating license will expire in October 31 of 2026. And Unit 2 did come in with an exemption request to allow them to renew the license before the operating license expires in 20 years as required by regulation.

The staff review has provided an SER with open items that were issued on March 5, 2006 and we went to Chairman Sieber's subcommittee in April. The overall status of the SER is that we have 56 commitments from the Applicant of which Unit 1 has 16; Unit 2 has 14 plant-specific and common, 26 for both units.

The implementation, Mr. Tim O'Connor said will be implemented two years prior to the period of standard operation for each unit.

Currently, at this time, there are no open items, no confirmatory items and three license conditions. The three license conditions are -- next page, please -- standard license condition that you all have seen in the previous license review.

In the next slide, I would like to walk through the way that the staff has spent time on this application. You noted that in September of '04 we did the scoping and screening audit and then for the AMP and AMR audit, we performed a total of six audits which normally requires about two audits for the plant. And the reason for this led to the 90-day stand-down that the Applicant has requested to fix the quality and completeness.

Again, the regional inspection also in effect performed four inspections; three prior to the amended application after that. So both the region and NRR staff have spent more effort on the review.

In the next slide, the reason for the stand-down of 90 days is because during the scoping the NRR staff felt that the 54.482 review has some loopholes in it. For instance, the staff did not see any plant insulation included and then during the audit, as the Applicant pointed out, the Applicant had a lack of technical support in responding to the staff audit and sometimes the question lingering on and the supplemental reply, sometime is inconsistent with the response we receive, not because of any changes but the way the document.

So we as a staff, we convey this to the Constellation Nine Mile Point management and to the staff concern the management has voluntarily come in and requested a 90-day to revamp the quality and resubmit the amendment on July 14 of '05.

In this new application, we call -- the OGC asked me to call it an amended application, but it's almost -- had a lot of new information. They have 40 new systems were added and about three previously included in the system were removed and not because of any safety significance, but the way the scoping previously.

And the staff identified that the license renewal drawing submitted regionally were not well prepared and so in the resubmittal the set of drawings were up to date and very clearly identified of the SSC within the scope of license renewal and also a full detail on AMR and that has helped the staff to expedite the review in a timely manner.

Even though we have a 90-day or equivalent of five-month calendar year, the staff are still within the limit of the review of 22 months.

Next slide, please.

MEMBER SIEBER: I would point out that all these problems did cause the staff to do an extraordinary amount of work to finish their review.

MR. LE: Thank you for staff. They told me they had a tough project manager.

(Laughter.)

MEMBER SIEBER: I believe that.

MR. LE: Thank you. Dr. Denning and I graduated from University of Tennessee, so I'm glad you're here to protect me.

(Laughter.)

In the highlight of the review, I would like to say that in the new submittal there are six new items added and the staff also counted 24 new commitments in addition to the original commitment that came in with the previous application.

For instance, the staff has brought in, in the scope of the CO2 and the Halon system, the firewrap insulation that we do in fire protection. The staff formally requests that the Applicant would implement a zero leak permanent repair for the Unit 1 control rot dry stub tube penetration.

CHAIRMAN WALLIS: Can you say a bit more about that? These were leaking, two penetrations which they had to fix?

MR. LE: Yes.

CHAIRMAN WALLIS: How many penetrations were leaking?

MR. LE: Offhand, George, do you have any -- 38.

CHAIRMAN WALLIS: Thirty-eight were leaking?

MR. LE: Yes, 38. Thirty-eight total, right? I'm not sure how many -- George, can you --

MR. INCH: This is stub tube locations. Thirty-three locations, 33 or 34 locations. I'll have to check that.

CHAIRMAN WALLIS: They weren't leaking very much?

MR. INCH: Well, the leakage has been over time. When it was first discovered in 1984, there was like 11 locations. The leakage rates varied from 10 or 20 jobs per minute to somewhere several hundred jobs per minute. Most of the leaking penetrations have been measured in drops per minute.

CHAIRMAN WALLIS: Just like maple syrup, maple sap. I understand that.

Well, that's quite a lot, 100 drops a minute.

MR. INCH: The last leaking location was

repaired in our last outage. It was location 5019 which was a repeat leaking location and it was identified at approximately 20 drops per minute.

CHAIRMAN WALLIS: It required license renewal to implement what should be done anyway.

MR. INCH: We have implemented the repair at all these locations.

CHAIRMAN WALLIS: Yes, but it seemed as if it was instigated by license renewal.

MR. INCH: No.

CHAIRMAN WALLIS: It seems like the staff claimed to have required it as a result of --

MR. LE: We talked about it a lot during the audit and we had in the Applicant's presentation they had come up with three different ways to make sure that there was zero leakage. So that's why I used the word, but then --

MEMBER MAYNARD: As I understand from the Applicant's presentation, they haven't seen any leaks for several years now. This commitment to do the zero leak repair is if they do identify that leak in the future.

MR. LE: If the leak reappears, yes, sir.

MEMBER MAYNARD: But there's not a commitment to go back --

CHAIRMAN WALLIS: They have had these 30 somewhat leaks that were in the past. I got the impression from your statement here that these leakers were actually leaking and you required them to fix them as a condition of license renewal. That's not the case.

MR. LE: It's one of the commitments. The Applicant has committed to the staff.

MR. DAVIS: I'm Jim Davis from the staff. These were all repairs that were done under a relief request and the Rule 5055a says you cannot rely on a relief request for the period of extended operation.

So that's why they have to make this commitment.

MR. LE: Thank you, George.

MEMBER SIEBER: The rerolling on these stub tubes, when it leaks, it's probably cutting. Rerolling it, you're trying to put plastic deformation in there to fill that gap. The question is will it be successful or not. That's why the weld repair is a better deal for getting to it.

CHAIRMAN WALLIS: I'm not really worried about it. I'm just concerned about the number of these and the timing. This was way back in the past, they had these many leakers and they were fixed.

MR. CHANG: The same is true of SER in 1987. They used the same request for the whole period.

CHAIRMAN WALLIS: So the problem essentially has been solved, is that really your view?

MR. CHANG: The problem has not really been solved. They just keep using the same relief request and to do their repair.

MEMBER ARMIJO: Let me make sure. I thought I Understood this, but now I don't. They've been repaired by this rolling program. And if that rolling continues to be effective and they don't leak, does this commitment require them to weld them anyway? If they do leak, they can't be just rerolled over and over again. Then they have to go to a different -- okay.

MR. CHANG: Because a regional SER at the moment they don't have the technology to do that with a repair. So we give them the relief.

MEMBER ARMIJO: But the relief, as long as it's working, that relief is still valid. They don't have to then say okay, the relief runs out of time and now you have to go to the new technology.

MR. DAVIS: This is Jim Davis again from the staff. A relief request cannot extend past the current interval, so if we approve this for the period of extended operation, we're free of approving a relief.

So they have to commit to do a code repair and then when they get into the next interval they can come in and either the code N730, can be used if it's endorsed by the NRC in Reg. Guide 1.47, 1.147 or they can come in for relief again, but we can't pre-approve relief.

MEMBER SIEBER: On the other hand, if it doesn't leak, you don't have to repair it.

MR. DAVIS: They have to either get relief or they have to follow a code. This is not a code repair at this time. Code N730 allows them to -- they do a 4 percent roll the first time. And if that stops the leakage, then they don't have to do anything. If they see leakage again, they're allowed to reroll to six percent. If that stops the leakage, then they're okay. If that doesn't work, then they have to do the code repair.

MEMBER SIEBER: On the other hand, the original manufacturing was rolling.

MR. DAVIS: No. These are stress corrosion cracks.

And instead of doing a code repair, they did a 4 percent roll. They did some experimental work to see what they need to stop the leakage. In the original relief request, they were allowed a certain amount of leakage and then when they did the reroll, they were allowed 10 times the amount of leakage and the ASME code that I was a member of when we worked on this code case, we refused to allow the -- we only allowed zero leakage.

MEMBER SIEBER: Thank you.

MR. LE: To go on with this slide, the other item that the staff has brought in to the scope of Unit 1, non-EQ inaccessible medium voltage cable, for some reason it was left out and -- but the most important thing is the staff requires visual examination of Unit 1 drywell shell as a data point to collect and for turning prior to entering the PO operation, to go along with a newly added AM to monitor the corrosion in the drywell shell that we'll be discussing the open item that we will come up next.

In the next slide, I will not -- I will provide some examples of the staff enhancement requirement and for the sake of time, I will go down to the next slide to talk about open item 3.03217-1.

During the original staff SER, we had two open items and during the staff discussion with

Chairman Sieber, the subcommittee chairman, we said that the -- I'm sorry, Dr. Sieber.

MEMBER SIEBER: That's all right.

(Laughter.)

MR. LE: I just want to see if he's awake. Anyway, I apologize for that.

The dry shell after the audit was done, the staff also re-reviewed the information and discovered that the Applicant had reported that in 2003 there were six corrosion spots that were found during the refueling outage and so the staff opened this as an item until we know what the Applicant are going to do with that to prevent future corrosion.

On March 27, '06, they came in and had a very good conversation with the staff about what they're going to do and that the corrosion was not as profound as was reported. It was just a deep rusty spot. And so this will be discussed in detail at the last slide.

In the next one, our next slide, I did want to put on here that during the aging management of the in-scope inaccessible concrete the staff review noted the following value that we do on most of the license renewal with the PA,the chloride and the sulfate.

We have a note there that no phosphate or phosphoric acid tests have been performed because this is below-grade environment is very nonagressive.

That ends the highlights of the review. Now I would like to come in in the next slide on TLLA. This is that there are seven areas of TLLA. The first four, the staff had reviewed them and among them are metal fatigue that the Applicant committed to implementing the FatiguePro monitoring software to make sure that it would stay that way.

For the containment liner and -- next slide -- penetration fatigue analysis, the Applicant had projected and the staff concurred and confirmed that the fatigue uses would remain in acceptable limit within the period of standard operation and the Applicant will monitor the critical Nine Mile 1 and Nine Mile 2 location using the fatigue monitoring program to provide additional assurance.

Next slide. In the 4.7, this is the other plant-specific TLLA. During the staff discussion with Subcommittee Chairman Sieber we had closed out this open item and namely this is the calculation for TLLA was dependent on a non-NRC approved method and so we identified that an open item and the Applicant went back and did the recalculation and resubmit the data on January and March '06 and the report was at the value was less than one, 10^{17} neutron per centimeter square.

CHAIRMAN WALLIS: That's at the end of the new licensing period or what's that? What time is that at?

MR. MEDOFF: This is Jim Medoff with the staff. I was the reviewer for the bioshell TLLA. Basically, they had found a number of flaws in the bioshield. Some of them they repaired, but there were a few flaws in the bioshield that they left in service under fracture mechanics evaluation.

Fracture mechanics evaluation was based on fluence, so that was a time-limited parameter in the evaluation and they -- it's a carbon steel material, so for embrittlement, the threshold for irradiation and britleness it 1 times 10^{17} neutrons per square centimeters and square energies greater than 1 MEV. When they reevaluated the fluence to see whether they had to redo their fracture mechanics evaluation. They used an unapproved methodology.

So we had Dr. Lambrose Lois, our fluence expert, request in an open item that they submit a fluence methodology for the bio-shield in accordance with I think it's Reg. Guide 1.160. We concluded that if they can demonstrate that the fluence for the bio-shield at 60 years was less than the threshold, we would agree that it was no longer a TLLA and they could remove it from the application.

And they submitted a fluence methodology in accordance with the Reg. Guide and we had Dr. Lambrose Lois look at it and he approved their fluence methodology and the value is less than the threshold, so we agreed that there wouldn't have to be a tail line anymore.

MR. LE: Just to complete the picture of TLLA during the briefing with Chairman Sieber, the Applicant -- since then the Applicant has submitted another TLLA on a reactor water cleanup system LLA.

CHAIRMAN WALLIS: What is Chairman Sieber doing all this time? He seems to be participating in the license reviews. The subcommittee meeting. Okay, all right.

MEMBER SIEBER: I work hard, too.

CHAIRMAN WALLIS: The subcommittee meeting. Right.

MR. LE: He is here to protect me like Dr. Denning. As we discussed before on the reactor vessel, neutron embrittlement the staff independently verified the upper share energy value for both Unit 1 and Unit 2. And the staff are so independent that so Nine Mile Point 61 EFPY additional probability for the reactor vessel circumferential well abounded by the NRC analysis.

And the staff also independently verified that an analysis of the conditional failure probability of Unit 1 and Unit 2 reactor vessel actual weld. He also bound it by the NRC analysis in the staff March 7 of 2000 supplement SER.

With that I would like to conclude that the TLLA provided by the Applicant adequately met the regulation 54.3 and also 54.21(c)(1)(i), (ii), and (iii) and will be valid for the period of the standard operation and projected through the end of period of operation and aging effect will also be managed.

Also 54.21(b), sufficient supplement of the SER will be done and 54.21(c)(2), there will be no plant specific exemption.

And with that and with the concurrent -- with the staff in front of you, the Nine Mile Point Unit 1 and Unit 2 amended application had met the requirement of the regulation CFR part 54 in the scoping and screening and aging management review and program and also in TLAA. With that the staff finishes the presentation.

MEMBER SIEBER: Thank you. Are there any questions from ACRS members? If there are no questions, I would again like to thank the Applicant and the staff. A lot of work has been done on this particular application. The work was well done and I appreciate that very much.

With that, Mr. Chairman, I turn the meeting back to you.

CHAIRMAN WALLIS: It just occurs to me that you should say that these are all the requirements of the 10 CFR Part 54. Is that right?

MR. LE: Yes.

CHAIRMAN WALLIS: You listed three and I think to make it clear for the record that you have concluded that the application meets all of the requirements for license renewal?

MR. LE: That's true.

CHAIRMAN WALLIS: Thank you.

MR. LE: Dr. Sieber had that conclusion back in the subcommittee.

CHAIRMAN WALLIS: Thank you very much and you have done a good job. Finished on time.

MR. LE: Thank you.

CHAIRMAN WALLIS: We having finished this item we will take a break until 10:15.

(Off the record.)

CHAIRMAN WALLIS: The next item on the agenda is "Results of the Study to Determine the Need for Establishing Limits for Phosphate Ion Concentration." My colleague Dana Powers is going to lead us through this item.

MEMBER POWERS: The members will recall that when we were first venturing into the area of license extension and renewal that the issue of what to do about concrete structures came up, and the staff posed to us some considerations they had.

Among those considerations was what is the nature of the groundwater that came around these plants because we know some groundwaters are aggressive toward structural concrete. Things like sulfate certainly has a reputation for decrepitating concrete, and chlorides got Peter Fordbury agitated because they will attack on mild steel, carbon steel structural reinforcing material.

And staff had limits on those particular ions in solution. The limits were cast in the form of when you get above these things, then go look at the concrete. If you're below that, you're probably okay.

Well, the question that promptly comes up is is that all there is. I mean there are a lot of ions in normal groundwater, and so I posed the question, well, what about phosphate ions. Had we had more nuclear power plants in the western United States, I would have asked about arsenate ions, but since we don't have a lot of them in the West where we have lots of arsenic in the water, I asked about phosphate because in the East there are places where you can get a substantial amount of phosphate ion in the water both naturally and from agricultural.

It's interesting where people have looked up till now. I don't think any of the license renewal plants have detected any significant amount of phosphate, but most of them don't look very hard.

The question came up: what about phosphate ion? And I naively assumed that somebody probably looked at this and saw what concrete did in a phosphate ion solution, but apparently not. So staff undertook an investigation on that, and I guess, Herman, you're going to discuss the results on this for us.

So I'll turn it to you and let you go with it.

MR. GRAVES: Okay. Thank you, Dr. Powers.

My name is Herman Graves. I'm with the Office of Research, as you can see from this slide, the Division of Fuels, Engineering, Radiology Research.

So with me I have Dr. Dan Naus to my right from Oak Ridge National Lab and also Dr. Les Dole, who is sitting to the left at the platform over there.

We also have members from Nuclear Reactor Regulations. Rebecca Karas in the Division of Engineering, David Jane and Sujit Sumanda on staff. We also have Dr. Jim Davis from the License Renewal staff.

So as Dr. Powers stated, we're here to brief the Committee on research that was done to determine the effective phosphate ion on concrete, and that's phosphate ion concentrations that may be necessary to cause these conversations to hydroxyapatite.

Our objective for the briefing is to characterize the significant factors that may lead to the staff establishing phosphate limits for groundwater and soil conditions.

The research received user need memo from NRR December 12th, 2003. In that user need memo, we were requested to conduct some research to determine what conditions phosphate concentrations may call degradation in the concrete, and to come up with some data and a basis document for establishing limits for the staff.

The background for that user need memo was June 24th, 2003 letter from the ACRS to the Chairman, former Chairman Diaz, where the staff was asked to consider whether similar limits that we had in the generic aging lessons learned document, Guidance for Phosphate Concentrations. The next slide shows those limits that we apparently have in the GALL.

We have what we term as inaccessible areas where we cannot perform the inspections, where we have imbedded parts of the containment structure or other structures, concrete structures that are below grade, are not really accessible.

What licensees normally do is they monitor the ground water for concentrations of pH that may be quite acidic because we know that acids have very harmful effects on the concrete.

The staff established some severe environmental limits by looking at chlorides greater than 500 parts per million and sulfates greater than 1,500 parts per million.

MEMBER KRESS: Excuse me. Is there a basis for the sulfates in the sense that they've seen concrete degradation in those kinds of levels of sulfates?

MR. GRAVES: Yes. The basis, I have two references listed at the bottom of the slide. The staff follows the American Concrete Institute Building Code 318, which is the general building code for commercial structures.

We have a Code 349 and 359, which are the nuclear structures, where they're pretty much based on the ACI-318 code. In the 318 code, they have limits for sulfates and also for chlorides because research has shown over time that chlorides can corrode the reinforcement in the concrete, and also if you have sulfates at certain concentrations, that they can cause concrete degradation.

MEMBER KRESS: Is it empirical evidence or supposition? They've actually seen concrete degradation?

MR. GRAVES: Actually, this results in a lot of concrete structures over time. It also is based on laboratory tests. ACI also has ACI-201.2(r) which is a guide to durable concrete where these limits appear. They talk about other things besides the limits that we have here, but primarily what we try to do is to make the concrete impermeable. We look at the water submit ratios and that kind of thing.

But in addition to establishing a durable concrete, we look at limits for chlorides, sulfates and the pH.

MR. BANERJEE: What happens to the concrete if it's exposed to this water?

MR. GRAVES: What happens to the concrete? It could lead to expansions of the concrete elements, very small, minute cracking. Once you get the cracking, you may have some water egress, and you get popouts of the concrete. So when you get cracking, it could lead to some kind of structural degradation.

MR. BANERJEE: So does this depend on the thickness of the concrete or it's independent of that?

MR. GRAVES: For chlorides, the thickness is important. We recommend certain cover distances or thicknesses for reinforcement to help protect that from degradation. So thickness is part of the equation also.

MR. BANERJEE: Do you feel a very thick piece of concrete then, it's just the surface layers that crack?

MR. GRAVES: Possibly, yes. Those that are exposed to the acids or sulfates.

MEMBER BONACA: So in the construction, do they use different cement mixes or different kinds of cements in order to deal with these conditions?

MR. GRAVES: Yes, that's correct. If they know that the structure is going to be in a harsh environment, then they specify certain cement mix, a different type of Portland cement. There are various types of Portland cement, and for example, if you're going to use it in a marine environment, you may be exposed to salt water conditions. You may specify a certain type of concrete mix, but also you may put add mixtures, what we determine, add mixtures in the concrete mix to help protect it from salts and that sort of thing.

MEMBER BONACA: So in the license renewal, we should look not only at how aggressive the water is, but also whether or not these precautions were taken during construction.

I mean, I'm not sure that early plants --

MR. GRAVES: Yes. During construction I put the reference there for 318, but in 318 and in 349 we have quality assurance guidelines for determining the quality of the concrete during the construction of the structure. So that --

MEMBER BONACA: Has this guideline been in place from even including the early plants where there was no quality assurance?

MR. GRAVES: Yes, pretty much. Before we had a nuclear structure code, the early plants followed ACI-318.

MEMBER BONACA: Okay, fine.

MR. JENG: Dr. Bonaca, this is David Jeng of the Division of Engineering.

In regard to the guidance decides this limit, we do require involved. For instance, water ratio .45 and the strength, they are about 3,500 pounds for these and other considerations which enforces part of the requirements in the ballpark.

MEMBER POWERS: Dr. Kress, coming back to your question on why, I'll remind you that if you assume the precipitation of gypsum is the cause of the sulfate problem of concrete and you do a calculation, where you would get that precipitation of sulfate, it's in this range, 750 to 1,500 parts per million and the water would be sufficient to precipitate gypsum.

There are sulfates that could precipitate, but gypsum is just as good a one, and the problem is gypsum is just bigger than what it was made from. So it expands and it creates this cracking Mr. Graves spoke of, and it progresses. As you crack and spall the concrete, then you expose more, and that cracks and spalls and just walks right through the structure when you're talking about time scales of decades. And we are for license renewal.

MEMBER KRESS: Is that a process that's controlled by the kinetics of this reaction?

MEMBER POWERS: It must surely have a kinetic component in it. Clearly, there's a mass transport component in it. Whether there is a crystallization component to it or not --

MEMBER KRESS: So the reaction takes place in the solid concrete itself.

MEMBER POWERS: Well, it probably takes place in the pour liquid.

MEMBER KRESS: Pour liquid?

MEMBER POWERS: Where you're getting a little bit of dissolution of the calcium salt.

MEMBER KRESS: So it comes out of the concrete.

MEMBER POWERS: And the sulfate reacts and then it goes back on the surface, and whether it self-passivates or not, we've got experts here from that famous institution of higher learning and outstanding science near you, I think, isn't it?

MEMBER KRESS: Somewhere close by. I was assuming that if cracking and decrepitation took place that the reaction was in the solid phase.

MEMBER POWERS: You're basically taking one solid and replacing it with another solid. How it exactly progresses I guess I'll defer to the experts.

MR. GRAVES: Okay. I think Dan may talk a little bit more about that as we get to the second part of the presentation.

The attendant regulatory use of this information is to help the staff in their assessments of license renewal applications, particularly conditions that may be exposed to the phosphate ion concentrations that cause degradation.

Our status right now, we have performed testing for 12 months on some concrete samples exposed to phosphate ions that Dan Naus is going to talk about. Analysis has been completed.

Now, we do have some samples remaining that we plan to test at 18 months also. Dr. Power has asked to prepare a primer report. We have a draft report available that we're going to leave with the Committee at the conclusion of this meeting. And we hope to publish a final NUREG report by fall of 2006.

That completes my remarks, and --

CHAIRMAN WALLIS: Could I go back to your page 3, your objectives? One of your objectives is to get through 50 slides in an hour and a half, and also the background you said was the staff should consider whether similar limits are needed. I think all we're going to hear about today is contractor reports on the science, but there's no evaluation of what this means from the staff? We're not going to hear anything from the staff about what this means to them?

MR. GRAVES: Well, we were asked to do research, and we think it's important that we present the results of that research.

CHAIRMAN WALLIS: Is it useful for making a decision?

MR. GRAVES: We think it will be, yes.

CHAIRMAN WALLIS: You think it will be?

MR. GRAVES: Yes. I'm certain that it will be.

CHAIRMAN WALLIS: Hope.

MR. GRAVES: No, I'm certain that it will be. Before we can establish limits, we need data, and what we have, we have test data from concrete data. We also performed a literature survey, a very extensive survey. We talked to the experts, concrete experts, in the U.S.

CHAIRMAN WALLIS: Maybe if we have time at the end someone from the staff can give an evaluation of whether this is adequate for their needs.

MR. GRAVES: Okay.

CHAIRMAN WALLIS: Thank you.

MR. BANERJEE: Is this sort of to supplement the ACI guidance? Because you've cited to ACI documents, right?

MR. GRAVES: Yes, the staff guidance in the GALL is based primarily on the ACI guidance.

MR. BANERJEE: So this is to improve on the ACI guidance.

MEMBER POWERS: I think it's fair to say one of the things that the Committee was concerned about when we renewed this, that the staff was in a position of taking the ACI guidance and saying, "Well, here's the number. I don't know where it came from. Here's the number."

And of course, that poses a problem because in each application, you know, that's not all that's in the water, and having some technological understanding of why that number is important seemed to me, seemed to the Committee to exist, and that's what we wrote in our letter.

But you need to understand why those numbers are there and how you apply them rather than just using a number because somebody said to use that number.

MR. BANERJEE: It's to improve the science basis for a decision.

MR. GRAVES: Yes, yes. We investigated numerous reports. We looked for reports where phosphate was cited to be a problem. We tried to determine that, and based on a lack of that information we designed an experiment to come up with some test data so as to enhance the guidance in ACI and to establish staff criteria.

MEMBER ARMIJO: One possible conclusion out of all of this work from the staff could be there's no need for limits for regulation in this area. I mean, it could be, yes, there is something needed and here is a proposed, and there's possibly none.

MR. GRAVES: Certainly, yes, that could be possible.

Okay. Let's move to the next presentation.

DR. NAUS: Okay. Thanks, Herman.

What I'd like to do is provide you with an overview of what we've done to date to try to establish the background on whether we need to set limits for phosphate ions in concrete such as you have for chlorides and sulfates.

And also, I'd like to acknowledge Catherine Maddis, who is a very important part of our investigation. She is the one doing the experimental studies.

Basically what I try to get through here this morning is nine topics here. I won't go through them n ow. Some of them I can skip over in the beginning fairly quickly because Herman has already addressed them.

First of all, we know that, as you've been discussing, Portland cement concrete as located in soils can be susceptible to chemical attack. A good example of this is the sulfate attack we've talked about where the sulfate ions basically attack the tricalcium aluminates that expand. They can disrupt the concrete. An example of this is shown in a 30 year old bridge substructure. This happened to be from the U.K.

Other forms of attack that concrete can see, acid attack. The pH gets below about four and a half. It's very severe to the concrete. There's several salts which can attack concrete. The importance of the chloride ions, of course, is it can depassivate the steel and cause corrosion of the steel reinforcements and get iron oxide which can increase in volume up to about six times or so, and this can crack and spall your concrete.

Also, there are organic compounds that can react with the calcium hydroxide and also you can have aggressive waters.

Just a couple of examples, pictures here of what can happen to concrete under the action of chlorides. You get corrosion of steel reinforcement. You can see what happens in the effect of sulfates. You get expansion that can lead to cracking and just general disruption of the concrete materials.

And as Herman said, ACI-318 and others have set limits for chloride contents depending on the type of member. Also there are a series of sulfate exposures which have been identified, and the way they address this, as was noted, you utilize a maximum water-cement ratio. There are specific sulfate resistant Type 5 cements that are utilized. You incorporate mineral add mixtures, fly ash, silica fume, and so forth.

Les has done some thermodynamic calculations here, and basically Dr. Powers in his white paper found that phosphate concentration as necessary for apatite formation is relatively low.

Les has run through some calculations using the database shown at the bottom of the viewgraph here on the left, and basically found that under the action of phosphates you can get volume changes in the ordinary Portland cementitious materials, and these volume changes are on the order of about 3.87 percent, I believe is what he calculated. Whereas if you look at an ordinary Portland cement, not in the presence of phosphates, it's on the order of four percent. So expansion is a little less than what is experienced normally, but it does support that phosphate can replace the calcium hydroxide in the cementitious materials.

Also, he looked at the equilibrium phases for an ordinary Portland cement concrete that is inundated with phosphate ions. The various phases here that can develop are shown, are color coded there. The phosphate phases are shown. It's a dark brown or probably looks almost black there, and the calcium hydroxide phases are shown in red.

But basically, the bottom line here is that in the ordinary Portland cement system, the formation of calcium hydroxyapatite is capable of replacing the 3-calcium and successfully competes for calcium in the aluminosilicate measures.

MR. BANERJEE: Is that purely equilibrium thermodynamics you're doing at some temperature?

DR. DOLE: Yes, yes.

MR. BANERJEE: What temperature? Room temperature?

DR. DOLE: I think that's approximately room temperature, yes.

DR. NAUS: Herman went over the objective here. Basically we're trying to understand the factors that may lead to establishment of limits, and then if limits need to be established, we want to provide recommendations that can be utilized to help establish meaningful limits for phosphate ion contents.

So the basic approach we followed here was to review the literature and available industry standards. We contacted a number of cognizant concrete research personnel and organizations both in the U.S. and Europe. We conducted a somewhat limited laboratory study. We hope to obtain and evaluate some concrete samples from a structure located in Florida that's in a high phosphate environment.

And as Herman noted, we prepared a report on factors that affect the durability of nuclear power plant concrete structures.

So basic deliverables under this program were an interim report on the assessment of potential phosphate ion-concrete interactions that was provided last August. The 12-month results of the laboratory investigation was provided this April. The report on durability and nuclear power plant concrete structures was provided to NRC last month, and the final report for this program is due later in this calendar year.

We conducted a literature review trying to identify instances where phosphate ion and concrete interactions were studied. There is a Navy report that identified phosphate compounds contained as an antioxidant in engine oil as a source of the concrete parking apron spalling. The cause here was attributed to phosphoric acid being in the fluid.

Phosphate compounds have been used as set retarders in concrete mixes. They've also been used as inhibitors for corrosion of steel reinforcement, and phosphate has been shown to reduce the expansion that results from alkali aggregate reactions.

Also, there's several magnesium phosphate mortar type materials that have been utilized in the repair of degraded concrete structures, and they are utilized because they have rapid strength gain. So you can get your structure back in service fairly quickly.

Also phosphogypsum, which is a main product of the fertilizer industry, has been evaluated as a road based material, and they also looked at its feasibility as a set retarder in Portland cement.

And we know that phosphoric acid will cause a slow disintegration of the Portland cement based materials and also we look at several articles addressing appetite and dental type applications.

MR. BANERJEE: Can you just remind me what Portland cement, the chemical composition is?

MEMBER POWERS: Do that quickly and easily, right?

(Laughter.)

DR. NAUS: There are four basic constituents of cement.

MR. BANERJEE: All of these thermodynamics have been done. We should know what it's being done on.

DR. NAUS: It's in the report. Does that help? There are basically four compounds.

MR. BANERJEE: All right.

DR. NAUS: You combine the compounds, and that determines the type of cement you get, whether it's Type 1, 2, 3, 4 and 5. It's like tricalcium aluminate, dicalcium silicate, C4AF, and what's the fourth one? I can't remember.

MR. BANERJEE: What is AF?

DR. NAUS: Aluminum ferrite.

DR. DOLE: The salient point is that when the cement reactions happen, one of the byproducts of the cement reaction is calcium hydroxide that precipitates into discrete crystals called Portlandite, and that is the most labile, the most soluble component of the cement matrix, and it's the one that reacts with the phosphate most intensely.

MR. BANERJEE: All of the sulfates, whatever, right? Is it the calcium hydroxide?

DR. DOLE: Or with the sulfate as well, yes, but it's usually this. The biggest impact of sulfate is the calcium aluminus silicate Ettringite (phonetic) that causes the most expansion. So it's a little more complex in the case of sulfite, but in this case calcium hydroxide is replaced with calcium hydroxyapatite thermodynamically, and it's about ten to 15 percent of the cement pace matrix based on the type of Portland cement you choose.

CHAIRMAN WALLIS: This apatite is presumably a phosphate.

DR. DOLE: Yes, it is.

CHAIRMAN WALLIS: Hopefully not appetite.

DR. DOLE: Not that appetite. It's calcium hydroxy apatite.

DR. NAUS: Okay. So I guess the bottom line on our literature review is we didn't really identify any pertinent information relative to interactions of phosphate ions and cementitious materials.

In parallel, we conducted a number of contacts with researchers that I know both in the U.S. and in Europe. A partial listing of them is provided here. We talked to Andrew Boyd, University of Florida. Florida is an area of high phosphate soils, and he basically wasn't aware of any problems.

He had a research program looking at the potential interactions of phosphate and waste materials. Also he was very instrumental in helping us contact the Florida Department of Transportation, and when we visited them, we had hopefully come up with an arrangement where they would identify a structure in a high phosphate environment for us and then take some core samples and we could take them back to Oak Ridge and evaluate them for phosphates, phosphate minerals in the samples if it has affected the integrity of the samples.

We're working on that right now. Unfortunately they may be rethinking this and don't really want to cut some holes in their structure to pursue that..

(Laughter.)

DR. NAUS: But they did identify a site for us.

Paul Brown at Penn State noted that if phosphates got in the cementitious materials it could react with the calcium hydroxide or calcium carbonate, but he didn't really see any problems with expansive reactions.

At Building Research Establishment in the U.K., they conducted a literature search for us and looked and identified basically there's no problems or no research going on addressing phosphates and cementitious materials.

Also contacted George Hoff who was at the Corps of Engineers for many years, the former President of the American Concrete Institute, and he basically told us that phosphate materials are used for repair of concrete structures and phosphoric acid can disintegrate concrete. Nothing new there.

I already noted we talked to a couple or at least one person at the Florida DOT. They didn't have any problems. Charles Ishee is developing the mix designs for many of the structures in Florida, and he said as far as he knew -- and he should -- there are no special requirements or standards that they follow when they design a structure for a high phosphate environment.

Neil Milestone of Sheffield, he noted that we might get some products that develop on the surface of the specimens. He didn't see any problems with expansion.

George Sommerville at British Cement Association wasn't aware of any work that was going on.

Peter Taylor at Construction Technology Laboratories in Skokee noted that phosphoric acid will disintegrate concrete.

And finally, Michael Thomas did not see any problems with phosphates and cementitious materials interactions.

Part of this might have been that they haven't considered it, too. We have to keep that in mind.

Also, there's a Phosphate Institute for Research which has been established by the phosphate industry, and basically they refused to talk to us.

I guess they looked as us as a regulatory organization or something.

(Laughter.)

DR. NAUS: Also I contacted IMC Phosphates, and they're the largest global supplier of phosphates, and they didn't even respond. So I don't know whether there's a problem or they just don't want to get involved. It's hard to say.

Okay. So based on the literature review and the contacts with the research personnel revealing very little information, we designed a laboratory study which started with some thermodynamic calculations and then proceeded to design and implementation of an experimental program.

Relative to the calculations, we did some studies looking at phosphate concentrations as controlled by soil minerals, and depending on the soil, the dominant cations may be calcium with magnesium or sodium, and this will determine the phosphate solubilities in the soil pore waters.

Then Les calculates some relative phosphate solubilities as it would be controlled by the respective phosphate compounds, and the application of this was to assist in the design of the laboratory experiment, as well as aid in interpretation of any field observations if we would be able to obtain some samples from structures in high phosphate environments.

An example of one of his thermodynamic calculations, the sodium magnesium, calcium rich system saturate, a phosphate aqueous system. The basic procedure, he took one mole of solids, placed it on one liter of water, and calculated the equilibrium concentrations, and it shows that the calcium rich cements and limestone dolomite aggregates will extract phosphates from nearly all groundwater. So it will put the phosphates in solution.

And also an important thing here is that the phosphate concentrations can be maintained with sodium or magnesium phosphate, and that's important for our experimental study.

MR. BANERJEE: What package was used for these thermodynamics?

DR. DOLE: Ultra compo, HSC, Version 5.1.

MR. BANERJEE: Is that referenced here?

DR. DOLE: Yes, in one of the first slides.

DR. NAUS: Also looked at the cement dolomite aggregate system exposed to CO_2 in either the air or groundwater confirms that calcium in cement agosystem will extract phosphate from solution and that calcium hydroxyapatite forms in sodium magnesium calcium systems in the presence of CO_2 also, either in air or groundwater.

Also found a reference in the literature that addresses the precipitation sequences of phosphate compounds and very important here is the ratio of the calcium to phosphate, and that there are a number of precursors to the formation of the calcium hydroxyapatite.

Do you want to add anything to this, Les?

DR. DOLE: Not really.

DR. NAUS: Okay. Similarly looked at the solubility products of some of the key phosphate compounds and used the idea of the solubility of the calcium hydroxyapatite. It's quite high, I guess, quite insoluble, I mean, inside.

The last of these shows --

MEMBER POWERS: Well, you have to understand those are the products of the ion concentrations, the makeup of material. You can't compare them one to the other. You have to look at the formula.

DR. NAUS: Also this points out the relative effect of pH and temperature and the sequencing and some general comments on the sequencing.

Okay. With that as background, we developed an experimental program, and what we tried to do as much as possible is sort of model it after programs that looked at the effect of sulfate ions on cementitious materials. So we utilized cube and prismatic test specimens. The prismatic specimens we looked at to find the effect of duration of exposure on lengths change or expansion of the material.

The cubes were looked at to look at weight changes and also to determine effect on compressive strength of the material.

Okay. In setting up the experiment, we utilized a cement paste, which is merely water plus cementitious materials, and the ratio of water to cement we chose by weight was .4, and this was done to provide a porosity somewhat similar to what you might see in some of the higher strength concrete materials.

And then we cast 54 cube specimens and 20 prismatic specimens for exposure in the solutions. We looked at three different solutions, a calcium hydroxide solution. This was our reference, our baseline solution. It's generally used as a comparison when you're trying to look at the effect of ions or whatever on cementitious materials. Also, by being a calcium hydroxide solution, we're not going to leach or remove calcium hydroxide from the cement based cubes.

We also looked at two solubility phosphates, a low solubility salt and a high solubility salt.

Then we looked at test intervals of one, three, six, and 12 months, and then we have some specimens remaining where we can extend the time period out to 18 or two years, depending.

And the basic tests we performed were compressive strength, length, and weight change, and then we also did some X-ray diffraction and SEM studies.

MEMBER POWERS: You didn't put the specimens that you had exposed through a freeze-thaw site?

DR. NAUS: No. That's adding another degree.

MEMBER POWERS: Yes, it's just personal experience that I find when sulfate is going to tear up my concrete it's after a freeze-thaw cycle.

DR. NAUS: You know, we could have looked at wetting-drying, you know. That's just other things to add. First of all, we want to try to look at very severe conditions and see if there's a problem, and then some of that might be involved in setting limits.

MEMBER POWERS: You face them here, but you ran with a saturated calcium hydroxide solution to prevent leaching.

DR. NAUS: That's our baseline.

MEMBER POWERS: And yet in the structures we're interested in, we won't have that.

DR. NAUS: Right, right. But we try to normalize everything so that we have knowns before we go off into other areas.

MEMBER POWERS: On the other hand, you didn't carry a sulfate known through this.

DR. NAUS: No. Sulfate is fairly well known, and we didn't see the point in doing that right now.

MEMBER POWERS: You need to calibrate your own testing procedure.

DR. KRESS: Yeah, if you had done this same thing with the sulfate and got the same results, that would give you pause for thinking about your test, I think.

DR. NAUS: Right, but it's different solutions, right? So we know sulfate attacks --

DR. KRESS: Yeah. You know, it does, but if you do the test and it doesn't, you've got to think about it.

MEMBER ARMIJO: Then you would have really resisting concrete if the sulfate didn't. You may have discovered a good concrete.

DR. KRESS: Or your test intervals may not be long enough.

DR. NAUS: Okay. You're saying --

DR. KRESS: Or some other.

DR. NAUS: -- it would have been good to use sulfates to demonstrate it does destroy the particular material we're using.

DR. KRESS: Yeah, or just --

DR. NAUS: Well, we're pretty certain of that I would say based on past research. You know, there's been years and years of research.

MEMBER POWERS: But not on your test method.

DR. KRESS: Not on your test apparatus though.

DR. NAUS: Well, we're basically using the same test methods they used. The difference is the solutions.

DR. KRESS: And the concrete.

DR. NAUS: Well, and the concrete, but you know. It's a general issue, ordinary Portland cement paste, and there's fairly tight chemical restraints on, you know, classifying the concrete, the type of cement and so forth. So it's not really comparing apples and oranges.

DR. KRESS: Well, let me ask you the other question then. Of these previous tests in the literature on sulfates, has one year been long enough to do the damage?

DR. NAUS: Not always. That's a concern, yeah, yeah. Because basically everything thermodynamically says something can happen.

DR. KRESS: Yeah, but that's equilibrium, and you're not factoring kinetics anyway.

DR. NAUS: So far we're not seeing it.

Okay. We have 12-month results on the length and weight change, compressive strength, diffraction, and SEM. This is some pictures of the specimens in the curing solution.

Basically what we did is as we said. We had saturated solutions. We placed the specimens on some PVC strips so that each surface of the specimens had exposure to the solutions, and then we periodically removed them and did our weight change, length change, and crushed some of the cubes to see what the effect was on compressive strength.

And these are pictures after 12 months' exposure for the calcium hydroxide.

CHAIRMAN WALLIS: These were buried underneath the solution?

DR. NAUS: There was a saturated water solution and they were submerged.

CHAIRMAN WALLIS: Were there any effects of wetting and drying on this?

DR. NAUS: Well, that's one of the other things we could have looked at, yeah.

CHAIRMAN WALLIS: Well, is there an effect known of wetting and drying? I think there might be.

DR. NAUS: There is, yes. It could be, yeah.

CHAIRMAN WALLIS: But you didn't look at that?

DR. NAUS: We didn't look at that. We tried to keep it fairly simple to see. We thought this would show something happening.

DR. KRESS: But did you look in the solution to see if you got the expected product of the reaction?

DR. NAUS: Well, it's saturated. We know

that, and we did measure the pH.

DR. KRESS: No, no, I meant the calcium product that you end up with.

DR. NAUS: Well, we looked at the products in the specimens themselves with X-ray diffraction and SEM. Is that what you --

DR. KRESS: If this is a decrepitation process, it might end up in the water.

DR. NAUS: Well, we did not analyze the water, no, no.

Basically after 12 months, we got some calcium carbonate crystals on the calcium hydroxide solution. We got some crystals also growth on the surfaces of the sodium and phosphates or the magnesium solutions. The magnesium crystals were a little heavier or a little larger and more frequent. And we recently checked the pH of the solutions. In the first two solutions the pH was around nine, and in the third solution it was 7.8.

Results for length change --

CHAIRMAN WALLIS: Were all stress free specimens, right?

DR. NAUS: Stress free, yes.

Length change results. Our baseline is shown in the red here, and you can see that the magnesium phosphate had similar length change to our reference solution. The sodium was a little less.

MEMBER ARMIJO: Do you have an explanation for that, what's going on there? Why is the length changing, and why would it be different in one solution than in another?

DR. NAUS: Well, what we had anticipated is we'd get a much larger length change in the phosphate solutions because of the formation.

MEMBER ARMIJO: If something was happening.

DR. NAUS: Happening, right, and we're not seeing this.

With respect to the sodium phosphate, it's possible some shrinkage might have been going on. I'm not sure what's going on there.

CHAIRMAN WALLIS: Well, this board variation means change, percent change?

DR. NAUS: Percent change in length from the reference. Let me step back a little.

What we did is we cast the specimens and we de-molded them after 24 hours. We put them into a 100 percent humidity environment for 28 days, and then we placed them into the solution.

And before that the reference length

change in all of the prisms was determined.

CHAIRMAN WALLIS: Fourteen percent? That's big.

MEMBER ARMIJO: Yeah, it seems like a lot. If you had just put them in pure water without calcium hydroxide or any of these others, is that the characteristic? Would these things grow on their own just exposed in water?

DR. NAUS: The carbonate probably does due to environment, right, Les?

DR. DOLE: Yes, but the point was we didn't want to put them in water because the water would leach the calcium out of the system, and there would probably be some shrinkage as you changed the calcium ratio in the hydrogels.

But the point was to compare the reactions of the phosphates. So, therefore, we chose the baseline to be the calcium hydroxide saturated solution. Therefore, that prevented any exchange of calcium from the system, and then that would create a baseline with no calcium change in the matrix.

MEMBER ARMIJO: I understand, but somehow, you know, I'm certainly not a concrete person, but somehow this thing is growing and chemically nothing should be happening. You know, the calcium is versus the calcium in the cement.

DR. NAUS: You have migration of the cement continually happening. One of the things that makes --

MEMBER ARMIJO: Oh, this is water being absorbed by the cement and causing --

DR. NAUS: Yeah, and chemical compounds are forming. It's a very difficult material because it's a living material really. It's continually changing.

DR. DOLE: The .4 water-to-cement ratio is a stoichiometric excess of water in the formula. So even if there was no external water, these chemical changes would be going on in the mass of the concrete with no external agency.

MEMBER POWERS: We looked at one concrete specimen that was 35 years old, and it still had unhydrated cores in the cementitious materials.

CHAIRMAN WALLIS: A thick piece of concrete. Then presumably the skin was exposed to this stuff. It would be trying to grow to 14 percent and the stuff in the middle would still be trying to stay the way it was. So there are a lot of stresses set up.

DR. NAUS: Yes. Well, this is an extreme

condition here. This is very high cement content really.

CHAIRMAN WALLIS: But uses a long time and the diffusion is such that the thing is uniform across its cross-section or is it different on the surface from the --

DR. NAUS: Loss of moisture from concrete is a very slow process.

CHAIRMAN WALLIS: So you think that the outside may be trying to grow to more than 14 percent. It's constrained by the middle.

DR. NAUS: Okay. If you're thinking of concrete though remember that about 75 percent or more of it is aggregate filler material.

CHAIRMAN WALLIS: Yeah.

DR. NAUS: So that varies.

CHAIRMAN WALLIS: That stops this, but I'm just talking about your experiment here. You've got this Toblerone bar. All right? You put it in, and then it grows, but presumably the outside is different from the inside, right? Because the inside doesn't have this reaction. Maybe; I don't know.

DR. NAUS: Well, you know, one inch. I wouldn't think it would be --

CHAIRMAN WALLIS: No, this isn't saying

that a thin sliver of it would grow by this percentage. It's the Toblerone bar did.

DR. NAUS: It's just what we're seeing under these --

CHAIRMAN WALLIS: But you've got to interpret it somehow.

DR. NAUS: I'm sure there's a geometric effect.

CHAIRMAN WALLIS: There's also the fact of diffusion in there, isn't it? The outside isn't the same as the inside, or it's presumably stressed in some way.

PARTICIPANT: Yes, cracks can form.

DR. NAUS: But that's part of the point of the calcium --

CHAIRMAN WALLIS: Did it crack?

DR. NAUS: I don't believe that Catherine has seen any cracks yet.

DR. DOLE: There are no cracks, and that goes to the point of why we use the calcium hydroxide, because you balance the diffusion inside and outside. They're both saturated with calcium inside the mass and outside the mass. So that eliminates that variable.

So all you're seeing now is the continued reaction of the cement components, the CS3H, C3S, and C3AF reacting with water that's already within the mass. There's very little exchange within the mass.

CHAIRMAN WALLIS: Diffusion is not an issue here.

DR. DOLE: It's a normal behavior. We're seeing a normal behavior of all cement base.

MEMBER POWERS: Let me give you another --

MEMBER ARMIJO: Let me just ask that question a different way to make sure I understand what's going on. If you just left it out sitting on a tabletop at the same temperature, would this thing have grown 12, 14 percent, this column?

DR. NAUS: I doubt it, no.

MEMBER ARMIJO: From internal processes?

DR. NAUS: See, you have shrinkage. You're going to get shrinkage due to loss of moisture and so forth. No, it wouldn't grow 14 percent.

MEMBER POWERS: Graham, let me introduce another complexity in your life here. The hydration reactions are exothermic enough so that it's not isothermal either.

MR. BANERJEE: Does the material have micropores or is it --

DR. NAUS: Oh, yeah, yeah.

MR. BANERJEE: So actually the diffusional process that Graham is referring to is not diffusion into a solid matrix. It's through a microporous material. So you could deliver things. It's a complex problem. It's more like a catalyst.

CHAIRMAN WALLIS: Anyway, this is what you observed.

DR. NAUS: Right, right.

MR. BANERJEE: Did you take microstructure of these materials with time?

DR. NAUS: Well, we have SEM and X-ray diffraction results. That's -- you know.

MR. BANERJEE: Does that give you the same sort of --

DR. NAUS: Well, we're basically looking for reaction products.

MR. BANERJEE: Right, but what about the porosity? What's happening to that?

DR. NAUS: The porosity is going to decrease with time because of migration.

MR. BANERJEE: Right, but do we know that in some concrete way.

(Laughter.)

DR. NAUS: Well, from experience and, you know, numerous research, yes. You know, I can't say --

MR. BANERJEE: But how do they determine that normally?

DR. NAUS: What, the pore?

MR. BANERJEE: The pore structures.

DR. NAUS: There's porosity, mercury methods of measuring porosity.

MR. BANERJEE: Oh, so that's how they do it?

DR. NAUS: Yeah.

MR. BANERJEE: Using mercury?

DR. NAUS: That's one method.

MR. BANERJEE: People have done that on concrete?

DR. NAUS: Yeah.

MEMBER POWERS: And if you want to see a debate that's been going on since probably when Portland cement was first invented is how to interpret the porosity measurements because the pores aren't empties. They're filled with water and gel and things like that, but if you dry them out, then you change them. So now how do you do a porosity measurement on that? It's --

MR. BANERJEE: The same with oil bearing rock.

MEMBER POWERS: Yeah, it's exactly the same problem, except this one is continuing to react whereas your rock is at least fixed.

MR. BANERJEE: We hope.

DR. NAUS: Okay. The weight change, the specimens experienced for the two phosphate solutions were a little less than what we got in our control solution. So, no, no significant -- what I'd call significant differences here. A little bit of this effect in the calcium hydroxide may have been some of these crystals, calcium carbonate on the surface that developed.

CHAIRMAN WALLIS: So would this study enable you to predict what happens in the foundations of a nuclear reactor?

DR. NAUS: Well, you know, our objective is to see if there is a potential problem first, and then come up with limits if need be. You know, that may be down the road a little ways, and that's where you would get into these maybe freeze-thaw and comparing it to sulfate solutions and things like that to try to help establish comparable limits.

Compressive strength over the 12-month period, similar trends for each of the three.

CHAIRMAN WALLIS: You don't have a similar experiment as my colleague Tom Kress said with the sulfates. So you --

DR. NAUS: That's right.

CHAIRMAN WALLIS: How do you interpret a comparison?

DR. NAUS: That's right. That will be something additional or down the road.

Similar trends, similar strengths.

VICE CHAIRMAN SHACK: Don't you have literature data? I mean, I don't see how you do anything without at least some notion whether from the literature or a baseline experiment. What does the literature tell you happens to the strength of concrete after 12 months of soaking?

DR. NAUS: That's hard to answer because it depends on when you get your cementitious materials. You know, the older cements -- part of the problem is they used to gain strength over, you know, a year, two years and so forth because they had different formulations. They were larger in particle size.

The newer cements are very fine, and they have changed the formulation somewhat. So you get all of your strength in 28 days. But you have an idea of trending, you know, what the strength is going to do.

You know, I can come up with a curve for you and so forth, but we have results to go one, three, nine, 12 months, you know, on here.

CHAIRMAN WALLIS: Well, after soaking, it's stronger than it was before.

DR. NAUS: Right. It continues to hydrate and so forth.

MEMBER ARMIJO: I found something funny in your data there. I don't understand why there's a discontinuity in the strength from the six month to nine month, and it happened on all three sets of data. Is that an experimental --

DR. NAUS: Oh, the size of the gain?

MEMBER ARMIJO: Yeah. There's a step change between six months and nine months. If you just draw a line, your average line for the nine and 12 month versus the first three months.

CHAIRMAN WALLIS: That's when the second shift came on.

MEMBER ARMIJO: Yeah, and it's repeatable. Unless there's something funny going on in concrete between six months and nine months, some sort of --

DR. NAUS: I really don't know. These were all done at a lab, TVA lab, I believe, ex-TVA lab, by the same people, right? The compressive strengths? I think Catherine --

MR. BANERJEE: Gestation period.

(Laughter.)

MEMBER ARMIJO: Come on, guys. It doubles the strength between six months and nine months. It doesn't make any difference whether it's magnesium phosphate, sodium phosphate or calcium hydroxide, but you know, there's something funny about the experimental set-up or technique.

MEMBER DENNING: When you talk about the range, you show those ranges there, how many samples are they and what --

DR. NAUS: Generally there's probably three per data set I would guess. It's a limited number of specimens.

MEMBER DENNING: If we look at the bar that's shown on that first one there, that shows quite a variation. Does that represent three samples?

DR. NAUS: It's the range that was obtained, and it's not what I would call real good. There might have been some air voids in there for some reason.

Les?

DR. DOLE: Okay. I guess I'm trying to figure out how to answer his question. After looking at these systems for over 30 years, I'm not surprised by that. I'm trying to figure out how to extrapolate my lack of surprise to your surprise.

Bottom line is if you look at the physical properties relative to the microfabric, you're looking at almost a step function. As the density reaches some critical value, then you get a big change in properties. It's like a tangent function.

And so at the lower levels the strength would be indicative of certain phases, but at some point when you get the growth of a dense phase, the strength suddenly then takes on the characteristic of that dense phase, and that transition between the less dense to the higher dense phase as it is appreciated by some external physical result like strength can be very abrupt.

DR. NAUS: Can be.

DR. DOLE: It can be because you go from a system that's dominated by a weak phase to a system that's dominated by a strong phase, and that can tip very rapidly.

MEMBER ARMIJO: That's in the framework of six to nine months that's typical?

DR. DOLE: It changes with the type of cement, but yes. The cement reactions continue. You know, the standard is 28 days, but as you can see, one month is just the beginning of the strength of the concrete.

CHAIRMAN WALLIS: It would be useful to have zero months, too, or a starting point.

MEMBER DENNING: So you think there is a real effect.

DR. DOLE: At zero months you can't get out of the mold in a solid. It's Jello at zero months.

MEMBER ARMIJO: It's very reproducible.

MEMBER DENNING: But it still isn't clear to me. What's the meaning of the bar?

DR. NAUS: That's the range. That's the range.

MEMBER DENNING: That's a range for three specimens?

DR. NAUS: Over three specimens.

MEMBER DENNING: Then I wouldn't be surprised if the variability of that is huge then. I mean if that's truly the range --

CHAIRMAN WALLIS: You can't conclude very much. It jumps.

MEMBER DENNING: -- you can't conclude much.

MR. BANERJEE: Well, it would be nice to have each specimen plotted so that we saw what happened to that rather than averages.

CHAIRMAN WALLIS: Doesn't it get broken?

DR. NAUS: Well, you know, I have every specimen. We have that. We could do that. That wouldn't be a problem.

MR. BANERJEE: Because with these error bars, it's not clear what's happening.

DR. DOLE: The specimen is destroyed in this test. You crush it. You take it to crush it and that determines the compressive strength.

MR. BANERJEE: Oh, you're actually crush it?

DR. DOLE: Yes, and so when you work with a small, two inch cube, you expect to see these kind of error bars. There's imperfections.

DR. NAUS: You have a small specimen which would provide more variability and plus a paste probably would provide more viability than something like a mortar or a concrete.

MR. BANERJEE: Well, this is compressive strength to failure.

DR. NAUS: Yes.

MR. BANERJEE: I see.

DR. NAUS: But we do have each individual test result obviously.

DR. DOLE: And flaws in the geometry of the specimen. You know, when you work with small specimens, it makes it much more sensitive, but the trend is clear. We were looking at no variation, no significant variation.

MR. BANERJEE: What is the high strength phase and what is a low strength phase?

DR. DOLE: Oh, different densities of CSH. The calcium silica hydrates densify with time, and then the matrix --

MR. BANERJEE: Expected that it would go through some sort of transition in strength?

DR. DOLE: Yes, yes. It is somewhat amplified because we're looking at just the paste. You know, when you have a more complex matrix, it has sand and aggregate in it. The paste is still doing this, but the strength is modified by the aggregates. So you don't see this kind of abrupt change perhaps, but it's what you expect to be in the fabric of the paste.

DR. NAUS: Go on?

Here are some X-ray diffraction spectra for each of the solutions. Results are quite similar.

Hydrated phases identified are Portland dyed calcium silicate hydrate, possibly Ettringite, and there were no minerals identified that had phosphates.

Also did some SEM testing, and these results basically confirm what we found by X-ray diffraction: no phosphate minerals were found either near the surface or interior to the specimens.

MEMBER ARMIJO: Did you take any X-ray image photographs while you were doing the SEM using the phosphorus finds?

You know, trying to get X-ray diffraction data, it's tough when you have very little, but you have this high magnification surface and you can get an X-ray image picture and it will tell you the chemistry of all the phases on the surface. Do you have any of that?

DR. NAUS: I'll have to defer to Les because that's not my area at all.

DR. DOLE: We did identify some sodium phosphates forming on the surface of the sodium phosphate, but if you turn and look at the next one -- that slide hasn't come up. And so we did identify some phosphate minerals, but none of them were apatite. That's the omission that bothered us most until we looked at the sequence of precipitation. In other words, hydroxyapatites did not fall directly out of solution. So you almost never see hydroxyapatite formed directly. It's a modification.

And on the next slide we also saw that the cement paste had no surprises. It looks like normal cement paste. So we didn't see hydroxyapatite form on the surface. We did see some precipitation because we're working with saturated solutions, and the cement matrix showed the usual suspects of Ettringite and calcium sulfoaluminates, but there was no apparent microscopic difference --

MEMBER ARMIJO: No enrichment with phosphorus?

DR. DOLE: -- in the cement paste than you would find in any normal cement paste.

CHAIRMAN WALLIS: You're not simulating the plant conditions. You're putting in a much more concentrated solution?

DR. NAUS: Yes. It's considered to be very severe.

CHAIRMAN WALLIS: So we have to wonder what this -- how we extrapolate this to a plant in some way. Can you explain that to us?

DR. NAUS: Well, we would go backwards to do that. First of all, we're trying to identify if there's a problem.

CHAIRMAN WALLIS: That's right, to see if there's anything happening in the extreme case.

DR. NAUS: Right, and then we would start trying to identify limits as such or somebody would try to identify the appropriate limits.

MR. BANERJEE: I guess what we're saying is the kinetics of whatever happened is relatively slow, right?

DR. DOLE: Very slow.

MR. BANERJEE: So that's why you don't see it.

DR. DOLE: Yes.

MR. BANERJEE: At least at room temperature.

DR. DOLE: Which is consistent with the other work on the precipitation, the precipitation formation of calcium hydroxyapatite.

MR. BANERJEE: But it is a very controlled.

MEMBER ARMIJO: But I think that's what's so important to have had samples in a sulfate solution to see that this experiment would even show an effect in something that's known to be aggressive, and that would have put our mind at ease. Yeah, you see sulfate damage in the time frame in this test. So, therefore, if there was going to be equivalent damage with these others, with phosphates, we should have seen something.

MR. BANERJEE: Also the kinetic effects would be very nonlinear here.

MEMBER ARMIJO: I understand, but if you can't detect it in sulfates, it's not conclusive that you didn't detect anything in the phosphates.

DR. KRESS: A negative result --

MR. BANERJEE: Necessary but not sufficient.

DR. DOLE: I mean, certainly from experience we would expect a reasonable amount of certainty that if we had placed these bars in saturated sulfate solution, they would have fallen apart by now.

MR. BANERJEE: Now, you have experiments that you've done previously with similar size bars and cubes with sulfate, right?

DR. DOLE: Yes.

MR. BANERJEE: I mean, could these results which were done in other studies maybe be part of the sort of valuations so that at least we have some evidence that within this one-year period, that there are effects of the sulfate, where there is no effects that you see on the phosphates even though the thermodynamics indicates the kinetics is relatively slow in some way.

DR. NAUS: We could definitely go back in the literature and look at sulfate testing. I believe there's a standard.

MR. BANERJEE: In a similar period of time and similar sort of situations, in the absence of actual data would claim they're the same, you know.

DR. NAUS: Right. Yeah, we certainly could do that.

DR. DOLE: I mean, this was a normal Portland cement, nothing chosen for sulfate resistance, no special additives for sulfate resistance, and you would expect that under the conditions of the sulfate test they would decrepitate very rapidly.

DR. NAUS: So our preliminary conclusions based on what we've seen to date are that there doesn't appear to be any harmful interactions of phosphates and cementitious materials unless the phosphates are present in the form of phosphoric acid.

As I noted, phosphates have been incorporated into concrete as set retarders.

Magnesium phosphate cement is used for repair, occluded to retard set, provide improved alkaloid aggregate reaction.

We did not identify --

CHAIRMAN WALLIS: But the no confluent direction is based on the compressive strength test. Is that what it's based on?

DR. NAUS: Alkaloid aggregate reaction? Again, that's an expansive reaction that the alkalide is in the cement and certain aggregate materials. That's not part of this.

CHAIRMAN WALLIS: But your conclusion of no harmful interactions is based on the compressive strength tests, not based on the growing of the stuff.

DR. NAUS: Well, it's based on our results, you know, our literature search, our experimental results, and so forth.

DR. DOLE: Also there was no change in the surface.

CHAIRMAN WALLIS: In fact, the compression strength went up rather than decreasing. Is that what it's based on?

DR. NAUS: It's part of it. It's in line with the calcium hydroxide solution.

DR. DOLE: And also there's no surface

spalling. The surfaces are completely clean.

CHAIRMAN WALLIS: Your conclusion is that phosphates are like sodium hydroxide solution. So you're then saying there's no harmful reaction with one because there isn't with the other. Is that the -- I'm trying to follow the logic that leads you to say there's no harmful interaction.

DR. NAUS: We're not seeing anything out of the norm in this time period.

CHAIRMAN WALLIS: No unusual interactions.

MR. BANERJEE: Well, with reference to your calcium hydroxide solution, that's your reference case, right?

DR. NAUS: Yeah, and that's a basic optimum curing situation for concrete.

MR. BANERJEE: So nothing over this period of time.

DR. NAUS: Over this period of time. Now, that doesn't mean something might not happen, you know.

MR. BANERJEE: Thirty years and it might be quite different.

DR. NAUS: Yes. Thermodynamically, you know, something apparently will happen, but genetically --

MR. BANERJEE: Is temperature an important factor here?

DR. NAUS: It could be an accelerator, I'd say.

MR. BANERJEE: I mean, many people do accelerated experiments simply by changing temperature, I mean, to look at long term effects if the effect of temperature is well understood.

DR. NAUS: Well, there are accelerated tests for sulfate exposure, and part of that is maintaining the pH at a certain level. You know, we could look into something like that, you know, to try to impose more severe conditions.

MR. BANERJEE: Well, I'm just saying is it -- I don't know the concrete literature at all, but imagine you wanted to do an experiment where you wanted to let a 30 year effect, but you only had one year to do it in. So one variable that one can look at is to keep everything else constant and just raise the temperature by a factor of five degrees or ten degrees or something and see if you see an effect or not.

DR. NAUS: We could do that. I'm not sure what it would mean.

MR. BANERJEE: I don't know what it means either. So I'm just asking if this sort of thing has been done in concrete with, say, sulfates or things which are known to affect things.

DR. NAUS: Well, there is an accelerated sulfate test, you know, that I mentioned.

MR. BANERJEE: And there is a strong temperature or is it --

DR. NAUS: I can't recall. To be honest, I can't recall whether they increased the temperature or not. I k now they maintained a pH at a certain level.

MEMBER POWERS: A way to accelerate concrete curing is to steam cure it, in steam rather than water.

DR. DOLE: Yes, with the following proviso. When you look at these systems of aluminum silicates, very small displacements in temperature change the reaction path of the system. So accelerating it with using a simple Arenius (phonetic) equation, you can accelerate diffusion and some other things, but you can modify significantly the reaction path of the system.

MR. BANERJEE: You change the equilibrium.

DR. DOLE: You change the mineral. You know, you look at the free energies of the minerals that form in this composition range like aufolite (phonetic) and tobermorite. They are very close. So a small temperature, 25 degrees C displacement in temperature completely changes what direction the system is evolving thermodynamically.

Now, kinetically it's still diffusion control and you get some acceleration of diffusion, but on the other hand, think about this. Carbonates and the phosphates have retrograde solubilities.

DR. KRESS: If it's diffusion control, can you increase the concentrations well above what you expect?

DR. DOLE: Well, that's what we have. We gone to the maximum possible concentrations.

DR. KRESS: Well, you can change the saturation level. That changes the temperature, at least the concentrations. It's saturated with those particular compounds. You can use different compounds.

CHAIRMAN WALLIS: What we're saying is there's no harmful interactions conclusion. It's based on the range of variables that you investigate.

DR. NAUS: The range of variables you investigated, contacts.

CHAIRMAN WALLIS: So I'm wondering whether it's possible to extend this in some way.

MEMBER MAYNARD: Personally I would put more into the literature research and the communication with people who have had concrete structures in high phosphorus areas for an extended period of time. I find this interesting, but I don't see how in a one year or a short term test you would ever really duplicate what would go on in 30, 40 or 50 years.

So I think their research and discussion with other long-term things probably has more usefulness at this point.

DR. KRESS: There's a lot of phosphates down in Florida.

MR. BANERJEE: Things which have been stocked in Florida soil.

MEMBER MAYNARD: Are still there.

MEMBER POWERS: Let me ask you a question about your set retarding. Interesting, but in fact, sulfates are used for set retarding, too. So, I mean, that doesn't get you out of the woods there.

DR. NAUS: True, true. It's just an indication that phosphates have purposefully been included.

MEMBER POWERS: Yes, but so have sulfates.

DR. NAUS: Right, right. To get back to the point that the previous speaker made -- Dana? Otto, Otto.

MEMBER MAYNARD: Otto.

DR. NAUS: Yeah, this is ultimately some of the weaknesses of the current ASTM testing. In other words, you're looking at a process that modifies on a microscopic scale the skin of a specimen that's inches in diameter, inches in dimension, and you're looking then for some impact on a gross physical change like dimension or strength.

That's why we back these up with careful examination, because I think that the SEM examination would give us an earlier indication than the actual physical properties of the bar.

But we do get the sense that when these phosphates do precipitate on the surface that they essentially pretty much make a diffusion barrier because when you compare the reaction of the bar with no diffusion by virtue of the calcium saturation with the phosphate addition, there's very little difference, which seems to show that the phosphate slows down the exchange of calcium with the environment, and so there's almost an indication that kinetically there's a protective shell formed by the phosphate at least over short periods of time.

DR. KRESS: Well, wouldn't you have seen that with your SEM?

DR. NAUS: Well, we saw phosphates on the surface, but we did not see hydroxyapatite. We saw some phosphates that precipitated out solution, which is consistent with the previous discussion of the sequences of phosphates, but we certainly expected --

DR. KRESS: Do those look like things that would passivate the surface and slow down the diffusion?

DR. NAUS: Again, please.

DR. KRESS: Those phosphates you saw, do they look like they'd do what you think in passivating the surface and slowing down the process?

DR. NAUS: Insomuch that you're plugging the surface pores, yes. You don't have to form a continuous surface to --

MR. BANERJEE: It looked like crystalline materials. All right? So why would they clog the surface pores?

DR. NAUS: Well, if they were nucleated by the pores or in the pores, then they would block the pores.

MEMBER ARMIJO: I don't think the crystals that we were shown are phosphate crystals there.

DR. NAUS: No.

MR. BANERJEE: What were they?

MEMBER ARMIJO: I don't think we saw any pictures of phosphate crystals. I haven't seen any in the report.

MR. BANERJEE: What were those crystals that you were showing us then?

MEMBER ARMIJO: There's crystals, but those aren't the phosphate ones.

DR. NAUS: These?

CHAIRMAN WALLIS: Those things there?

DR. NAUS: Now, those pictures are phosphate crystals and calcium hydroxide crystals because we're working with saturated solutions, and so the surface tends to nucleate them.

MEMBER ARMIJO: Well, you know, that magnification is so low I can't tell anything there.

MEMBER POWERS: Yeah, we should move on.

DR. NAUS: Okay. As I noted, we're trying to work with FDOT to obtain concrete core samples from a bridge substructure in Bartow County. They've gone as far as done a soil analysis adjacent to this structure, and then we need to keep pursuing trying to see if they will take a core sample or at least look at the structure down there so that we can get an idea if something is happening.

I think this would be of as much benefit as anything we've done so far.

CHAIRMAN WALLIS: These are the composition of what here?

DR. NAUS: That's the soil.

CHAIRMAN WALLIS: Of the soil.

DR. NAUS: Adjacent to the structure.

CHAIRMAN WALLIS: Oh, two, eight percent uranium.

MEMBER POWERS: As is typical of most phosphate soils.

MEMBER SIEBER: Go critical.

DR. NAUS: Yeah, that brings us to the report on durability of reinforced concrete. I think it probably addresses much of the early discussion we had here.

Basically it was set up into five chapters, also included three appendices, one addressing the safety related concrete structure, a description of it, a little bit about design and so forth, an appendix on operating experience of the nuclear power plant concrete structures, and there's sort of a controversy on cracking and corrosion, the effects of corrosion on cracking or the effects of cracking on corrosion.

So I looked in the literature, and I provided a section on that.

Basically in the introductory material concrete ages. Changes in the properties occur as a result of continuing microstructural changes. With respect to degradation processes, in probably almost all cases, if not all cases, you have to have water present for the concrete to degrade, and would expect the incidence of degradation to increase with age, particularly the environmental related factors.

In the second chapter, I provided sort of a historical perspective on concrete and longevity. Types of cement have been around for 12 million years. The oldest concrete is 7,600 years. The Commission of European Communities has done a study. I think it was related to waste applications of concrete materials, where they looked at number of old, antique or very old type structures, obtained samples from these structures, and tried to evaluate them. And their basic conclusion --

VICE CHAIRMAN SHACK: They get a sample from the Pantheon and you can't get one from a bridge in Barlow County, Florida?

DR. NAUS: Yep.

(Laughter.)

DR. NAUS: I guess they weren't associated with a regulatory organization or something. I don't know, or they just snuck in there and took it. I don't know.

But in any event, the key to why these structures survived had to do with careful selection of materials and construction. In general, the climatic conditions were fairly mild, and the key point here, they did not have steel reinforcement to corrode in the structure.

CHAIRMAN WALLIS: Didn't burn sulfurous coal.

MEMBER ARMIJO: That's true, too.

DR. NAUS: And Portland cement as we know it originated in about 1824 with Joseph Aspdin.

MEMBER POWERS: Interesting, both the Coliseum and the Pantheon are subject to sulfur degradation from fuel oil.

MEMBER ARMIJO: That would be recently.

VICE CHAIRMAN SHACK: Not for the first thousand years, right?

MEMBER POWERS: You don't think?

MEMBER SIEBER: Not until UVA.

CHAIRMAN WALLIS: Well, for a while oxide was disappearing.

MEMBER POWERS: Yep.

DR. NAUS: Okay. In Chapter 3, we talk about the basic materials of construction, nuclear power plant construction, the concrete materials, the different types of cement chemical formulations, standards, evolution of cement. We talk about the conventional mild steel reinforcement, generally 40,000 or 60,000 psi yield strength materials, pertinent ASTM standards.

The steel, of course, is added to resist tensile forces in the members and control cracking. Some of the plants also have prestressing steel to increase the rigidity. It also gives you additional margin for cracking and basically this is either a bar, strand or wire type material.

And finally, the liner plate, which is utilized to provide a leak type barrier in the containment. It's a mild carbon steel.

Chapter 4, which is the longest chapter of the report, addresses aging and durability of the material systems. If you're looking at the concrete materials, the degradation factors, we generally group them into either physical processes or chemical processes.

In the report there's a fairly detailed description of the mechanisms and wherever possible tried to include a picture of these different types of degradation processes, and also talked about the manifestation of these factors, and in large measure the primary manifestation of degradation is cracking of the concrete.

Similarly for the metallic materials. Primary degradation factor here, of course, is corrosion of the material, and there is some extensive discussion with respect to the corrosion of the mild steel reinforcement, in particular, here.

Chapter 5 is summary and commentary, some general observations that reinforced concrete structures deteriorate due to exposure in the environment. In one way or another this probably starts shortly after construction. Properties of concrete change with age. As I noted, water is a most important factor controlling concrete degradation, with the prevalent manifestation degradation being cracking.

And the most prudent approach to maintaining your margins of these structures, as well as extending the usable life is through an aging management program.

Okay. Appendix A provides background on the codes which were used to design the structures, as well as some supplementary guidelines from the NRC, a description of the various Category 1 or what are called safety related concrete structures.

Appendix B provides a summary of quite a few of the incidents of degradation that have been identified. Early on most of the instances of degradation were due to construction or design errors. However, as the structures get older, we'd expect to see more degradation resulting from environmental effects.

CHAIRMAN WALLIS: So this is part of your work product from this research?

DR. NAUS: Yes.

CHAIRMAN WALLIS: So when do we get to what do we do about phosphates? Your conclusion seems to be there's no problem with phosphates. Is that it?

DR. NAUS: From what we've seen so far, right.

CHAIRMAN WALLIS: Is that something we can hang our hat on? Is that really what you want to conclude from this work, that there's no problem with phosphates? There should be any limit in groundwater?

That's what it's all leading up to, is it? That's the bottom line, isn't it?

MR. GRAVES: Yes, it is. To answer Dr. Wallis' question, yes, the staff, based on its literature review, the tests, lab work that we've done to date, the bottom line is that we don't see any effect from the phosphate --

CHAIRMAN WALLIS: The real question should be what's the sufficiency of the work done to date and what's the sufficiency of the evidence. Is there some sort of range where it's dangerous to extrapolate or something?

Isn't that what you should focus on?

MEMBER DENNING: Well, is research now saying we don't see any effect now but we think we have to continue testing for another year and draw a judgment, or are you ready to say, "Okay. There's no evidence. Let's cut the research now"?

MR. GRAVES: No, at this point we're not ready to cut the research.

MEMBER DENNING: Why not?

MR. GRAVES: As I mentioned, we do have remaining samples. We would like to get the data at 18 months.

MEMBER DENNING: Okay. At 18 months you

think --

MR. GRAVES: Close to 18 months. We get the data at 18 months.

MEMBER DENNING: I can't tell whether you're just afraid that if you say we're going to cut the research now that Dana is going to come up and say, you know, "What's the basis for that?" You know, I'm just kind of curious as to where do you say enough is enough.

MR. GRAVES: Right. We came in to report at this time because, as I mentioned, we received a user need memo December 2003, and I've run into Tanny Santos and Sam Duraswami and say, "Hey, when are you guys going to come in and talk to us about phosphates?" They talked to me six months ago.

I said, "We're coming. We're going to come and talk to you."

So we're here with what we have at this point. We've almost completed the research. We want to take your comments back and give you, give the staff, NRR -- they sent us a user need -- respond with what we think is a comprehensive answer with lab reports, literature survey, and also we want to recommend to Oak Ridge to include sulfate attacks.

There is a report by the Portland Cement

Association where they performed tests on sulfate attacks on concrete for 16 years. They had tests in the field, but also they had prisms that Dan had in the laboratory, and they did a comparison of that continuous wet and dry like a fill beings that were cast to the laboratory samples.

So we can summarize that work and we also can make that report available to the ACR staff if you find that would be necessary.

So at this point, the bottom line, we haven't seen the effect of phosphates to make us want to put limits as we have for sulfates, chlorides and having pH.

MR. BANERJEE: What are the chances of getting samples from this Florida bridge?

DR. NAUS: I don't know. I'll try again.

MR. BANERJEE: It's not something that can assure that you'll get up to them. Is it a sampling problem?

DR. NAUS: Well, it's a problem in that you take probably a three inch by six inch core. It depends on the aggregate size. Let me clarify that. Probably three by six inch core out of their structure, and they probably do not want that to happen. It might tend to expose the rebar to corrosion or something like that. You lose your cover we talked about earlier.

VICE CHAIRMAN SHACK: We'll repair it with a magnesium phosphate cement.

MEMBER SIEBER: There you go.

MR. BANERJEE: And if the bridge collapses because of that, then we know that there's a problem.

DR. NAUS: No, that's not going to happen.

MEMBER SIEBER: You could go to Pennsylvania. They have a lot of bridges that are ready to collapse.

MEMBER DENNING: No, in your report, you did have in your summary and commentary, you did have a specific recommendation that says, "The prudent approach for maintaining adequate structural margins is through an aging management program."

Now, what are the implications of that to underground structures? I mean, when you said that, what kind of program are you suggesting is appropriate for assuring ourselves that underground structures are not in an unseen manner degrading around us? What do you suggest? What does that mean?

DR. NAUS: Well, I think this all gets back to ASME Section 11, GALL report, and so forth. They have specific sections that address underground structures, you know, by indirect sampling of the soil or groundwater adjacent to the structures. If they're below the levels in chlorides and sulfates, you have reasonable assurance that nothing is happening.

MEMBER DENNING: Okay. So that would be adequate in your viewpoint. It's just monitoring and seeing that they're below these limits. You're not imply here actually look at the concrete. You're saying just look and make sure that you're below these water levels?

DR. NAUS: No, no. This has all been addressed under the structural aging program and your ASME and things like that, as far as an aging managing program as such. It just means don't neglect structures is what I'm trying to say, you know, which in a lot of cases has been done.

MEMBER DENNING: I think I understand.

DR. NAUS: Not anymore, but --

CHAIRMAN WALLIS: But the question is phosphates, isn't it?

DR. NAUS: Pardon?

CHAIRMAN WALLIS: Is there a problem with phosphates? Should there be some rule about what's tolerable in the groundwater?

DR. NAUS: Right.

CHAIRMAN WALLIS: We seem to be moving to the point where the NRC is going to say, "No, there shouldn't be anything."

MEMBER DENNING: And in six months they're going to say --

CHAIRMAN WALLIS: I'm just wondering what are we supposed to contribute to that. Are we supposed to contribute or say that the agency has enough evidence to make this decision? Do you want us to try to reach that kind of conclusion or what do you want us to do about phosphates or do you want us just to say we have had a preliminary result from you, "Thank you very much. Go away and finish the job"?

What would you expect us to say?

MR. GRAVES: At this point let me ask Tony Shaw, who is my Branch Chief, if he --

MR. SHAW: Dr. Wallis, yes. I'm Tony Shaw from Research.

Based on the research results we have so far, we believe -- I agree with what Herman said earlier -- we believe there's no need to set limits on phosphate at this time.

As far as user need, we will certainly take all of the comments from the Committee today incorporating into our final NUREG CR report. You will certainly get a copy and also furnish you with the primary reports. Now you have a draft.

As far as the user need, we have been interacting with our colleagues at NRR. We'll continue to do so, but at this moment, I believe they have also been satisfied with what we have provided so far, but we will continue to make sure when the reports are finished that we'll satisfy all of their needs.

We will like to hear from the Committee endorsement of what we're supposed --

CHAIRMAN WALLIS: -- final report, have you? So you're asking us to give some assessment now?

MEMBER DENNING: Well, the comment that could be made is you haven't tested long enough. I mean, I'm not suggesting that because as I -- I mean, that would be the comment, if there was a technical basis that said you haven't tested long enough or maybe there's something --

MR. SHAW: Or maybe tested in the right way. But also, Dr. Maynard you said earlier, Otto?

MEMBER MAYNARD: Otto, yes.

MR. SHAW: Yes, you said earlier that another important factor we have included but we may need to stress a little bit more is based on the literature survey and discussions with the people who have had experience for 20, 30 years with concrete, what kind of impact phosphate may have. That's an important factor we certainly will stress.

MEMBER BONACA: The trouble is that even if you get a sample from that bridge, I mean, how do you isolate the effect of phosphate from the effect of chlorides. I mean, you still have to have the reactions from different locations, and you could possibly infer something.

MEMBER ARMIJO: I tend to think you've done very good experiments, except that you left out the clincher which would have been to put the same thing into sulfate even though you know the answer. We don't, and if this stuff was readily detectable that you got damage with the sulfates and you got no damage with the phosphates, I'd be happy.

MR. BANERJEE: Well, maybe with phosphoric acid as well.

MEMBER ARMIJO: Well, phosphoric acid they know. Yeah, whatever. All the bad stuff works bad; all of the good stuff works good. You know, it's done.

MEMBER DENNING: But I'm not sure that that -- I think it would have been interesting to see that. I'm not suggesting that they ought to do that at this point, but I'm not sure that that's the clincher either because it could be that it happens quickly for the one and it doesn't happen quickly for the other. It's still a long ways between one year and 60 years.

MEMBER ARMIJO: You'd have to have a mechanism.

MEMBER DENNING: You'd have to have a mechanism.

MR. BANERJEE: Under two ruins in Florida? I mean, why does it have to be a bridge? It could be any damned thing, right?

MEMBER SIEBER: It could be a part of containment.

MR. BANERJEE: In the ground.

VICE CHAIRMAN SHACK: Well, I think there is experience. I mean, it's like an epidemiologist. I mean, you know, if somebody has got a record of bridge repairs in counties with high phosphate versus bridge repairs in low phosphate, you know, that --

MEMBER MAYNARD: Well, I'd like to make a suggestion because I think information has been presented, but there hasn't been any real conclusion or recommendation. There is still some going on. I'd almost recommend that maybe in six months or a year when they've wrapped up whatever additional testing they're going to do, I think the staff should come back and make a recommendation, whatever that recommendation is, and we can either endorse that recommendation.

Right now we don't really have anything to endorse or to reject. We can just make comments, but I think they need to come to us with a recommendation that either this be dropped or be continued and that we either agree or disagree with that.

I don't see any immediate problem. I think from what they've done, they haven't identified anything that says action needs to be taken right now.

MEMBER SIEBER: Right.

MEMBER MAYNARD: So that would be my recommendation.

DR. NAUS: What would have been ideal is if we could have talked to the phosphate producers and talked to some of their designers or their facilities and see if they do any special precautions and then to observe some of their structures. But I don't know if we can swing that or not. We might try that.

CHAIRMAN WALLIS: When you talk about Florida, aren't there some Roman remains in phosphate rich areas of Europe somewhere?

MR. BANERJEE: They aren't Portland cement.

MEMBER MAYNARD: I think the ACRS should go look at some of those myself.

(Laughter.)

MR. BANERJEE: Possibly there must be stuff that's underground built after 1824 with Portland cement that are in phosphate rich areas.

CHAIRMAN WALLIS: Ruins after the First World War. There are lots of things.

MR. BANERJEE: We don't have to go to bridges to get samples of that.

MEMBER POWERS: Your testing program. Could you tell me again on your solutions, your sodium biphosphate solution was on the order of what concentration?

DR. DOLE: Ten to the minus one molar phosphate.

MEMBER POWERS: And your magnesium biphosphate?

DR. DOLE: Ten to the minus three.

MEMBER POWERS: Okay.

DR. DOLE: If you look at a natural water system, as phosphate percolates through the soil its solubility is going to be controlled by the calcium-magnesium dominate ions in the soil until it's overwhelmed, and so what we tried to do is emulate what would happen in a soil that was saturated with phosphate.

MEMBER POWERS: What I know about phosphate, aqueous phosphate chemistry is that you get concatenation of the anions. Wonder if you had been too concentrated that in running the saturated solution you've guaranteed that you've got concatenated ions instead of the bare phosphate or biphosphate ion.

DR. DOLE: I mean, it's possible. That's why we chose two concentrations.

MEMBER POWERS: Yeah, I understand. Ten to the minus third you'd ordinarily think is not, but I'm not sufficiently familiar with phosphate chemistry I can do the analysis in my head. But I just toss that question out.

Clearly, at tenth molar you should have relatively few single ions out there. I mean, there's now water in tenth molar solution. It's all tied up and coordinated. But I wonder if it's too concentrated.

DR. DOLE: Well, that was why we chose it.

You know, there are obviously corrosion effects that happen at 80 percent saturation rather than 100 percent saturation.

MEMBER POWERS: Okay. Just as a final thing. You have listened to our comments. You're not looking for us to write a letter on this?

MR. SHAW: No, not at this moment, but I follow what Otto said earlier. I think for our final report next year, we should make a recommendation.

MEMBER POWERS: And I would say from my perspective the best thing that's coming out of this research is, in fact, your primer on concrete and your collection of examples where you can use photographs to tell people this is the kind of stuff to look for. I think phosphate ion was an excuse to raise this issue: do we know what we're looking for in this? And it seems to me that this primer may be the real tangible benefit, the really most singular benefit that's coming out of this research.

Are there additional comments?

CHAIRMAN WALLIS: One has to respond to the objective we had at the beginning here, which was could there be a limit on phosphate concentration.

MEMBER POWERS: Well, I think you see that they're driving toward saying no, that in fact, there's no and whatnot. They've got a couple of things to think about here on what their experimental basis and their experiential basis are for making that conclusion, but you see where they're driving to.

I mean, we've given you our comments. Those are the questions we'll raise when you come back with your recommendation.

CHAIRMAN WALLIS: And we're not going to write a letter, it seems to me.

MEMBER POWERS: I mean, I don't see any benefit of writing a letter beyond to continue.

CHAIRMAN WALLIS: I think it was on the schedule.

MEMBER SIEBER: They never answered the fundamental question. So you can't write a letter.

CHAIRMAN WALLIS: It's a very interesting presentation.

MEMBER SIEBER: Yes.

DR. NAUS: Thank you.

MEMBER SIEBER: What containment is that that delaminated?

DR. NAUS: There's two containments in Florida that delaminated.

MEMBER SIEBER: Oh.

DR. NAUS: One was a combination materials problem and reinforcing problem, but there was no radial reinforcement, and the other they said was unbalanced prestressing forces. The aggregate materials in Florida are fairly poor. So they're weak in tension, and they didn't have reinforcement.

PARTICIPANT: Full of phosphates.

(Laughter.)

MEMBER POWERS: One question on your primer real quickly. Are you going to deal with Hack Holliman (phonetic) cement?

DR. NAUS: I think I mention it in there as not using it.

MEMBER POWERS: There's one plant that actually does use it in their base, and they worry about leaching.

DR. NAUS: Right. I think that's mentioned in there, if I remember.

MEMBER POWERS: Any other comments?

MR. SHAW: Dr. Powers, just one question. When we finalize those NUREG report and the primer report, do you want us to come back to give another briefing or just make sure you have the reports? That will be sufficient?

MEMBER POWERS: Well, let's start by looking at the report, and if it looks like it is sufficiently interesting to discuss. I mean, you gave us a pretty good outline of what it's contact here, and if members have additional interest, which I'll bet we would do just from the pictures, we can discuss that, what the timing, and things like that.

MR. SHAW: Okay. We'll await your decision.

MEMBER POWERS: Yeah. Let's start with the report.

PARTICIPANTS: Thank you.

CHAIRMAN WALLIS: Finished then?

MEMBER POWERS: I'll turn it back to you, sir.

CHAIRMAN WALLIS: Okay. So we've reached the time when we're going to take a break. Based on well known biochemistry, appetite increases with time and I think it's time to take a break until one o'clock. So we'll do that.

(Whereupon, at 11:56 a.m., the meeting was recessed for lunch, to reconvene at 1:00 p.m., the same day.)

CHAIRMAN WALLIS: Let's come back into session. We will hear presentation on integrating risk and safety margins. I will ask my colleague Bill Shack to introduce it. Please go ahead.

4) INTEGRATING RISK AND SAFETY MARGINS

4.1) REMARKS BY THE SUBCOMMITTEE CHAIRMAN

VICE CHAIRMAN SHACK: We are going to be discussing some work that RES has been doing on a framework for integrating risk and safety margins, safety margins is something that has been of interest to us as we look at things like upgrades and that and we discuss the notion of whether margins are being maintained.

In Reg Guide 1.174, we evaluate changes in risk, but we're also asked to determine whether there are adequate safety margins being retained. And so in some sense, I have always thought of safety margins as a measure of defense-in-depth.

Safety margins are a concept that comes out of our deterministic analyses, by and large. And, yet, risk we know is in a probablistic world that looks at, instead of a design basis accident world that looks at a much more realistic set of scenarios for a plant. And the RES work is a project here that tries to have a framework to merge this deterministic world of the design basis accidents and safety margin with risk.

And Ms. Gavrilas will present her work and show us how she proposes to integrate the two.

MS. GAVRILAS: Thank you.

4.2) BRIEFING BY AND DISCUSSIONS WITH REPRESENTATIVES OF THE NRC STAFF REGARDING A PROPOSED FRAMEWORK FOR INTEGRATING RISK AND SAFETY MARGINS

MS. GAVRILAS: I found this quote rather recently, "The natural consequence of uncertainty is risk." And I found it to be a good leading quote because our way of dealing with uncertainty is having safety margins. Therefore, there must be a natural nexus between the two.

As Dr. Shack just mentioned, the purpose of this presentation is to discuss the RES project, which produced a framework. It's a proposed framework to merge deterministic, probablistic, and engineering data, including uncertainties, into figures of merit that can be used to assess a plant modification. That was, I believe, the first item mentioned by Dr. Shack. And the comparison of this risk metric should be achievable against, should be done against existing acceptance of risk guidelines.

The topics I will cover are the motivation for this work. I will provide a very brief background because the background has been extensively written in other places.

I will talk about the objective. The objective is, as you have seen on the first slide, to quantify the changing plant safety margin caused by any conceivable physical modification.

And I want to mention up front the constraints under which this work has proceeded. The constraint was use existing tools and techniques and demonstrate the methodology to a current regulatory issue.

The method. The method is developed with two main areas in mind. One is, what is safety margin? And the second one is, how can safety margin be integrated into risk, if it can be integrated in risk?

I will briefly discuss the results of what this proposed framework actually accomplishes. And I'm going to show a proof of concept application. There's a simplified application in the draft NUREG report that you have been reviewing. And I will end with a discussion on when safety margin ought to be integrated with risk.

The background is several sort of highlights of background information. One is that in our current regulatory structure, PRA and deterministic calculations are used in a complementary fashion, but they remain separate and distinct.

Another point of information is that maintaining margin means different things to different people. And I will try to illustrate that in a short while.

And, finally, phrases like "Sufficient margin exists" and "This increases the available margin" are often used in a highly qualitative manner without the burden of quantification. I hope this framework can quantify such statements to some extent.

And then the final point is that there is indeed a wealth of tools and techniques that have evolved that can be used to accomplish this integration.

I have a little diagram of a couple of milestones that basically go into the methodology that you're going to see today, which starts in the '30s with exercising Monte Carlo algorithms and the tolerance intervals of the '40s. Basically the fundamentals of what you are going to see had been established by '67, when the 1D stress-strength interference was published by Freudenthal.

And, as you see in the 1985 and later, you can start seeing how these fundamental tools and techniques start to appear in our industry with quantifications of uncertainty and severe accidents, the best estimate plus uncertainty methods, NUREG-1150 and so on.

And the last two that I have mentioned are highly relevant to this work. They're the reliability of passive thermal hydraulic systems, which are quite similar to what you are going to see. And that was in around 1997 as part of an OECD effort and the pressurized thermal shock that has some connection to the work that you will see.

Now, as you see, the effort sort of culminates in combining all of those tools and techniques in relatively recent years. And I believe that there is a reason for that. I believe that the fact that our computational power has increased to the point to which we can effectively combine them has a lot to do with it.

And I mentioned that you see on this graph, it shows when the PC was introduced. And then you see NUREG-1150 a few years afterwards. And Mary Jo told me yes, the PC existed, but that doesn't mean that we didn't use the mainframe computers during it. So we're getting to a point at which these techniques can be merged and refined in a manner that is applicable and useful.

Now, Dr. Shack mentioned the plant modifications, power uprates. And if you take a cursory look at the type of plant modifications that have been proposed, you can look at the sort of first order implication of these plant modifications on something we care about and something we track as part of ensuring safety. And if you look at power uprates, the effect is on safety margins, on probabilities of occurrence of certain events and event sequences, and on the consequences of accidents.

And then you see I've color coded the others and flagged material burnup and MO_x fuel would impact safety margin. Aging and grid reliability would impact certainly probability of occurrence of certain accidents. And the ones that I left black would be impacted in all of these areas. That's just a very cursory superficial look at the list of modifications.

So from looking at that list, if you're trying to think, "I need to keep track of all of these modifications at one time. Somehow I need a risk matrix that puts together all of these effects," you can come up with the elements that comprise, that form the foundation of this risk metric.

And you will see that the first element is the probability that a certain accident sequence will occur. And you are very superficially -- I am just going to say that it is provided by our existing methods and probablistic risk analyses.

The probability that loss of function will occur given that particular accident sequence.

CHAIRMAN WALLIS: This is a key part of your thesis is this loss of function. Most PRAs have a kind of loss of function because they have a yes/no pull, where you go this way or you go that way.

But in many, say, thermal hydraulic sequences, you don't have a loss of function. You have a partial loss of performance.

MEMBER SIEBER: Degradation.

CHAIRMAN WALLIS: And then there are other partial losses of performance. And the consequences are sort of a continuum. They're not a yes/no response to a loss of function. That complicates things because obviously yes/no event tree is easier to follow than one which has more of these continuous responses.

MS. GAVRILAS: Let me see if I understand your question because I believe that there are two questions there.

CHAIRMAN WALLIS: A statement, really, as well, yes.

MS. GAVRILAS: Is there a question for me or --

CHAIRMAN WALLIS: Well, I'm just saying that loss of function may not capture the reality.

VICE CHAIRMAN SHACK: It's a probability of a loss of function.

CHAIRMAN WALLIS: Yes, but the loss of function is, does it fail or does it not?

VICE CHAIRMAN SHACK: Right.

CHAIRMAN WALLIS: I'm saying --

MS. GAVRILAS: The probability.

CHAIRMAN WALLIS: -- lots of things partially don't work.

MS. GAVRILAS: That's --

MEMBER SIEBER: Yes. That's where margin comes in.

MS. GAVRILAS: I will tell you my thoughts to the statement you just made. My thoughts are that you are actually talking about two things. One is the success criteria, and one is the end state.

The success criteria and the reality are not you have failed or you haven't. You might inject some fluid but not enough to achieve the function that you wanted to achieve.

And the second part I think of your statement is, how would that be reflected in the end state? Would it be because now your end state is not a one or a zero, but now your end state is somewhere in between.

I believe that this framework does address that with the proper amplification of event trees to capture the subtleties that you just mentioned and with allowing at the end of the event tree a probability basically, rather than a one or a zero, which would be, for example, the core damage or okay state. So yes, this will be a portion of my talk to follow.

And, finally, the third element that you saw in that list of items to be considered when developing this framework is that the consequences of a given event sequence will also differ.

And then an example of that is if you have a rather skewed power profile and you perturb it, you're probably going to ruin a couple of fuel bundles. But if you flatten the power profile and now you perturb that, you can damage a larger fraction of the core.

I think the first one, the peaking factor, basically, the two have similar peaking factors. So the peaking factor would be under the probability of losing function. But, again, in terms of risk, that's not a sufficient measure.

CHAIRMAN WALLIS: What function is lost when you have lost integrity of the fuel, but the question is by how much, really, which goes back to my original question? All core damages are not equal. We talk about core damage frequency. Really, all core damages are not equal.

It's very much of a simplification to have to say a CDF. One rod slightly damaged is very different from 60 rods damaged.

MS. GAVRILAS: That's right. So if your risk metric includes both --

CHAIRMAN WALLIS: It's a continuum of consequences then.

MS. GAVRILAS: It's a continuum of consequences. I think I know where you're going. Unfortunately, this is not going to give you the answer.

CHAIRMAN WALLIS: Okay. No. It's --

MS. GAVRILAS: It's going to be on the last slide under "Future Work."

VICE CHAIRMAN SHACK: Let me come back to a question that when you integrate risk and safety margins, how is this different from a PRA with a full uncertainty analysis?

If your only metric of interest is risk that is a product of a PRA and you seem to be very concerned with uncertainty, well, I can deal with uncertainty in the context of a PRA and evaluate that metric on risk.

I normally think of safety margin as a defense-in-depth kind of consequence that, you know, not only do I want to protect against risk. I want additional levels of protection. I want to protect my barriers, whether or not they lead to a severe accident.

And so I look at safety margins as a defense-in-depth, but you have integrated the two now. And is there a difference now with the PRA with uncertainties and your integrated framework?

MS. GAVRILAS: I think that there is a difference. And I think that the difference is not as much in the methodology. I think that this methodology is very much consistent with PRA with full-fledged uncertainty propagation.

But the difference is in what I consider failure at the event of the path. And I think I am going to get into that in a couple of slides. I mean, where do I consider that I failed? When does this conditional probability of failure occur? So let me see if two slides from now maybe I have addressed your question.

So the one thing that I think by this time becomes rather obvious is that integrating safety margins and PRA is laborious and expensive. One of the first questions that you ask yourself is, when do you need this? And I think that clearly if you have sufficient margins, you don't need it. And I've made the analogy of how closely you keep your --

CHAIRMAN WALLIS: You are now defining a sufficient margin by the statement. Sufficient margin is sufficient when knowing any more doesn't benefit you, having any more doesn't benefit you --

MS. GAVRILAS: Definitely true.

CHAIRMAN WALLIS: -- in terms of the consequences or the risk or something?

MS. GAVRILAS: In terms of --

CHAIRMAN WALLIS: It doesn't change the risk.

MS. GAVRILAS: Exactly, in terms of imperceptible to risk.

CHAIRMAN WALLIS: So the probability of failure is now negligible. Is that what happened?

MS. GAVRILAS: That's exactly right. So when you have sufficient margin, when you're operating -- I'll give you an example of what I was thinking.

I was thinking I was looking at CSAU. And in the executive summary, they have the peak core temperature calculated was 1,272. And they had a plus/minus 300-degree uncertainty associated with that value. So they were at 1,572. That was the conservative value that they listed for their analysis.

A few days ago I was looking at some other document in which the calculated peak clad temperature was 1,950. And it occurred to me that that is quite a substantial difference.

CHAIRMAN WALLIS: In regulatory space, it makes no difference at all.

MS. GAVRILAS: Agreed. And, as you will see in here, it makes no difference whatsoever. But I mention that because I was thinking the 2 sigma bound was 1,572. That's sufficient margin. That's a case where you wouldn't worry about this. But it's exactly like Dr. Wallis said. It makes no difference the 1,950 either.

So when would the process benefit from exercising this rather expensive framework? It would be when you have a case of limited margin. And I'm giving as an example the net positive suction head in GSI-191.

Furthermore, that margin can be reasonably tied to a loss of function. And, by that, I mean, there is no redundant system that will fulfill that function. And, finally, there is a justification needed to continue operation. Those would be the three conditions under which I can see something like this becoming useful.

Under those circumstances, your decision may be easier if the current decision process is augmented by an analysis of this type. And this analysis will go beyond using deterministic and probablistic analysis as separate principles.

And now we're getting into the question of what is safety margin. The origin is in conservative. You have a conservative calculation. And here is a trend for a peak clad temperature history done under conservative appendix K conditions.

And then you have a region of damage that you see in the rectangle at the top of the graph. And within this region of damage, people identified some key points.

I think there's onset of damage, which is when a significant number of the parts subjected to that type of load are going to fail. And then what was often used and historically used was the actual failure, which we can think of as the mean of that damage distribution.

There are several definitions of margin that I have seen at different times. I am adding here the safety limit, which is drawn hopefully somewhere under where damage becomes perceptible.

And this is a few combinations. These are three combinations, definitions of safety margins, that I have seen: peak value to actual failure; peak value to safety limit; and, finally, safety limit to onset of damage.

CHAIRMAN WALLIS: The margin is loosely determined in terms of whatever happens to be the axis on the *y* axis, which is not really much of a measure of anything. It's just arbitrary. It's the sum of physical and quantitative.

I like the approach where I saw in part of your paper where you were trying to get a probablistic definition of margin, which was dimensionless and, therefore, meaningful to me. If I plotted something else, like the log of the temperature or temperature in some other kind of unit or something, I might get a different looking margin, which is not a very good thing to have.

MS. GAVRILAS: I am still in the background material. And I believe that this audience is highly familiar with these. So maybe I should --

CHAIRMAN WALLIS: Yes.

MS. GAVRILAS: -- speed up going over these slides. Maybe that's what you're saying.

CHAIRMAN WALLIS: No. I think it's useful. It's useful.

VICE CHAIRMAN SHACK: I am learning something.

MEMBER BONACA: No because, I mean, the discussion and all, you were pointing out, Bill, that the limit is a regulatory limit. It's arbitrary.

VICE CHAIRMAN SHACK: Well, what you were calling the safety limit I would call the regulatory acceptance limit.

MEMBER BONACA: Yes.

VICE CHAIRMAN SHACK: And that's to me a somewhat arbitrary number.

MEMBER BONACA: Because it's drawn there at 2,200, but it could be 2,220 or it could be 2,180. It's just a point below the actual physical onset of damage.

MS. GAVRILAS: I believe I am covering that in the next slide. And I think that, actually, I regard that as the most controversial part of this presentation, which is why I'm --

MEMBER DENNING: Let me see if I understand, though. Do you differentiate between the term regulatory limit and safety limit? See, I would have thought in your case here you might have picked the onset of damage for your safety limit.

MS. GAVRILAS: For the purpose, I have a separate slide that shows exactly what I would define as safety margins given our state of knowledge today. And that is coming up in a second. This is more of historical --

CHAIRMAN WALLIS: Just saying these are some ways people have tried to define safety margins.

MS. GAVRILAS: That's right.

MEMBER BONACA: The reason why I think it is so important is that those limits right now are in the tech specs. They are in the FSARs. They're all over the place. They're called limits, 2,750 for the pressure or on a PWR, 2,200. So that's why you can't just forget about them. I think any discussion has to refer to what --

MS. GAVRILAS: I would like to answer your question because I mentioned on the second slide one of the constraints for the current work. One of the constraints for the current work was make it so that it's applicable to something of current regulatory interest.

Therefore, what you're seeing throughout the report is an assumption that the safety limits a they exist on the books for lightwater reactors, for currently lightwater reactors are it. That is the safety limit, so the 2,200, for example.

Without the qualifier on adequacy except under one point, where I say for future thinking, I mention at one point, for example, the containment pressure design limit is very low relative to the actual failure point, where you start having non-negligible failure on the probability density function.

And I haven't qualified the statement, but I said in some cases, it's worth if you have such differences and you can justify changing. It might be worth considering what you are going to use as the safety limit.

But throughout my talk, the safety limit is the safety limit that is in the books right now.

MEMBER BONACA: The only other thing I

want to say about it, the reason why it has been so important is that something that ensued in the industry that says anything below the safety limit belongs to the licensee and they can claim it through analysis. Anything beyond the safety limits belongs to the regulator and it can't be touched. So there is such a historical foundation in the licensing basis that we cannot neglect the existing definitions. So I'm saying it has even legal meaning.

CHAIRMAN WALLIS: It's gets worse than that because we heard with several of those BWRs, you get this so that this factor for D and B, D and B ratio, which somehow gets set by the licensee in different ways in different plans, then accepted by the agency.

MEMBER DENNING: I think that's exactly the point that Mario was making. That's the domain that's up to the -- in which they could play. So it's effectively --

CHAIRMAN WALLIS: Once they have chosen the 1.3 or 1.5 or something, they're stuck with it until they come back to the agency again. So they don't have the margin. They've given it up to the agency.

MEMBER BONACA: Well, they can come back

and claim it.

MEMBER DENNING: Because they can come back and claim it. That's right. Right.

CHAIRMAN WALLIS: Right.

MEMBER BONACA: In fact, at one of the most recent power uprates, you know, with Westinghouse, they went all the way to 2,750 notice in the PT envelope And the reason is so that they don't have to perform any fissile calculations below that because they already claimed it. So it's right there on the document.

MEMBER MAYNARD: When you go back through it, there is a safety limit that is hard and fast. On the cases that we were looking at, there are two sets of margins. And the licensee will set where they want to make that line, but there's still margin in both of those areas that belong to the licensee. But to change the division, they have to come back to do that.

MS. GAVRILAS: They changed the limit. I'm adding. And this I'll go very quickly. I'm adding that with allowing best estimate predictions, with their uncertainty band, of course, the range of safety margin is increased even further because now you have another comparison, the range of possible definitions of safety margins.

CHAIRMAN WALLIS: Just say there that these uncertainties include the uncertainties that you know how to quantify. And uncertainties due to the fact that you have a lousy momentum balance at your nodes isn't in there at all. And that's something extra. That's why you often have an extra safety margin, to allow for the fact that --

MS. GAVRILAS: May I?

CHAIRMAN WALLIS: -- there are things you didn't know about.

MS. GAVRILAS: We are once again anticipating the next slide. So here is "I think what you are saying" is the heading of the slide, which is in the nuclear industry, there are two prongs to safety margins. And the two prongs leave room for the unknown unknowns that I believe Dr. Wallis was just mentioning.

There are a few probability density functions, one the inherent capacity of the barrier, for example. And the second one is the probability density associated with your core prediction which is the load. Somewhere above that is the appendix K prediction. In some cases somewhere, there's an assumption that it is above it.

So the first prong of safety margin, as I understand it, is that a safety limit is set such that as long as you're operating underneath it -- but what I mean by "operating underneath it" is the substantial part of the load probability density function stays under the safety limit -- your probability of losing that barrier, your probability of failing that barrier is negligible.

And then the second prong is now that you have the safety limit, stay under the safety limit and stay under the safety limit for the design basis accidents, either with the conservative assumptions imposed by appendix K or by doing a best estimate plus uncertainty at the required confidence level.

MR. BANNERJEE: How does this deal with the unknown unknowns?

MS. GAVRILAS: What deals with the unknown unknowns is setting the safety limit below the capacity.

MR. BANNERJEE: Imagine that your results on that left-hand side are dependent on scale and you cannot do large-scale testing. Okay? So that's an unknown that I have no estimate of the uncertainty.

MS. GAVRILAS: That's right.

MR. BANNERJEE: How does that blue line

and the black line separation and that red thing have anything to do with this unknown? It could be that the blue line will come right over to the right-hand side of large scale.

MS. GAVRILAS: It could be, but the intent of the safety limit is to deal to the best of people's knowledge with unknown unknowns. The way I --

MR. BANNERJEE: This is engineering judgment.

MS. GAVRILAS: That's exactly what it is. And they're achieved, actually, from what I know. They're achieved by negotiation very often, where the regulator is on one side of the table, the industry on the other. And I think the 2,200 was decided exactly that way, let's split the difference.

So yes. But you're hoping that these experts, who are sitting around the table, know something.

MR. BANNERJEE: It's like the world trade agreement or something, WTO. It's got nothing to do with reality.

MS. GAVRILAS: It only has as much to do with reality as the experts sitting around the table can infuse into it. You're absolutely right.

CHAIRMAN WALLIS: Be careful, Sanjoy,

because you may be making some of these things.

VICE CHAIRMAN SHACK: The other thing that is unrealistic about this argument is that if I'm going to do a best estimate with uncertainty, my appendix K prediction is probably to the right of the safety limit.

And the reason I'm doing the best estimate with uncertainty analysis --

CHAIRMAN WALLIS: To bring it back.

VICE CHAIRMAN SHACK: -- is to get below my safety limit. I'm pushing my core to get something here.

CHAIRMAN WALLIS: Well, are you going to continue and tell us what safety margin is?

MR. BANNERJEE: No, but you haven't clarified to me yet how you deal with the unknown unknowns. I don't think you can, frankly.

CHAIRMAN WALLIS: You can't. You can't.

MR. BANNERJEE: You cannot.

MS. GAVRILAS: You cannot. The answer is you cannot.

MR. BANNERJEE: If you give me an answer saying I cannot, I mean, I will accept it.

MS. GAVRILAS: That's the answer.

MR. BANNERJEE: All right.

MS. GAVRILAS: The answer is you cannot.

CHAIRMAN WALLIS: Well, you can, but you can't do it with very much confidence.

MS. GAVRILAS: Right.

MEMBER BONACA: But in many cases, however, even when there was no knowledge. For example, take safety limit for the containment design pressure, 50 psi. We didn't know at that time that the actual capacity of the containment was maybe three times as high or more, but we knew that there was margin above that. And then, of course, there was testing being done for lick rate. And we knew that functionally it wasn't licking at the safety limit.

So the unknown was we didn't know where the margin above that was, but we knew that there was a solid limit. Now, we discovered later on through research that there was a big margin.

Now, in other parameters, it's not as clear because it is not as large.

MS. GAVRILAS: I am talking very little in this presentation about what is done in terms of separating the known unknown and the variabilities and the epistemic and dilatatory uncertainties. And to some extent, I have tried to pass the buck sort of in the draft NUREG, too, because it is an area of growth and an area of development.

But I will give you an example of what is being done. What is being done is there are techniques that generate a lot of these probability density functions, each of them corresponding to a set of epistemic uncertainties, lack of knowledge on certainties. So then, instead of getting one probability density function, you get a family of probability density functions. And those sort of give you an idea of how much your lack of knowledge is impacting any of these distributions.

MR. BANNERJEE: You are saying you will extrapolate from your experience based on doing things in the past and say --

MS. GAVRILAS: There are some techniques that are going in that direction. And you're extrapolating. You're saying sort of if you know that this is what you don't know, then maybe you have the basis for making a guess on where you should --

CHAIRMAN WALLIS: That's just guesswork. I mean, looking at Sanjoy's scaling question, you do experiments at a lot of scales, maybe up to half scale. Maybe you can't do it at full scale. And then you can sort of see what pattern they form.

You can do theoretical analysis to develop a code. And if it, mechanistically based, represents the data at all of these scales, then you get more confidence in extrapolating it to full scale. You can do a lot of things which help you to more confidently extrapolate. You can never extrapolate exactly with confidence one, but you can get closer to it.

MR. BANNERJEE: I'll accept that argument.

CHAIRMAN WALLIS: Which is what we do. Now, I want to see what you define safety margin as. That is a key point.

MS. GAVRILAS: That's it.

CHAIRMAN WALLIS: Well, tell us what it is.

MS. GAVRILAS: Well, it is the distance. The actual safety margin --

CHAIRMAN WALLIS: The distance.

MS. GAVRILAS: -- is the distance --

CHAIRMAN WALLIS: Kilometers or something?

MS. GAVRILAS: How about the distance for --

MEMBER SIEBER: In relativistic space.

MS. GAVRILAS: It applies to only one event scenario.

CHAIRMAN WALLIS: Okay.

MS. GAVRILAS: What you are seeing here is one event sequence, one accident, one accident that has one damage mechanism at the end. There's one damage mechanism. This damage mechanism is represented by the safety variable that you see on the *x*-axis.

CHAIRMAN WALLIS: Okay.

MS. GAVRILAS: In that case, the safety margin is the distance between where the probability of the load becomes basically substantial to where the probability of the capacity becomes non-negligible.

CHAIRMAN WALLIS: So in your definition, it depends on what you define as negligible because there could be an overlap, even when you define --

MS. GAVRILAS: I'm assuming that there is --

CHAIRMAN WALLIS: I had trouble with your paper because you define safety margin as the distance between the bounding prediction of the load and the point at which failure becomes non-negligible. So that would mean that if you have a safety margin, there's negligible probability of failure.

MS. GAVRILAS: Or that --

CHAIRMAN WALLIS: Why do you have any safety margin at all? There's negligible probability of failure with your definition.

MS. GAVRILAS: For the accident for which -- yes, for that particular accident.

CHAIRMAN WALLIS: But, then, in another part of your paper, you see, you say, "The safety margin, as defined in the glossary, gives the probability of loss of function." And it seemed to me you had defined it so there was no probability of loss of function. It cannot be one thing and the other.

MS. GAVRILAS: This is for one accident.

CHAIRMAN WALLIS: But I have a lot of problems there because I thought when you said, "The safety margin gives the probability of loss of function," I said, "Hallelujah. Someone at last has got a proper definition of safety margin."

I look at the glossary. You have got this thing, where it depends on what you mean by negligible. It depends upon the scale you use for your *x*-axis and --

MR. BANNERJEE: Why didn't you simply non-dimensionalize it with the means and the standard deviation?

CHAIRMAN WALLIS: Or something.

MS. GAVRILAS: Right now let me go on because --

CHAIRMAN WALLIS: Wait a minute now. Do

you mean it's the separation between these things, where nothing could happen, --

MS. GAVRILAS: Or a design basis --

CHAIRMAN WALLIS: -- or is it the overlap which gives you the probability of something happening? Those are very different things.

MS. GAVRILAS: The overlap is the probability. The overlap --

CHAIRMAN WALLIS: Is that what you mean by safety margin, some measure of overlap? I thought that's what you meant in your whole paper.

MS. GAVRILAS: Actually, it's not the probability of overlap between the capacity. It's worse. It's the exceedance. That's why I keep trying to interject.

Let me address your first question.

CHAIRMAN WALLIS: I want to be clear by what you mean by safety margin, though. Is it the separation? If you separate with a safety margin, nothing can go wrong?

MS. GAVRILAS: Or the design basis accidents.

CHAIRMAN WALLIS: Or is it the other definition, where safety margin is a measure of the probability of something going wrong? There are two probably different ideas.

MS. GAVRILAS: I agree.

CHAIRMAN WALLIS: Which is it?

MS. GAVRILAS: What you see over here. This moves from accident to accident, which means that if you have drawn the safety limit so that this stays under it for design basis accident, that doesn't meant that this probability density function is not going to shift to the right such that you will actually start interfering with the capacity in a non-negligible way --

CHAIRMAN WALLIS: That doesn't tell me what you mean by safety margin.

MS. GAVRILAS: -- in other accidents. I mean this by safety margin. Some --

CHAIRMAN WALLIS: If there is a safety margin like this, you're saying nothing can happen, an accident cannot happen, damage cannot happen, because there is a space between these probability distributions?

MS. GAVRILAS: That's right.

CHAIRMAN WALLIS: But nothing can happen. Yet, in your text, you say the safety margin gives the probability of --

MS. GAVRILAS: In some accidents, these

two come together.

CHAIRMAN WALLIS: But then your definition has got to be consistent. That's all I'm asking for.

MS. GAVRILAS: Okay. I'm --

CHAIRMAN WALLIS: Either it gives a probability or it gives the condition of zero probability. It cannot be both.

VICE CHAIRMAN SHACK: Let me come back. In the case of dealing with the unknown unknown, the safety margin is the difference between that onset of failure and your safety limit.

That best estimate plus uncertainty isn't the real world. That's only a calculation. If you're wrong, that's why you have the safety margin. The safety limit is set below the safety margin because, in fact, even though you're calculating your best estimate plus uncertainty, it could be wrong. And the uncertainty is not what you think it is.

Your appendix K calculation is intended to be conservative, but if it isn't conservative, what additional margin you have is --

CHAIRMAN WALLIS: You're down from a boiling, which you didn't put into it.

VICE CHAIRMAN SHACK: -- safety limits and the onset of failure.

CHAIRMAN WALLIS: Right.

VICE CHAIRMAN SHACK: So I would argue that the portion of this thing that addresses the unknown unknowns is that delta. The safety margin you have shown is a fictitious thing because I don't know where the real distribution of loads is.

MS. GAVRILAS: But the fact that the safety margin is defined in this way does not bear on calculating the risk. How's that? It does not bear on calculating the risk.

Let me go on to the next slide.

VICE CHAIRMAN SHACK: It bears on when I am losing safety margin. If all my calculations are below the safety limit, I haven't lost any margin, --

MS. GAVRILAS: Yes.

VICE CHAIRMAN SHACK: -- even though I am sometimes closer or further from the safety --

CHAIRMAN WALLIS: Even though you are closer, right.

MS. GAVRILAS: That's right.

VICE CHAIRMAN SHACK: If my appendix K is really conservative, my probability of failure just isn't going up.

CHAIRMAN WALLIS: It's still zero.

VICE CHAIRMAN SHACK: It's still zero.

It's only when I go over that safety margin --

CHAIRMAN WALLIS: So how can safety margin be measured by the length between the arrows, then, if it doesn't change when you move that thing around?

MS. GAVRILAS: It does not. It doesn't --

CHAIRMAN WALLIS: It only changes when it crosses a boundary.

MS. GAVRILAS: The initial work that was done here -- I think there are several questions now. I am going to try to -- there are several issues. I am going to try to take them one by one.

The initial work that I did in this area actually attempted to quantify -- and it's in the appendix. It's a very brief -- attempted to quantify the loss of margin incurred when you move that best estimate plus uncertainty distribution to the left. Yet, you still stay under the safety limit.

The problem with that is it flunked the test on current -- demonstrate your methodology to an issue of current regulatory interest because we don't have acceptance criteria for evaluating any such loss of margin.

If I just move that blue distribution a bit to the right, yet, it doesn't impinge on the safety limit, I don't have an acceptance criterion for that. We're saying that it's okay.

But one thing is that the safety margin -- I believe that this is the definition of safety margin. Yet, to calculate the probability, to calculate a risk metric, this definition is going to just stay a definition. It's just informing what safety margin is.

MEMBER BONACA: The beginning of the bracket there is the best estimate calculation plus uncertainty?

MS. GAVRILAS: The blue one. This one. This is the best estimate value. And this is --

MEMBER BONACA: The uncertainty?

MS. GAVRILAS: The uncertainty.

CHAIRMAN WALLIS: Where did you cut off the tail?

MS. GAVRILAS: I'm sorry?

CHAIRMAN WALLIS: Where are you going to cut off the tail?

MS. GAVRILAS: Not exactly, didn't even make an attempt at putting numbers to what I mean by negligible or non-negligible. This part is far from that.

CHAIRMAN WALLIS: I'm assuming you can calculate this probability distribution. Now, you may calculate, you know, '99 values of PCT, which are 1,500, plus 2, which are 2,300. What do you do now?

You know, it's a double hump distribution. You're assuming that something like that changed. It may not be. It may be that once you get in across some bifurcation, you get a disaster. So you have a probablistic distribution, which has nothing here and then another --

MS. GAVRILAS: I am drawing them as normal or convenient.

CHAIRMAN WALLIS: Not necessarily. It's a whole lot of --

MS. GAVRILAS: I'm not making any assumption about it being normal. As a matter of fact, there's a bit of formalism, the background, that I think says yes, it's okay to draw that margin the way I did.

CHAIRMAN WALLIS: There's a problem. It's a problem I'm raising, which is how do you establish this curve that you drew there? And what do you have to do in order to establish it? You have to do a number of experiments. You have to actually quantify what it is you mean by the certainty with which you can predict that curve.

MS. GAVRILAS: And you do it by, for

example, the best estimate plus uncertainty methodology that's accepted for large break LOCA calculations in the design basis.

MEMBER BONACA: But it should be the set of the bracket there.

MS. GAVRILAS: And you do it to 95, 95 confidence level.

CHAIRMAN WALLIS: No. That's again the question. If I do 59 runs or say I do lots more because I want to get it, you know, make it more evident, so 210 runs. So I can take the top four or something. And I find that 2 of them are 2,300. I might say, what were the conditions that led to those 2,300?

I'm not going to just accept this thing. I'm going to look at how I got there because there's something odd about the fact that I've got a group of points where, you know, there's a certain combination of circumstances where I leap over them at the boundary, right?

There is a whole lot of questions that come up with these kinds of methods. And when you draw a curve like that, you're sort of assuming that that is the way things are.

MR. BANNERJEE: And it can happen

practically in experiments.

CHAIRMAN WALLIS: It can happen practically in experiments, right.

MR. BANNERJEE: Because let's say in one case you drain the steam generators or something and you get enough water inventory to re-wet the system and in another case you don't.

CHAIRMAN WALLIS: Like the CMTs. The CMTs and AP600 can drain at different times.

MR. BANNERJEE: That means it doesn't re-wet. So you can get totally different clad temperature. So in practice, if you look at experiments, you can get bimodal distribution. So it's not that she's just pulling it out of the hat.

MS. GAVRILAS: I believe it. And I will tell you I haven't thought about it, and it doesn't seem to be a trivial question that I can answer right now. I have put it down as something to consider and to think about.

CHAIRMAN WALLIS: I think if you concentrate on what I thought was a good definition, which was the overlap probability, and how accurately you can calculate that, I think that is a very good way to start.

MS. GAVRILAS: Should I skip these?

CHAIRMAN WALLIS: It doesn't matter if it's bimodal. It doesn't matter what it is. You know, as long as you're saying, "That's my definition," then I can use that. I can't use something which assumes normal distribution. It's not general enough.

MS. GAVRILAS: I hope I have not. And if I have, I will go over the report with a fine toothpaste --

(Laughter.)

CHAIRMAN WALLIS: Toothed comb.

MS. GAVRILAS: -- to remove it.

MR. BANNERJEE: Why don't you go back to the previous slide?

MS. GAVRILAS: Let me go to the previous because --

MR. BANNERJEE: Show it with a weird shape. Don't show it normal.

MS. GAVRILAS: I will do that.

MR. BANNERJEE: That will take care of it.

MS. GAVRILAS: I will do that. But, as I said, the previous slide is the definition of safety margin.

CHAIRMAN WALLIS: That's what I have trouble with. I don't know what you mean by safety margin yet.

MS. GAVRILAS: It will not have a bearing on calculating the risk metrics. And I think --

CHAIRMAN WALLIS: Is that relevant?

MS. GAVRILAS: I believe so.

CHAIRMAN WALLIS: Get that slide right. Let's forget it.

MS. GAVRILAS: Not just that slide. From our discussion right now, if it's a cause for confusion --

VICE CHAIRMAN SHACK: If it is meaningless, why do we have to integrate it with risk?

MS. GAVRILAS: I'll leave that one and try to --

MR. BANNERJEE: Now, does safety margin matter or doesn't it matter?

MS. GAVRILAS: Well, that's a great question. Safety margin does not matter unless you have lost it, unless you have lost enough of it, unless you have lost enough of it to exceed the safety limit. Safety margin only starts mattering when you have lost enough to exceed the --

CHAIRMAN WALLIS: Your thesis --

MR. BANNERJEE: In other words, if it becomes negative.

MS. GAVRILAS: -- as used in this framework here.

CHAIRMAN WALLIS: Your thesis, your thesis -- I think it's right, -- I think I've got it right, which I like -- is that you're focusing on the probability of loss of function.

MS. GAVRILAS: That's right.

CHAIRMAN WALLIS: And safety margin is such a qualitative thing that it doesn't really help you until you have a probablistic definition. Is that right?

MS. GAVRILAS: I hope so.

CHAIRMAN WALLIS: That wasn't clear from your paper. That's what I want to get clear.

MR. BANNERJEE: Neither from your presentation up to this point, actually.

MS. GAVRILAS: Because I am still at this point. That's why, I hope, if I managed to --

MR. BANNERJEE: In the first slide, you have to make your point. Otherwise everybody is going to ask you questions.

CHAIRMAN WALLIS: See, otherwise it's a distraction and we get the wrong idea of what you're doing.

MS. GAVRILAS: Well, I believe that the

reason is that safety -- I'll leave it. I'll leave it because I'll just get myself into more hot water. So let me just skip over that.

CHAIRMAN WALLIS: As long as the hot water isn't too hot.

MS. GAVRILAS: Sitting here, it's awful.

CHAIRMAN WALLIS: Less than 2,200.

MR. BANNERJEE: Exceeded your safety margin.

MS. GAVRILAS: I have not yet, thank God. I'm getting close to the limit, though.

(Whereupon, the foregoing matter went off the record briefly at 1:55 p.m.)

MS. GAVRILAS: Well, I am going to mention why I believe -- and I am going to skip over this very -- why I believe that that drawing of safety margin is actually substantiated, not just by what we understand in the industry with those two prongs, but also if you look at more formal definitions of safety margin as the difference between the two means over the square root of the two standard deviations, you actually capture the same image that I had --

CHAIRMAN WALLIS: Definition of safety margin minus the log of the probability of failure.

MS. GAVRILAS: Again? Sorry?

CHAIRMAN WALLIS: The probability of failure is 10^{-6}. The safety margin is six. Well, even with natural log, we -- minus the log of the probability of failure.

MS. GAVRILAS: Haven't seen that one.

CHAIRMAN WALLIS: The bigger it is, the better it is.

MR. BANNERJEE: Divided by the standard deviation, multiplied by the --

MEMBER DENNING: This stuff -- are you going to go through this?

MS. GAVRILAS: I would like to skip over it because I think that this is historical, what we mean by safety margin. And, therefore, it justifies the probability that I am going to calculate for losing for loss of function.

CHAIRMAN WALLIS: Well, let's get there. Let's get going.

MEMBER DENNING: I just had a couple of quick points on it, though.

MR. BANNERJEE: The definition she's got on --

MEMBER DENNING: Now, as a definition, the definition that's here is not exactly the same as the definition you had previously. It's comparable in some ways, this one, but it's not the same.

And I got a little confused in the report as to whether you were saying that they were the same or whether this is just an alternative.

MS. GAVRILAS: It's consistent. It's not the same. But it is consistent with that physical conceptually with the way I -- as opposed to -- I'll tell you why that appears there.

I have seen safety margin defined as the difference between the means. And I believe many of you have seen that. But it is in the open literature. You see it a lot, the difference between the means of the two distributions. And I've just said that that's --

MR. BANNERJEE: This one is non-dimensional. It's not three miles.

MS. GAVRILAS: It will disappear. This slide is strictly in response to a question that you haven't raised, which means there is another parameter. The convolution between the two --

CHAIRMAN WALLIS: We said this. We already said the shape of the probability distribution mattered.

MS. GAVRILAS: No. This says --

CHAIRMAN WALLIS: But you're saying it

again.

MS. GAVRILAS: Exactly.

CHAIRMAN WALLIS: Right.

MS. GAVRILAS: This is it's not just safety margin that's formally defined, but also these two have the same mean and they have the same standard deviations. Yet, one would choose very different safety factors to --

MEMBER POWERS: What if there were Laurentz distributions?

MS. GAVRILAS: Sorry?

MEMBER POWERS: What if there were Laurentz distributions?

MS. GAVRILAS: I'm sorry?

CHAIRMAN WALLIS: Laurentz.

MS. GAVRILAS: I couldn't hear it.

MEMBER POWERS: What happens if there are Laurentz distributions? We tend to use Gaussian to describe experimental uncertainties, though, in fact, uncertainties probably are Laurentz-distributed. Now, what happens in that case?

MS. GAVRILAS: Haven't given it any though.

MEMBER POWERS: There is no definition. The variance is undefined.

MS. GAVRILAS: Fortunately for me, the probability of the losing function that then goes into the risk metric does not depend on the shape of the --

CHAIRMAN WALLIS: You guys have the same standard deviation. They don't have the same mean, do they? You have to move one over in order to do that.

MS. GAVRILAS: Yes, I have to.

CHAIRMAN WALLIS: I think if you move the green on over, you would make your point better that the green one --

MS. GAVRILAS: Right. I have to make one --

CHAIRMAN WALLIS: -- would then overlap the safety variable. That's the whole point.

MS. GAVRILAS: One ought to go like this and the other one ought to go like this.

CHAIRMAN WALLIS: Then it would move it over. Then it would move the green one over. Then you would make your point. You've got the same mean and standard deviation, but the green one has some mechanism for disaster and the purple one does not.

MS. GAVRILAS: Thank you. Yes. And it actually makes the point better.

CHAIRMAN WALLIS: This one doesn't make the point. This one does make the point.

MEMBER POWERS: Clearly anything else will be at least as good.

CHAIRMAN WALLIS: The probability of making the point with this one is zero.

MEMBER POWERS: Then anything else will be at least as good.

CHAIRMAN WALLIS: We're being supportive. So please go on.

MS. GAVRILAS: I can tell. I'm overwhelmed by your support.

(Laughter.)

(Whereupon, the foregoing matter went off the record at 2:00 p.m. and went back on the record at 2:01 p.m.)

MS. GAVRILAS: Let's move on because the idea is -- and we talk about these distributions. And maybe we have talked to them too much, but I wanted to have, what is the safety margin? But now how do we translate the concept that's embedded in safety margin into something that can be embedded in risk?

The concept, I said, how about if we use the safety limit as a surrogate for the capacity for the entire distribution of the capacity? The reason for doing that other than its convenience is if you assume that failure occurs discretely when you reach the safety limit, of course, your life is much easier computationally. And it captures the safety margin. What it captures about the safety margin --

CHAIRMAN WALLIS: Failure could cost the regulation. Certainly occurs when you exceed some limit. So that's a good definition. Operationally in terms of what you do when you submit an application, that's exactly what happens.

MS. GAVRILAS: Yes. The assumption is exactly that. Now, what it does and what it captures out of the concept of safety margin is that it leaves room for unknown unknowns. And, as I said, how much room, that remains to be determined. But for current reactors, that's not an issue, like I said in the beginning.

CHAIRMAN WALLIS: Why does it leave extra room for unknown unknowns?

MS. GAVRILAS: Because you are --

CHAIRMAN WALLIS: Because you're staying further away --

MS. GAVRILAS: The safety limits have been set in a conservative manner. That is a presumption throughout the report --

CHAIRMAN WALLIS: Okay.

MS. GAVRILAS: -- that relative to the

load, the safety limit has left some room. That's why.

MR. BANNERJEE: But you are saying you are setting a direct delta function for the capacity here. So what you are --

MS. GAVRILAS: I am using the direct delta function at a value of the safety limit as a surrogate for the capacity in the interference of capacity and load. This is the part that --

MR. BANNERJEE: You are using the capacity at the safety limit, at putting it directly at a function for --

MS. GAVRILAS: Yes.

MR. BANNERJEE: That's not clear from that.

CHAIRMAN WALLIS: Disaster occurs at 2,200 degrees.

MS. GAVRILAS: That's exactly right. You have lost function at 2,200 degrees, not at 2,400. That's exactly right.

CHAIRMAN WALLIS: What is the excuse for having that to be 95, 95, then? Because then five percent of the time, you're going to have disaster.

MS. GAVRILAS: One needs to cut off, right, one --

VICE CHAIRMAN SHACK: That temperature is going to exceed 2,200.

CHAIRMAN WALLIS: Yes, but she has defined it as disaster.

MS. GAVRILAS: One needs to define negligible. I believe that would be the excuse for that, right? It's basically how do you define negligible? And in that case --

CHAIRMAN WALLIS: I expect my brakes on my car to work more than 95 percent of the time. Let's move on here.

MS. GAVRILAS: Yes. Finally, I believe that one of the justifications for doing this is that without leaving room for these unknown unknowns, if you calculate the risk number, even under ideal circumstances, you're going to have a non-conservative risk estimate.

MR. BANNERJEE: I am not sure. What do you mean by that last statement?

MS. GAVRILAS: What I mean is that let's assume that you have nothing but aleatory uncertainty. And let's assume that that's true and you can get both the probability of the load, the probability density function of the load, and the probability of the capacity, density function of the capacity, exactly.

And you convolute the two. And you get your probability of failure out of the convolution of the two.

If you haven't included the fact that unknown events can happen, your risk is non-conservative. The risk number that you calculate that way would be non-conservative.

VICE CHAIRMAN SHACK: The correct delta is because we don't know what the distribution --

MS. GAVRILAS: That's in the report. That's right. We have so few data. That's the first bullet. Let me back off because I was hoping that that is the first bullet. I don't need to back off.

CHAIRMAN WALLIS: Another argument is regulatory consistency and understandability. If a speed limit is 65 miles an hour, people understand it. If you start talking about probability distribution, you know, it's very easy to have a direct delta function as a limit. It's very easy to administer. It's a good --

MEMBER KRESS: Yes, but the real world is a probablistic one. And we need to understand the real world --

CHAIRMAN WALLIS: There's a lot to be --

MEMBER KRESS: -- and then back off from

the real world to this. I think we're going about it backwards.

MEMBER POWERS: You don't ever want to back off the real world.

MEMBER KRESS: I mean back this out. I'm sorry. Back this out of the real world. And the real world means you have to have some estimate of the full probability distribution. You can't just say there are unknown unknowns. You have to have some sort of guess at what they are.

CHAIRMAN WALLIS: That's what science and research is all about.

MEMBER KRESS: That's right. And I think you are starting from the wrong end here. You should start from this whole probability --

VICE CHAIRMAN SHACK: It's not so easy to know that your safety limit is, in fact, a safety limit. That's an accomplishment in itself.

MEMBER KRESS: That's right, but if you knew the probability distribution, you would have had some guess at it. You would know.

CHAIRMAN WALLIS: If it's defined by the NRC, it is a safety limit.

MR. BANNERJEE: I guess he is proposing an axiom.

MEMBER KRESS: I am. Yes, yes.

MR. BANNERJEE: And then you have to see what happens.

MEMBER KRESS: Yes. That's what I was proposing, yes.

CHAIRMAN WALLIS: So this is a simplification here, right?

MS. GAVRILAS: It's a substantial. So, then, how do you calculate? Under this assumption, how do you calculate the conditional probability of losing function? You have --

CHAIRMAN WALLIS: You have to slide it along.

MS. GAVRILAS: You slide it along. And everything that exceeds the safety limit is your probability of exceeding --

CHAIRMAN WALLIS: I understand that.

MS. GAVRILAS: Your conditional probability of it.

CHAIRMAN WALLIS: What is the margin, now? Does this have anything to do with the margin discussion we had before?

MS. GAVRILAS: I will say it again, that I will probably after our discussion today remove chapter 2 in its entirety.

CHAIRMAN WALLIS: But as you slide it to the left, you're gaining margin because you have less probability of failure. And it's a very good way of describing it. Why don't you stick with that? And then you'll --

MEMBER DENNING: Well, wait a second. What would you define as margin here?

CHAIRMAN WALLIS: It goes along with the probability of failure. Essentially it's the amount of overlap, the purple stuff. If you slide it to the left, you get more margin.

MEMBER DENNING: Non-margin to me.

MS. GAVRILAS: One minus.

CHAIRMAN WALLIS: Minus the log. You have minus the log.

MS. GAVRILAS: One minus the log of the purple stuff.

CHAIRMAN WALLIS: One minus the log of the probability of failure.

MS. GAVRILAS: One minus the log of purple stuff.

CHAIRMAN WALLIS: No, no. Minus because --

MS. GAVRILAS: Minus.

CHAIRMAN WALLIS: Log of 10^{-6} is -6. And minus -6 is 6.

MS. GAVRILAS: Okay. So why am I calling it conditional? I'm calling it conditional because, once again, that probability was calculated for one event sequence based on a deterministic calculation.

And I'm giving here an example of a calculation that would have a specific break size. It would have sequence of actuation signals. Certain mitigation systems will come into play. And, thus, the calculation would be. Thus, a computed probability of losing function is conditioned on the occurrence of the event.

Now, the question is, when is margin important? And if you have an event sequence in which this is a power uprate event sequence, the seventh path in a large LOCA eventually for Browns Ferry -- and you'll see on this graph the blue is the lower bound of two sigma and the red is the upper bound, it's calculated rather crassly with just decay power and pump flow rate as variables.

So before the power uprate, you have a probability of losing margin of about 33 percent.

CHAIRMAN WALLIS: This is for one particular event?

MS. GAVRILAS: For one single event, as I said, a large LOCA 7.

CHAIRMAN WALLIS: You could conceivably just have LOCA as a variable, too, LOCA size. And then that would give you a spread like this, too.

MS. GAVRILAS: That's right.

CHAIRMAN WALLIS: Incorporate it into your statistics.

MS. GAVRILAS: That's right. That could be one of the variables that is treated as a distribution, sure.

Now, the point of this slide is that you have -- yes, you have lost margin clearly here. As a matter of fact, you have lost enough margin to have some purple, as it's become known.

But because this event is so infrequent, it really isn't of concern to risk. So a well-devised metric that considers loss of margin ought to also consider the frequency of occurring at the event in which margin was lost.

MEMBER KRESS: Yes. That's what I was saying previously. You have to do the real risk calculation and get the real probability's distribution.

CHAIRMAN WALLIS: All the way through.

MEMBER KRESS: Yes, all the way through.

You have to really start from that end.

CHAIRMAN WALLIS: Right.

MR. BANNERJEE: But there is an uncertainty in that probability.

MEMBER KRESS: Oh, yes. And you can't just have a probability. You have to have a distribution. And you have to figure out some way to quantify that, even though it's --

CHAIRMAN WALLIS: You need a confidence.

MEMBER KRESS: -- got both kinds of uncertainty in it. You have to quantify both kinds of uncertainty some way.

CHAIRMAN WALLIS: You need a confidence in your probability probably, --

MEMBER KRESS: Yes, that's right.

CHAIRMAN WALLIS: -- something like that.

MEMBER KRESS: So I think we're starting from the wrong end.

CHAIRMAN WALLIS: I think you have gotten to something which is valuable.

MEMBER KRESS: Yes. I think she's got a good take on where are we going, but I think this --

CHAIRMAN WALLIS: I think margin has sort of disappeared from the discussion, though. Now we're talking about probablistic risk analysis.

MS. GAVRILAS: I will say it once again, that I will remove chapter 2.

MEMBER DENNING: How did you get the probability of the occurrence of this event being one times 10^{-8}?

MS. GAVRILAS: SPAR model.

MEMBER DENNING: Well, now, wait a second. This sequence in PRA, the probability of this sequence, is zero. I mean, this has no risk in PRA space.

CHAIRMAN WALLIS: Because it uses the mean?

MEMBER DENNING: Because we use criteria that are associated with success criteria.

CHAIRMAN WALLIS: Okay.

MEMBER DENNING: And I think this success criterion here is that this is successful, that the ECCS works. So that if we did this analysis in PRA space, we would get zero risk for this scenario, I think.

CHAIRMAN WALLIS: Because this PRA has no way of accounting for uncertainties in thermal hydraulics, does it?

MEMBER DENNING: Well, I mean --

MEMBER KRESS: It does.

MEMBER DENNING: It does, but, I mean, it's a matter of let's --

CHAIRMAN WALLIS: In this way, though?

MEMBER KRESS: You can decide on success criteria by using --

MEMBER DENNING: Yes, you could, but it's go or no go.

MEMBER KRESS: Yes, but that --

MEMBER DENNING: And it could --

MEMBER KRESS: It's a big difference between one pump off and the other one. It's such a big difference that you've calculated that probability. Probability when you've got everything running is like one of success. When you've got to lose one, the probability of success is like zero. So you really are counting for that the probability is in the success criteria.

CHAIRMAN WALLIS: The PRA doesn't run the thermal hydraulic codes or 500 times to get a probablistic distribution in order to figure out whether it goes this way or that way.

MEMBER DENNING: Now, it's possible that one might decide over here that this is -- and maybe that is what you were saying, Mirela, is you look at this and say, "Oh. Well, I say that this is actually the failure in PRA space from my success criteria."

MS. GAVRILAS: After the power --

MEMBER DENNING: And that's probably what that one --

MS. GAVRILAS: After that power uprate, you might relabel that path as failed.

MEMBER DENNING: Label that path as a core damage.

MS. GAVRILAS: But, really, for a more likely task --

MEMBER DENNING: If you look at it probablistically, you're doing --

CHAIRMAN WALLIS: If you look at the current regulations, you can have a power uprate. And you can have a power uprate whereby the ECCO criteria are violated. You've got temperatures of 2,300 degrees or something in some LOCAs.

And, yet, when you look at the PRA, there's no change at all in risk. That can happen. The PRA doesn't do the same kind of calculations that go into the realistic thermal hydraulics code.

So I thought that was what you were trying to do, was to pull together these deterministic regulations, like the realism and the 95, 95, 2,200, somehow relate that to what happens in the PRA. So the PRA could be more responsive to the thermal hydraulics and the thermal hydraulics could be more responsive to the accident sequence. And that would be wonderful.

MS. GAVRILAS: That's what I think --

CHAIRMAN WALLIS: Wonderful.

MS. GAVRILAS: -- this is doing. I mean, that's --

CHAIRMAN WALLIS: I think the idea is good, yes.

MS. GAVRILAS: Now you have the probability that an event sequence will occur, basically calculated from the initiating event and the sequence of events, and you have the conditional probability that the core will lose function, for example, estimated, as I showed earlier, in terms of exceedance of the safety limits.

CHAIRMAN WALLIS: With a lot of probablistic uncertainties incorporated.

MS. GAVRILAS: With all the uncertainty captured --

CHAIRMAN WALLIS: Because deterministic calculations --

MS. GAVRILAS: -- in the load --

CHAIRMAN WALLIS: Yes.

VICE CHAIRMAN SHACK: This really is an uncertainty analysis for the PRA.

CHAIRMAN WALLIS: That's right. That's where it is, right. That's what it looks like.

VICE CHAIRMAN SHACK: I mean, I don't see the difference between this and -- I mean, when I do my thermal hydraulic calculations, if I'm doing an uncertainty analysis, I don't do one thermal hydraulic calculation for a sequence. I do a bunch of them.

But I get a success or a failure for each one of those that I do for that. And I add it up. I get a probability that I am going to exceed about one-third.

MS. GAVRILAS: And that's that means of basically --

VICE CHAIRMAN SHACK: Is this any different, then, than a PRA with an uncertainty analysis?

MS. GAVRILAS: I believe that the safety limit, using the safety limit, as opposed to the capacity, is the difference. It's the difference. But otherwise it's the same. But I'm after meeting an objective, the objective being capture all of these different types of changes.

VICE CHAIRMAN SHACK: Okay. If you

maintain exceeding the safety limit as it -- sooner or later, you end up making your safety limit into core damage.

CHAIRMAN WALLIS: I think the safety limit becomes the PRA success criterion.

MS. GAVRILAS: That's it.

VICE CHAIRMAN SHACK: No. Well, it becomes the probablistic success criterion.

CHAIRMAN WALLIS: That's the same thing. It becomes the success criterion.

VICE CHAIRMAN SHACK: That's right. Okay.

MR. BANNERJEE: That's the postulate.

CHAIRMAN WALLIS: It's an operating --

VICE CHAIRMAN SHACK: Well, it's the conditional probability that the core will lose function makes it sound a whole lot like a PRA. If you want to say the conditional probability that my safety limit will be exceeded, then you have something different. The way you have got the slide, it's a PRA.

CHAIRMAN WALLIS: But I think she's trying to say it's the same thing.

VICE CHAIRMAN SHACK: No, they don't have to be. You can --

MS. GAVRILAS: But it isn't the same

thing. So I should fix it.

VICE CHAIRMAN SHACK: Yes.

MS. GAVRILAS: It is not the same thing.

VICE CHAIRMAN SHACK: If you want to make it the same thing --

MS. GAVRILAS: That's right.

VICE CHAIRMAN SHACK: -- then you will have a PRA with uncertainties. If you want to make it the safety limit, then you have something different.

MS. GAVRILAS: I'll fix it. Okay. Generalizing to multiple barriers. And this is a thought exercise towards applying this methodology for advanced reactors, probably in PRA now of setting safety limits for advanced reactor.

The premise is that any reactor is going to have fission products that are going to be enclosed by multiple barriers, one or more barriers and that for each of these barriers, you can define, you can identify damage mechanisms, and that you can identify the safety variables that govern the onset of those damage mechanisms.

CHAIRMAN WALLIS: You can make a generalization of CDF and LERF. When CDF is breaking one barrier, LERF is breaking several barriers.

MS. GAVRILAS: Several, right, three.

CHAIRMAN WALLIS: Isn't it a generalization of CDF and LERF?

MS. GAVRILAS: It's exactly that. It's just taking it --

CHAIRMAN WALLIS: I mean, this can be done for all reactors.

MS. GAVRILAS: A step further.

CHAIRMAN WALLIS: Because conceptually you can talk about breaking a barrier for anything, any kind of break.

MS. GAVRILAS: Yes.

CHAIRMAN WALLIS: I don't know what you do with salt maybe, but that's all right, too. Anyway, so you are saying that --

MS. GAVRILAS: I thought the electromagnetic field --

CHAIRMAN WALLIS: -- you are working towards generalizing concepts like CDF and LERF to redesign.

MEMBER KRESS: If you want a real generalization that incorporates all reactors, including the salt, you will talk about the frequency of release of given magnitudes of radioactivity.

CHAIRMAN WALLIS: To the environment? Well, it's the whole thing.

MEMBER KRESS: Yes. Well, you can separate it --

CHAIRMAN WALLIS: From one region to another region.

MEMBER KRESS: -- frequency of release from the fuel, for example.

CHAIRMAN WALLIS: From one region to another region.

MEMBER KRESS: Yes.

CHAIRMAN WALLIS: Right. That's okay.

MEMBER KRESS: That's a real generalization.

CHAIRMAN WALLIS: That's right. I like that. That's what we had in mind, wasn't it, with that?

MEMBER KRESS: That's exactly what we had in mind.

CHAIRMAN WALLIS: Is that what we had in mind?

MEMBER KRESS: That's why I remembered it.

CHAIRMAN WALLIS: That's why I was trying to put my words into her thing --

MS. GAVRILAS: Here's how this would work.

CHAIRMAN WALLIS: That's right. That's it. That's what we said that Mirela had so much trouble with.

MEMBER DENNING: I don't think that's really true, but if go ahead.

MS. GAVRILAS: No. I'm enjoying this. You agree, right, with something?

(Laughter.)

MS. GAVRILAS: So here the concept is basically propagating the concentration of fission products in whichever units you would like through successive barriers. And you can calculate the consequences --

CHAIRMAN WALLIS: There are no consequences, presumably, until it goes through the last barrier.

MS. GAVRILAS: Well, I was thinking the control room operator, for example.

CHAIRMAN WALLIS: Well, there might be some. Okay. Good thinking.

MEMBER DENNING: Go ahead. In principle. Go ahead because I really don't think, in practice, it really is of value, but let's continue. We will get back and talk about it.

MS. GAVRILAS: Okay. So the probability of releasing to the public is just basically the probability of the initiating event and failing --

CHAIRMAN WALLIS: It's not a sequence like that.

MS. GAVRILAS: -- failing subsequent barriers.

CHAIRMAN WALLIS: Dependent on conditional on the other failures, right?

MS. GAVRILAS: Yes because, actually, when you simulate a CDR accident, for example, in MELCHOR, you are assuming certain failures to fail the next barrier.

MEMBER DENNING: But it's one. I mean, for lightwater reactors, you melt a core and you fail every barrier to some degree, even the containment.

MEMBER KRESS: It's a difference in timing.

MEMBER DENNING: Yes.

MEMBER KRESS: But he's exactly right. They're not independent barriers.

CHAIRMAN WALLIS: The reactor just might be --

MS. GAVRILAS: They are not independent.

MEMBER DENNING: Yes.

MS. GAVRILAS: So the failure of the next barrier is conditioned on the failure of the --

MEMBER DENNING: But it's almost when you melt the core, you fail every barrier in the lightwater reactor. Now, it's arguable in a large, dry containment to what extent you fail it, but even if it's just design leakage, you fail it. And if it's a boiling water reactor, then there's a high probability that it's fairly significant.

So, you know, I don't think that this is the equivalent. I don't think that in a generalization, that you gained value from looking at barrier analysis in this way. And I don't think it leads, then, to what Tom is trying to do.

MEMBER KRESS: No, it doesn't lead to my fission product --

MEMBER DENNING: I don't think it leads to the --

MEMBER KRESS: I don't think it does either.

MEMBER DENNING: -- overall fission produce release.

MEMBER KRESS: You have to dispense with the thought of barriers and talk about movement of radioactivity.

MEMBER DENNING: Ultimately that's what you have to do. You just have to calculate the amount of radioactivity.

CHAIRMAN WALLIS: But you could design the reactor in which something like this was more realistic, not like the present lightwater reactors.

MEMBER KRESS: In fact, the EPR tried to do something like that.

CHAIRMAN WALLIS: Yes.

MEMBER DENNING: Well, it already -- and, I mean, for lightwater reactors, this is a design concept. But then it doesn't have much value when you're calculating risk, as I see it, because they are so dependent. The dependence between the barriers is so great. You know, it's not that minor accidents get contained at one barrier and then you go to a next level of accidents.

CHAIRMAN WALLIS: They're different from the probability of a paper written by an RES person getting to the ACRS success. It has to go through the peer review and the supervisor and these and eventually --

MEMBER KRESS: Not the same thing, no.

CHAIRMAN WALLIS: Okay.

MEMBER KRESS: Consequences are different.

CHAIRMAN WALLIS: Well, the consequences are minor in one case versus the other.

VICE CHAIRMAN SHACK: Can we take our

break?

CHAIRMAN WALLIS: Do you want to take our break?

MEMBER KRESS: Do you need a rest?

CHAIRMAN WALLIS: Are you getting to the --

MS. GAVRILAS: I don't, but it there --

CHAIRMAN WALLIS: Are you getting to the end? Well, we should probably take a break.

(Whereupon, the foregoing matter went off the record briefly at 2:24 p.m.)

MR. BANNERJEE: I suppose it's not just the probability of failure that matters here, but how much release there is between the barriers.

MEMBER KRESS: That's what I was thinking, yes.

MEMBER DENNING: And you have to analyze that. There's no question about that. But I'm not sure that this --

CHAIRMAN WALLIS: But in terms of the public, the public really has about the last one, doesn't it? The public doesn't --

MS. GAVRILAS: There have been people who have suggested that transitioning from this to the frequency consequence curve is driven. And I have said that it's not.

I mean, I am sitting here having said that now it is not. So I believe it can be done, I think, but I think it has to be looked at with a lot of care, not -- and I don't think that the language is obvious.

MR. BANNERJEE: But imagine that there was so much release when you produced these fission products or whatever. Then there is some probability of mitigation of this between the barriers, right?

MS. GAVRILAS: But I think this takes it into consideration.

MR. BANNERJEE: This is just the probability of failure. You are just using one criterion.

CHAIRMAN WALLIS: But the mitigation case is sort of a barrier, isn't it?

MS. GAVRILAS: But the mitigation is sort of -- the mitigation is both in the probability of failure if you mitigate. And the other type of mitigation is you reduce the consequences, which would be captured here. So there are two things.

MR. BANNERJEE: Where does the probability of consequences come up?

MS. GAVRILAS: Mitigation is going to -- mitigation can act on two things. One is reducing the probability of failure. Two is reducing the consequences. And the risk metric that has both those in it, both the probability of failure --

CHAIRMAN WALLIS: The containment could fail, but all the radioactivity is already been captured in the suppression pool. So nothing happens.

MS. GAVRILAS: So, then, you would have basically the consequence term go to zero. So your risk metric would be zero.

MR. BANNERJEE: Go to the next slide. Let's have a look. Where is the consequence down here?

MS. GAVRILAS: Hold on. Sorry. Here it is. Here is the consequence.

CHAIRMAN WALLIS: The consequence is soon going to be we are going to have a break, isn't it, Bill?

VICE CHAIRMAN SHACK: If we ever stop asking questions.

CHAIRMAN WALLIS: Well, that is never going to happen. You are going to have to assert yourself.

MEMBER SIEBER: There's not a great probability of that.

VICE CHAIRMAN SHACK: We will recess for

ten minutes.

CHAIRMAN WALLIS: Thank you very much.

(Whereupon, the foregoing matter went off the record at 2:26 p.m. and went back on the record at 2:43 p.m.)

CHAIRMAN WALLIS: Please come back into session. Before we continue with this very interesting presentation, there's a matter I'd like to do while we're still on the record today. Theron, I want it to be shown on the record that on July the 12th, 2006, Theron Brown was awarded a certification for 30 years of government service, and it's my great pleasure, Theron, to give it to you.

(Applause.)

CHAIRMAN WALLIS: That pleasurable activity being finished, I'd like to go back to our agenda. Mirela, would you continue, please.

MS. GAVRILAS: We were talking about the probability of losing function, and this is a generalization to multiple barriers, so you have the failure of Barrier N being conditioned on the failure of Barrier N minus one, and all the previous barriers. And, naturally, on the occurrence of the initiating event.

CHAIRMAN WALLIS: Actually, if the

initiating event comes from outside, the sequence is reversed.

MS. GAVRILAS: Can you account for a probability of having --

CHAIRMAN WALLIS: I'm not sure I can, but if it comes from outside, the sequence is reversed. If you've got a meteorite strike, let's say.

MS. GAVRILAS: I thought about that, and I believe that it can be included.

CHAIRMAN WALLIS: Yes, I'm sure it can be included.

MS. GAVRILAS: It's not a deal-breaker, that it can be included.

CHAIRMAN WALLIS: I'm sure that it can be included. It's just that the sequence is reversed.

MS. GAVRILAS: And then the risk for one event sequence would be the probability of the occurrence of the event sequence, the probability of losing function for the various barriers, multiplied by the consequences, where the consequences include these transmission factors that account for dilution and other losses to the dose as various barriers are penetrated.

CHAIRMAN WALLIS: Let me interject here. Consequences, if they're measured in terms of dose to the public, the only thing that matters is the final barrier being breached. My colleagues keep telling me I shouldn't keep saying that, because it's unacceptable to have core damage. The public would be terribly shocked if we had a core damage accident; therefore, we have to make sure we don't have any significant CDF. But that's a political consequence, that is not the physical damage to the public. It's not a health risk, but again we have this great emphasis on core damage frequency, and then the containment failure. Well, that's only going to be just ten -- one probability --

MR. BANERJEE: But as long as we're looking at this generically, I mean, consequence can be whatever it is.

CHAIRMAN WALLIS: Whatever it is. Well, obviously, in the case of core damage it must be political, because -- and also economic.

MR. BANERJEE: Well, yes. Also, the --

CHAIRMAN WALLIS: Not health to the public. TMI didn't, we are told, kill anybody, or even damage anyone's health, except psychologically.

MEMBER DENNING: What's the advantage of this construct? That's what bothers me at the moment. I mean, certainly, that's effectively what we do in calculating the risk of a scenario, but when we look at fission product retention, it depends upon each scenario as to how much retention you get in the reactor coolant system, how much do you get in the containment. It just depends, it's so scenario dependent that I have to run a computer calculation to determine it. So what's the advantage of this construct that you put there?

MS. GAVRILAS: It doesn't not make less work. I mean, the means of simplifying it, as far as I can tell, are the means that have already been identified. I believe that the only place where it does make less work is it changes the burden from getting the capacity, and then being informed with that capacity distribution at every step. But I don't believe that in other places it achieves any savings in terms of expanded effort, if that was the question, if it was in terms of --

MEMBER DENNING: Well, are you going to bring this back then in some way to margins? Is that why you're going this pathway, or you were just look at this as --

MS. GAVRILAS: That's it. Basically, because just as you said, from this point on from having the risk from one sequence you calculate the total risk, which then you compare with whatever risk guidelines are available to you. And in this case, I mentioned Commission safety goals, and Reg Guide 1.174, if you stop at core damage, for example, if you just look at the probability of failing the first barrier. But that's the final metric. It does not accomplish any other saving. This is, actually, as a matter of fact, it's the opposite; it's labor-intensive. So I have this diagram that is just the elements of the methodology, and it's the relatively recent edition. But I think it shows that there's two parallel paths. One is the plant designs characteristics, and under those I include initiating events, the systems that mitigate those initiating events, operator actions, initial conditions, and boundary conditions. And then there's another path, which is, which barrier is challenged by a particular change. And the safety limit is sort of a crucial point, and we were talking a little bit during the break about what role the safety limit plays. And in the safety limit I show this is the only place where you can actually account for unknown unknowns.

In other words, this is the only place where you can build in margin in your risk calculation. And you can reverse this. I believe, I haven't looked into it, but I believe that all these arrows that you see in blue on the diagram can actually be reversed so that the final objective is to establish, to have a more educated way of establishing the safety limit, as opposed to --

CHAIRMAN WALLIS: I think I might accept that, but the risk metric seems to me to come from the left-hand side. Safety margin is something that's determined by the sort of expert sitting down and saying well, we don't think we know this; therefore, we better be more cautious. That's not something which really gives you a risk metric, is it?

MS. GAVRILAS: I agree with you, otherwise, being the only opportunity we have to actually build in margin.

CHAIRMAN WALLIS: But it doesn't feed into the PRA, does it?

MS. GAVRILAS: If you calculate the probability of exceedance, as opposed to the probability of losing function.

CHAIRMAN WALLIS: As soon as you put the safety margin in, you said we sort of push these things apart so that we're accounting for unknown unknowns by trying to make the probability of failure negligible by pushing them apart, knowing that, in fact, it's not quite negligible. Isn't that what the whole idea was of safety margin? I don't see how you can put that into a risk metric, how it can feed into calculating a risk metric, since by it's very nature, it endeavors to push them apart so that nothing can go wrong, given what you know.

MS. GAVRILAS: But I believe it endeavors to push them apart -- I'll take that back. I believe you're right, and I think that until we exercise it to see how much insight it gives us into it, we won't know.

CHAIRMAN WALLIS: Okay.

MR. BANERJEE: On the right-hand side it's all deterministic. Right? I mean, if you go the right-hand side of the box going down the deterministic models there, probabilities don't enter that side, do they?

MS. GAVRILAS: They enter in event sequences.

MR. BANERJEE: Yes, but that's on the left-hand side.

MS. GAVRILAS: Yes. Yes.

MEMBER DENNING: He was talking about barriers.

MS. GAVRILAS: Okay. Oh, here.

MR. BANERJEE: Here, and even in the right-hand side in the calculation of the safety parameter minus load PDF. Where does that PDF come from? Is that just an assumption? No, right. Look on that box there, you see safety parameter minus load PDF.

MS. GAVRILAS: Yes.

MR. BANERJEE: That PDF is some assumed PDF, right?

MS. GAVRILAS: It's calculated.

MR. BANERJEE: How is it calculated?

MS. GAVRILAS: It would be considering all the --

MR. BANERJEE: How is that calculated?

MS. GAVRILAS: -- uncertainties that are -- no, safety parameter not minus load, safety parameter PDF, probability density function of the safety parameter, so this would be the probability density function of the peak clad temperature, for instance.

MR. BANERJEE: So the deterministic models are being exercised in some way to generate that?

MS. GAVRILAS: That's right. By assuming that there's variabilities, that you have variabilities in boundary conditions, initial conditions, certainly the time at which the operator acts, and the distribution for breaks, for instance.

MR. BANERJEE: But I would have thought that one of the major uncertainties in those models have to do with the model parameters themselves.

MS. GAVRILAS: They do.

MR. BANERJEE: That is the real uncertainty.

MS. GAVRILAS: That's one contributor to epistemic uncertainty, and I believe --

MR. BANERJEE: Well, why doesn't that show up somewhere?

MS. GAVRILAS: It doesn't show up independently. It shows up in here. It's embedded in deterministic models. I would have added more colors, maybe I should have.

MR. BANERJEE: I think in order to make this clearer to people, at least clearer to me, I don't know to anybody else, I would like to know how you generate that PDF. And to me, it doesn't seem sufficient just to vary those boxes on top, because they're only the -- they only give a small part of the uncertainty. The real uncertainties come because the models are usually very uncertain.

CHAIRMAN WALLIS: Like the momentum valves and the nodes.

MR. BANERJEE: So that part of it doesn't seem to be done by anybody.

MS. GAVRILAS: There is an opportunity to do that. There is an opportunity to include model uncertainty in this. As a matter of fact --

MR. BANERJEE: But you should show it explicitly.

MS. GAVRILAS: I will research it and show it explicitly. As a matter of fact, there is -- I know that the working -- GRS is working in that direction, and has been working for several years. And I have a stack of papers that they've published in my office that I haven't --

MR. BANERJEE: There is another source of uncertainty. I mean, in addition to the person running the model, that makes a big difference, of course, whoever runs it. There's the nodalization problem. There is the model uncertainties. When you put it all together, you need a pretty big safety margin. That's really -- the way currently the uncertainties are done simply by running the same old model a few times, doesn't really give you any idea of the real uncertainties.

MS. GAVRILAS: Which is, I believe --

MEMBER KRESS: That's why NUREG-1150 was done with the combination of that, and expert opinion. And it was the expert opinion that was supposed to capture those very things you were talking about. And that's the only place I know of where we have the full uncertainty distribution.

VICE CHAIRMAN SHACK: But if you're just sticking with Sanjoy's question of things like thermohydraulic uncertainty, you can do that.

MEMBER KRESS: You can do it with that, because there's not that much model uncertainty.

MR. BANERJEE: There is.

MEMBER KRESS: There is some, yes.

VICE CHAIRMAN SHACK: In PTS where they tried to do it, they actually found that the largest uncertainties came from the initial conditions and the boundary conditions, because you don't deal with every sequence. You're bundling sequences together, and by the time you look at the sequences that you've bundled together, you've changed the initial conditions enough that the dominant contributor to uncertainty was actually the uncertainty --

CHAIRMAN WALLIS: Operator actions are pretty uncertain, too, sometimes.

VICE CHAIRMAN SHACK: Well, that was

typically covered in a different portion.

CHAIRMAN WALLIS: I just know that safety margin is the last thing you put in before you get the risk metric, so what I would see happening is you calculate your CDF and you say well, it's 10 to the minus 8, and then you say well, we'll put in a safety margin and call it 10 to the minus 6, because it appears right at the end before you calculate the risk metric, so it's not a physical thing. It's got to be something to do with probability. It's the last step in the calculation. That's what people do, they calculate the CDF and say 10 to the minus 8, and say we can't believe, 10 to the minus 16 or something, we can't believe that, so we'll add two orders of magnitude or something. Is that what you're saying when it's right at the end like that?

MR. BANERJEE: I think we could legislate that all sequences were 10 to the minus 3 and we'd probably be right.

CHAIRMAN WALLIS: Yes, but I don't see how it fits in at the end of the process. You see what I mean, right at the bottom there, just before you get the risk metric.

MEMBER MAYNARD: Well, I don't see that you're just inserting a number in there. Isn't that the difference between the far right side, the safety limit, and the --

MS. GAVRILAS: Yes. It's a rather crucial link. It is there. I mean, it's at the end, but it's a rather crucial link between --

CHAIRMAN WALLIS: What does it do? How does it work?

MS. GAVRILAS: -- the load and the capacity.

VICE CHAIRMAN SHACK: Put PDF in the safety limits, you compute your probability of failure.

CHAIRMAN WALLIS: But the safety margin is something you add on, like a safety factor, after you've done all that. Right? Yes, it is. Isn't that what --

MS. GAVRILAS: Certainly, that was not the presumption throughout our writing this.

MEMBER MAYNARD: In this case, the safety margin is the difference between your safety limit and your safety parameter behavior PDF.

MS. GAVRILAS: I believe that it was almost strictly determined as a relationship between these two boxes.

CHAIRMAN WALLIS: Oh, it's a probability

of failure then you're calculating.

MS. GAVRILAS: But what I'm saying is it would be nice if we turn some of these arrows around and inform the safety limit with what's happening on this side.

MEMBER SIEBER: There's margin between the safety, a capacity PDF and the safety limit. That's a politically established kind of margin. And it's not, by your definition, not included as a part of the safety margin.

CHAIRMAN WALLIS: Well, I'd have to see operationally how you do it. I don't understand.

MR. BANERJEE: Yes. I mean, the safety limit is set by a combination of technical and political factors. All right? So it's been done.

MS. GAVRILAS: Yes.

MR. BANERJEE: Now we somehow calculate this PDF based on some uncertainty analysis, which may or may not be hokey, and then you get this safety margin, which is just the difference between those two.

CHAIRMAN WALLIS: That's the probability of failure. Is that what the safety margin means?

MS. GAVRILAS: That's right. That's exactly right. That's the --

CHAIRMAN WALLIS: Well, why don't you just call it probability --

MS. GAVRILAS: It should be probability of exceedence.

CHAIRMAN WALLIS: Call it probability of failure because it's not a safety margin.

MS. GAVRILAS: I should call it --

MR. BANERJEE: How do you use those three numbers, the event sequence frequency, the consequences, and the probability of failure to go wherever you're going? I guess that's the question.

MS. GAVRILAS: That was on the previous slide. This is basically --

MR. BANERJEE: Which is which, now?

MS. GAVRILAS: Probability of event sequence occurring, probability of barriers failing, which is that box that I called safety margin. I should really change that box. Consequences. For each event sequence, that's the risk metric for the event sequence.

MEMBER POWERS: It only works if those probabilities are all independent.

CHAIRMAN WALLIS: They're conditional probabilities, aren't they?

MS. GAVRILAS: They're conditional.

CHAIRMAN WALLIS: Because I think as Rich showed us, you can't really calculate them. You've got to calculate all the sequences.

MEMBER KRESS: If they're not independent, then there's no one number for that.

CHAIRMAN WALLIS: That's what Rich pointed out, I think, is that you can't say you calculate them independently. You've got to look at each sequence, and the probability is some sort of a summation of all these sequences convoluted in some way, so it's easier just to calculate all the sequences.

MEMBER DENNING: But I think, Dana, the way she had it before was those are conditional, they're all conditional --

MS. GAVRILAS: They are conditioned.

MEMBER DENNING: Conditioned against the previous event.

MS. GAVRILAS: Each of them are conditioned on the previous one, but I think that what you're saying is condition vertically in the tree, as opposed to condition horizontally. I've conditioned them horizontally as you go through the event tree, or as you go through the barriers, but I haven't given any thought to condition --

MEMBER KRESS: Back up to the slide, the

one that we had just previous, one forward. No, the other direction. Keep going. I want to see your deterministic -- the chart. That one.

MS. GAVRILAS: Okay.

MEMBER KRESS: Now if I look at that, and I take the box that says safety limit, and the box that says safety margin, and just throw them out, this all together, what I have is a PRA.

MS. GAVRILAS: That's right.

MEMBER KRESS: And what I am interested in is how do I take PRA results, which gives me one kind of risk metric, and how do I relate what I call the deterministic system, which is design-basis, a set of design-basis accidents, which have the safety limits built into those, but PRAs don't have safety limits, but design-basis accidents do. And the question I have is, how do I set those safety limits, and the difference between the calculated value in that, and how does that impact my risk metrics? That's the thing I'm interested in trying to find out.

CHAIRMAN WALLIS: Very simple answer to that, just do away with design-basis accidents.

MEMBER KRESS: Well, that's easy to say, but I'm not sure we want to, because that's one way to do it. But even still, you have a problem, because you have risk acceptance guidelines. You have to decide on what those are, and so the margin would be the difference between the risk metric and the risk acceptance guidelines.

CHAIRMAN WALLIS: Independent worlds. PRA is a different world from design-basis accidents. They don't communicate.

MEMBER KRESS: That's the problem, and if we're going to integrate risk and safety margins, I think you have to recognize that that's what we're talking about, two sets of things that --

MEMBER BONACA: That's why she was trying to put together a Chapter 2.

MEMBER KRESS: Yes.

MEMBER BONACA: I gave you heartburn, but --

CHAIRMAN WALLIS: Then the DBAs have to be defined differently, somehow, as part of the PRA.

MEMBER KRESS: They're not exactly separate, but they're related in some way, but they're design-specific related, because every reactor out there meets the DBAs.

CHAIRMAN WALLIS: But they don't lead to core damage, do they?

MEMBER KRESS: Every reactor out there

meets the DBAs, but every reactor, there is a distribution of risk profiles for all these, so there's not a one-to-one correspondence between the DBAs and risk. And that's the whole problem of trying to integrate these. And I don't know how to cross that bridge, but that's the one I thought we were dealing with.

MEMBER DENNING: Before you throw away design-basis accident, don't forget we use them to design plants.

MEMBER KRESS: Yes.

MEMBER DENNING: Design systems.

MEMBER KRESS: That was what I was going to say.

MEMBER POWERS: But what role do they play in the regulation of plants? As far as I can tell, they only confuse the regulation of plants. It seems to me that what you said is entirely correct, Tom, but it seems to me you go through this debate even if you work out, in strictly the probabilistic world, because of the stylized way we phenomenologically describe the accidents, that you still end up saying okay, what if my PRA is completely wrong, or my phenomenological analysis, or God help me if my momentum equation is wrong. That doesn't happen, so I don't really worry about momentum equations, but --

MEMBER KRESS: I think you're right.

MR. BANERJEE: I like the DBAs because they do the unknown unknowns. Too much faith in PRAs, where you've got all sorts of uncertainties.

MEMBER POWERS: No, we never have too much faith in PRAs. They're God-given.

MR. BANERJEE: Yes, I know, beyond God-given.

MEMBER KRESS: I don't want to throw away the DBAs, because I think they give you --

MR. BANERJEE: I think them because I feel secure.

MEMBER KRESS: Yes, they give you some --

MEMBER POWERS: I think they simply lead you to focus on things that are unimportant.

MEMBER KRESS: I think they do that, too.

MEMBER POWERS: Mine is a statement of the practicality, they have.

MEMBER KRESS: I want to have DBAs, but I also want to have PRAs.

CHAIRMAN WALLIS: Well, you want DBAs that come out of the PRA in some way. They're related in some way.

MEMBER KRESS: I think that's possible,

too.

MR. BANERJEE: That means you believe the PRAs, which every time we ran LOFT and we ran a code against LOFT, the code didn't agree. So we kept on tuning it, and it was a new phenomenon, another new phenomenon, another new phenomenon. I can imagine there are 30 new phenomena which you actually run a real reactor and had an accident, which are not imagined by these codes right now. I wouldn't put any faith in them.

CHAIRMAN WALLIS: You can't tune the PRA, because you can't test it.

MEMBER POWERS: It's not PRAs' fault that you couldn't run LOFT right.

MR. BANERJEE: Yes, we had a problem with LOFT, but --

CHAIRMAN WALLIS: Bad experiment.

VICE CHAIRMAN SHACK: Remember, the PRA depends on MAAP. You really --

mEMBER DENNING: Let's forge to the end so that we can get back to the --

CHAIRMAN WALLIS: Yes. Shall we go back to the presentation?

MEMBER POWERS: Yes, let's do that.

MS. GAVRILAS: Proof of concept, and I'll probably have to say that about three times - proof of concept, proof of concept, proof of concept. In other words, it's not meant to say anything about -- it's just strictly an example. It has no value other than just demonstrate what I've been talking about. This is what I was told. Failure as the loss of function is assumed to occur if you lose NPSH margin, so for the purposes of this simple --

CHAIRMAN WALLIS: So now you're using margin as the difference in NPSH from what you need to what you get?

MS. GAVRILAS: Because if you remember in the beginning, I said if you can tie that margin to loss of function, then that's what you need to exercise that. And the assumption is you lose that margin, you've lost the core.

CHAIRMAN WALLIS: Well, the distance is irrelevant. It's just whether or not you cross a boundary. It's a yes/no thing. Do you have margin or do you not? The length of the margin is irrelevant.

MS. GAVRILAS: As long as you're below the length of the margin is irrelevant, but if you start exceeding, you get credit if you only exceed it a little bit.

CHAIRMAN WALLIS: You do?

MS. GAVRILAS: Yes.

CHAIRMAN WALLIS: Oh, I thought it was a cliff, it's direct delta function.

MS. GAVRILAS: But you convolute it with a load, right? So if the load only exceeds a little bit, you get credit for that. If the load exceeds a lot --

CHAIRMAN WALLIS: Okay.

MS. GAVRILAS: The model for this --

VICE CHAIRMAN SHACK: No, if it exceeds it frequently.

MS. GAVRILAS: If it exceeds it in frequent events.

VICE CHAIRMAN SHACK: Only if exceeded by a little bit.

CHAIRMAN WALLIS: It doesn't matter.

VICE CHAIRMAN SHACK: The distribution isn't the magnitude of the load, it's the frequency.

CHAIRMAN WALLIS: The frequency.

MS. GAVRILAS: Both numbers are there.

CHAIRMAN WALLIS: But the amount you exceed doesn't matter.

VICE CHAIRMAN SHACK: Whether you miss it by a mile, or you miss it by an inch, it doesn't matter, it's that total area.

CHAIRMAN WALLIS: It's probability of crossing the line.

MS. GAVRILAS: That's exactly right. And the two numbers, there's a product between them, so if you exceed 10 percent of the time versus exceed 10 times more frequently, you come up with the same value in terms of impact on risk.

CHAIRMAN WALLIS: It's all probability, the amount is irrelevant.

MS. GAVRILAS: So the model --

MR. BANERJEE: Is that a good definition? I mean, if you exceed it a few times by a very large amount, isn't that more likely to lead to a big bang than a little bit?

MS. GAVRILAS: I haven't thought about it, because I think the metric puts together all the information you have. That's the information that you have, and you've put it together.

MR. BANERJEE: Well, we go with this for the moment.

MS. GAVRILAS: You have this relationship for available net positive suction head, and together with the NUREG CR correlation for determining pressure drops or debris bed, they constitute the model for this application.

MR. BANERJEE: Patching faith in that correlation.

MS. GAVRILAS: Blindly in this case because, again, it's a proof of concept. But if the point is that I haven't put some model on certainty, and indeed, I have not.

CHAIRMAN WALLIS: It's a proof of concept. You just assume you have a good correlation. You don't have to say which one it is.

MS. GAVRILAS: But I think the point he's bringing up is, could I have put model uncertainty into this. I believe I could have.

MR. BANERJEE: Well, in this case it's a couple of orders of magnitude.

MS. GAVRILAS: I'll put it in. I'll try to redo the example. So generating the risk space, events only are those events that challenge NPSH margin need to be included. The event sequences must be refined to capture all important variabilities in order to generate those probability density functions. The deterministic computation might input into the model that I've used. I'm not doing that for the purpose of the simple example, and I'm just noting here that there's probably more formal processes for developing guidance in terms of what parts of PRAs need to be altered. And some of it is contained in 1150, and I think the thought process of 50.50 can be adapted to some extent, but again, that's a general consideration.

So here's an example for the large LOCA tree, and I've highlighted the first path, because that's the only success path. In the other path, we already have core damage by other mechanisms. We don't need to consider those. Truncate low probabilities, a simplification that's standard, consider additional factors to simplify the event tree; such as, does that event, does that path actually generate sufficient debris.

Now generating the probability of loss of margin, which is we're starting probability of exceedence, as I've called it. List the variables in a PIRT-like approach. I've mentioned a couple of times the best estimate plus uncertainty adaptation to this methodology, list the nominal values, ranges of variability and probability densities, and sample to generate the probability density function to the desired confidence level. And the numbers that I got was the example is, what happens if I go from 100 square foot screen to a screen that's about 1,100 square feet? And I've used few variables. There's been some generic reports that gave me the values, the approximate values that I've put in this table. I've used the various contributors to the debris beds, the screen area, and you see in red, that's the parameter that changes between these two distributions. The water temperature, screen loss, as I said from NUREG CR 62.4, pool level above suction, friction losses, cavitation pressure. And I fixed NPSHr for my calculation just for simplicity, I fixed it. And again, the third column shows the nominal values. These are percentages of the nominal over which I have ranged it to generate what you see, the pink PDF and the CDF in blue.

So the conclusion, and I think I sampled, I believe it was 500 time out of an Excel Sheet, very simplistic, the conclusion is that the probability of loss of margin is about 100 percent for the small screen. And when you use the larger screen, the probability of loss of margin goes to about 23 percent, because several of the parameters, several of the variables in this table have changed.

CHAIRMAN WALLIS: If you use the extreme values, maybe you could get the left-hand side one pretty close. If it's 100 percent probability of failure, it almost looks as if you could use the extreme values, and demonstrate in the extreme case, even in the best case it's going to fail.

MS. GAVRILAS: That's right. That's right. I mean, even in the best case --

CHAIRMAN WALLIS: Simple way to do it.

MS. GAVRILAS: Yes. You can definitely simplify in this case and say even if you use the minimum in this column, you're going to get failure.

CHAIRMAN WALLIS: The probability of loss of margin now means essentially probability of failure of the pump.

MS. GAVRILAS: Probability --

MR. BANERJEE: No, cavitation.

CHAIRMAN WALLIS: Oh, cavity of cavitation.

MS. GAVRILAS: That's right. That's right.

CHAIRMAN WALLIS: I understand that idea. I just wonder if the word "margin" contributes to the discussion, because margin means other things to other people. If you simply say probability of cavitation --

mEMBER DENNING: Because I could look at that and say I still don't have margins.

CHAIRMAN WALLIS: You still don't have a

margin, right.

MR. BANERJEE: But it's useful because you don't have margin in one case, and you have margin in the other case. But it does tell you that having margin in the other case still gives you 23 percent probability of failure.

MS. GAVRILAS: You may have margin, depending on how --

MR. BANERJEE: In both cases, right?

MS. GAVRILAS: -- low you've set NPHr. So if you've set it low enough, you may have built in margin. And I just assumed a standard value, but that's where, in this case, that's where you would account for the unknown unknowns in this example.

MR. BANERJEE: Well, let me ask this question. In the case with 1,100 square feet screen, if you just did a calculation without any probabilities or anything, does it indicate that you have margin?

MS. GAVRILAS: I remember looking at the nominal value, and the nominal value is at the bottom, which is minus 45 and plus 5, so it shows that you're okay.

MR. BANERJEE: Yes. Whereas, in reality --

CHAIRMAN WALLIS: We looked at that for Vermont Yankee. I looked at that. You go to the temperature distribution of the river and all that. If you took the mean value, everything was okay. But the probability of failure looked at the distributions, was something like 30 percent or something.

MR. BANERJEE: Which is very useful.

CHAIRMAN WALLIS: Well, that's what they started to do with the Vermont Yankee NPSH.

MR. BANERJEE: And then if we take the model uncertainties into account, then the probability of failure is almost one. Right?

MS. GAVRILAS: Now I did the same thing for all the event paths that were not core damage, and I changed the table to correspond to medium LOCA and small LOCA, and I changed the corresponding conditions, and calculated basically by doing the multiplication between the probability of occurrence of the event scenario, and then the probability of losing function calculated as shown on the previous slide. I calculated the change in core damage frequency. And when you go -- the number I came up here is 2 times 10 to the minus 4, so for this example, this is an example of improving plant safety.

CHAIRMAN WALLIS: You've changed it by an order of magnitude.

MS. GAVRILAS: I've changed it by, yes, an order of magnitude, by changing the plant. Yes.

CHAIRMAN WALLIS: It might not be risk significant.

MS. GAVRILAS: From these numbers, no conclusions can be drawn because they are -- I mean, I --

CHAIRMAN WALLIS: In terms of compliance, in terms of the present ECCS criteria, 50.46, compliance with the long-term cooling, they would be out of compliance, presumably, with -- because they can lose the margin with a probability which is not negligible.

MS. GAVRILAS: I believe you're right.

CHAIRMAN WALLIS: So how should the Agency decide?

MR. BANERJEE: Well, that's a very interesting point. I mean, if the regulation says that you should not exceed -- you should not go into cavitation --

CHAIRMAN WALLIS: It must always work. It must always work.

MR. BANERJEE: Always work. Then that 23

percent should be zero.

CHAIRMAN WALLIS: Right. And then you would always fail. We suggested that they use the risk-informed approach to some screen blockage.

MS. GAVRILAS: I was very happy when I saw that letter.

CHAIRMAN WALLIS: But that doesn't seem to have been done.

MS. GAVRILAS: I was very happy when I saw that letter.

MEMBER KRESS: I would think looking at that 2 times 10 to the minus 4, that that would fail the risk criteria. That screen would fail what I would say a reasonable risk criteria.

CHAIRMAN WALLIS: The 100 foot one.

MEMBER KRESS: Yes.

CHAIRMAN WALLIS: But the 1,100 foot --

MEMBER KRESS: No, no, the 1,1000.

CHAIRMAN WALLIS: With the one to use minus 5?

MR. BANERJEE: 1.6 times 10 to the minus 5.

MS. GAVRILAS: 1.6 times 10 to the minus 5 for the --

MEMBER KRESS: Reg Guide 1.174, we talked about delta CDFs on the order of 10 to the minus 5, but that's the whole delta CDF, and this is for one sequence. So you drop that down a factor of 10 --

MS. GAVRILAS: No, no, no. This is not for one sequence.

CHAIRMAN WALLIS: There's a whole lot of sequences. All the sequences.

MS. GAVRILAS: This is for the entire -- for all the event trees, LOCA small, medium, and large.

MEMBER KRESS: Well, still it fails because it's bigger than 10 to the minus 5.

MEMBER DENNING: It didn't fail because it's in the positive -- it's improvement.

MS. GAVRILAS: It moved in the right direction.

VICE CHAIRMAN SHACK: If you've got it down to 1.6 times 10 to the minus 5 --

MEMBER ARMIJO: This is an exercise, right? I mean, this --

mEMBER DENNING: This is an exercise, exactly.

VICE CHAIRMAN SHACK: I mean my argument is, though, but since our figure of merit here really is delta CDF, this is a level one PRA with uncertainties. And I'm not illustrating my safety margins argument here. This is my probability example.

MR. BANERJEE: But it also fails on safety margins, or it could be interpreted to fail.

CHAIRMAN WALLIS: I think the problem is that --

VICE CHAIRMAN SHACK: Because it's all one-to-one. In this model, loss of NPSH is CDF. This is basically a level one PRA with uncertainty.

MEMBER KRESS: That's right.

VICE CHAIRMAN SHACK: Which is a good thing.

MEMBER KRESS: Yes, good thing to do.

MS. GAVRILAS: With the only difference being that NPSHr is not the probability density function as it ought to be, but rather an imposed --

VICE CHAIRMAN SHACK: A full uncertainty analysis.

MS. GAVRILAS: -- value, yes.

CHAIRMAN WALLIS: We don't know how the staff is going to interpret these large scale tests of screens, and how they're going to apply them to a plant. We have no idea whether they're going to accept CDF as a measure, whether they're going to accept probability of loss of NPSH, whether they're going to require that the worst possible conditions they must never cavitate. We don't have acceptance criteria for that, do we, as far as I know.

MR. BANERJEE: Well, the regulations, I guess are --

(Simultaneous speech.)

CHAIRMAN WALLIS: So there must never be a -- it probably must be zero.

VICE CHAIRMAN SHACK: Only for design-basis accidents.

CHAIRMAN WALLIS: The probability must be zero. Okay. That would never lead to core damage, anyway.

MR. BANERJEE: This is what my point was, that if you go well into cavitation, rather than a little bit of cavitation, you see --

CHAIRMAN WALLIS: It makes a difference.

MR. BANERJEE: It makes a big difference.

CHAIRMAN WALLIS: A little cavitation, it would work perfectly well. There would be enough water to work.

MEMBER KRESS: And, in fact, the net positive suction head is a certain degree of cavitation already.

CHAIRMAN WALLIS: She's have a delta function rather than this. So I think what you've done is very useful. I just don't quite understand why we need the word "margin" in it at all.

MR. BANERJEE: Well, the margin is there in a sense because it's a regulatory margin she's talking about.

MS. GAVRILAS: Because it relates to safety limit, because it embeds safety limit. That's why margin is there.

CHAIRMAN WALLIS: When you get into probabilistic world and you talk about probability of failure, I understand what you're doing. I don't understand what this separation margin thing has to do with that. That just confuses everything.

MR. BANERJEE: It's semantics.

CHAIRMAN WALLIS: Yes.

VICE CHAIRMAN SHACK: Well, no, I think the difference -- I mean, I would argue that this becomes a margin's argument when your final figure of merit is something other than CDF. If the end goal of this thing was I would not have a peak clad temperature over 2,200 F, whether or not I had core damage, I have introduced a subsidiary goal, I'm treating that margin in itself. To me, that is a defense-in-depth argument, and that's a true margins argument.

MR. BANERJEE: Because it adds an additional margin or unknown.

VICE CHAIRMAN SHACK: And when I go to CDF, I look at this as basically a Level One PRA with uncertainties.

CHAIRMAN WALLIS: Yes, that's about what it is.

VICE CHAIRMAN SHACK: And it's my only -- margins, to me, says I'm introducing defense-in-depth by --

CHAIRMAN WALLIS: Something more.

VICE CHAIRMAN SHACK: -- essentially putting up intermediate criteria.

MR. BANERJEE: As she points out, though, it's the only way we have of putting in the unknown unknowns right now.

CHAIRMAN WALLIS: It's also a way of making margin --

VICE CHAIRMAN SHACK: No, as Tom points out, once I get to the CDF, I still have to make a decision on what's an acceptable CDF. I mean, I can put my unknown unknowns on that. I can put my unknown unknowns various places.

CHAIRMAN WALLIS: You can put your margin on the CDF.

MEMBER DENNING: Well, I think we put it on the NPSH value, is what we really put it on here. That's where it is.

MR. BANERJEE: But if you look at what she's got on her graph on the right-hand side of that graph, explicitly in what she calls the safety limit, which we may want to call a regulatory limit, nonetheless, that limit takes implicitly the unknown unknowns into account, which is why we have said it the way -- why the rulemaking or whatever was done set it that way.

VICE CHAIRMAN SHACK: But is that a margin or a safety limit? It's a conservatism in the PRA, is the way I'd look at what we did with NPSH, in the same way that we neglected cavitation. To me, the safety margins argument has to come somewhere where you're forcing a criterion other than CDF as your acceptance criteria.

MEMBER DENNING: I'd like to go back to a statement that Bill made, though. This example is a little bit confusing because it's actually a place where we've made a safety improvement. In the normal situation where we're looking at risk-informed, we make an increase in delta CDF, right? And then we ask ourselves the question - and it satisfies the criteria - then we ask ourselves, have we preserved safety margin, right? That's what we do. And I'm not sure, and I'd like to ask you that question, how do we, in that case, which is, I think, the case that --

MEMBER BONACA: Power uprate.

MEMBER DENNING: Yes, power uprate, or --

MEMBER BONACA: Or using some NPSH.

MEMBER DENNING: So we satisfied Reg Guide 1.128, and then we ask ourselves have we preserved safety margin, because we're supposed to do that. And does this definition or this approach help us in some way to say --

MEMBER KRESS: What we could have done here is look at granting, feeding the net positive suction head by containment over-pressure without changing the screen size, and that would be a case like your's.

MEMBER DENNING: An example like that. So have you done an example like that?

MS. GAVRILAS: No.

MEMBER DENNING: And you understand the point that I'm trying to make, is that when we do Reg Guide 1.128, we agree --

VICE CHAIRMAN SHACK: 1.174.

MEMBER DENNING: All right. 1.174, and we --

VICE CHAIRMAN SHACK: Get a delta CDF.

MEMBER DENNING: -- get a delta CDF, and it's satisfactory, we still have to ask ourselves have we preserved safety margin.

MEMBER SIEBER: Well, that would be a 50.59 kind of thing.

MEMBER KRESS: No, it's 1.174, because 1.174 says you will preserve margins.

MS. GAVRILAS: And it has nine lines underneath that --

CHAIRMAN WALLIS: It doesn't tell you what margin is.

MS. GAVRILAS: -- basically say you will preserve margins, period.

VICE CHAIRMAN SHACK: No, you still have adequate safety margin. You don't have to preserve.

MS. GAVRILAS: That's right.

VICE CHAIRMAN SHACK: They're independent considerations in 1.174, supposedly.

MS. GAVRILAS: They're independent.

CHAIRMAN WALLIS: I think what we're getting at here is the best measure of safety margin is the change in CDS.

VICE CHAIRMAN SHACK: That's a different position, but it's a position.

CHAIRMAN WALLIS: How can you then do it independently?

VICE CHAIRMAN SHACK: Set up other independent criteria they have to meet.

MS. GAVRILAS: Again, that was beyond the scope.

CHAIRMAN WALLIS: Yes.

VICE CHAIRMAN SHACK: But you're looking at ideas here.

MR. BANERJEE: I think this is immediately useful to us.

VICE CHAIRMAN SHACK: You defined the scope problem, whether this is a good idea, or a bad idea, I think you chased the idea, and then we discuss later on.

CHAIRMAN WALLIS: Well, maybe we conclude that the whole idea of margin is a bad one, and the world should be abolished, and then we could talk about probability of failure.

MR. BANERJEE: Whatever you want to call it, I think it's useful because when it comes to say CHF, when you're bring these cores and flattening them axially, as they're doing, as well as radially, I think if you use this type of probability argument and looked at the exceeding of CHF criteria, that was much lower, I'm sure, with the different peaking factors that we had. So that today the fact that we are bringing much more fuel closer to the margins begins to -- closer to the, whatever you want to call it, the CHF limit. Okay?

MEMBER SIEBER: The margin, which is the difference between the safety limit and the operating parameter could stay the same, even though more fuel could approach that.

MS. GAVRILAS: That's right.

MR. BANERJEE: It would be interesting to evaluate it.

MS. GAVRILAS: The margin alone would not be enough for a risk metric.

MEMBER SIEBER: Right.

MS. GAVRILAS: This example stops at probability of event sequence, conditional probability of failure, has no consideration of consequences.

MEMBER SIEBER: Well, you actually have to go to consequences to get the full measure of what the risk is.

MS. GAVRILAS: This example does not.

MEMBER SIEBER: I know.

MEMBER BONACA: And, in fact, if you take a power uprate, this is the only way you can see effectively whether or not you have a reduction in margin, because you can calculate releases in containment.

VICE CHAIRMAN SHACK: I was going to say, just let's move on now.

MS. GAVRILAS: We've had some of this discussion, why should margin be integrated with risk because uncertainty is a major role player. For example, in passive systems of advanced reactors, and because the unknown unknowns portions of uncertainties should be explicitly considered in risk assessments. When does the safety margin framework add value to the decision?

CHAIRMAN WALLIS: Did you show us how to put unknown unknowns into the risk? I'm not sure you did.

MS. GAVRILAS: I'm sorry?

CHAIRMAN WALLIS: Did you show us how to put --

MR. BANERJEE: Because it came through for all the safety limits.

MS. GAVRILAS: By establishing the safety limit and then substituting the safety limit for the capacity probability density function in determining the conditional probability of failure.

CHAIRMAN WALLIS: It was just a conservative definition of failure then.

MS. GAVRILAS: That's right. But conservative, by what, I hope, is an informed amount.

CHAIRMAN WALLIS: You're only worry about the unknowns in failure, not the unknowns in the prediction of the event. It may be the same thing, maybe it comes to the same thing.

MS. GAVRILAS: It's my understanding that the safety limits have been set with due consideration to both uncertainties in load and capacity. That is, with consideration of how good are models for predicting the load are.

CHAIRMAN WALLIS: Go back to the example that Sanjoy and I were talking about, where there are events where either your core make-up tanks drain or they don't at certain times in the event, we know in the AP600 they can drain early or late. That changes the whole scenario. Now that means that in sort of 99 out of 100 events, you don't have disaster, but one you do, and it's way up here somewhere. Moving the boundary around isn't going to make any difference.

Moving the safety limit around doesn't make -- because that one is so far beyond the safety limit no matter where it is. It won't make any difference, at all.

MEMBER BONACA: Some cases that's the way it is, but that's because we learn later on, on the containment example I made before --

CHAIRMAN WALLIS: It doesn't take account of it. I'm just saying I'm not sure that --

MEMBER BONACA: You have containment, 50 psi as a safety limit, and then you discover that --

CHAIRMAN WALLIS: I guess I'm saying the unknown unknowns have more dimensions than you capture just by having a delta function in the safety --

MR. BANERJEE: I guess she has the simplest definition.

CHAIRMAN WALLIS: One way, the simplest way to do it.

MR. BANERJEE: The simplest way you can do it right now.

VICE CHAIRMAN SHACK: If you have it in multiple parameters, you presumably capture more of the unknown unknowns.

MS. GAVRILAS: If you're looking at an event tree that has multiple damage mechanisms for the same barrier, then at each place you have the unknown unknowns corresponding to that damage mechanism.

MR. BANERJEE: And what this does is it also lumps the unknowns in your model implicitly into --

CHAIRMAN WALLIS: This is why we have a safety limit of 4:00 for this discussion, because there lots of unknown unknowns about how many interruptions there will be. We're doing pretty well, so --

MS. GAVRILAS: One of the examples that I thought about where it could be of use would be one where there is a trade-off, where there is one modification, or one event that occurs that has some good consequences, and where consequences is used in the general term, general sense, and some bad consequences.

CHAIRMAN WALLIS: Be good with this business of screen blockage, make the screen bigger, you don't challenge the pumps but you let more debris get through to the core.

MS. GAVRILAS: I thought about TSP, for example, which is, again, along the same lines, that you're removing, you're reducing the probability of core damage due to chemical effects, but you're increasing the releases. So now if you're conservative in your treatment of this, you're going to hide any benefits, so you have to truly be true to propagating uncertainty. And this is a means of doing it that can target just those things that are affected.

CHAIRMAN WALLIS: Well, you really want to measure which incorporates and balances off all these different things, which is something like risk, isn't it?

MS. GAVRILAS: That's right. So in summary, we're not --

MR. BANERJEE: Did you do this TSP example?

MS. GAVRILAS: I'll talk about that in one slide, just one second, please, because -- no, we're thinking about it. Integrated risk and safety margins considers the things that we've talked about, and most importantly, frequency of events, deterministic calculations, and engineering data. The integration is done such that existing guidelines can be used, for example, CDF and LERF if you stop at the probabilities of losing function, or the Commission safety goals, if you're including consequences. It does use established methods and tools. There's nothing that's unfamiliar to those who have been in these buildings for a while, and it is supposed to take advantage of state-of-the-art developments in all the areas. And there are advances that are being made in all the areas that contribute to calculating the risk metric.

CHAIRMAN WALLIS: Let me go back to power uprate. We get people come here with a power uprate. They increase the power by 20 percent, and they convince us, or they try to convince us that there's really negligible change in risk. And we say well, this negligible change in risk, but surely you're giving up some margin, and we never get an answer to that. Would you help, would your method help to explain that in some way to us, or would it not? Because there is no change in risk, given that they are not cheating. If they really show there's no change in risk --

mEMBER DENNING: At least, we don't do -- they don't do --

CHAIRMAN WALLIS: Is there any change --

mEMBER DENNING: -- with uncertainty analysis the way that one could.

CHAIRMAN WALLIS: If they did it with uncertainty, we think that would reveal the change in margin then?

MS. GAVRILAS: I don't know, because I'm

not convoluting the two probability density functions. I'm convoluting over the safety limit, so if anything, I'm going to get lower numbers using this methodology. But originally when I started in this direction, I was measuring the difference if you went from 1,500 degrees Fahrenheit to 1,600 degrees Fahrenheit, I was normalizing that loss, and aggregating over the entire event sequences and coming up with a figure of merit. That would quantify loss of margin, but where exceedence is not involved.

The problem with that is it's a practical problem. This is a mighty expensive methodology to apply to something for which you don't have acceptance criteria, so it wouldn't get much traction to just see how much margin you have lost. But there is a way of modifying this to actually see how much margin you lost, if that's the question.

MEMBER BONACA: I think the problem is that there are releases in severe accidents tied to -- with a power uprate you have more severe releases, and they are not accounted for in the basis, so it's like if you had a PRA and you cut out all those branches that had to do with those, with releases, and that's a problem there.

CHAIRMAN WALLIS: That's not a question of margins, that's a question of consequences.

MR. BANERJEE: Yes. But, Graham, I think this is -- the question you asked, I thought was precisely the question that was answered by the example of the screen. If you look at it, you have certain margins to CHF, to performance of long-term cooling and so on, which are stressed by the power uprates. Okay? And what this allows you to do is to calculate, even though you might have what looks like plus 5 NPSH or whatever, but in reality, you're exceeding that 23 percent of the time.

CHAIRMAN WALLIS: Well, what you're really saying, I think, is if you put the uncertainty into the PRA, then this would reveal there had been a change in CDF in a way which doesn't come about nowadays.

MR. BANERJEE: Well, at the moment -

CHAIRMAN WALLIS: You've got a change in CDF, but with a power uprate claim no change in CDF.

MEMBER MAYNARD: But typically, your power uprate doesn't really change your probabilities. It changes the consequences from what fuel inventory you have, but typically for a power uprate, you're not doing anything that you couldn't do with your current power level. You take away your operating margin, you uprate the power, you're going to be reducing trip set points, and taking away operational flexibility and stuff that you have. But the bottom line is, from your safety analysis stuff, you're going --

CHAIRMAN WALLIS: You say there's no loss of margin in that setting?

VICE CHAIRMAN SHACK: The design-basis space there's no loss of margin.

MR. BANERJEE: But I guess it's how you interpret that design-basis space.

MEMBER MAYNARD: You have much more fuel.

MR. BANERJEE: It's a question of interpretation, because if you looked at it just with the nominal parameters, you have plenty of margin for NPSH. But if you do what she did, you see that 23 percent of the time you -- now there's a judgment as to whether that's okay or not.

MEMBER DENNING: But not in the power uprate. In the power uprate, there still is this very substantial margin. I mean, this 23 percent --

MR. BANERJEE: With a power uprate let's give a scenario that your water is warmer in the long-term cooling. Okay? So, therefore, your margin to NPSH, let's say, is reduced. Okay? However, it still is plus 2 feet or something like that. But in reality, so it went from plus 10 feet, let's say, to plus 2 feet. Now the issue really is, does that plus 2 feet mean that 50 percent of the time you're going to exceed it?

CHAIRMAN WALLIS: Well, in Vermont Yankee it was the other way around. They had a bounding calculation, got them to go across, and they made these sort of extreme assumptions which got them to cross over to the point where they failed NPSH. They didn't have enough NPSH. If they put in the realistic analysis with uncertainty, they claim they could come down to the point where they could show that the probability of challenging NPSH was essentially zero, so it was the other direction. It could go the other way.

MR. BANERJEE: You have more margin, perhaps.

CHAIRMAN WALLIS: Right. They were claiming that realistically there was much more margin than --

VICE CHAIRMAN SHACK: You didn't have more margin. What you had was the case where Appendix K is on the right, the safety limit is here, and the best estimate analysis is underneath it.

CHAIRMAN WALLIS: That's right. That's

right.

VICE CHAIRMAN SHACK: And that's all you did in the --

CHAIRMAN WALLIS: But with uncertainty, but they uncertainties, too.

VICE CHAIRMAN SHACK: Yes, the best estimate with uncertainties --

CHAIRMAN WALLIS: Was beneath it.

VICE CHAIRMAN SHACK: -- was beneath it.

MR. BANERJEE: Except that Vermont Yankee did not do the uncertainty --

CHAIRMAN WALLIS: Well, they partially did it.

VICE CHAIRMAN SHACK: They partially did it. And impressionistic uncertainty analysis.

CHAIRMAN WALLIS: But the temperature alone, and that contributed quite a bit. The temperature of the water in the river and so on, you could do a couple of things pretty easily.

MR. BANERJEE: I'm simply saying it does give you a tool to evaluate how close you are coming to your safety limits or whatever, and whether you have a chance of exceeding it.

CHAIRMAN WALLIS: That's all.

MR. BANERJEE: It may be going the other

way, maybe you have more.

CHAIRMAN WALLIS: I think I'll go back to my first question. We need to have -- you need to have a very clear definition of what you mean by margin. Use it very consistently throughout the presentation.

MEMBER MAYNARD: But is it possible to have a single definition?

CHAIRMAN WALLIS: It's in the glossary, and the thing in the glossary doesn't help me with the way it's used in the --

MEMBER MAYNARD: What I'm referring to is when you're talking about a parameter from the deterministic standpoint, the safety limits, you're going to define safety margin in terms of degrees or some parameter there, or a percent of that parameter. Whereas, if you're talking about the probabilistic approach, it's going to be talking about margins in terms of change in the probability or CDF.

CHAIRMAN WALLIS: It really doesn't talk about percent in temperature because it depends on whether it's absolute temperature, or -- it doesn't mean anything. There's no zero of temperature.

VICE CHAIRMAN SHACK: It's also a matter of just how you're allowed to meet the regulations.

I mean, in the Vermont Yankee case, you're supposed to meet that in the design-basis, and you have rules for how to do that. You need, essentially, a change in acceptance criteria to say that you can meet that with the best estimate models.

CHAIRMAN WALLIS: That's why the operational definition is absolutely key, how do you actually interpret the regulations. And you can waffle as much as you like about margins, or you can give a wonderful exposition about margins, but if the regulations say you do something, you do that.

MR. BANERJEE: No, but we gave them an exception, or we give exceptions allowing containment over pressure because people come up and tell us --

CHAIRMAN WALLIS: Yes, but if you're going to put margins into this somehow, the regulations have to have a proper definition of it, and it has to be operationally understandable and usable.

MR. BANERJEE: We want some --

VICE CHAIRMAN SHACK: But you didn't allow containment over pressure in Vermont Yankee. What you made was the argument that a realistic, a best estimate plus uncertainty analysis, even though you eyeballed it off the top of your head, said you didn't need it.

CHAIRMAN WALLIS: I wouldn't take the qualification, when done partially.

VICE CHAIRMAN SHACK: Right. Well, that's what I just said, an eyeball best estimate 95^{th} percentile.

MEMBER DENNING: I think that there still are a couple of more viewgraphs --

CHAIRMAN WALLIS: Yes, let's go ahead, and we're going to get to the end. Thank you.

MS. GAVRILAS: The bottom line of the summary is that this is, if not the proper way, a proper way to measure changes in overall margins, but it's too expensive to be exercised solely for that purpose.

CHAIRMAN WALLIS: Why? Have we done a cost benefit analysis?

MS. GAVRILAS: Because there's an assumption that is indeed - and here, I'm talking fairing under, losing margin under --

CHAIRMAN WALLIS: The cost is simply in computation time, is that what the cost is, or what is it?

MS. GAVRILAS: Computational time modifying the event trees --

CHAIRMAN WALLIS: But you showed there was two orders of magnitude improvement in computation cost.

MS. GAVRILAS: I still need an analyst to do it.

CHAIRMAN WALLIS: Oh, you need smart people. Okay.

MEMBER SIEBER: And wages continue to go up, I think.

CHAIRMAN WALLIS: Oh, okay.

MR. BANERJEE: Exponentially.

CHAIRMAN WALLIS: I wouldn't be sure it's too expensive.

MS. GAVRILAS: So where possible and necessary, it can eliminate conservatism. You can obtain a risk metric through a systematic and transparent process. You can focus on investigating phenomena that have the largest risk impact. For example, the net positive suction head in GSI 191 or other issue, and it integrates probabilistic, and deterministic, and engineering data, and imposes consistency in the derivation of the risk metrics.

CHAIRMAN WALLIS: And these are the claims that you make?

MS. GAVRILAS: Yes. Potential future work - there's a lot of desire to have this applied somehow, and there's several potential candidates. Among them, GSI-191, containment over-pressure credit for power uprate was mentioned, and revising the enthalpy deposition rate limit.

CHAIRMAN WALLIS: You're just picking on recent topics raised by the ACRS, right? Recent topics considered by the ACRS. That's good.

MS. GAVRILAS: It has to be a concerted effort not just on our side.

CHAIRMAN WALLIS: Well, let me bring up something here.

MS. GAVRILAS: It has to be several --

CHAIRMAN WALLIS: You can do a lot here with your framework. A lot depends on the knowledge base. I mean, the enthalpy deposition is based on a limited number of experiments, and GSI-191 is based on limited number of experiments. And this whole thing is tied in with what sort of a knowledge-base you need, and how much uncertainty is there in the knowledge-base when you start applying it. You can't just deal with probabilities without asking where they come from, so I think that the key to all of this, too, is to consider how you integrate this with your evaluation of what you know.

MS. GAVRILAS: As in --

CHAIRMAN WALLIS: Well, suppose I have 10 experiments on the enthalpy deposition with various conditions, and the French data are different from the American and so on, what do I conclude from that about what I know that I'm going to put into your framework?

MS. GAVRILAS: I believe that that's an example, the reason for which I mentioned that, is because I think the separation of epistemic and aleatory uncertainty is almost intrinsic, at least in the traditional probabilistic way to treating probabilities and event sequences, and consequences the way that this framework proposes. So the idea would be to exercise this to see if it can add, if it can deal with cases in which you have substantial gaps of knowledge.

CHAIRMAN WALLIS: Look at something historical like LOFT, and as Sanjoy was saying, we ran LOFT, and then we had code, and we kept tuning it and tuning it until it fit a few LOFT experiments. Now how do you conclude from that what your knowledge is about this accident you're going to put into your uncertainty analysis? It seems to me a difficult problem.

MS. GAVRILAS: I believe it isn't. I don't think I have an answer for you until we exercise it. I don't think that we know if the problem is unsurmountable, or if it's -- if we gain insight. I just don't know until we tackle it.

CHAIRMAN WALLIS: We have these sort of expert opinion margins. It's just because of these things, where they say well, LOFT - we know people fiddled around with the code and they tuned it, so it's not as good as it's claimed to be in these uncertainty analyses, so we'll add a little bit of margin. So that's what's happened.

MS. GAVRILAS: And, again, I don't think that we can answer that until we actually -- I don't know if applying this adds any formalism to the process, or it doesn't. I'm not sure at this point. So the issue with any kind of potential application is that it sort of requires the involvement of other stakeholders. It certainly can't be done without substantial contribution by others.

CHAIRMAN WALLIS: Do these stakeholders have to understand your framework?

MS. GAVRILAS: I believe so, yes. I believe so. To investigate extension to advanced reactors linking frequency, linking this to the frequency consequence curve, I do not believe that to be a trivial matter, so again, it would be something that requires additional development. This is one of the topics that's being brought up in the context of CSNI. And then, of course, it would be helpful to revise it as advances occur to have a framework that can be updated as advances occur in all those subsidiary areas that yield those figures of merit.

And finally, this is the one that's probably of most interest to me, which is people are working on furthering the state-of-the-art in all these areas, but there aren't many efforts to see what criteria can be put in place to simplify the framework, as opposed to expanding it. There's ways to make it easier. And that deserves some attention by researchers.

And I think that concludes the presentation. I have here a graph from PTS from Mark Kirk, and I'm talking about how you establish criteria, when do you stop? I think this is very telling. It's December '02 to December '04 evolution of data, computations done for PTS. And I looked at this, and I saw that two orders of magnitude band in which all of these data stayed over the course of those two years.

CHAIRMAN WALLIS: There's no increase in certainty as you move along in time?

MS. GAVRILAS: It seems to me to stay within a certain -- I'm thinking the rule of thumb, plus/minus and order of magnitude.

CHAIRMAN WALLIS: The latest ones maybe have a little less scatter, the latest ones.

MS. GAVRILAS: It looks like they do.

CHAIRMAN WALLIS: Oh.

MR. BANERJEE: But that's a computer code. Right?

MS. GAVRILAS: That's a computer code, but the --

MR. BANERJEE: What does the data look like?

CHAIRMAN WALLIS: Through-wall cracking, you want data on through-wall cracking in vessels?

MR. BANERJEE: I mean, it depends what thickness the vessel is.

MEMBER SIEBER: It could be a steam generator, too.

MS. GAVRILAS: And that's the last slide.

CHAIRMAN WALLIS: Now what's the position? This looks to me like something which has a lot of promise, but probably needs more work. Is this something to which RES has some sort of long-term commitment, or it just trying to sort of fly this thing up by us and see if it gets shot down? What's the idea?

MS. GAVRILAS: I'm so glad Farouk came back.

MR. BANERJEE: But him on the hot seat.

MR. ELTAWILA: It depends on the answer that I'm going to -- the letter that I'm going to get from the ACRS. We had an interest in that subject for a long period of time, and I think you raised a lot of questions during this discussion that I really need to go back and reflect on them before I give you a final answer about whether we will continue to develop that methodology or not. I think there are a lot of issues that have been raised today that I'm concerned with. Does that answer you, Graham?

CHAIRMAN WALLIS: Well, I don't know. You could have said I am sure that this has a future. I've already committed, do my best to keep it supported for the next two years because I think this is a very good start. You haven't reached that point.

MR. ELTAWILA: No, I really think there is fundamental things in applying the method that I don't know. I think you alluded to it complete in your discussion, but the methodology will have utilities only if the Agency is willing to accept risk number instead of compliance. That's when you get that delta additional margin that you leave on the floor when you insist about compliance with your regulation. So as long as we have every application according to 1.174, that they have to demonstrate compliance with existing regulation, the utility of the methodology is limited. And as Dr. Shack indicated, just do this systemic and PRA with a lot of uncertainty analysis. But if you want to take advantage of the margin overlapping of the fragility, for example, versus the load or something like that, you have to let go of some of our requirements, and I don't think that's in the cards right now.

VICE CHAIRMAN SHACK: I would have thought it was a tool for building more margin in. If I want to let go of margin, I just do the risk numbers, do a full analysis with uncertainty. Risk is my total final metric.

MR. ELTAWILA: If risk is your final - yes. But as long as you still have that requirement in 1.174 for the compliance requirement, you will never reach that point.

VICE CHAIRMAN SHACK: Right. And that's deliberate.

MEMBER BONACA: I thought it was a good start. I thought that there's a lot that can be changed, should be modified, but I think that it's one way to try to tackle this issue of definition of margin. There is a definition in deterministic space, there are definitions in probabilistic space, and there has to be a way that is being attempted to discuss them in common terms. And as a minimum, bring some clarity about some of the issues to do with setting limits, and what they mean, and the discussion we had today, I think, was enlightening in many ways. I would be disappointed if there was no further work being done on this. That's just my opinion.

MEMBER DENNING: I agree with that. Are we going around the table now?

CHAIRMAN WALLIS: Yes, we are.

MEMBER DENNING: If I may, then, I agree. I think this is a good first step. Obviously, there's more that has to be done, and I think that assuming there is more, I think that we'd like to stay really closely in tune with the direction that it goes. But some of -- I think that there should be definitely a focus towards the 1.174 question of that. And I think that RES ought to be in a position that when 1.174 is redone, that we're in a position of saying what we mean by safety margin, if we want to keep that kind of stuff in there any more. I do think that safety margin really is a deterministic side concept, and we may be going too far in thinking that we really rationalize the risk assessment in the deterministic pathway, that the real purpose of the safety margin is to maintain that independent deterministic pathway in some way that makes sense. Now I'm not positive that this all works, but that's what I think.

One of the things I thought that was very interesting in what you did with the safety margin is I think that you really have kind of perturbed it into a way to do risk analysis that accounts for the effects of uncertainties on acceptance, not acceptance criteria, on the success criteria, and that for problems like the one that you looked at, that we have to make sure that when we do an uncertainty analysis for those things that are really close on the success criteria, that that uncertainty analysis really gets into the definition of success criteria. But I think everything that you did can be done, in that particular thing, can be done within the context of PRA and should be. Whether it was really necessary to make that an extension of the safety margin I'm not sure, but I thought it was interesting and valuable concept that was important for risk analysis. And I pass on to the next.

CHAIRMAN WALLIS: And then the containment over-pressure issue, we suggested that if you did a proper uncertainty analysis, you might not need to do a PRA. You might actually be able to show that the probability of getting this loss of net positive suction head was so low that you really didn't need to incorporate it into risk, because when you've done the realistic physical analysis of things, there was such a huge margin already that you didn't need to go further and look at the risk.

MEMBER SIEBER: But the regulations call for deterministic judgment as to --

CHAIRMAN WALLIS: They seem to be based on a bounding worst possible case.

VICE CHAIRMAN SHACK: I mean, there are several ways to do that. You can look at the probability, you can look at a best estimate calculation of a design-basis analysis; that is, you eliminate some of the conservatism in the design-basis, but not necessarily --

MEMBER SIEBER: That's right.

VICE CHAIRMAN SHACK: That's what we've done with 50.46 to this point, still looking at design-basis arguments, but you're doing a best estimate analysis, so there's various ways to handle this.

MEMBER SIEBER: I think that's a perfect example of how you can use and misuse the term "margin". For example, once you put safety limit in there, swing the safety limit and when the event physically occurs, there is margin built in, for example, Appendix K is one of those. You have the correlation, which is a conservative thing. You have the DKA curve, which is a conservative thing. Those are put in there as conservative measures to perhaps overcome unknown unknowns in the methodology. And that establishes a safety limit, so between when the phenomenon occurs and the safety limit, there is implicit margin put in there. And then when you look at the difference between the safety limit and the operating condition, that's what we are calling margin here. And I think that that is only part of the margin.

For example, if I modify the technique that I use to calculate when the phenomenon that I don't want occurs, I'm playing with the margin between the safety limit and that phenomenon, because you may refine the calculation to the point where it occurs at a different point, maybe a less conservative point, or more conservative than you wanted. And it's because of that, and because the idea of margin is used so many places in the regulations, Reg Guide 1.174, 05.59, and so forth, you have to really be careful, I think, in how it's defined, and how it's used, and it needs to be consistent. And so that's one of the key things.

The overall methodology, though, I think this is a good approach and worth pursuing, because I think it really does clarify and brings integration into two different ways of assuring reasonable compliance with the design requirements in the regulations. So I guess if I was going to pick something out to really concentrate on, this whole concept of margin is important to me.

CHAIRMAN WALLIS: I would concentrate on working out examples of current issues. I would consider that you've got to get customers behind you, you've got to get NRC and NRR to think we really need this, it's useful to us. You've got the people who are doing the utility studies of sumps to say gee whiz, if we did it this way, it would save us money.

We'd be able to make a much better case to NRC. You've got the public who is saying gee whiz, they're now at last being rational about this discussion of margins, so we know what they're doing. And I would address these customers by saying, by looking at current issues like the sumps, and say if you do it this way, or if you did the containment over-pressure this way, then you'd have a much better argument for these customers to use. That's what I would do, just try to make this thing fly. I think you've got hold of some ideas which are promising.

MEMBER MAYNARD: I think it's obvious that you've done a lot of work, a lot of good work. And I also compliment on you sticking through this meeting and not walking out. I think you've done a good job.

I believe that one of the things needed to occur is some good discussions, probably, between research and NRR as to what are the goals of this program, and will it really be used, and get maybe a level of commitment, because I think it's going to still be a substantial work effort. I think it's worthwhile, but only if it's actually going to be used, and is done for the right reasons and for the right customers. The ACRS has an interest in this, but we're not your ultimate customer on this. It's really the stakeholders and NRR, and I think that there needs to be some communications there, and set some goals, and make some determinations before you continue to pursue it.

CHAIRMAN WALLIS: Well, I was always told about sales by business school people. It's very difficult to sell a customer on something which he isn't already looking for. So perhaps find out what it is that they are looking for that you can help them with.

MEMBER ARMIJO: I've had a different background, and I've never seen a good idea that came proposed to an organization, that the first response wasn't we don't need it, it's too complicated, nobody uses it, and we don't want it. And the ones we pursued that had champions that really pushed it, really got us out of trouble. And I think there's some really good ideas here. And I'm a fan of technology, anyway. I just think you need a champion, but if the rest of the organization isn't going to help you, I think it won't work, but I think it should be pursued. I think it's too early to say let's pull the plug.

MR. BANERJEE: I think it's interesting

work, and to me, maybe in the immediate short term I see an application of this to some of these power uprates which are coming through. And it has some generic importance, whether NRR uses it today, tomorrow, it doesn't really matter. I think it's important that we understand some of these things better.

The idea of using what is a mandated safety limit, and showing in, if you like, probabilistic terms how likely we are to exceed that safety limit is a useful concept, I think. Just for that, it's worth doing and pursuing. And I can think of many applications which will come in front of us in the future where we will want to see this, whether NRR does it or not.

VICE CHAIRMAN SHACK: Well, unless NRR wants it, we're not going to see it, because nobody is going to do it.

MR. BANERJEE: Yes, nobody is going to do it, but then we'll keep asking the question. Right?

MEMBER SIEBER: Right.

MR. BANERJEE: Well, what is the probability of exceeding this safety limit? And then how can you tell us, assure us. They may not answer, but we'll keep asking that question. That's for sure.

MEMBER KRESS: I think that is a useful concept. Let's think in terms of a new reactor design. We've got the design-basis accidents out there with their limits, speed limits, figures and merits. Let's pretend for a moment that we didn't have those. We have a reactor that we don't know what the design-basis accidents are for, but we do have a way now to do a PRA, even though it's going to have uncertainties in it. We can think of initiating events, and we can analyze the system to see how they go, so how would I come up with two things for that system? How would I come up with a definition of design-basis accidents and the speed limits to go with it, the limits? Well, that's a good question.

What I think I would do is I'd have a PRA with acceptance criteria on things like FC, probably, frequency consequence, but it could be a CDF or something, depends on the type of reactor, but FC would be the most general. And then I would say all right, let's look at this PRA and pick out each accident type that I've got, which is what we do with design-basis accidents in the first place. Then we pick the dominant sequence out of those, and then we'll say now, I'm going to constrain that sequence to some limit, and I may back off to a temperature, I may back off to something. I'm going to constrain that sequence to have some limit on it. I'm going to do that for each reactor type, and then I'm going to say all right, now design the system so that I've met these design basis accidents, each type, and they meet their limit. Then I'm going to go back and run through my PRA again, and see how close I come to my real acceptance criteria, and that's the FC curves. If I met them with a certain level of confidence, I'd say well, I've got some good design-basis accidents, I've got some good limits.

Now let's presume that that's what we have for our current LWRs. We don't really have that, but let's presume that's what we have. So we've got design-basis accidents, we've got speed limits, and we've got actual overall risk acceptance criteria. Now when I ask the question, in the design-basis space, if I use up that margin to the speed limits, how much margin do I have, and what is this margin, how are we defining it, what's acceptable, how can I live with it, how can I make decisions?

Well, the margins are simply the difference between my calculated value and the speed limit in the design-basis space. Now you might want to do t his probabilistically, and I think there's a lot of value in doing that probabilistic, that particular part. But as I lose that margin by moving up or changing things, the real question is how do I make a decision on whether that's an acceptable loss of margin, or what margin do I need in the first place? Well, the margin I need in the first place depends on how the whole set of sequences that this is a surrogate for allows me to come to a certain confidence level in my overall risk calculation.

That's why I said, you have to separate the two, but they have to be integrated by a process that's design-specific, plant-specific, and the speed limits you set ought to be plant and design-specific. And that's the problem we have, the speed limits we have are not plant and design-specific. They're there in design-basis space, and they're the same for all plants. And that's where we end up having this problem, I think. We can't change those limits, and we can't make them plant specific.

CHAIRMAN WALLIS: You have the same speed limit for all cars, although you know that some are much safer at higher speed than others.

MEMBER KRESS: That's right, so that's

where the problem is. But I think thinking through this process the way I just did will lead you to a way to integrate risk margins in design-basis space, and how to design margins, how to define margins. I think it's the thinking process that I'm trying to throw out, and if I were going to say work on this problem some more, which I'd like to see because it's a great problem to work on, that this is the process --

CHAIRMAN WALLIS: For the Part 53 thing, the earlier basis, it's not just current reactors, current problems. It's how you'd approach future reactors.

MEMBER KRESS: Yes. It's a new tool.

VICE CHAIRMAN SHACK: Yes. I'd look at a different direction. I'm sort of with Rich. To me, I'd like to see how this impacts 1.174. The things that we -- we know how to compute delta CDF in 1.174, sort of. What we don't know is how do you preserve or assure that you have adequate margin, and the defense-in-depth philosophy. To me, this gives me a potential tool for quantifying margins, and quantifying structuralist approach to defense-in-depth. And that's, to me, a tool that -- because you're off in your rationalist world. You're going to assess uncertainties --

MEMBER KRESS: I want to convert that rationalist thinking into --

VICE CHAIRMAN SHACK: But I'm a structuralist defense-in-depth man, so I think this gives me a tool to do that. What I don't know is exactly which criteria I'm going to decide to defend with this tool. And, to me, that may be the hardest thing to come up with, is okay, I've got a tool that I can use to defend structural defense-in-depth. Where do I choose? And that's where I'd like to see some thinking come in. I'm looking at this as a tool to quantify my structuralist defense-in-depth, and just exactly how and where I draw those lines I don't know yet, but I think that's where I'd like to see this work go if it continues.

MEMBER KRESS: Structuralist defense-in-depth needs to deal some way with uncertainties, and how incomplete you know about those, what you know about those uncertainties. So if you're going to do that, you still have to do my thinking in terms of what are your acceptance criteria, what are the uncertainties in the risk. And you have to think in that direction.

VICE CHAIRMAN SHACK: No, no. I'm not

thinking about uncertainties in risk any more. I'm thinking about uncertainties in some structuralist defense.

MEMBER BONACA: I want to say I understand. I am interested, however, also specifically in the issue that she brought up. When it comes down to plant changes, because we are facing changes to these plants, and when you look at what is the impact on margin, whatever you call it, we are being confronted with always with the blinders of the design-basis. And you can't think out of the box. And this allows us to move out of the box, because you get back into probably the distributions, and it brings in PRA insights. I just cannot help but think if you have the power plant and you increase your amount of fuel by large amount, and you do not consider sequences where you may have releases because they are beyond design-basis; and, therefore, you have people coming in and telling us that you have - you can put in 30 percent more fuel, et cetera. And, in fact, we have reduction - you have an increase in margin because they're making a little tinkering here or there, or something. I am not proposing that we don't support power uprates. We do, we have a methodology, and we follow it, but I think we have to be aware of what we are presented and what it means. And so, I think in the context of - and the presentation attempted to bring some examples to do with plant changes, because they're confronting us all the time with those.

CHAIRMAN WALLIS: We've spent about three hours on this, and it's --

MEMBER BONACA: And we are lucky that George wasn't here, because it would have been five hours.

MEMBER SIEBER: Yes, we are.

CHAIRMAN WALLIS: We arranged it carefully so that George wasn't here. Do we want to say any more about this today, or are we ready to take a break and move on to the next item?

MEMBER SIEBER: A break.

VICE CHAIRMAN SHACK: Break.

CHAIRMAN WALLIS: Then we don't need the recorder, we don't need the transcript after this, so you may leave. Thank you very much for your work. Thank you very much for this very interesting and stimulating - obviously, it aroused a lot of interest among this committee, and they're all trying to contribute to it, not just criticize it. That's very encouraging. So we will take a break until 4:30, and then we will take up the matter of the sumps and what we said are the EDO in the light of the subcommittee report from the meeting we had two weeks ago, or so.

VICE CHAIRMAN SHACK: We're also going to go through at least the first reading of my letter so I know where I'm --

CHAIRMAN WALLIS: I think so. We're going to probably go and have a first reading of everything tonight. We'll see how far we can get. Right.

(Whereupon, the proceedings went off the record at 4:18:50 p.m.)

CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: Advisory Committee on Reactor Safeguards 534th Meeting

Docket Number: n/a

Location: Rockville, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Charles Morrison

Charles Morrison
Official Reporter
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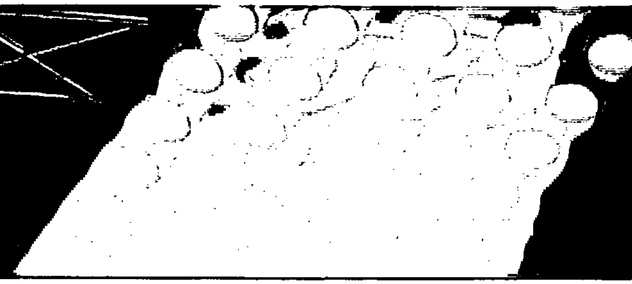
Constellation Energy



Nine Mile Point License Renewal Units 1 and 2

Presentation to ACRS Full Committee

July 12, 2006
Tim O'Connor
Pete Mazzaferro
David Dellario

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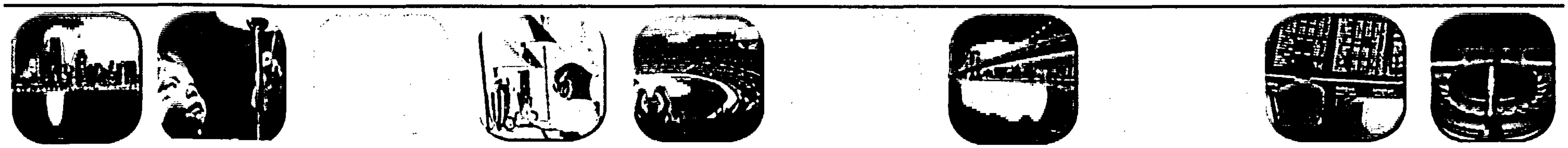


In Attendance

- Tim O'Connor - Vice President, Nine Mile Point Nuclear Station (NMPNS)
- John Carlin - Asst. Vice President, CE Nuclear Technical Services
- David Dellario - Director, Calvert Cliffs Reactor Vessel Head Project
- Raymond Dean - Director, NMPNS Quality and Performance Assessment
- Robert Randall - Director, Ginna Licensing
- Peter Mazzaferro - NMPNS LR Project Manager
- George Inch - NMPNS Design Engineering
- Michael Fallin - CE Corporate Engineering Technical Consultant
- Jeff Poehler - CE Corporate Engineering Senior Engineer

Agenda

- Description of NMPNS — T. O'Connor
- Current NMPNS Performance — T. O'Connor
- License Renewal Recovery Project — T. O'Connor, D. Dellario
- Operating History — P. Mazzaferro
- Plant Improvement Initiatives — P. Mazzaferro
- License Renewal Commitments — P. Mazzaferro
- Summary — T. O'Connor

Description of NMPNS

- Nine Mile Point Nuclear Station owners:
  - CE - 100% of NMP1 & 82% of NMP2
  - Long Island Power Authority - 18% of NMP2
- CE effective ownership date:
  - November 11, 2001
- Operator: NMPNS
- Location: Lycoming, NY
- Ultimate heat sink: Lake Ontario
- NSSS and turbine supplier: GE

Description of NMPNS Units

- NMP1 Specific Information
  - BWR2 - Mark I Containment
  - Rated Thermal Capacity: 1850 MWt
  - Rated Electrical Output: 615 MWe
  - Commercial Operation: 12/1/69
  - License Expiration Date: 8/22/09
- NMP2 Specific Information
  - BWR5 - Mark II Containment
  - Rated Thermal Capacity: 3467 MWt
  - Rated Electrical Output: 1144 MWe
  - Commercial Operation: 3/11/88
  - License Expiration Date: 10/31/26 (Exemption from 10 CFR 54.17 granted by NRC)

Current NMPNS Performance

- The current NMP1 and NMP2 Reactor Oversight Process (ROP) performance indicators are GREEN
- There are no open inspection findings with a status greater than GREEN
- NMP1 and NMP2 are in Column 1 (Licensee Response Column) of the ROP Action Matrix

License Renewal Recovery Project

Constellation Response

- LRA submitted on May 26, 2004
- In March 2005, CE and NRC mutually concluded there were quality concerns with initial LRA
- CE and NRC mutually agreed that further LRA review be deferred to allow grace period for CE to improve LRA quality and submit Amended LRA (ALRA) to facilitate NRC review
- Root Cause Analysis performed (Corrective Action Program) & extensive corrective actions taken

License Renewal Recovery Project

Corporate Oversight

- Assigned to Fleet Licensing
  - Extensive checks and balances
  - Key Performance Indicators (KPIs)
  - Challenge Boards
  - Weekly management status meetings
  - Periodic meetings with Chief Nuclear Officer and President of Constellation Generation Group
- Added resources
- Recovery Plan based on extensive industry benchmarking

License Renewal Recovery Project

Site Lessons Learned and Application

- All projects/initiatives belong to and are controlled through Site VP
- Pre-established results, interim milestones, and metrics
- NMP Staff assigned as a team to Projects
- Validating progress/results through Challenge Boards
- Independent oversight (Corporate/Q&PA/SMEs)
- Site communication for education and engagement

License Renewal Recovery Project

Results of Project

- NMPNS submitted ALRA on July 14, 2005
- Addressed NRC-identified quality concerns
- Accelerated transfer of LR knowledge to NMP
- Successful Audit and Inspection

Operating History

Material Issues Addressed & Design Margin Restored

- NMP1 Reactor Recirculation System Piping
  - Piping replaced with resistant material
- NMP1/NMP2 Core Shroud
  - Tie rod and clamp repairs (Unit 1 – ongoing evaluation pursuant to May 2006 Part 21 notification)
  - Acceptable by inspections and evaluation (Unit 2)
- NMP1 Emergency (Isolation) Condenser
  - Tubing & tubesheet replaced with resistant material
- NMP1 Control Rod Drive (CRD) Stub Tube
  - Roll repairs
- NMP1 RBCLC Piping
  - Threaded pipe replaced by heavier wall welded construction

Constellation Energy — The way energy works.℠

NMP1 Containment Shell Exterior Environment

- NMP1 response to GL 87-05:
  - Remote visual inspection of each of the 10 sand cushion drain lines
  - Remote visual inspection of small portion of air gap and shell surface adjacent to 2 of these drain lines
  - Remote visual inspection of reactor head cavity seal leakage drain shelf
    - Included entire circumference of the concrete shelf and shelf drain scupper
  - Remote visual observation of water, leakage from reactor cavity wall puncture, running into concrete shelf drain line
- Reactor head cavity seal leakage shelf drain line instrumented to detect flow
- Sand cushion drain line exits (in Torus Room) inspected once per operating cycle for wall staining

NMP1 Core Shroud Cracking

- Tie Rod repairs installed in 1995 to structurally replace horizontal welds H1 through H7
- Identified shroud beltline vertical weld cracking in V9 and V10 welds in 1997
- Vertical weld clamps installed in 1999 to structurally replace V9 and V10 vertical welds
- Noble Metals applied 2000/HWC started in 2000
- Full vertical weld and ring segment weld inspections performed in 1999
  - Re-inspection interval 10 years
  - Full re-baseline inspection to be completed 2007 and 2009

NMP1 CRD Stub Tubes

- CRD Stub Tube leakage repairs
  - NRC approved use of roll repairs via SE dated March 25, 1987
  - ASME approval of Code Case N-730 pending for roll repair methodology
  - If, during period of extended operation (PEO), a rolled stub tube re-leaks, one of following zero leakage repairs will be implemented:
    - Welded repair consistent with BWRVIP-58A as endorsed by NRC in RG 1.147
    - Variation of welded repair geometry specified in BWRVIP-58A, using Code Case N-606-1, subject to NRC approval
    - A future developed mechanical/welded repair method subject to NRC approval

Plant Improvement Initiatives

CE Committed to an Ongoing Program of Station Improvement

- Implemented Noble Metal Chemical Addition and Hydrogen Water Chemistry at NMP1 (2000) and NMP2 (2000-2001)
- NMP2 Spent Fuel Pool (SFP) to be re-racked eliminating use of Boraflex (2007)
- Implementing use of corrosion inhibitors in selected NMP1 and NMP2 Closed-Cycle Cooling Water Systems prior to entry into PEO
- NMP1 115kV Reserve Station Service Transformers and Switchyard Disconnect Switches replaced (2005)
- Spent Fuel Dry Storage to be available for use prior to loss of storage space in NMP1 & NMP2 SFPs (2011)

License Renewal Commitments

- NMP Commitments managed and tracked via Nuclear Commitment Tracking System (NCTS)
- 56 LR Commitments
  - 43 NMP1 commitments implemented prior to entry into PEO (support NRC inspection)
  - 41 NMP2 implementation commitments to follow NMP1
- NMPNS priority for completion of regulatory commitments is second only to priority for plant safety consideration
- Implementation Plan and Schedule
- NMP senior management monitors implementation status weekly

Summary

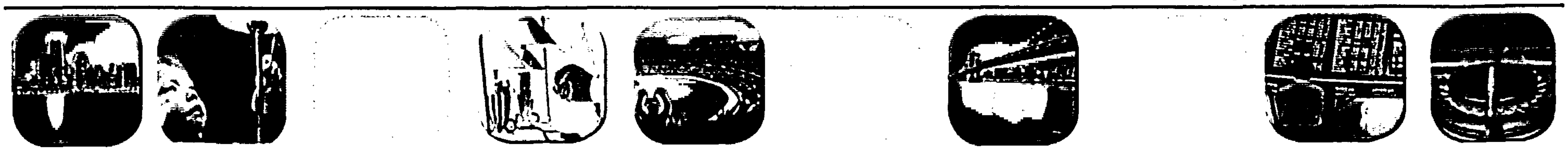
- Successful Recovery Project
  - Results of NRC's Audits and Inspection
  - Only 2 SER Open Items which have been closed
- NMPNS manages plant aging issues effectively
- NMPNS will successfully implement its LR Commitments
- LR implementation is an ongoing process through the PEOs at NMP1 & NMP2
- CE committed to Excellence and is, therefore, ever improving operation and reliability of NMPNS

Constellation Energy

Nine Mile Point License Renewal Units 1 and 2

Presentation to ACRS Full Committee

The way energy works.™



NINE MILE POINT NUCLEAR STATION
Units 1 and 2
License Renewal
Final Safety Evaluation Report

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Staff Presentation to the ACRS

Tommy Le, Senior Project Manager
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Division of License Renewal, NRR

July 12, 2006

Introduction

- Overview
- Highlights of the Review
- Time-Limited Aging Analyses (TLAAs)
- Conclusion

Overview

- LRA submitted by letter dated May 26, 2004
- GE Boiling Water Reactors

  Unit 1: - Mark 1, GE BWR 2
  - 1850 Mwt, 615 Mwe
  - Operating License expires August 22, 2009

  Unit 2: - Mark 2, GE BWR 5
  - 3467 Mwt, 1144 Mwe (with 4.33% Power Uprate in April, 1995)
  - Operating License expires October 31, 2026
  - Schedular Exemption issued October 8, 2002
- NMPNS located six miles northeast of Oswego, NY
- Request OLs Extensions 20 years beyond current expiration dates

Highlights of Review

- SER w/ 2 Open Items was issued on March 3, 2006
- Final SER was issued on June 1, 2006
  - 56 commitments:
    - Unit 1: 16
    - Unit 2: 14
    - Common: 26
  - Implementation: 2 years prior to Unit's PEO
  - No Open Items and No Confirmatory Items
  - 3 License Conditions

Highlights of Review
(continued)

- Three (3) license conditions
  - FSAR update following the issuance of renewed license
  - Commitments completed in accordance with schedule
  - Reactor Vessel Surveillance Program
    - Implement Staff approved BWRVIP Integrated Surveillance Programs (ISP)
    - Obtain NRC staff review and approval for any changes to the capsule withdrawal schedule, if necessary

Highlights of Review (continued)

- **Audits & Inspection Time Line**:

NRR Scoping and Screening Methodology Audit
- 9/27-10/1, 2004

NRR AMP/ AMR Audit
- 8/5-13/04, 8/13-17/04, 10/21-22/04, 10/25-26/04
- 9/19-24/05, 10/24-28/05

Region I LRA Inspection:
- 2/14-18/5, 2/28–3/4/05, 4/4-8/05
- 12/12-15/05

Highlights of Review (continued)

- **Staff Audits identified issues resolved through RAIs and Audit Questions:**
  - 10 CFR 54.4(a)2 – NSR affecting SR
  - Evaluation of Plant Insulation
  - Required changes to LRA Tables and new AMPs
  - Applicant Requested a 90-day grace period
- **Applicant submitted Amended LRA (ALRA) on July 14, 2005:**
  - 14 new systems were added,
  - 3 previously included systems removed
  - New LR drawings identifying SSC's were provided
  - ALRA expanded clearly identified SCCs within scope of LR and subject to AMR
  - ALRA now used standard components types and component intended function consistent with SRP-LR and NEI-95-10

Highlights of Review (continued)

- Examples of Staff-Value Added:
  - New Bolting Integrity Program
  - Brought into scope Halon and CO2 systems
  - Brought into scope fire wrap insulation used for fire protection
  - Required applicant to implement zero leakage permanent repair on NMP1 CRD Stub Tube Penetrations
  - Brought into scope NMP2 Non-EQ Inaccessible Medium Voltage Cables
  - Required Volumetric Examination of NMP1 Drywell shell as data points prior to entering of PEO for a newly added Drywell Supplemental Inspection Program beyond that of applicant's IWE requirements

Highlights of Review
(continued)

- EXAMPLES of Enhancements

-BWR Vessel Internals Program

Enhancements: For example: 100% Inspection of Top Guide for Unit 1 (Commitment 13)

-Reactor Vessel Surveillance Program (RVSP)

The RVSP manages loss of fracture toughness due to neutron irradiation embrittlement in the RV beltline materials.

The RVSP is based on the integrated surveillance program criteria in BWRVIP-78 and BWRVIP-86.

Enhancement: The RVSP will be enhanced to include conformance with the updated integrated surveillance program criteria in BWRVIP-116 (Commitment #22-NMP1, #20-NMP2).

Highlights of Review (continued)

Containments, Structures and Component Supports

- **Open Item 3.0.3.2.17-1:** NMP1 Drywell Corrosion
  - Found 6 identified corrosion areas on shell inside Drywell
  - As reported in Owner Inservice Inspection 2003 Report

- **Resolution:** March 27, 2006, Meeting in Rockville
  - Applicant Letter dated April 4, 2006 provided new AMP to continuing monitoring of areas with previously found corrosion beyond the applicant's IWE Inspection Program
  - The staff finds the AMP acceptable

Highlights of Review (Continued)

Aging Management of In-Scope Inaccessible Concrete – Measured NMPNS Ground Water Parameters

	Acceptance Criteria	NMP 1 & 2
pH	>5.5	6.79 – 7.83
Chlorides	<500 ppm	7.7 – 49 ppm
Sulfates	<1500 ppm	28 – 60 ppm

- Plant located adjacent to an inland lake with ground water testing performed once every six months
- Above data [from April & October, 2003 tests] indicate below grade environment is non- aggressive
- Because below grade environment is non-aggressive: No phosphate and phosphoric acid tests were performed

Time-Limited Aging Analyses (TLAAs)

- 4.1 Identification of TLAAs
  - No TLAA-based Exemptions identified
- 4.2 Reactor Vessel (RV) Neutron Embrittlement
  - Analyses verify that the integrity of the RV will be maintained throughout the PEO.
- 4.3 Metal Fatigue
  - Committed to implement FatiguePro monitoring software (commitment #5 for U1 & #4 for U2)
- 4.4 Environmental Qualification of Electrical Equipment
  - EQ program together with other plant programs will adequately manage aging effect during PEO

Time-Limited Aging Analyses – TLAAs (Continued)

- 4.5 Concrete Containment Tendon Prestress – N/A
- 4.6 Containment Liner Plate, Metal Containment and Penetration Fatigue Analysis

The applicant projected and the staff confirmed that the fatigue usage will remain within acceptable limits through the period of extended operation.

The applicant will monitor critical NMP1 and NMP2 locations using the fatigue monitoring program to provide additional assurance.

Time-Limited Aging Analyses –TLAAs (Continued)

- 4.7 Other Plant Specific TLAAs

  (1) Open Item 4.7B.1-1:

  Staff RAI 4.7B.1-1: TLAA evaluation for NMP2 Bioshield Wall (BSW) calculation not based on NRC-approved methodology

  Resolution

  - Applicant Letters dated January 11, and March 29, 06, provided revised neutron fluence value
  - Staff finds value < 1.0x10E17 n/cmE2 threshold and NMP2 BSW no longer a TLAA

  (2) Applicant submitted new TLAA 4.7.5, Reactor Water Cleanup System Weld Overlay Fatigue Flaw Growth Evaluations for NMP1 as part of their Annual Update to ALRA

4.2 Reactor Vessel Neutron Embrittlement

- The staff independently verified that the USE values of the NMP1 and NMP2 RV beltline materials will continue to comply with the USE requirements of 10 CFR Part 50, Appendix G throughout the POE.

- The staff independently verified that the NMP1 64 EFPY conditional failure probabilities for the RV circumferential welds are bounded by the NRC analysis in the staff's SER of the BWRVIP-05 report, dated July 28, 1998. NMP2 has not submitted a relief request for the elimination of the circumferential weld inspections for the remainder of its 40-year licensed operating period.

- The staff independently verified that the analysis of the conditional failure probabilities for the NMP1 and NMP2 RV axial welds is bounded by the NRC analysis in the staff's March 7, 2000, supplemental SER of the BWRVIP-05 report.

TLAAs Summary

- TLAAs
  - 10 CFR 54.3: TLAA list adequate, as amended
  - 10 CFR 54.21(c)(1)(i), (ii), (iii): remain valid for PEO, projected to the end of PEO, aging effects will be managed
  - 10 CFR 54.21(d): Sufficient supplements to FSAR
  - 10 CFR 54.21(c)(2): No plant specific exemptions

CONCLUSION

- The NMPNS, Units 1 and 2, ALRA has met the requirements of
  10 CFR Part 54:
  - Scoping and Screening
  - Aging Management Reviews and Programs
  - Time-Limited Aging Analyses

Assessment of the Potential for Phosphate Ion-Concrete Interactions

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534th ACRS Meeting

July 12-14, 2006

Presentation Outline

- Background
- Objective and Approach
- Primary Deliverables
- Literature Review
- Contacts with Researchers
- Design of Experiment
- 12-Month Test Results
- Preliminary Conclusions
- Primer on Concrete Durability

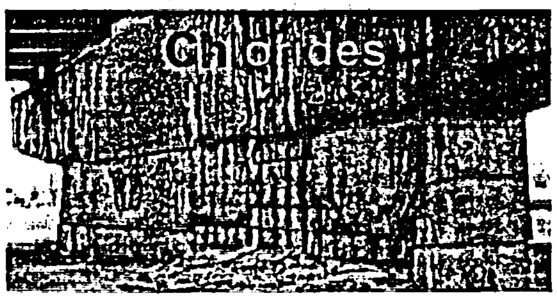
- **Background**

Portland Cement Concretes Located in Soils can be Susceptible to Chemical Attack

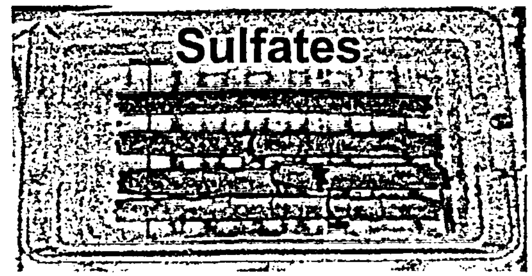
Sulfate attack of 30-year-old bridge sub-structure

- Sulfate attack - sulfate ions attack C_3A to form ettringite and gypsum that can expand to disrupt concrete
- Acid attack - carbonic, humic, and sulfuric acids can cause dissolution the cement paste matrix
- Salts
  - Magnesium - replace calcium in C-S-H leading to loss of binding properties
  - Ammonium - form soluble salts that are leached away
  - Chloride ions - surface scaling due to salt crystallization
- Organic compounds - react with calcium hydroxide to produce physical expansion
- Aggressive CO_2, pure water, salt crystallization, and microbial

Potential Degradation of RC Structures Due to Chloride and Sulfate Ions has Resulted in Building Codes Establishing Exposure Limits



Corrosion of steel reinforcement in bridge superstructure



TDOT study at Univ. Texas 0.352 molar, 5% $NaSO_4$ soln.

Type of member	Maximum water soluble Cl^- in concrete, % by wt. cement
Prestressed concrete	0.06
RC exposed to chloride in service	0.15
RC that will be dry and protected from moisture	1.00
Other RC construction	0.30

Sulfate Exposure*	Water soluble SO_4 in soil, % by wt.	SO_4 in water, ppm
Negligible	0.00-0.10	0-150
Moderate	0.10-0.20	150-1500
Severe	0.20-2.00	1500-10,000
Very severe	Over 2.00	Over 10,000

*Also Maximum, w/c, minimum strength, and cement type req'ts.

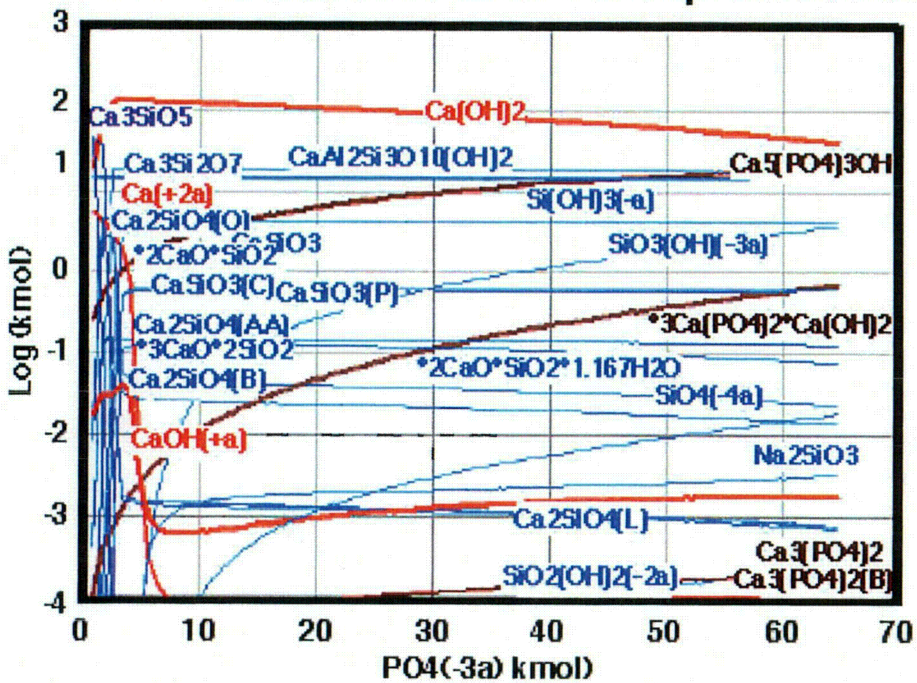
If $Ca(OH)_2$ in Pore Structure were Converted into Apatite (Hydroxyapatite) Due to Presence of Phosphates, Concrete Decrepitation Might be Possible

- Dr. Powers found that phosphate concentration necessary for apatite formation is relatively low ($P_t = 1.52 \times 10^{-17}$ moles/kg H_2O)

Phosphate replacement of $Ca(OH)_2$ in OPC [$5Ca(OH)_2$+$3PO_4$(-3a) = $Ca_5(PO4)_3OH$+9(OH)(-a)]					
T (°C)	ΔH (kcal)	ΔS (cal/K)	ΔG (kcal)	K	Log K
0	-7.725	127.84	-42.64	1.33E+34	34.122
20	-7.391	129	-45.21	5.08E+33	33.706
40	-6.563	131.73	-47.81	2.36E+33	33.372
60	-5.497	135.02	-50.48	1.31E+33	33.118
80	-4.271	138.6	-53.22	8.63E+32	32.936
Formula	FM (g.mol)	Conc. (wt, %)	Amt. (mol)	Amt. (g)	Vol (l or ml)
$Ca(OH)_2$	74.095	56.527	5	370.473	165.39
PO4(-3a)	94.971	43.473	3	284.914	0
$Ca_5(PO4)_3OH$	502.32	76.645	1	502.321	159.98
OH(-a)	17.007	23.355	9	153.066	0
Thermodynamic database in Outokumpu's HSC Chemistry V5.11 Code					Volume change = -3.3%

Phases in OPC that Form Under Increasing Exposure to Phosphate

Equilibrium Phases for an OPC that is Inundated with Phosphate Ions

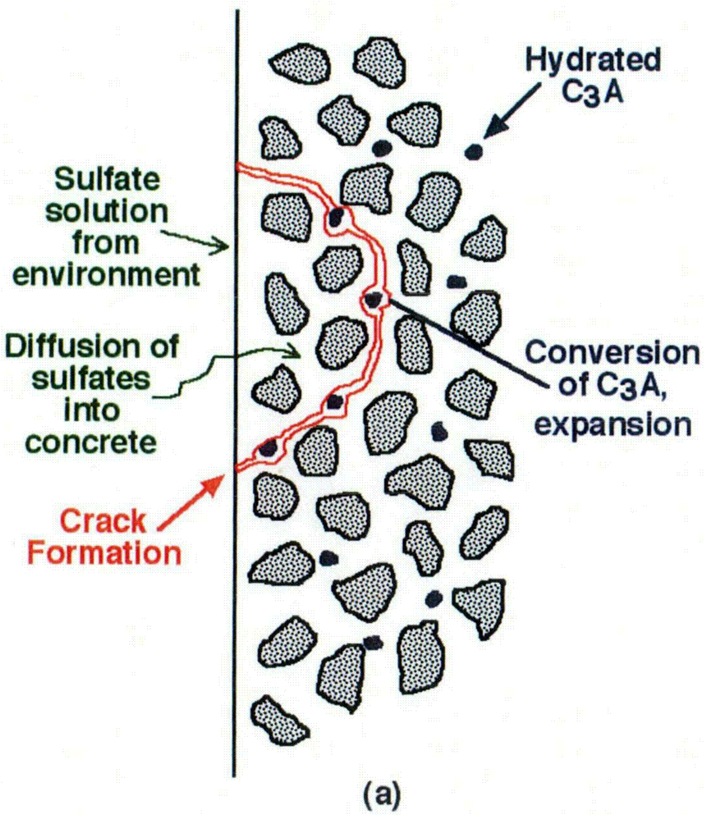


Ca(OH)$_2$ phases,
Aluminosilcate phases,
Phosphate phases

In an OPC system the formation of calcium hydroxyapatite is capable of replacing the free calcium (Portlandite) and successfully competes for calcium in aluminosilicate matrices

- **Objective and Approach**

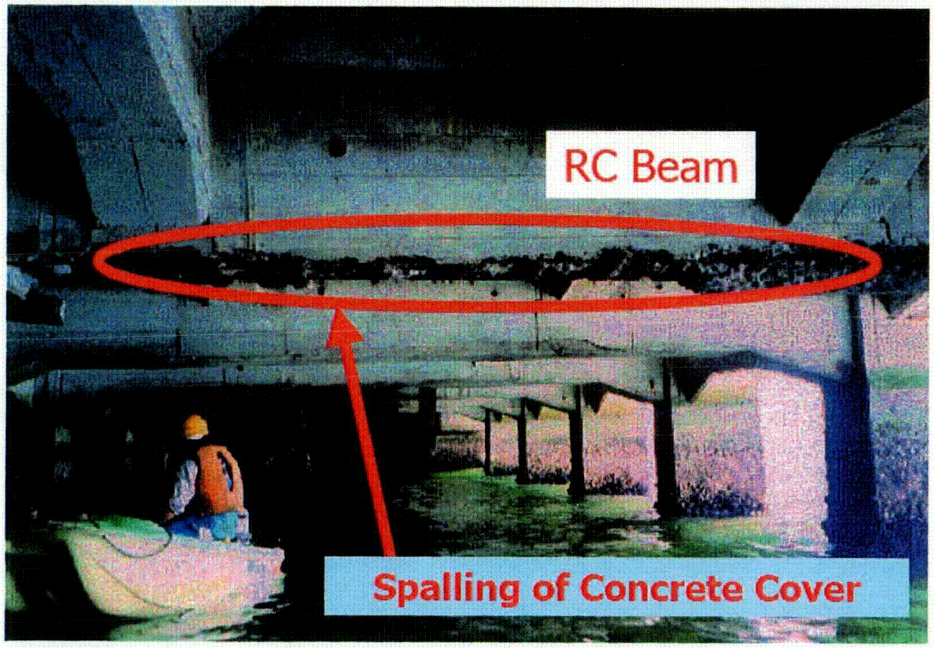
Program Objectives



Mechanism of sulfate attack

- Understand significant factors that may lead to the establishment of phosphate limits
- Provide recommendations (technical basis), as appropriate, on whether a limit on phosphate ion concentration in ground water is required to avoid degradation of concrete structures
- Provide recommendations, as appropriate, in the form of Staff guidance on phosphate ion concentration limits

Approach



Steel reinforcement corrosion

- Review literature and available industry standards
- Contact cognizant concrete research personnel and organizations
- Conduct "limited" laboratory study
- Obtain and evaluate concrete samples from structures in high phosphate environments
- Prepare primer on factors that affect durability of NPP concrete structures

- **Program Deliverables**

Primary Products

- "Interim Report: Assessment of Potential Phosphate Ion-Concrete Interactions" - August 2005
- "Laboratory Investigation on Effect of Phosphate Ions on Concrete Materials' - April 2006
- "Primer On Durability of Nuclear Power Plant Concrete Structures - A Review of Pertinent Factors" - June 2006
- "Criteria for Assessment of Phosphate Effects on Nuclear Power Plant Concrete Structures" - November 2006

• Literature Review

Literature Review Did Not Identify Any Pertinent Information Relative to Interactions of Phosphate Ions and Cementitious Materials

- Navy report identified phosphate compound contained as antioxidant in engine oil as source of aircraft concrete parking apron scaling
- Phosphate compounds have been used as set retarders in concrete mixes
- Phosphate materials have been used to produce a number of cement-based binders or phosphate-cements
- Phosphogypsum, main by-product of phosphate fertilizer industry, has been evaluated as road base material and set retarder in Portland cement
- Phosphates in form of phosphoric acid will cause slow disintegration of Portland cement-based materials
- Several articles addressing apatite and dental applications

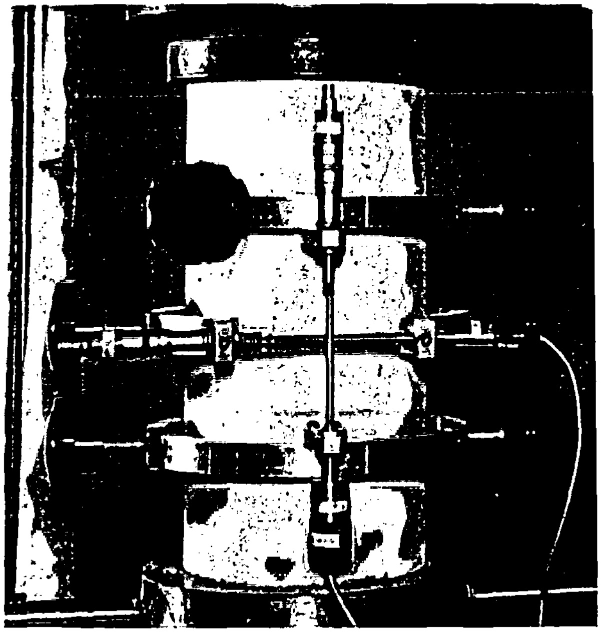
- **Contacts with Researchers**

Recognized Experts Contacted were Not Aware of Potential Deleterious Phosphate Ion-Cementitious Materials Interactions

Contact	Organization
Dr. Andrew Boyd	University of Florida
Dr. Paul Brown	Penn State University
Dr. Gerard Canisius	Building Research Est. (UK)
Dr. George Hoff	Hoff Consulting LLC
Mr. Charles Ishee	Florida DOT
Mr. Richard Kessler	Florida DOT
Dr. Neil Milestone	University of Sheffield (UK)
Dr. George Sommerville	British Cement Association
Dr. Peter Taylor	CTL Group
Dr. Michael D. A. Thomas	University New Brunswick
-	Florida Inst. Phosphate Res.
-	IMC phosphates

- **Design of Experiment**

As Literature Review and Contacts with Cognizant Research Personnel Revealed Little Information, A Laboratory Study was Designed and Implemented



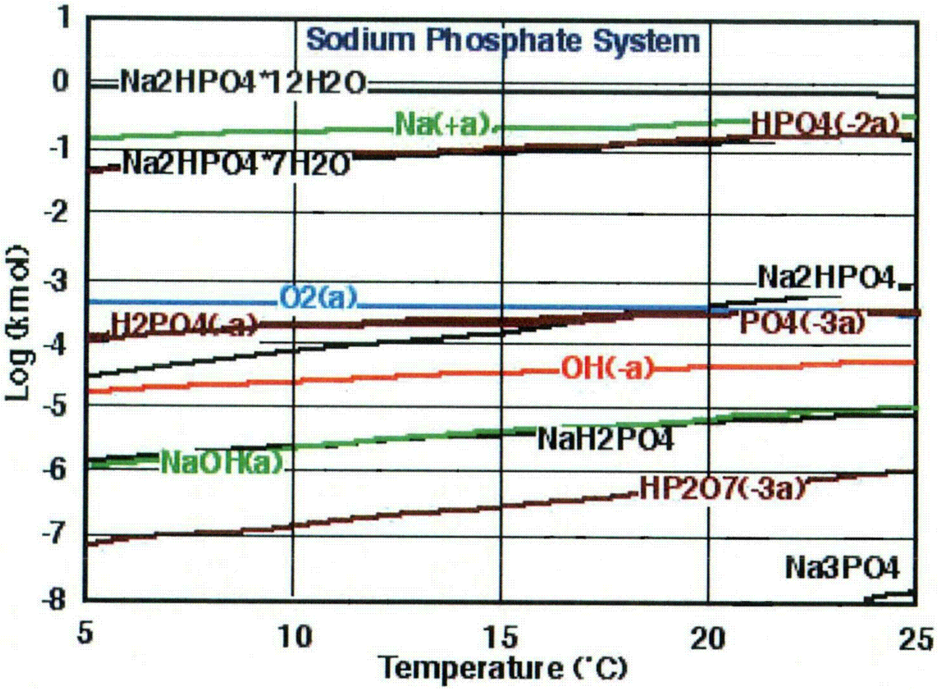
Compression test of Concrete cylinder

- Thermodynamic calculations investigating phosphate concentrations as controlled by soil minerals
- Experimental program
  - Cement paste
  - Exposure solutions
  - Test specimens
  - Test procedures

Study of Phosphate Concentrations as Controlled by Soil Minerals

- Depending on soil, dominant cations may be calcium with magnesium, and/or sodium - determine phosphate solubilities in soil pore waters
- Relative phosphate solubilites calculated as they would be controlled by respective phosphate compounds
- Application
  - Assist in design of laboratory exposure tests
  - Aid in interpretation of field observations of concretes exposed in situ

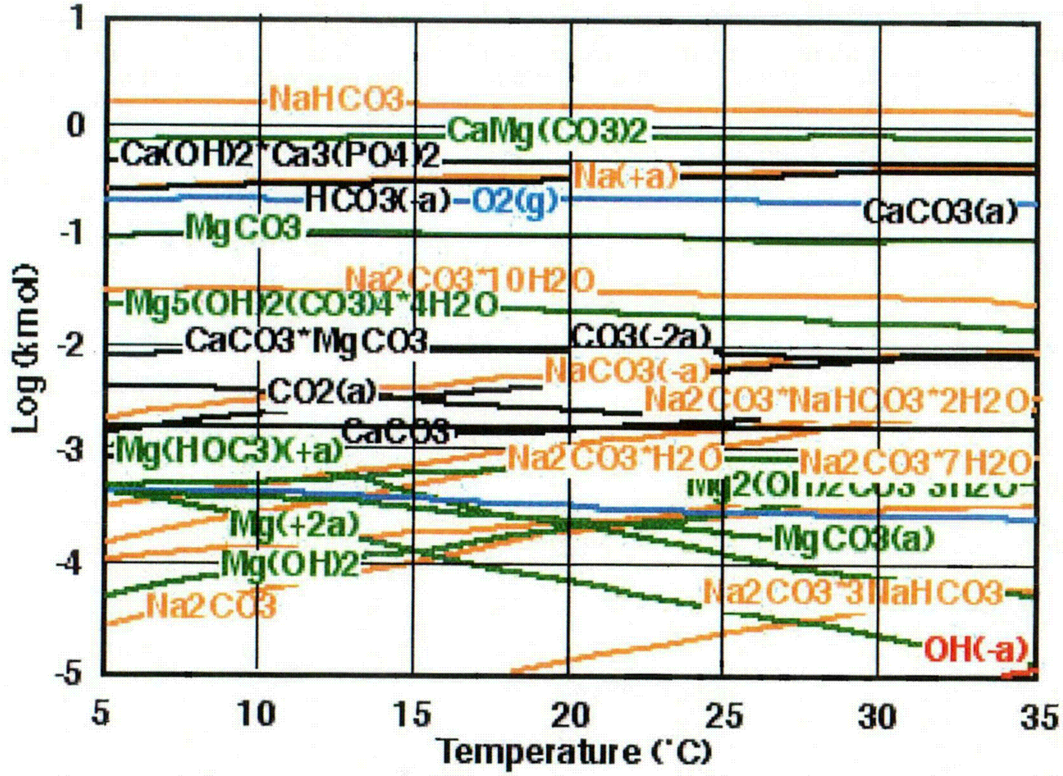
At Equilibrium, Na-, Mg-, and Ca-Rich Systems Saturate Phosphate Aqueous System



System	Molar Range
Na	10^{-1}
Mg	10^{-3}
Ca	10^{-5}

- One mole of solids placed on one liter water and equilibrium concentrations calculated
- Calcium-rich cements and limestone/dolomite aggregates will extract phosphates from nearly all ground waters
- Phosphate concentrations maintained with Na_2HPO_4*$12H_20$ or $Mg_3(PO4)_2$

Cement-Dolomite Aggregate System Exposed to CO_2 in Air or Groundwater



- Calcium in cement-aggregate system will extract phosphate from sol'n
- Calcium hydroxyapatite forms in Na*Mg*Ca systems in presence of CO_2 from air or ground water

Phosphate Precipitates in a Sequence of Compounds

Phase	Abbreviation	Compound	Ca/P
Brushite	DCPD	$CaHPO_4 \cdot 2H_2O$	1
Monetite	DCPA	$CaHPO_4$	1
Octacalcium Phosphate	OCP	$Ca_4H(PO_4)_3 \cdot 2.5H_2O$	1.33
Whitlockite -Tricalcium Phosphate	TCP	$Ca_3(PO_4)_2$	1.5
Calcium Hydroxylapatite	HAP	$Ca_5(PO_4)_3OH$	1.67
Amorphous Calcium Phosphate	ACP	-	-

Source: M.J.J.M. Van Kemenade and P.L. De Bruyn, "A Kinetic Study of Precipitation from Supersaturated Calcium Phosphate Solutions," *J. of Colloid and Interface Science* **118**(2), August 1987.

Solubility Products of Key Phosphate Compounds

Compound	Abbreviation	25°C	37°C
Calcium Hydroxlapatite	HAP	6.3×10^{-59}	2.35×10^{-59}
Octacalcium Phosphate	OCP	1.25×10^{-47}	5.1×10^{-50}
Brushite	DCPD	2.1×10^{-7}	1.87×10^{-7}

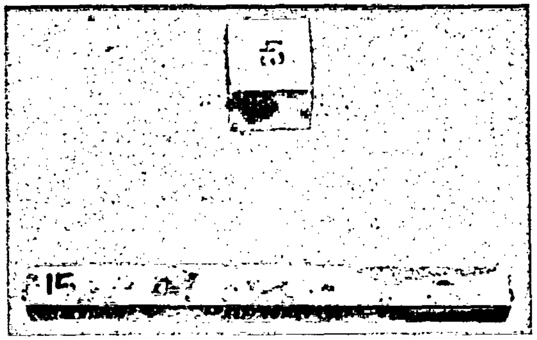
Source: M.J.J.M. Van Kemenade and P.L. De Bruyn, "A Kinetic Study of Precipitation from Supersaturated Calcium Phosphate Solutions," *J. of Colloid and Interface Science* **118**(2), August 1987.

Precipitation Sequence of Calcium Phosphate Compounds from Supersaturated Calcium Phosphate Solutions

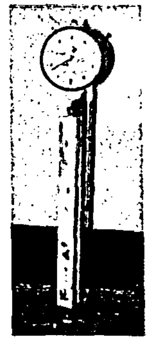
pH	T (˚C)	Precipitation Sequence	Comment
6.7	26	DCPD = OCP---->HAP	Initial OCP forms at medium saturation at exclusion of all other phases
7.4	26	ACP---->OCP---->HAP	ACP dominates initial phase at high pH
6	26	OCP---->DCPD(---->)HAP	HAP is the most thermodynamically-stable phase
6.7	37	DCPD---->OCP---->HAP	Homogeneous formation of HAP even at low supersaturation is *never* seen

Source: M.J.J.M. Van Kemenade and P.L. De Bruyn, "A Kinetic Study of Precipitation from Supersaturated Calcium Phosphate Solutions," *J. of Colloid and Interface Science* **118**(2), August 1987.

Experimental Program Incorporated Approach Utilized to Investigate Sulfate Resistance of Cementitious Materials

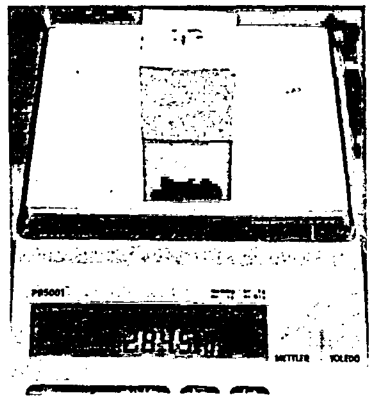


Prism and Cube Test Specimens



Length Change

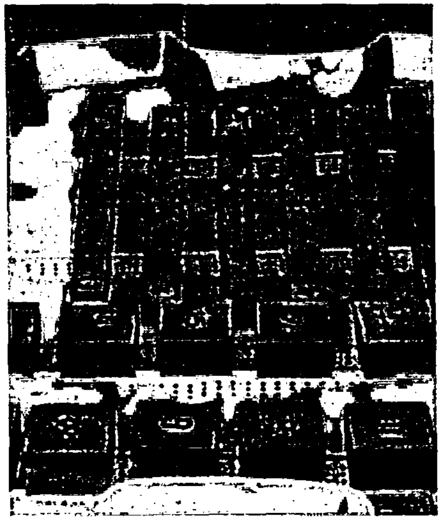
Compression Test



Weight Change

Laboratory Investigation

- Portland cement paste (w/c = 0.4) cubes (2" x 2" x 2") and prisms (1" x 1" x 11")
- Exposure solutions
  - Saturated calcium hydroxide (reference)
  - Saturated magnesium phosphate (low-solubility salt)
  - Saturated sodium hydrogen phosphate dodecahydrate (high-solubility salt)
- Test intervals
  - 30-days
  - 3-months
  - 6-months
  - 1-year
- Examination
  - Compressive strength
  - Length and weight change
  - X-ray diffraction/SEM



Na_2HPO_4 - 1 Month Exposure

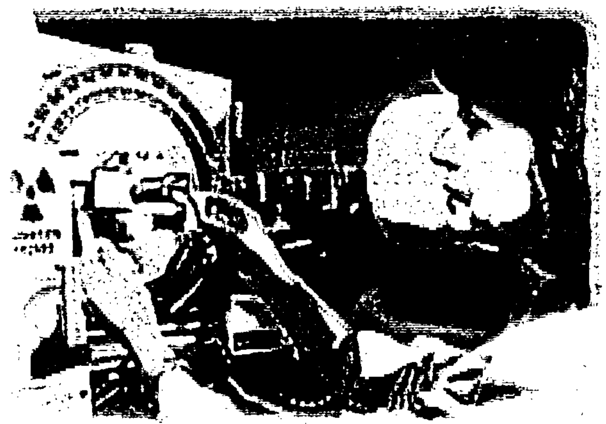
Test Specimens

- **12-Month Test Results**

12-Month Test Results Provided in a Letter Report

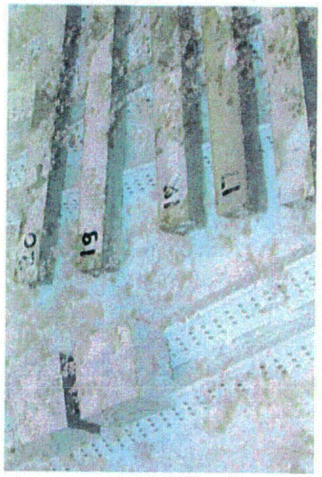
- Length and weight change
- Compressive strength
- X-ray diffraction
- SEM examination

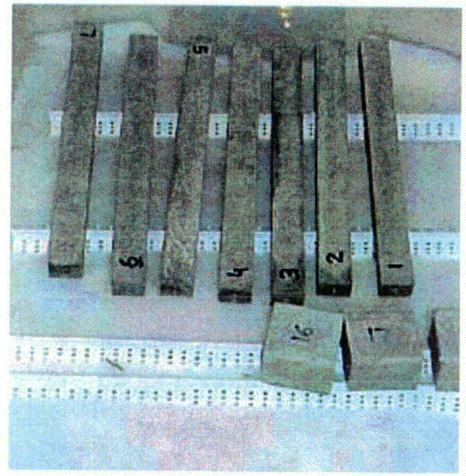
Field Emission
Scanning Electron Microscope

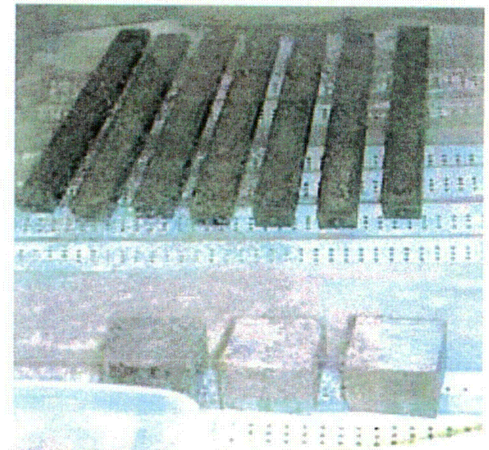


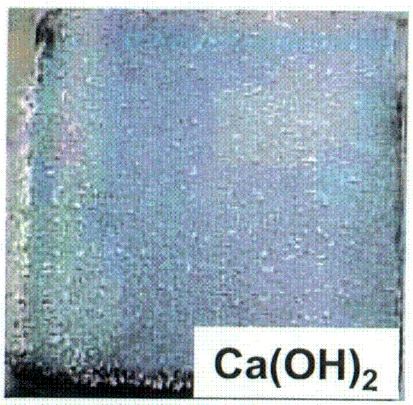
Room Temperature
X-Ray Diffractometer

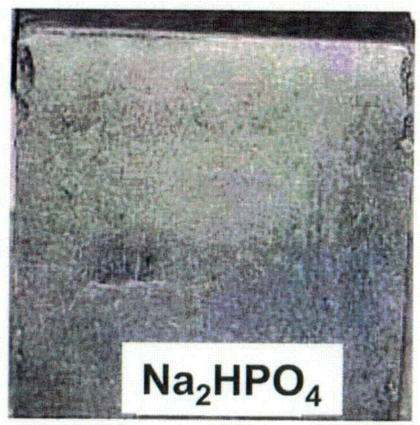
Excess Solids of Salts were Poured on Bottom of Containers with Sufficient Water To Cover Specimens

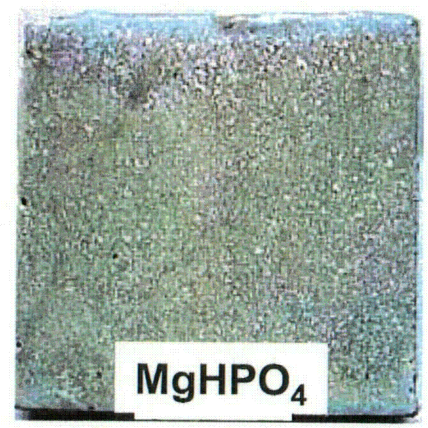




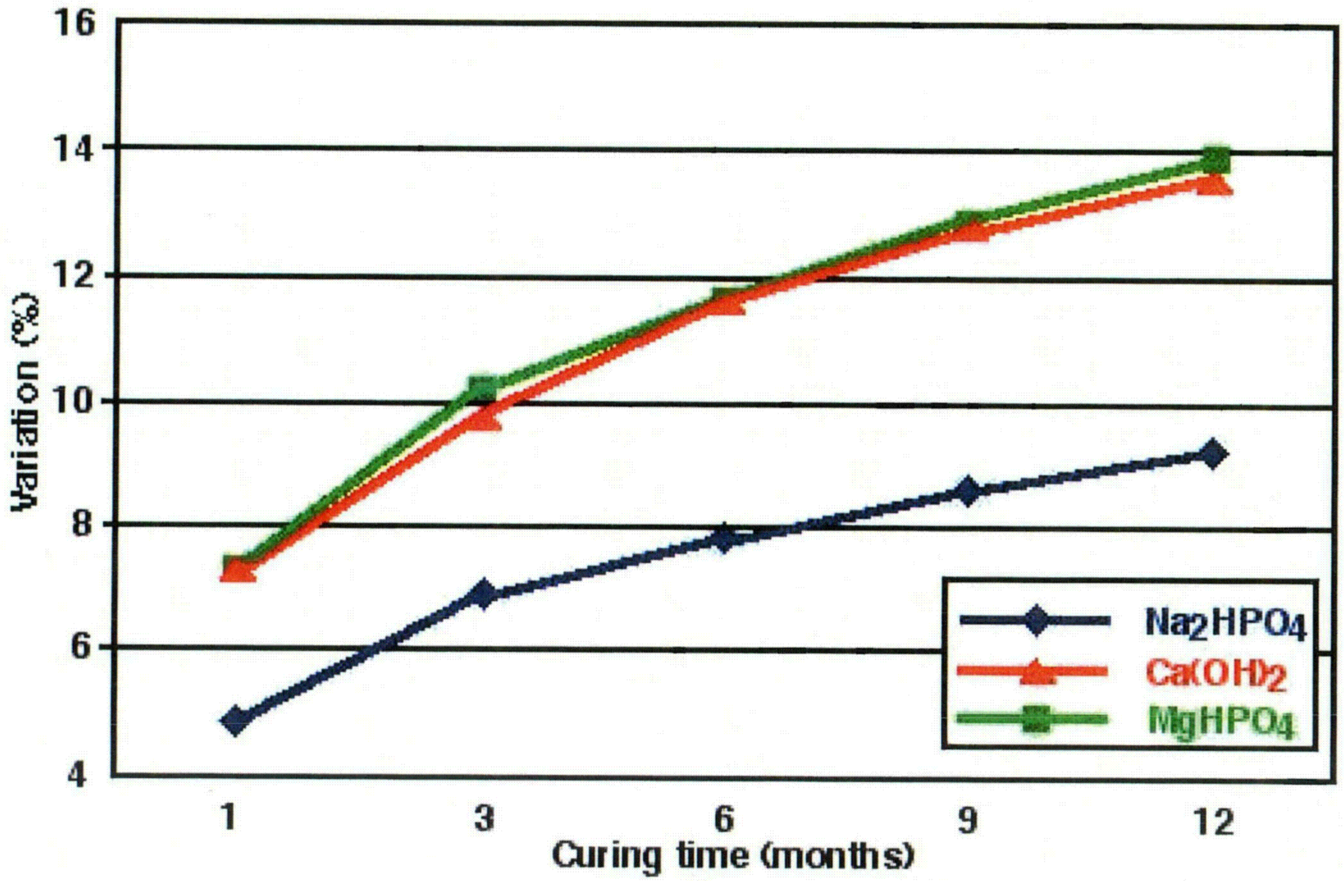








Specimens Cured in Phosphate Solutions did not Exhibit Excessive Length Changes



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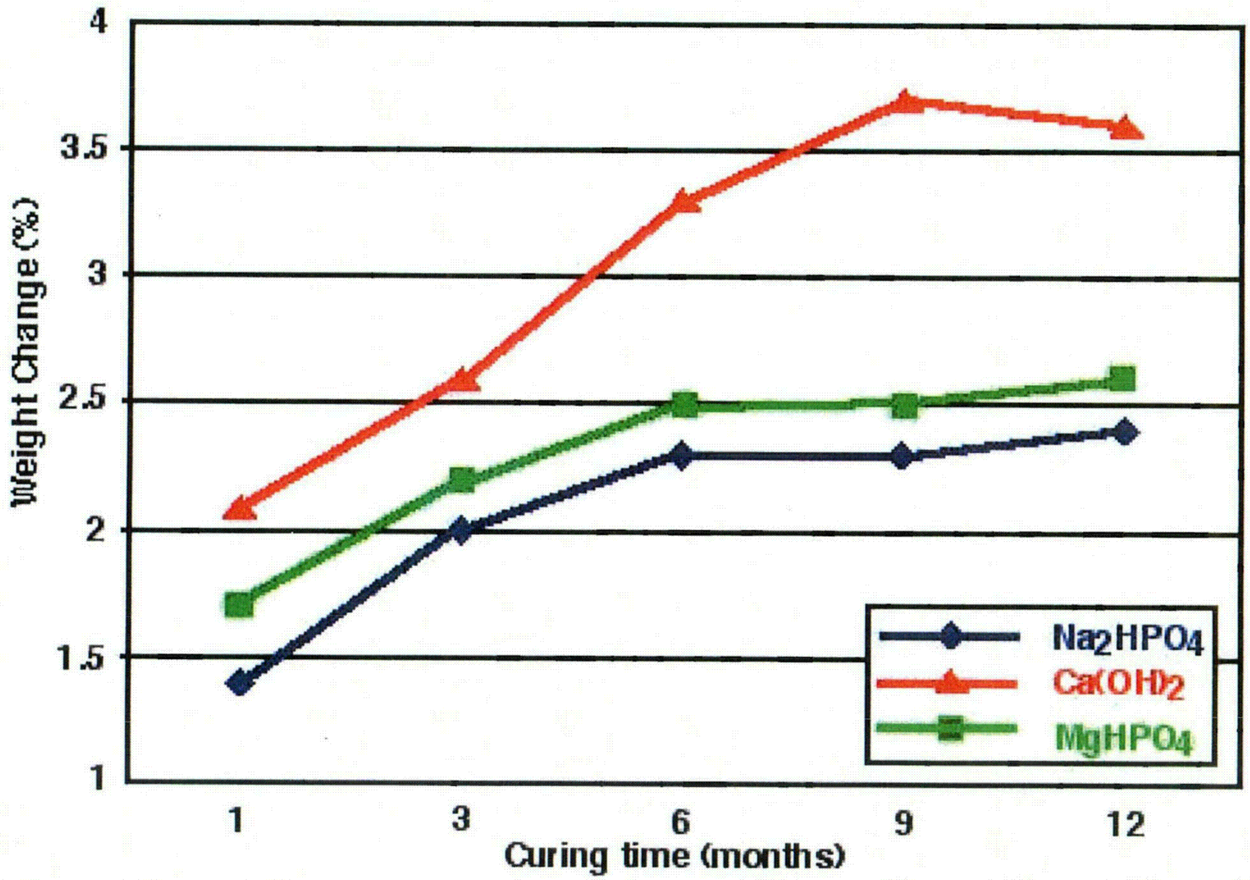
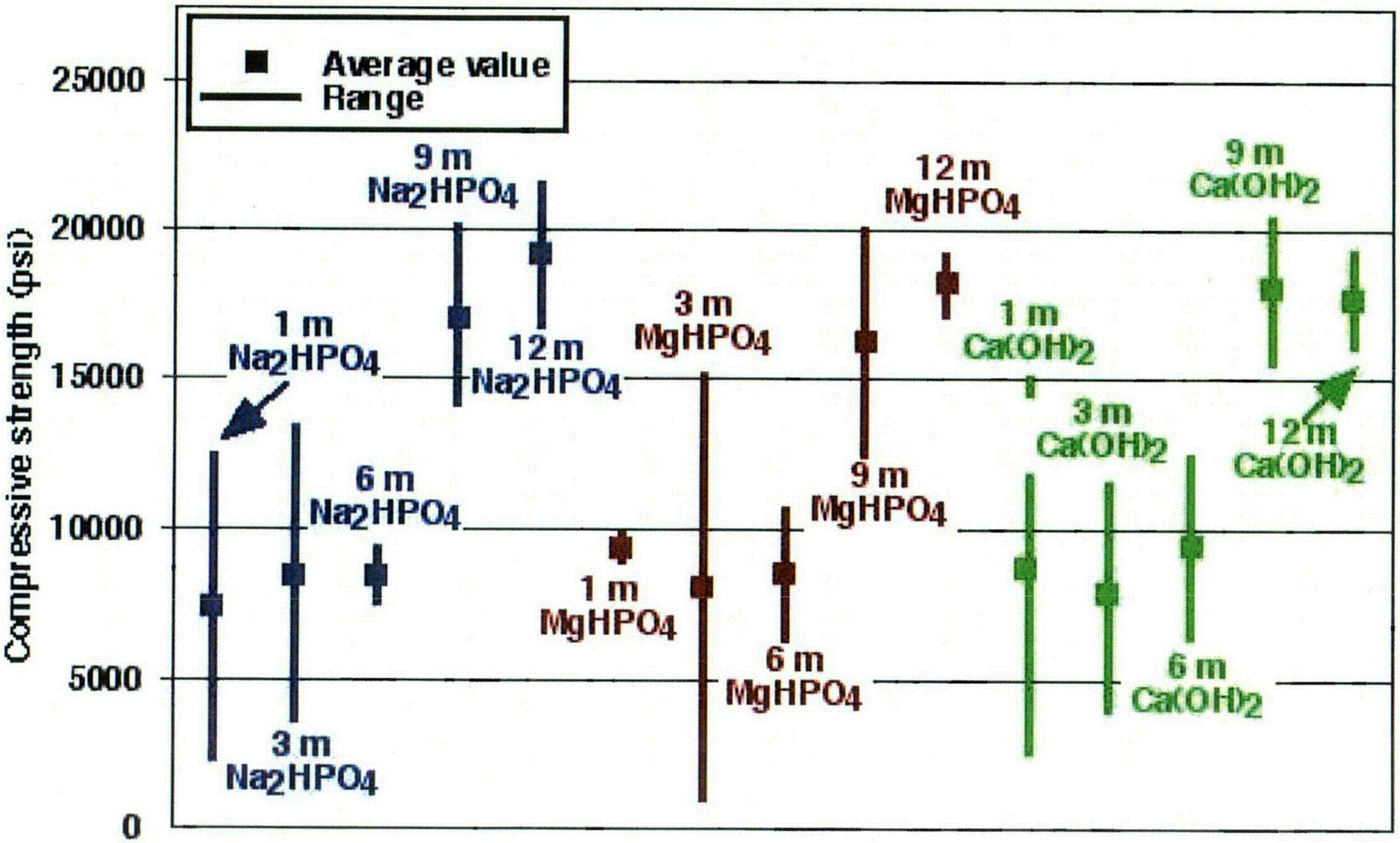
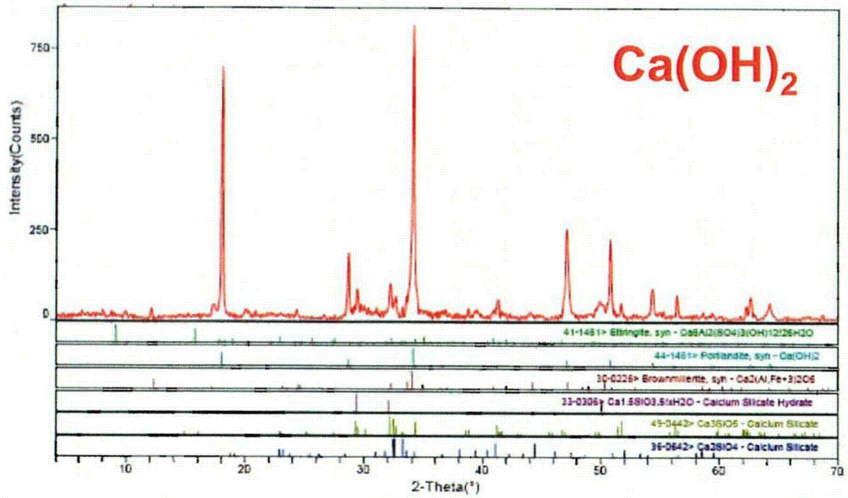


Compressive Strength Results were Consistent for Each of the Solutions

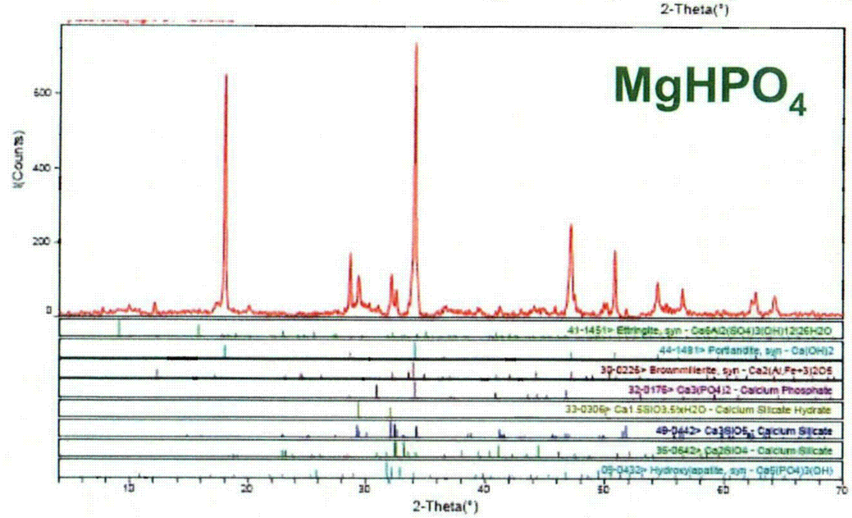


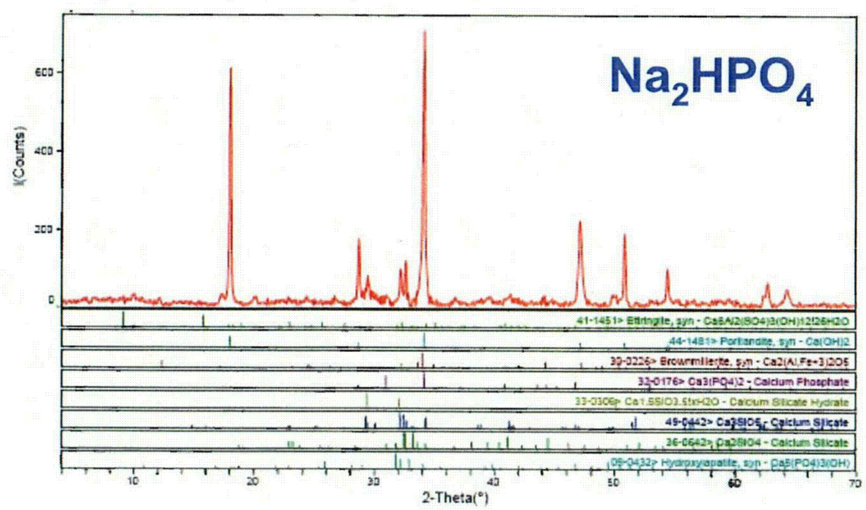
X-Ray Diffraction Spectra Obtained were Very Similar for Each Solution



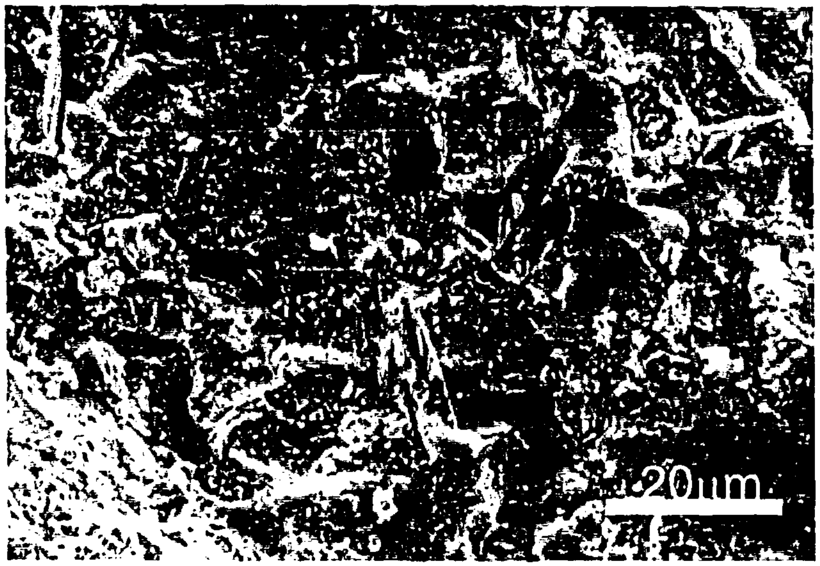
Hydrated Phases Identified

- Portlandite
- C-S-H
- Ettringite (?)
- No mineral w phosphate





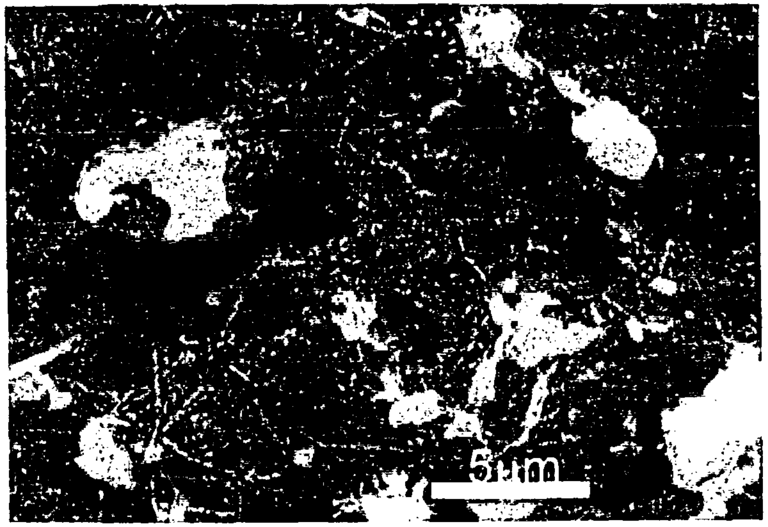
SEM Confirmed Results found by X-Ray Diffraction



View of Cement Paste:
Na_2HPO_4 at 12 months

C_3S in Dense Layer of C-S-H
$Ca(OH)_2$ and Calcium Sulfo-aluminates Visible in Cement Paste:
Na_2HPO_4 at 12 months

SEM Confirmed Results found by X-Ray Diffraction (cont.)



Ettringite in Cement Paste:
$MgHPO_4$ at 12 months

Calcium Sulfoaluminates Abundant:
$MgHPO_4$ at 12 months

- **Preliminary Conclusions**

Thermodynamics Supports Potential for Expansive Reactions Involving Phosphate Ions and Cementitious Materials, but to Date Kinetics Does Not

Ettringite Needles
(X 2000)

- Preliminary conclusions
  - No harmful interactions of phosphates and cementitious materials unless phosphates are present in form of phosphoric acid
  - Phosphates have been incorporated into concrete as set retarders, phosphate cements used for infrastructure repair
  - No standards or guidelines pertaining to applications of RC structures in high-phosphate environments
  - Contacts with researchers indicate that potential interactions between phosphates and cementitious materials has not been a concern
  - Twelve-month laboratory results indicate similar performance of specimens submerged in phosphate solutions and calcium hydroxide

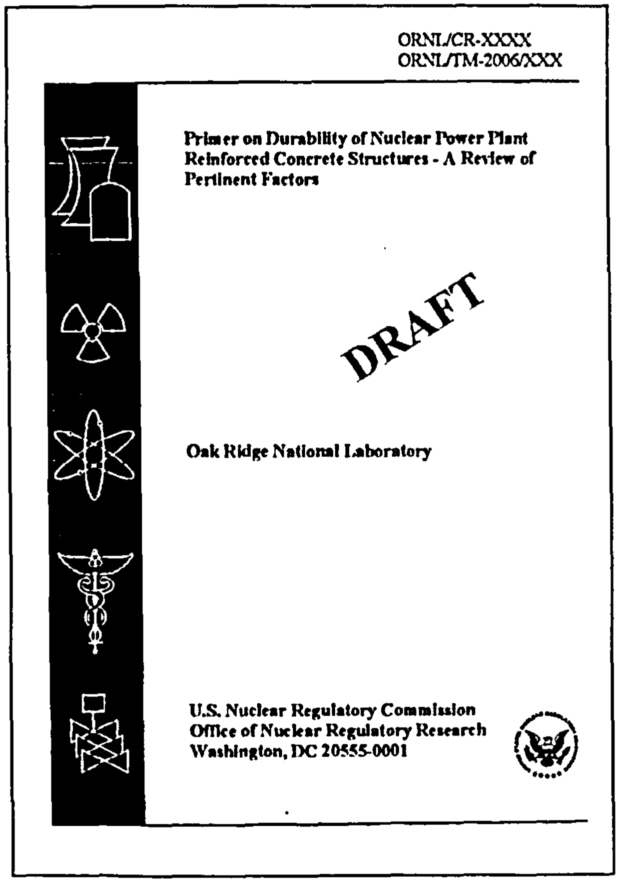
- **Structural Sampling**

Working with FDOT to Obtain Concrete Core Samples from Bridge Substructure in Bartow County

Analyte	Calibration Status	Compound	Concentration (%)	Calculation Method
Al	Calibrated	Al	3.224	Calculate
Si	Calibrated	Si	24.243	Calculate
P	Calibrated	P	18.444	Calculate
S	Calibrated	S	0.547	Calculate
K	Calibrated	K	0.591	Calculate
Ca	Calibrated	Ca	44.552	Calculate
Ti	Calibrated	Ti	0.712	Calculate
Mn	Calibrated	Mn	0.234	Calculate
Fe	Calibrated	Fe	6.653	Calculate
Zn	Calibrated	Zn	0.226	Calculate
Sr	Calibrated	Sr	0.306	Calculate
Y	Calibrated	Y	0.035	Calculate
Zr	Calibrated	Zr	0.093	Calculate
Ba	Calibrated	Ba	0.112	Calculate
U	Calibrated	U	0.028	Calculate

- **Primer on Concrete Durability**

Report on Durability of Reinforced Concrete has been Prepared



ORNL/CR-XXXX
ORNL/TM-2006/XXX

Primer on Durability of Nuclear Power Plant Reinforced Concrete Structures - A Review of Pertinent Factors

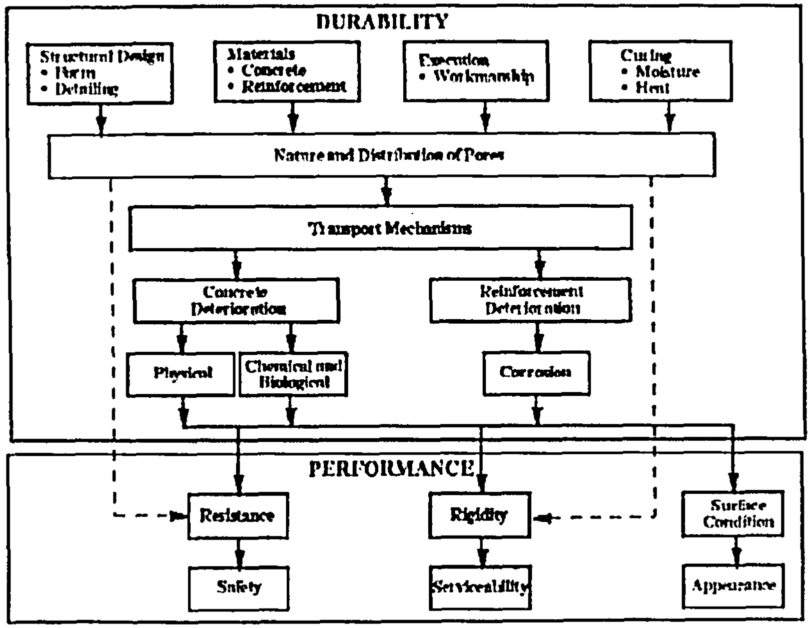
DRAFT

Oak Ridge National Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

- Introduction
- Historical Perspective on Concrete and Longevity
- Materials of Construction
- Aging and Durability
- Summary and Conclusions
- Appendix A: Safety-Related Concrete Structures
- Appendix B: Nuclear Power Plant Concrete Structures Operating Experience
- Appendix C: Commentary on Cracking and Corrosion

1. Introduction



Relationship Between Durability and Performance

- As concrete ages, changes in its properties occur as a result of continuing microstructural changes
- Water is single most important factor controlling degradation process
- Incidences of degradation will increase with age, primarily due to environmental-related factors

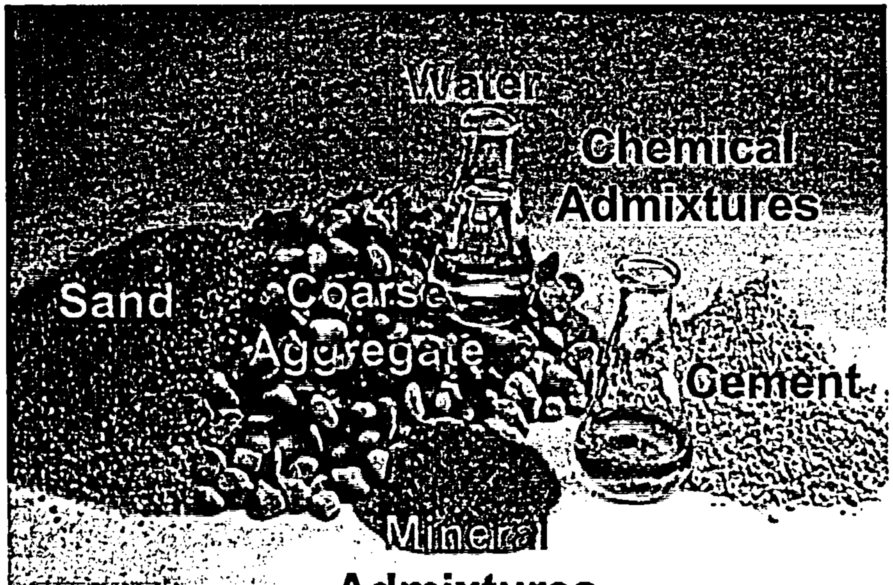
2. Historical Perspective on Concrete and Longevity

Pantheon (Built 119-128 A.D.

Colosseum (Comp. 80 A.D)

- Cement has been around for 12 million years with oldest concrete about 7600 years old
- Ancient structures survived because of careful materials selection and construction, mild climatic conditions, and lack of steel reinforcement
- Portland cement invented in 1824

3. Materials of Construction



Admixtures

Basic Concrete Constituent Materials

- Concrete
- Conventional steel reinforcement
- Prestressing steel
- Liner plate

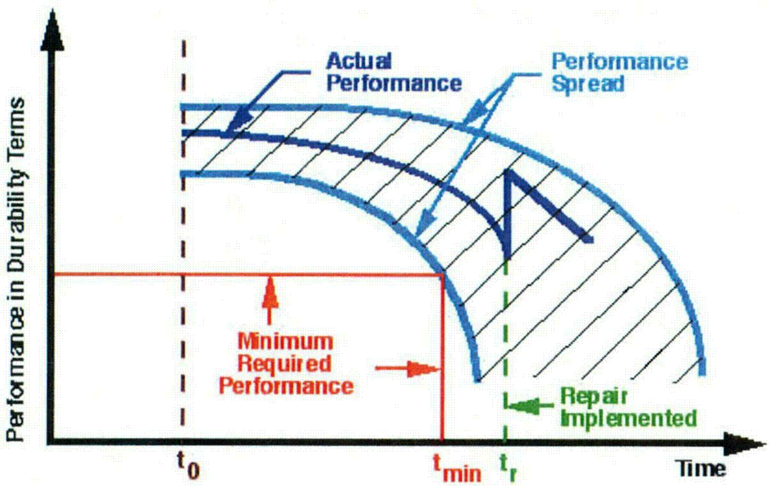
4. Aging and Durability

Mat'l System	Degradation Factor	Primary Manifestation
Concrete	*Physical processes*	
	Cracking	Reduced durability
	Salt crystallization	Cracking/loss material
	Freezing and thawing	Cracking/scaling/disintegration
	Abrasion/erosion/cavitation	Section loss
	Thermal exposure/thermal cycling	Cracking/spalling/strength loss
	Irradiation	Volume change/cracking
	Fatigue/vibration	Cracking
	Settlement	Cracking/spalling/misalignment
	Chemical processes	
	Efflorescence/leaching	Increased porosity
	Sulfate attack/DEF	Volume change/cracking
	Acids/bases	Disintegration/spalling/leaching
	Alkali-aggregate reactions	Disintegration/cracking
	Aggressive water	Disintegration/loss material
	Phosphate	Surface deposits
	Biological attack	Increased porosity/erosion

4. Aging and Durability (cont.)

Mat'l System	Degradation Factor	Primary Manifestation
Mild Steel Reinforcing	Corrosion Elevated temperature Irradiation Fatigue	Concrete spaling/cracking/section loss Decreased strength Reduced ductility Bond loss
Post-Tensioning	Corrosion Elevated temperature Irradiation Fatigue Stress relaxation/End effects	Strength loss/reduced ductility Reduced strength Reduced ductility Concrete cracking Prestress force loss
Liner/Strutural Steel	Corrosion Elevated temperature Irradiation Fatigue	Section loss Reduced strength Reduced ductility Cracking

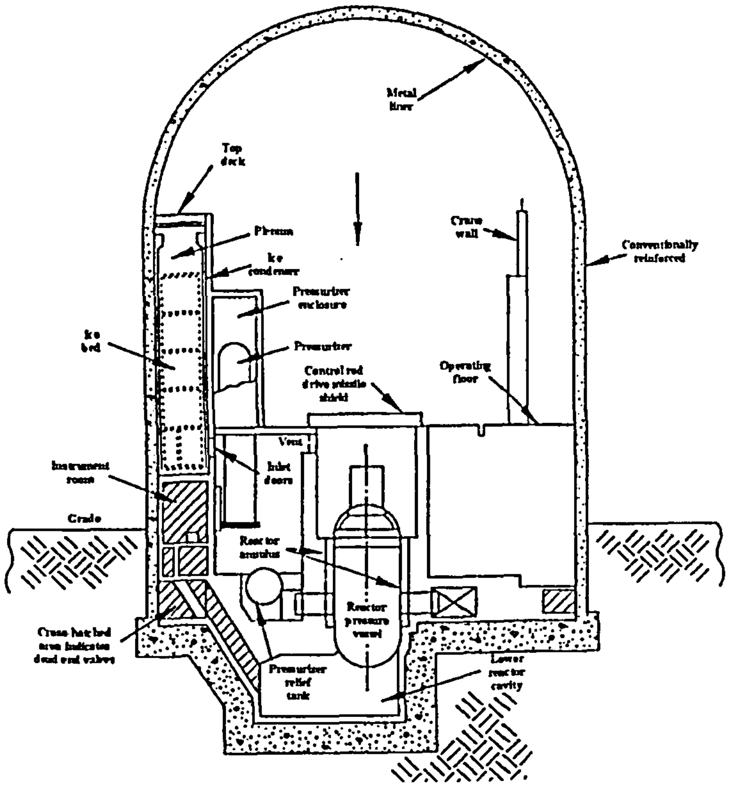
5. Summary and Commentary



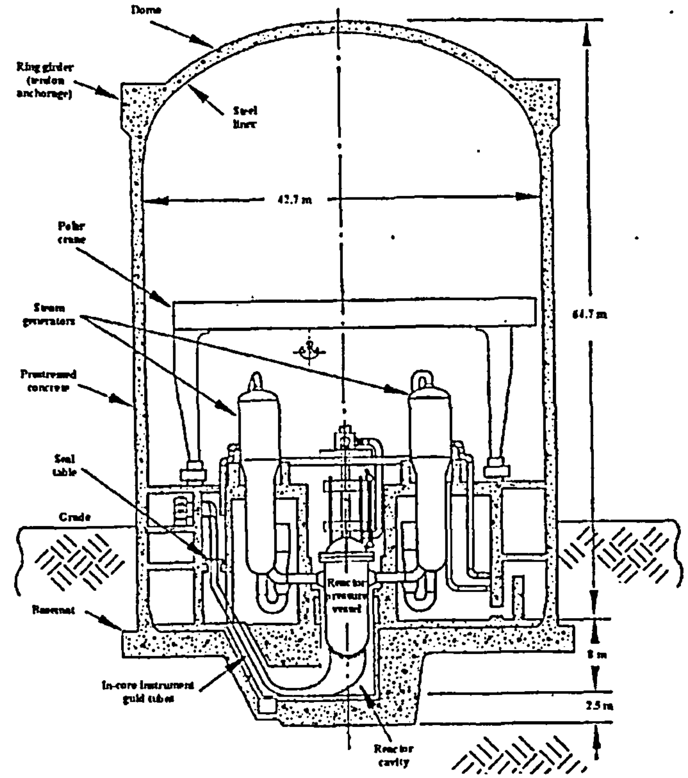
Relationship Between Performance and Service Life

- Reinforced concrete structures deteriorate due to exposure to environment
- Properties of concrete change with age
- Water is most important factor controlling concrete degradation
- Most prevalent manifestation of concrete degradation is cracking
- Most prudent approach for maintaining adequate structural margins as well as extending usable life is through an aging mangement program

Appendix A: Safety-Related Concrete Structures



PWR Reinforced Concrete
with Ice Condenser



PWR Large Dry
Prestressed Concrete

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

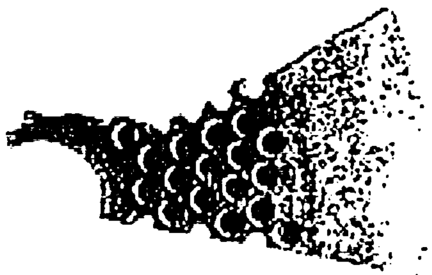
UT-BATTELLE

Appendix B: Nuclear Power Plant Concrete Structures Operating Experience

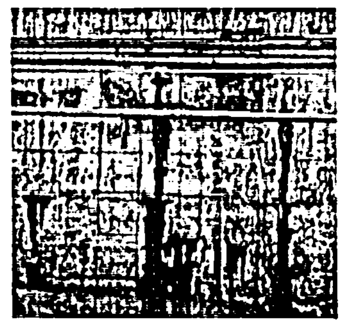
Containment Dome
Delamination Repair

Leaching in
Tendon Gallery

Water Intake Structure
Rebar Corrosion



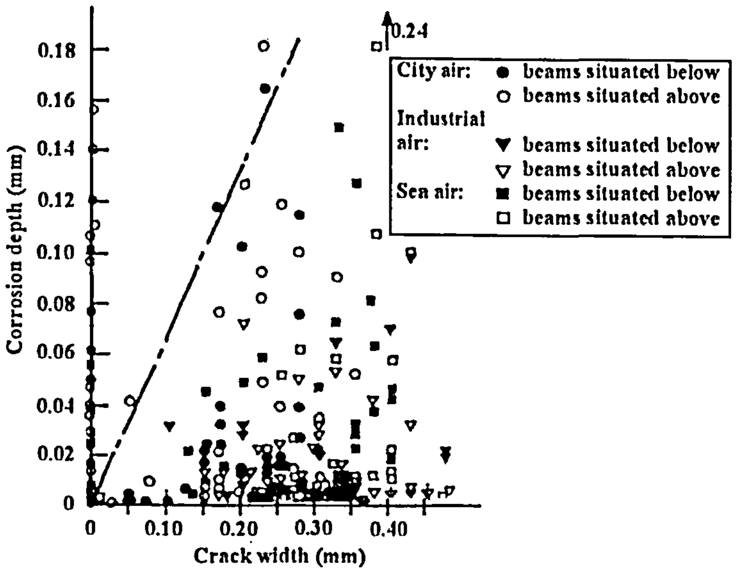
Anchorhead Failure



Concrete Cracking
With Grease Leakage

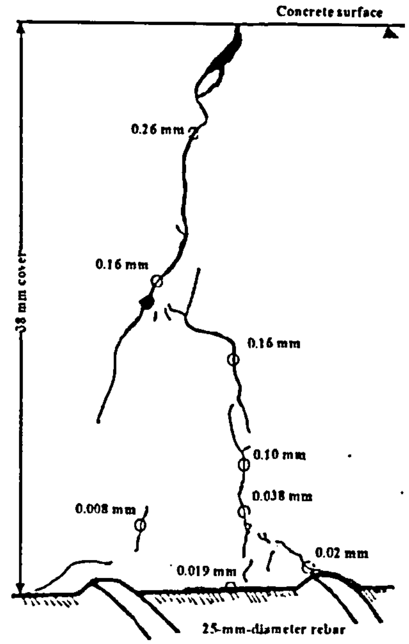
Appendix C: Commentary on Cracking and Corrosion

Crack Characteristics and Corrosion



Corrosion Depth vs Crack Width
After 10-Year Exposure

Corrosion Significance And Crack Characteristics



Variation of Crack Width
With Depth

EFFECT OF PHOSPHATE ION ON CONCRETE

Herman L. Graves
Office of Nuclear Regulatory Research

Dan J. Naus
Les R. Dole
Catherine H. Mattus
Oak Ridge National Laboratory

534th ACRS MEETING
July 12-14, 2006

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Effect of Phosphate Ion-Concrete

- PURPOSE OF THIS MEETING:

  is to brief the ACRS on the staff's research to determine the effect of phosphate-ion on concrete. (phosphate-ion concentrations necessary to cause conversions to hydroxyapatite).

Effect of Phosphate Ion-Concrete

- Objective
  - Characterize the significant factors that may lead to establishment of phosphate limits (ground water and soil conditions.)
- Motivation
  - User Need Memo received from NRR December 12, 2003
- Background
  - June 24, 2003, letter to Chairman Diaz, ACRS recommended "The staff should consider whether similar limits and guidance are needed for phosphate ion concentration."

Effect of Phosphate Ion-Concrete

- Generic Aging Lessons Learned (GALL) Limits

  Inaccessible Areas (below-grade concrete)

  pH < 5.5

  chlorides > 500 ppm * (**)

  sulfates > 1,500 ppm *

* American Concrete Institute (ACI) 318, "Building Code Requirement for Reinforced Concrete"

** ACI 201.2R, "Guide to Durable Concrete"

Effect of Phosphate Ion-Concrete

- Intended Regulatory Use
  - Provide information to aid staff's assessment of license renewal applications and to establish a staff position on phosphate ion concentrations.

- Status
  - Testing and analysis completed.
  - Primer Report in draft form.

- Schedule
  - NUREG/CR publication date scheduled for Fall, 2006.

A FRAMEWORK FOR INTEGRATING RISK AND SAFETY MARGINS

Mirela Gavrilas, Ph.D.
RES/DRASP/NRCA

"The natural consequence of uncertainty is risk."
Bruce R. Ellingwood, NIST/Johns Hopkins University

...and our way of coping with uncertainty is operating with sufficient safety margins.

Purpose of This Presentation

Discuss an RES project which produced a framework that merges deterministic, probabilistic and engineering data, including uncertainties, into figures of merit that can be used to assess a plant modification against existing risk acceptance guidelines

Topics

Motivation:

- Background
- ***Objective: quantify the change in plant safety margin caused by any conceivable physical modification(s)***
- ***Constraints: use existing tools and techniques, and demonstrate the methodology on a current regulatory issue***

- Method:
  - What is safety margin?
  - How can safety margin be integrated into risk?
- Results
  - Simplified tradeoff example application
  - Proof-of-concept example application
- Discussion
  - When should safety margin be integrated with risk?

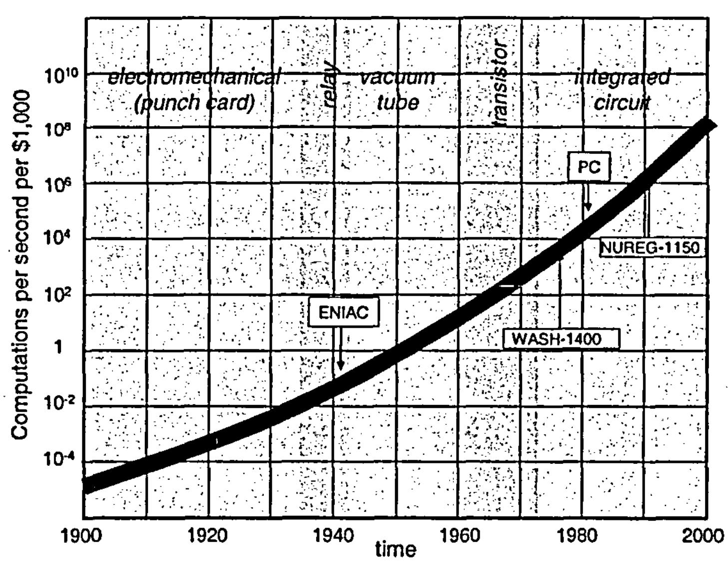
Background

- Current approaches treat PRAs and the deterministic calculations of margin as complementary but separate and distinct
- "Maintaining margin" does not mean the same thing to everyone
- Phrases like "sufficient margin exists" and "this increases/decreases the available margin" are often qualitative
- A wealth of tools and techniques exist to accomplish the integration

A Few Milestones

- 1930's ← Monte Carlo Methods (Enrico Fermi's use of existing statistical sampling algorithms)
- 1940's ← Tolerance Intervals (Samuel Wilks)
- 1965
- 1D Stress-strength Interference (Albert M. Freudenthal; "structural reliability")
- Importance Analysis (Zygmund Birnbaum)
- 1975 (The) Reactor Safety Study (Rasmussen)
- Risk; Random vs. Lack-of-knowledge Uncertainties (Kaplan and Garrick)
- Dynamic PRA (Amendola and Cacciabue) →
- 1985
- Quantifying Uncertainty in a Severe Accident Sequence (BNL)
- Best Estimate plus Uncertainty (PIRT/CSAU) →
- Severe Accident Risks (NUREG-1150)
- 1995
- Risk Oriented Accident Analysis Methodology (ROAAM) →
- Reliability of Passive TH systems (OECD efforts) →
- 2005
- Pressurized Thermal Shock →

Increase in Computational Power Over the Last Century (adapted from Wikipedia)



Why Should Plant Changes Be Assessed Through a Methodology That Merges Probabilistic and Deterministic Approaches?

Potential effects (first order, only) of select plant modifications

- power uprates → safety margins; probabilities of occurrence of certain accidents; consequences of an accident
- clad material
- allowable burnup
- plant operating conditions
- fuel cycle length
- ageing
- MOX fuel
- grid reliability
- risk-informed changes to technical specifications

Elements of Integrated Risk/Safety Margins

The probability that an accident sequence will occur

- To be provided by probabilistic risk analyses

The probability that loss of function will occur following a given event sequence

- To be provided by deterministic calculations using all applicable engineering data (thermal-hydraulic and/or reactor physics codes, for instance)

The consequences of a given event sequence in which function is lost (to capture plants with the same power peaking factor but different power profiles—difference would not be seen in 1 or 2)

- To be provided by severe accident calculations

When Is Integration of Safety Margins Into PRA Important?

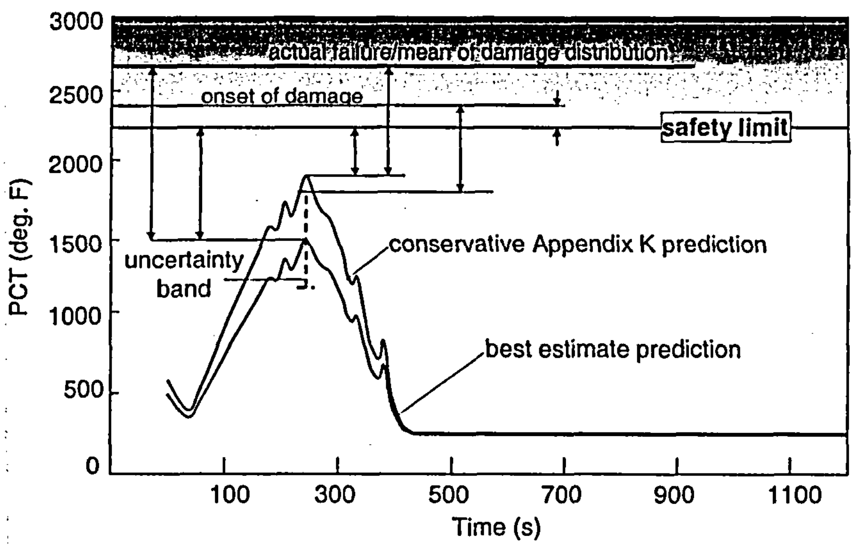
- When "sufficient margin" exists, we do not have to know exactly how much margin there is
- However, the decision process can benefit from the quantification of safety margin when the following conditions are met simultaneously:
  - Limited margin exists (e.g., net positive suction head in GSI-191)
  - Margin can be reasonably tied to loss of function (i.e., there is no redundant system that can fulfill the same function)
  - A justification is needed for continued plant operation (10CFR50.12)

⇒ Augment existing decision factors with integrated risk/safety margins

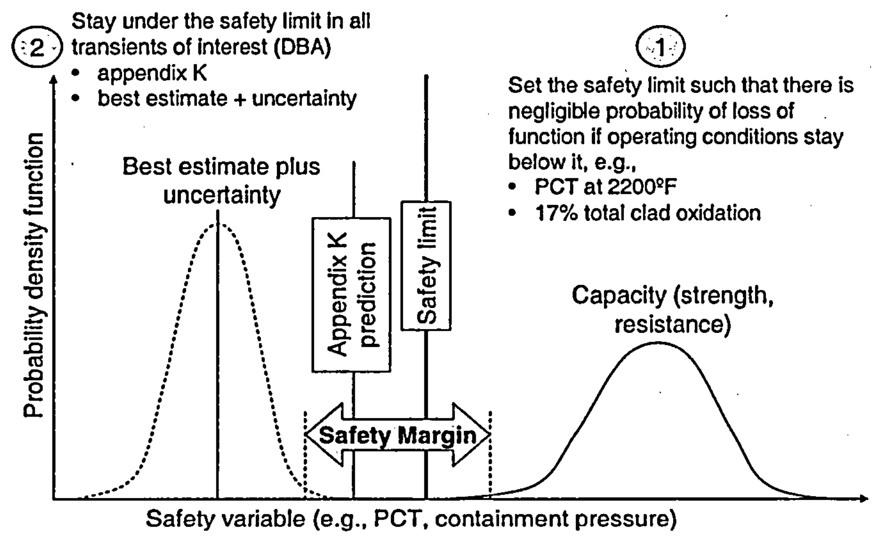
⇒ Go beyond using deterministic and probabilistic analyses as separate principles, which can leave room for conflicting results

What Is Safety Margin?

the term originated in design analyses (e.g., pressure vessels)



Safety Margin In The Nuclear Industry:
the two prongs that leave room for "unknown-unknowns"



Consistent with Structural Reliability Definition (see for example O'Connor, P .D.T., "Practical Reliability Engineering," 3rd Edition)

- Load-strength interference discussion is background material in support of the definition of safety margin adopted in the draft NUREG

Reliability and probability of failure are calculated from the joint probability (the joint probability of occurrence is about ½ the overlap area)

$$R(S) = \int_0^\infty f_S(s)\left[\int_0^s f_L(l)dl\right]ds = \int_0^\infty f_S(s)F_L(s)ds$$

$$P_f(s) = \int_0^\infty f_L(s)F_S(s)ds$$

• For S & L Gaussian distributions, reliability is the standard normal cdf of the safety margin
• For large safety factors and thus large safety margins, the reliability is high—design objective

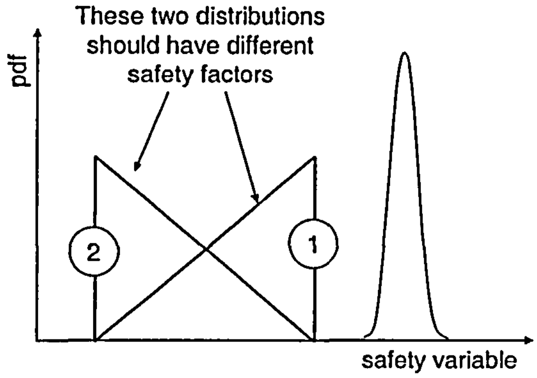
$$SM = \frac{\overline{S} - \overline{L}}{\sqrt{\sigma_S^2 + \sigma_L^2}}$$

Loading roughness needs to be considered together with the safety margin in establishing the correct safety factor for a given target reliability.

$$LR = \frac{\sigma_L}{\sqrt{\sigma_S^2 + \sigma_L^2}}$$

Why is Loading Roughness Important?

- The two load pdf's have the save means and standard deviations, but the consequences of a perturbation in pdf 1 are much more significant than the same perturbation in pdf 2



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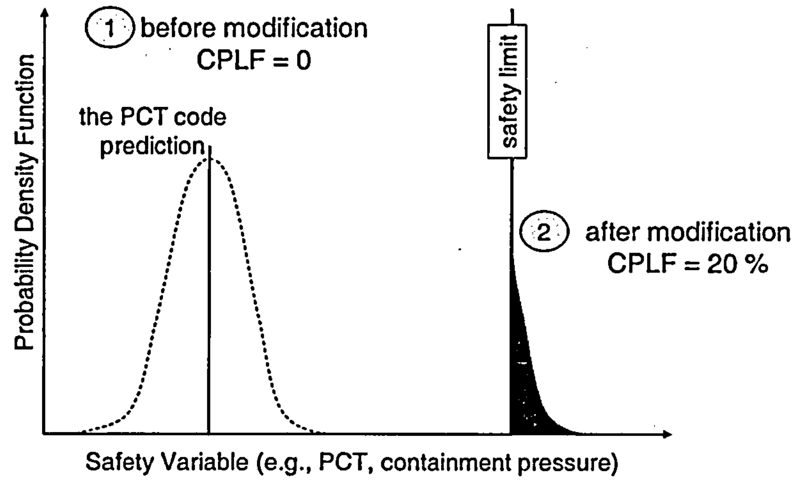
Using a Dirac-delta Function for Capacity

- Assumes that failure occurs discretely when the safety limit is reached
- Leaves extra room for unknown-unknowns
  - how much room remains to be determined—guidance to be developed
  - for current reactors not an issues, because safety limits exist
- Without leaving room for unknown-unknowns even the ideal analysis (i.e., one in which only aleatory uncertainty exists that is propagated meticulously) is non-conservative

Gavrilas; ACRS presentation 07/12/2006 14 the amount by which the load exceeds the safety limit is the conditional probability of losing function (CPLF)



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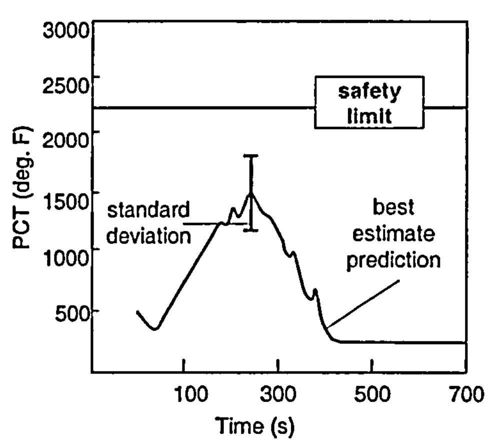
How Can Risk and Safety Margins Be Integrated?

any deterministic calculation assumes a specific series of events, e.g.,

- a break of a specific size has occurred
- when a certain actuation signal is received, the injection system starts
- when a certain pressure is reached, the accumulators inject



⇒ ***The peak clad temperature computed deterministically is "conditioned" on the event sequence simulated.***

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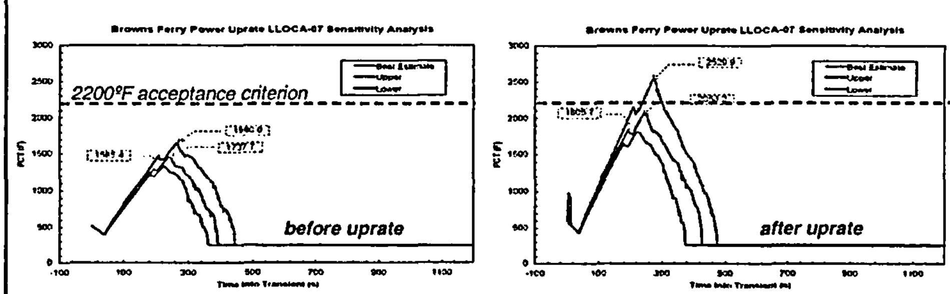
When Is Margin Important?



- Considering the principal sources of uncertainty in calculating the PCT (e.g., decay power, pump flow rates) the probability of losing margin is 0.33 after the power uprate
- This information alone can be misleading, because the probability of occurrence of the event sequence is 1.16E-08

⇒ A well-devised risk figure of merit has to **consider both**

What Is The Probability Of Losing Function In An Event Sequence?

probability that event sequence will occur & conditional probability that the core will loose function

from event tree frequency (→ probability that event sequence will occur)

from engineering data, safety limits and deterministic calculations (the CPLF) (→ conditional probability that the core will loose function)

Steps (perform all before and after the modification):

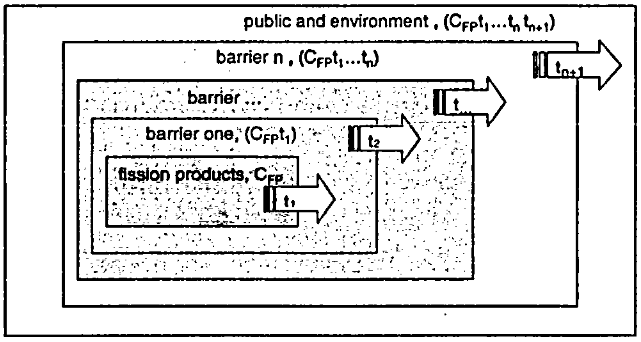
1. "draw" the event trees
2. decide on uncertainties in the deterministic calculations for the particular safety margin
3. complete best estimate plus uncertainty calculation
4. multiply frequency with CPFL for each event
5. add over all event sequences to get cumulative core damage frequency

Generalizing to Multiple Barriers: beyond CDF to QHO

Premises:

- Any existing or future nuclear power plant can be summarily described as a volume that contains the fuel and fission products surrounded by one or more physical barriers (this would include barriers electro-magnetic confinement or other radical departures from current designs)
- For any physical barrier, safety variables can be identified that demarcate the transition from intact to damaged, (e.g., PCT, enthalpy deposition rate, containment pressure)
- PRA tools exist to identify event scenarios that can lead to the loss of margin of any barrier

Consequences of an Event Scenario in Which Barrier n is Lost



$(C_{FP}t\ldots)$—concentration of fission products within the barrier

t_n—transmission factor from barrier n to barrier n+1 is a function of:

- volume confined by each barrier
- extent of damage to the barrier
- time between the breach of successive barriers
- pool scrubbing, ...

Probability of Loss of Function in Event Sequence i

The probability of a release to the public and the environment for event sequence i, p_i, is the conditional probability that the event will occur, and barriers one through n will loose their function

$$p_i = p(ES_i \cap B1 \cap B2 \cap \ldots) = \\ = p(ES_i) \cdot p(B1|ES_i) \cdot p(B2|ES_i \cap B1) \ldots$$

where:

- $p(ESi)$ is the probability the event sequence i will occur
- $p(B1|ES_i)$ is the conditional probability that barrier one will fail given ESi, and
- $p(B2|ES_i \cap B1)$ is the conditional probability that barrier two will fail given ES_i and the failure of barrier one.

Risk From a Single Event Sequence

Probability

probability that event sequence will occur, p_{ES} & probability that barrier 1 will fail, p_{B1} & ... & probability that barrier n will fail, p_{Bn}

from event tree analysis

from engineering data and deterministic calculations; this is a ***conditional probability***

Consequences

$C_{FP} t_1 \ldots t_n$

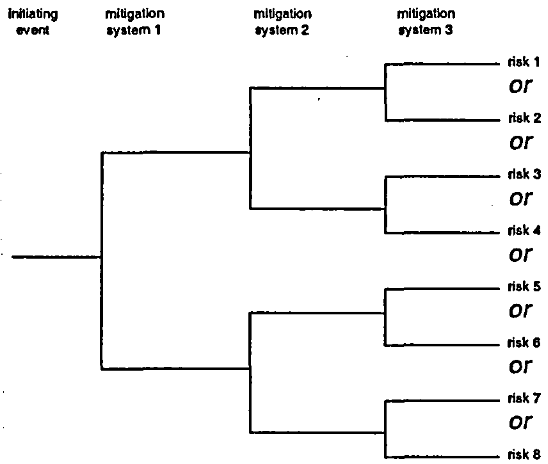
from deterministic calculations

Risk for event sequence i

$$risk_i = p_{ES,i} \cdot p_{B1,i} \cdot \ldots \cdot p_{Bn,i} \cdot (C_{FP,i}\, t_{1,i} \ldots t_{n,i})$$

Risk From All Event Sequences

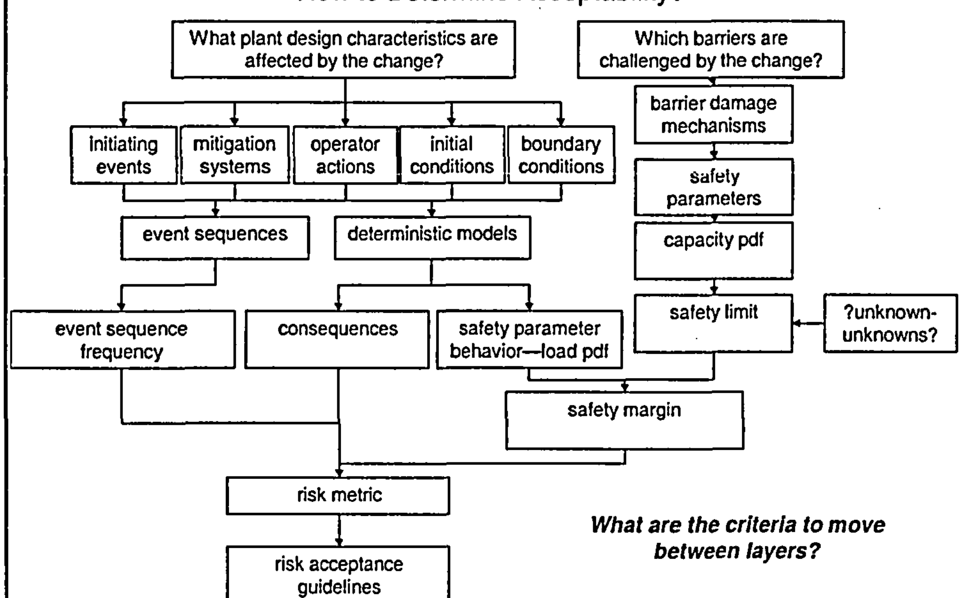
Assuming that only one event can occur at any given time:



$$\text{total risk} = \sum_i \text{risk}_i$$

Compare to Commission's safety goals or RG 1.174 thresholds.

How to Determine Acceptability?



What are the criteria to move between layers?

NPSH Example—proof of concept

- Failure (i.e., loss of safety function) is assumed to occur when the available net positive suction head ($NPSH_a$) is less than the $NPSH_r$ required for the specific pump
- In practice, the magnitude of $NPSH_a$ is determined by many, variable factors

$$NPSH_r \le NPSH_a =$$

+ Pressure Head (containment pressure)

+ Static Suction Head (sump level)

- Vapor Pressure (at maximum pumping temperature)

- Friction and K-loss Head (in the suction side)

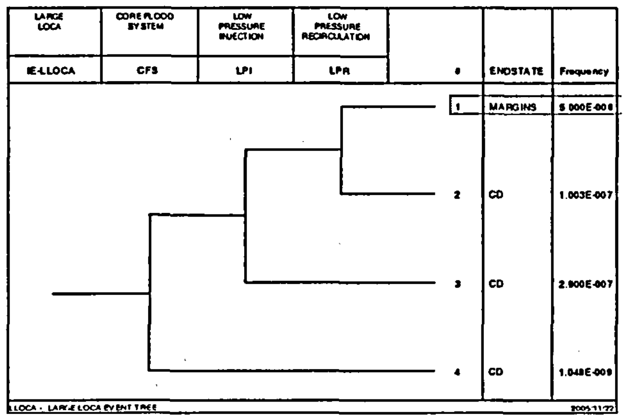
- For this example, the above equation and the NUREG/CR 6224 correlation constitute the models for the deterministic calculation.

Generating the Risk Space for NPSH

- Initiating events that challenge NPSH margin must be considered
- Event sequences must be refined to capture important input variabilities (e.g., action of containment spray, variabilities in input and boundary conditions)
- The deterministic computation output is the set of variables that go into the calculation of $NPSH_a$ (e.g., containment pressure, sump level and temperature)
- In general, a more formal process can be developed from guidance contained in NUREG 1150 and adapting the thought-process of 10CFR 50.59

Example: LLOCA Tree

- CD paths do not need to be considered
- Truncate low probabilities events (e.g., <10E-7)
- Consider additional factors in generating event scenario frequency (e.g., probability of generating enough debris for blockage)



Generating the Probabilities of Loss of Margin

Starting with the physical description of the particular margin, e.g., the NPSH equation:

All variables are listed; PIRT-like approach

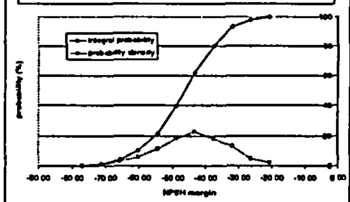
- Nominal values
- Ranges of variability and
- Probability densities

are defined and explained for each event sequence

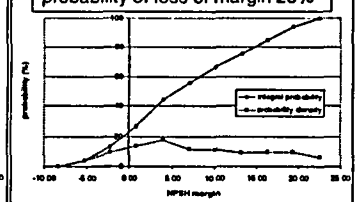
Variables are sampled to generate a probability density function of losing margin to the desired confidence level

Example: What is the Impact of Going from a 100 ft^2 Screen to One of 1,100 ft^2?

small screen:
probability of loss of margin **100%**



large screen:
probability of loss of margin **23%**



Data reporting is compact and transparent, e.g., LLOCA-01

Variable	Units	Nominal	*min*	*max*	Range Comment
Mineral wool	ft^3	126	*80*	*100*	maximum debris
Dirt-Dust	lbm	170	*80*	*100*	maximum debris
Qual_Epoxy	lbm	260	*80*	*100*	maximum debris
Paint-Chips	lbm	95	*80*	*100*	maximum debris
Flow Rate	gpm	8700	*90*	*110*	10% controller range
Screen Area	ft^2	100/1100	*80*	*100*	allow for up to 20% blockage
Water Temperature	°F	243	*74*	*100*	range from 180°F to 243°F
Screen Losses	ft	-57.75			
Containment $p_{st-part}$	ft	19.23	*80*	*100*	max. between saturation and atmospheric
Pool Level Above Suction	ft	20	*90*	*110*	maximum pool level
Friction and K Losses	ft	-3.00	*80*	*100*	account for impurities
Cavitation Pressure	ft	-19.23	*100*	*100*	
NPSHr	ft	-12.53	*90*	*110*	
NPSHa	ft	-26.31			
median NPSH margin	*ft*	*-45/+5*			

Generating the Final Figure of Merit

	frequency	small screen		large screen		change
Rest of Time	1.00E+00	p(loss|ES)	p (loss)	p(loss|ES)	p (loss)	
LLOCA-01	5.00E-06	100%	5.00E-06	23%	1.15E-06	3.85E-06
LLOCA-02	1.00E-07					
LLOCA-03	2.90E-07					
LLOCA-04	1.05E-09					
MLOCA-01	4.00E-05	100%	4.00E-05	7%	2.80E-06	3.72E-05
MLOCA-02	1.90E-07					
MLOCA-03	4.60E-10	*100%*	*4.57E-10*	*100%*	*4.57E-10*	
MLOCA-04 to 09	2.53E-10					
SLOCA-01	4.00E-04	50%	2.00E-04	3%	1.20E-05	1.88E-04
SLOCA-02	3.31E-06	50%	2.00E-04	3%	1.20E-05	1.88E-04
SLOCA-03	1.03E-06					
SLOCA-04	4.00E-07	50%	2.00E-04	3%	1.20E-05	1.88E-04
SLOCA-05	2.19E-08					
SLOCA-06	4.83E-09					
SLOCA-07	1.48E-09	*100%*	*1.48E-09*	*100%*	*1.48E-09*	
SLOCA-08	1.20E-11	*100%*	*1.20E-11*	*100%*	*1.20E-11*	
SLOCA-09	3.24E-12					
SLOCA-10	1.45E-12	*100%*	*1.45E-12*	*100%*	*1.45E-12*	
SLOCA-11	5.74E-14					
SLOCA-12	1.91E.13					
SLOCA-13	8.00E-07	100%	8.00E-07	3%	2.40E-08	7.76E-07
SLOCA-14	6.64E-09	*100%*	*6.64E-09*	*100%*	*6.64E-09*	
SLOCA-15	2.05E-09					
SLOCA-16	8.00E-10	*100%*	*8.00E-10*	*100%*	*8.00E-10*	
SLOCA-17	4.36E-11					
SLOCA-18	1.60E-07	100%	1.60E-07	4%	6.40E-09	1.54E-07
SLOCA-19	7.63E-10					
SLOCA-20	1.60E-08					
SLOCA-21	8.18E-10					
TOTAL			*2.46E-04*		*1.60E-05*	2.30E-04

This is the ΔCDF by going from 100 ft^2 screen to 1,100 ft^2.

Discussion

- Why should safety margin be integrated with risk?
  - because uncertainty is a major role-player; see for example the passive systems of advanced reactors
  - because the "unknown-unknowns" portion of uncertainties should explicitly be considered in risk assessments
- When does the safety margins framework add value to the decision?
  - when a given modification is both beneficial and detrimental to safety, one cannot afford to be "conservative" because benefits are overshadowed

Summary

Integrated risk/safety margins considers simultaneously

- frequencies of events
- deterministic calculations (best estimate preferred but conservative Ok)
- engineering data

Integration is done such that existing risk guidelines can be used to judge the acceptability/benefit of a plant modification

- ΔCDF and ΔLERF of Reg. Guide 1.174
- Commission's safety goals

Uses established methods and tools

- in the "limit", the methodology reduces to current practice
- posed to take advantage of state-of-the-art developments in PRA, deterministic analyses, uncertainty treatment

It is the proper way to measure changes in overall margins, but it is to expensive to be exercised solely for that purpose

Benefits

- Where possible and necessary, eliminate conservatism in generating the risk profile of a plant
  - replace conservative assumptions with realistic probability distributions (e.g., break size)
- Obtain risk metrics through a systematic and transparent process
  - known sources of uncertainty are treated explicitly
  - unknown uncertainty is "addressed" explicitly in setting the safety limits
- Direct focus on investigating phenomena that have the largest risk impact, e.g., a specific safety margin (net positive suction head for GSI-191)
- Integrating probabilistic, deterministic and engineering data imposes consistency in deriving the risk metrics

Potential Future Work

- Application to a regulatory issue; potential candidates:
  - GSI-191
  - containment overpressure credit needed in a power uprate
  - revising the enthalpy deposition rate limit

  Will require the involvement of interested stakeholders.
- Investigate extension to advanced reactors
  - linking to frequency-consequence curve

  Will require substantial additional development
- Revise as advances occur in support areas, e.g.,
  - separate propagation of uncertainties of different types (random and lack-of-knowledge)
  - best estimate methods
  - consequence analyses
  - dynamic PRA
- People are working on furthering the state-of-the-art, but few are even thinking about criteria for doing as much as necessary but no more given a particular safety question

PTS: Accruing Knowledge
(graph courtesy of Mark Kirk, RES/DFERR)